Wheat Yield Sensitivities in the Canadian Prairies to Climate Change

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ABSTRACT

Canadian agriculture has been one of the top three wheat exporting nations over the last decade and therefore changes in Canada's *capacity* to produce wheat could have profound effects on the Canadian economy and the international supply of wheat. Previous studies have indicated that wheat production systems in the Canadian prairies would be sensitive to a range of scenarios for global climate change. This study builds upon this foundation by evaluating the combined impacts of climate change, elevated CO_2 levels and selected adaptive strategies on wheat yields in the Canadian prairies. The CERES-WHEAT model was used to estimate yields and climate change scenarios were derived from the GISS, GFDL and UKMO GCM 2 X CO_2 experiments. Adaptive strategies considered in this study included earlier seeding dates and irrigation. The main conclusions were: (i) yield responses were sensitive to climatic change scenario and location, (ii) the climatic change scenarios tended to reduce and in some cases offset the beneficial effects stemming from elevated CO_2 levels, and (iii) the effectiveness of response strategies varied according to the location, climatic change scenario and selected response strategy.

INTRODUCTION

Canadian agriculture has been identified as a sector which could be affected by a greenhouse gas induced global climatic warming, and there have been numerous studies into its potential impacts on agro-climatic resources, crop yields and regional production potential (Arthur, 1988; Bootsma et al., 1984; Brklacich and Smit, 1991; Singh and Stewart, 1991; Smit and Brklacich, 1988; Stewart, 1990; Williams et al, 1988). Current agro-climatic conditions for many regions in Canada are characterized by relatively short frost-free periods, and therefore it should not be surprising that much of the Canadian research into the agricultural impacts of global warming has focused on possible alterations in the growing season properties for annual crops with concomitant adjustments to productivity levels.

Consistent with impact assessments elsewhere, research into the effects of altered climates on Canadian agriculture is characterized by studies which have:

- considered a 2 x CO_2-induced climatic change,
- estimated independently the effects of either a climatic change or elevated CO_2 concentrations,
- considered particular regions in isolation, and
- employed a comparative static approach (i.e. rate at which climate and other conditions change is beyond a study's scope).

This study builds upon this foundation. Its overall purpose is to evaluate the combined impacts of several climatic change scenarios, elevated CO_2 levels and adaptive responses on wheat yields throughout the three Canadian prairie provinces: Alberta, Saskatchewan and Manitoba.

Wheat production occurs over a vast area in the Prairie region and traverses several soil and climatic zones. In addition to this agro-climatic diversity, global climatic change scenarios suggest that long-term climatic alterations may not be distributed uniformly across the Prairie region. In order to capture some of the spatial variability in biophysical properties and in the estimates for climatic change, 7 indicator sites covering all major biophysical sites in the prairie provinces were used (Figure 1). The extent to which these indicator sites represent the region as a whole is not known, and therefore no attempt is made to generalize the findings across the region.

A summary of the procedures and data used is presented in the next section. This is followed by a summary of the estimated impacts of alternative climatic conditions, elevated CO_2 levels and adaptive responses on wheat yields. The paper concludes with a brief discussion of the major findings.

DATA, PROCEDURES AND ASSUMPTIONS

CERES - WHEAT Model Overview

The primary analytical tool used in this study is the CERES - WHEAT crop growth and productivity model. The version of this model used in this research is described in Ritchie and Otter (1985). 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.

Climate Data

The application of the CERES - WHEAT crop productivity model (Godwin et al., 1989) requires the following daily weather data: minimum and maximum temperature, total precipitation, and solar radiation. Summaries of data sources and methods used to develop the climatic baseline and climatic change scenarios follow.

Baseline Climate

The climatic baseline covers the 30-year period from 1951 to 1980. The required data temperature and precipitation data were obtained from Atmospheric Environment Service (AES), Environment Canada. Solar radiation observations were not available for the full baseline period at all indicator sites. These data were estimated as a function of observed values for daily bright sunshine hours, solar radiation at the top of the atmosphere and daylength, using the procedures described in Doorenbos and Pruitt (1977). Sunshine data was obtained from AES, whereas the latter data were taken from Russelo et al. (1974).

Climatic Change Scenarios

The 3 climatic change scenarios were based on the 2 X CO_2 results from the Goddard Institute for Space Studies (GISS) (Hansen et al., 1983), Geophysical Fluid Dynamics Laboratory (GFDL) (Manabe and Wetherald, 1987), and United Kingdom Meteorological Office (UKMO) (Wilson and Mitchell, 1987) General Circulation Models (GCMs).

A 3-step procedure was employed to link the GCM data with the 7 indicator sites. First, the GCM grid point located closest to each indicator site was identified. Then, for each of the identified grid points, an estimate of change was obtained by comparing the mean monthly temperature, precipitation and solar radiation values calculated under the 2 X CO_2 run to the values from the control (1 X CO_2) run. Changes in the monthly mean values derived under Step 2 were then applied to the observed daily baseline record.

Examples of temperature and precipitation changes estimated for 2 of the indicator sites are presented in Figures 2 and 3 respectively. A summary of the major characteristics of the climatic changes estimated under each of the GCMs follows.

Temperature projections from the 3 GCMs indicated considerable temperature increases for all months, with the largest increases occurring in the winter. The GISS and GFDL results were similar. Estimates for monthly temperature change in the southern Canadian prairies were in the 3 - 6.5°C range, with somewhat larger increases estimated for the more northerly parts of Alberta (i.e.: Fort Vermillion). Increases in summer temperatures tended to track 2 - 3°C lower than estimated winter increases. Relative to the GISS and GFDL estimates, the UKMO scenario was characterized by considerably larger temperature increases, as well as differences in the spatial and seasonal distribution of temperature changes. Temperature increases were typically in the 5 - 12°C range under the UKMO scenario. The winter increases tended to be 3 - 5°C higher than the summer estimates, and were more pronounced for the Alberta and Manitoba sites.

The GCMs estimated precipitation increases for most months, but the magnitude of these estimates varied considerably. For a particular month, the GCMs tended to give widely varying estimates for precipitation change at the indicator sites. As well, there was considerable variation in the estimated change from one month to the next.

For the crop growing period of May through August, estimated precipitation increases from the GISS model ranged up to 25% above the current average with considerable variation across the sites. The GISS scenario was also characterized by precipitation declines in the fall, followed by somewhat wetter winters. The UKMO model tended to estimate larger precipitation increases in the winter than in the summer. The GFDL precipitation estimate differed from the other GCMs in that no one trend was discernable. The estimates for sites in Manitoba and Saskatchewan tended to be considerably different than the estimates for Alberta sites. Late winter and spring precipitation levels for Manitoba and Saskatchewan tracked 50% to 75% above current averages. Summer precipitation levels ranging up to +50% of the current were estimated for the Manitoba sites, but for the Saskatchewan sites the 2 X CO_2 summer levels resembled the current. The maximum increase for the indicator sites in Alberta was limited to about 50% above the current, and for the summer months precipitation levels were tracking between no change and declines of up to 25%.

Solar radiation was less affected by a doubling of CO_2 than were the other 2 climatic properties. The GFDL model estimated sizeable solar radiation increases during the January to March period for the entire Canadian prairies. For the April to December period under the UKMO model and for the full year under the GISS and GFDL GCMs, solar radiation estimates tended to approximate present levels.

Non-Climatic Data Input to the Crop Model

Wheat Cultivars

The spring wheat cultivar and associated genetic co-efficients used in this study were based on the Manitou variety. Manitou was an important variety in the 1960s and 1970s, and many of the varieties used in the 1980s were derived from it. The major differences between Manitou and important varieties in the 1980s are confined to plant characteristics not considered by CERES - WHEAT and therefore it is reasonable to expect that the genetic co-efficients associated with Manitou are still applicable (Morrison, personal communication).

Winter survival is the main factor which currently deters winter wheat production on the Canadian prairies. A global warming, especially if there is a substantial increase in winter temperatures and sufficient snow cover to ensure winter survival, would allow cereal grains to take better advantage of spring moisture reserves and thereby contribute to a more favourable set of conditions for winter cereals. The analyses presented later in this paper investigate the extent to which a global warming might alter opportunities for winter wheat production. The genetic co-efficients for winter wheat used in this study are representative of winter wheat varieties currently used in the northern plains of the USA (Godwin et al. 1989).

Seeding Date

Current Seeding Dates: Long-term average spring wheat seeding dates were derived from Bootsma and De Jong (1988a) using the observed weather record for 1951 to 1980. Year-to-year weather conditions result in a considerable range in seeding dates. For example, the earliest and latest seeding dates estimated for Lethbridge between 1951 and 1980 were April 24 and May 23 respectively, which represents the smallest range around the average. At the other extreme is Winnipeg, where the estimated seeding dates ranged from April 24 to June 9. This study employs the average date for the 30-year period, and hence this study does not consider the impacts of an early or late spring on seeding date, on crop growth and on grain yields.

Altered Seeding Dates: Two adaptive strategies which would influence seeding date are considered. One of these strategies focused on earlier seeding dates for spring wheat. It is difficult to estimate the extent to which global warming might advance seeding dates and therefore a range of earlier dates was employed. These earlier dates were based upon advancing the average dates estimated for the 1951 - 1980 period by 2, 4 and 6 weeks respectively.

The other adaptive strategy affecting seeding dates appraised the degree to which global warming might impact the prospects for winter wheat production. Winter wheat seeding dates were derived from provincial field crop production guides (Manitoba Agriculture, 1988; McLelland, 1985a; Saskatchewan, 1981). Winter wheat is not grown widely in the Canadian prairies and the impact of a global warming would have on seeding dates is unknown. In the absence of additional information, current guidelines for seeding dates were employed in conjunction with the global climatic change scenarios.

Planting Density

Planting densities for spring and winter wheat were obtained from field crop production guides and agronomists familiar with wheat production in the Prairie provinces (Manitoba Agriculture, 1988; McLelland, 1985a & b; Saskatchewan Agricultural Services Co-ordinating Committee, 1981). The mid-point in the recommended seeding rate was selected and seeding rates expressed as kg/ha were converted to plants/m^2 using an "average" seed weight of 30 mg (Fei and Ripley, 1985).

Fertilizer

Typical fertilizer application rates used by farmers in the Canadian prairies add no more than 45 kg N per ha per annum. Crop moisture deficits are the norm under the current climatic regime and these moisture deficits result in considerable plant stress that suppress yields. The addition of 45 kg N per ha does not result in optimal N levels but with moisture deficits being the major yield reducing factor, these less than optimal fertilizer application rates do not effectively limit crop growth or reduce yields. Therefore nitrogen was assumed to be non-limiting in this analysis.

Irrigation

The analyses are based on both dryland and irrigated wheat production. Irrigation was triggered when the soil moisture estimate for the 1.2 metre rooting zone dropped below 50% of moisture holding capacity. It was assumed that the amount of water required to return the rooting zone to field capacity was applied at that time, with an irrigation efficiency of 100%.

Soil Profile Data

A representative soil was identified for each indicator site and the required data on horizon depths, texture, bulk density, organic carbon, coarse fractions, pH and soil classification were obtained from the Canada Soil Information System (CanSIS) (Canada-Alberta, 1989; Canada-Manitoba, 1989; Canada-Saskatchewan, 1989) and Scheelar and Odynsky (1968). Additional information on permeability, drainage, slope, quantity of roots and soil colour were estimated by Shields (personal communication).

Soil Moisture at Seeding

The CERES - WHEAT model uses soil profile data to estimate total soil moisture storage capacity. This estimate represents the maximum amount of soil moisture that could be available to the crop at seeding. The model does not estimate soil moisture recharge between harvest and seeding, but it does allow users to specify soil moisture conditions at seeding as a percentage of the estimated storage capacity. Since soil moisture reserves of Prairie soils at seeding are typically well below the moisture holding capacity, it was necessary to adjust the initial soil water conditions. Estimates of soil moisture conditions at seeding were derived from De Jong and Bootsma (1987). Values used represent the 1951 - 1980 average values for the entire soil profile.

Performance of CERES - WHEAT Model in the Canadian Prairies

The CERES - WHEAT model has been used to estimate spring wheat yields in the Canadian prairies but it has not been fully validated and calibrated under Canadian conditions. Fei and Ripley (1985) employed CERES - WHEAT to estimate wheat yields from 1964 to 1984 for the Saskatoon crop reporting district in central Saskatchewan. After accounting for technological advances, their main conclusion was the 20-year average yield estimate from CERES - WHEAT overestimated the average observed yield by 24%.

In this study, the CERES - WHEAT model estimates of the number of days required to mature spring wheat compared favourably with expected values for all sites considered in this analysis (Table

1). For most sites, the modeled estimates tended to overestimate the time required for spring wheat to mature, with the greatest discrepancies occurring at Prince Albert and Lethbridge.

With respect to grain yield at Winnipeg, Dauphin, Swift Current, Prince Albert, and Lethbridge, the CERES - WHEAT long-term average yield estimates were within 25% of the expected. However estimates for Ellerslie and Fort Vermillion, the indicator sites for central and northern Alberta, were less reliable, suggesting the model has not adequately captured the influence of either yield reducing factors in these more northerly locations or longer day lengths and lower light intensities associated with more northerly latitudes.

These performance characteristics suggest that results from the Canadian yield analyses should be employed in a similar fashion to the results obtained from GCMs. That is, assessments derived from the crop model runs should be used to provide a relative measure of the direction and magnitude of change, rather than a direct measure of wheat yield sensitivity to an altered climate.

IMPLICATIONS OF GLOBAL WARMING, CO_2 INCREASES AND ADAPTIVE STRATEGIES FOR WHEAT YIELDS

These analyses consider both negative and positive effects that a CO_2 - induced global warming might have on wheat yields in the Canadian prairies. Temperature increases would lengthen the frost-free season and reduce the risk of frost damage, but the higher temperatures would hasten the crop maturation process and thereby suppress yields. Elevated CO_2 levels would enhance plant growth and improve water use efficiency (WUE), and thereby tend to offset the potential negative effects of shortened crop maturation periods.

The analyses begin with an assessment of the effects on wheat yields of increases in atmospheric concentrations of CO_2 to 555 ppm coupled with the 1951-80 climatic baseline (i.e. CO_2 increases without climatic change). This paper recognizes other gases such as CH_4, N_2O and CFCs are contributing to the greenhouse effect, and therefore the equivalent of a 2 X CO_2 atmosphere will be reached before there is an actual doubling of CO_2. To account for this, an atmospheric CO_2 concentration of 555 ppm is employed to represent the equivalent of a 2 X CO_2 atmosphere.

Then the analysis considers the combined impacts of these elevated CO_2 levels and the 3 scenarios for global climatic change. The final component of the analyses evaluates the effectiveness of 3 adaptive strategies.

CO_2 Increases in Isolation

CO_2 increases coupled with the current climate would cause considerable increases in wheat yields throughout the prairie region (Figure 4). The most noticeable changes would be in the driest regions where the benefits of increases in WUE would be expected to increase crop yields by more than 50%. Moisture deficits are less severe in the other regions, and therefore the benefits of improved WUE would be less pronounced. Nevertheless, substantial increases averaging about 40% are estimated for these other regions.

CO_2 Increases and Climatic Change

The considerable temperature increases associated with the GISS, GFDL and UKMO scenarios imply that the heat required to mature a crop would be accumulated over a shorter period of time than is currently the case, and this would in turn reduce the amount of time required for spring wheat to mature (Figure 4). For the indicator sites in the southern portion of the Canadian prairies, GISS and GFDL scenarios imply a growing period that is 11 to 14 days shorter than the current. The impacts on days required for maturation are more pronounced for the northern sites, with the GISS scenario shortening the growing period by approximately 3 weeks compared to the more than 4-week reduction associated with GFDL. A similar but more pronounced trend is estimated for the UKMO scenario. A 3-week reduction in the amount of time required for spring wheat to mature is estimated for the southern sites under this scenario, with a 4 to 5 week reduction estimated for the more northerly sites in the Canadian prairie.

The shortened maturation periods associated with the GISS scenario would negate most of the benefits of elevated CO_2 levels at all the indicator sites except those in the driest areas (Figure 5). For the 2 sites in the driest part of the Canadian prairies, Swift Current to Lethbridge, the improvements in WUE would outweigh the disadvantages of less time for grain filling, and yield increases in the 40% to 50% range are estimated. Elsewhere it is estimated yield increases would be limited to about 15%.

The GFDL scenario estimates precipitation increases for the eastern prairies. The combination of a more favourable moisture regime coupled with additional CO_2 more than outweigh the disadvantages of higher temperatures, and crop yields would be expected to increase. This is most pronounced in the driest areas, where it is estimated that the benefit of more moisture and improved WUE would increase wheat yields by more than 60%. However the GFDL scenario also includes drier conditions for the western prairies. This decline in the quality of the moisture regime along with less time for grain filling offset benefits derived from elevated CO_2

concentrations and a decline in wheat yields for the sites in the western prairies would be expected.

The yield impacts under the UKMO scenario are positive for the driest area and negative for all other regions in the Canadian prairie. Once again, the benefits of enhanced WUE is most noticeable in the drier regions where estimated yield increases are in the 15% to 20% range. Elsewhere, the benefits of elevated CO_2 levels would temper, but not offset, the negative impacts of the higher temperatures, and yield declines ranging from 25% to 40% are estimated.

Responding to Global Climatic Change

The analysis presented earlier in this section isolated the effects of several climatic change scenarios on wheat production opportunities in the Canadian prairie provinces. It is anticipated that these sorts of climatic change could occur over a period of several decades. It is therefore reasonable to assume many other biophysical and socio-economic conditions will also change during this time period, and that these adjustments will act in concert with global climatic change to affect crop yields. In this section, 3 possible responses (irrigation, planting earlier and conversion to winter wheat) are evaluated. The selected response measures represent various levels of technological and economic adaptation, with earlier seeding dates being the easiest to invoke and irrigation being the most costly of the 3 options. The yield effects of each response option, relative to the GISS, GFDL and UKMO climatic change scenarios, and CO_2 concentrations of 555 ppm were analyzed. Appraisals of the technical or economic feasibility of each option were beyond the scope of this study.

Irrigation

Under all 3 climatic change scenarios and for all indicator sites, the results suggest irrigation would be a more effective response measure than either earlier seeding or converting to winter wheat (Figures 7, 8 and 9). The effects of irrigation on wheat yields would be expected to vary across the prairie Provinces, with yields at the driest sites (Swift Current and Lethbridge) being most responsive to enhanced water supplies.

Winter Wheat Conversion

The results indicate that conversion to winter wheat would enhance yields at sites in the southern areas. This would allow for better usage of spring moisture supplies and diminish the negative impacts of higher summer temperatures. For the northern locations (Fort

Vermillion, Ellerslie and Prince Albert), the temperature increases would not be sufficient to eliminate cold damage and winter kill, and thereby limit the effectiveness of converting to winter wheat at these sites.

Earlier Seeding

Other analysis suggest that earlier seeding would take advantage of cooler temperatures and thereby lessen the negative yield impacts stemming from a reduced maturation period caused by higher temperatures. Results show the earlier seeding option would be most effective in the driest areas. Under the UKMO scenario, which forecasts the largest temperature increases, earlier seeding dates would diminish the yield reducing impacts, but nevertheless, yield losses are estimated for all areas other than the driest. Under the GISS and GFDL scenarios, the earlier seeding option would enhance crop yields at all sites except Ellerslie and Fort Vermillion. Overall, earlier seeding is probably the easiest of the 3 options to implement, but the results indicate it is the least effective, and in some instances, it would not offset the yield reducing impacts associated a CO_2-induced warming.

SUMMARY AND CONCLUSIONS

This study investigated the extent to which global climatic change, increases in atmospheric CO_2 concentrations to 555 ppm and selected adaptive strategies might combine to alter wheat yields in the Canadian prairie. Three scenarios for global climatic change were analyzed with the CERES - WHEAT crop growth and productivity model The analyses were conducted at 7 sites throughout the Canadian prairie. An assessment of the CERES -WHEAT model under Canadian conditions indicated that the model provides an estimate of the direction and magnitude of yield shifts stemming from a potential climatic change, but the model does not necessarily provide reliable yield estimates for a particular year. The 7 sites were selected to give an indication of the extent to which yield responses might vary across the Prairie region.

The main conclusions from this study are:

- while each of the GISS, GFDL and UKMO GCMs project temperature increases under a 2 X CO_2 climate for the Canadian prairie provinces, each scenario implies a different set of agro-climatic conditions for this region,

- the benefits of increases in CO_2 on wheat yields are most pronounced in the driest parts of the prairies,

- each of the climatic change scenarios tends to imply a different wheat yield response at each of the selected sites across the prairie Provinces,

- the estimated impacts of climatic change on wheat yields will not be distributed uniformly across the Canadian prairies (i.e impacts are both scenario and site sensitive),

- for the scenarios derived from the GISS and GFDL models, temperature increases reduce the time required for crops to mature, and thereby tend to reduce the beneficial effects of higher CO_2 concentrations,

- under the scenario derived from the UKMO model, the temperature increases are sufficient to more than offset the potential benefits of enhanced CO_2 concentrations at all indicator sites except Swift Current and Lethbridge,

- the overall impact of increasing CO_2 concentrations and global climatic change on Canadian wheat yields may not be negative, but it appears that a considerable re-distribution in yield patterns is possible, and

- the effectiveness of response strategies can be expected to vary from region to region, and therefore it is reasonable to expect that no single response strategy will adequately mitigate negative impacts across the Canadian prairie provinces.

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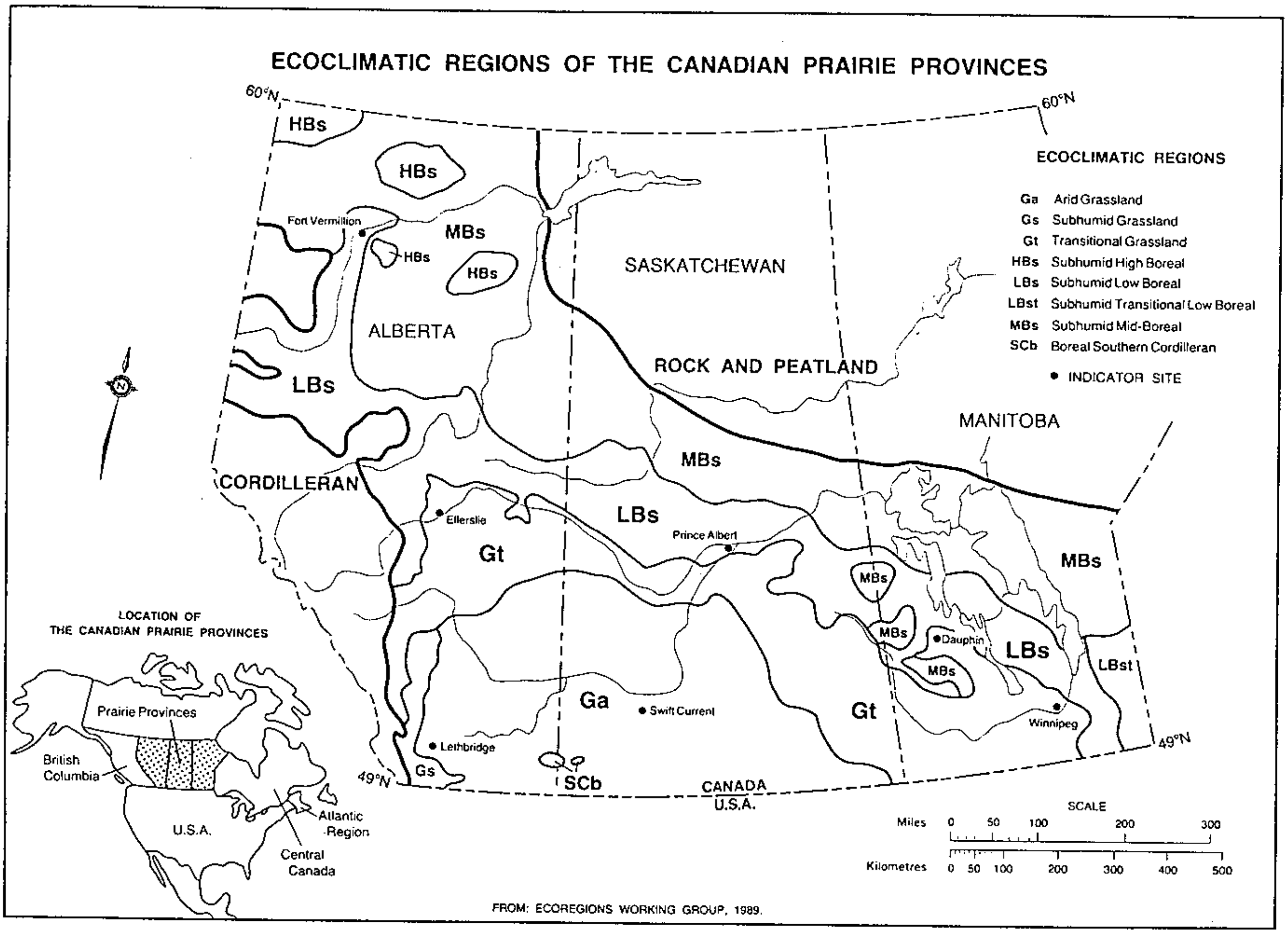

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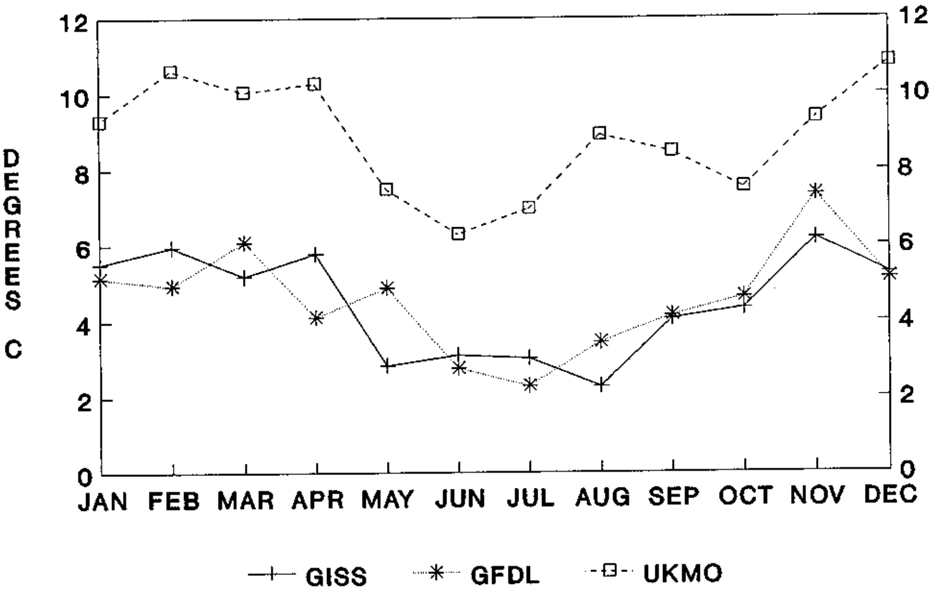
Fig.1 Ecoclimatic regions of the Canadian prairie provinces

WINNIPEG: TEMP. CHANGE
2xCO2 - 1xCO2



LETHBRIDGE: TEMP. CHANGE
2xCO2 - 1xCO2

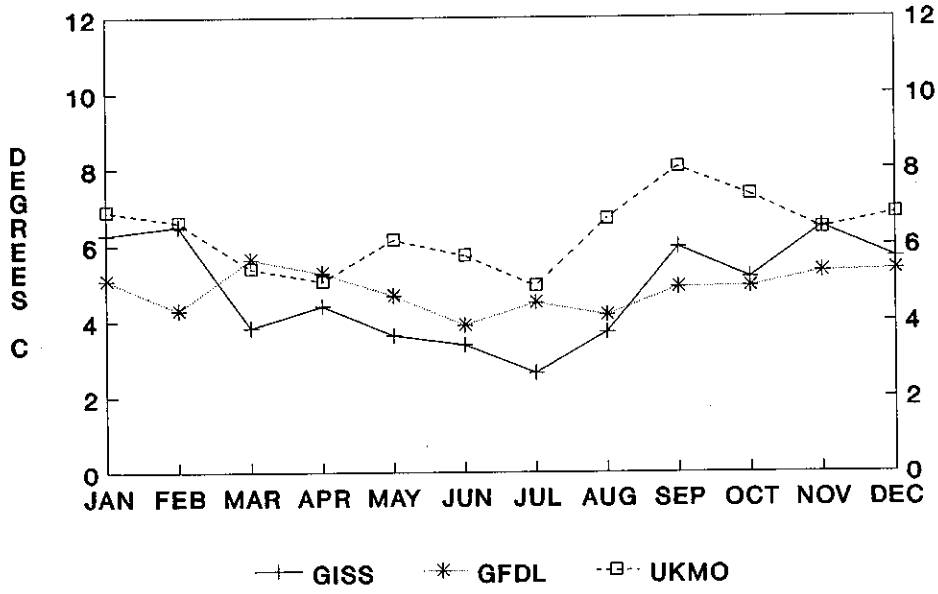
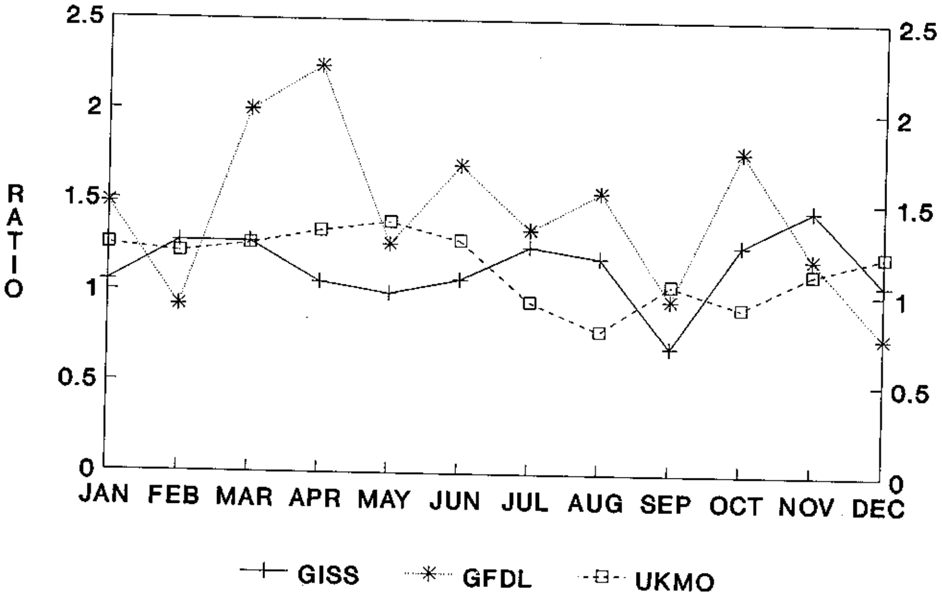
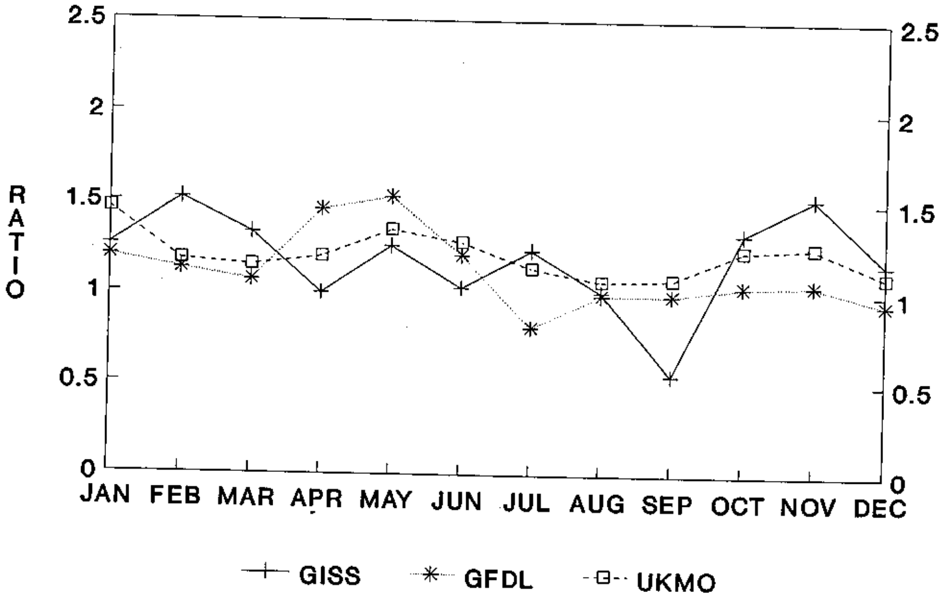


Fig.2 The temperature change estimated in Winnipeg and Lethbridge.

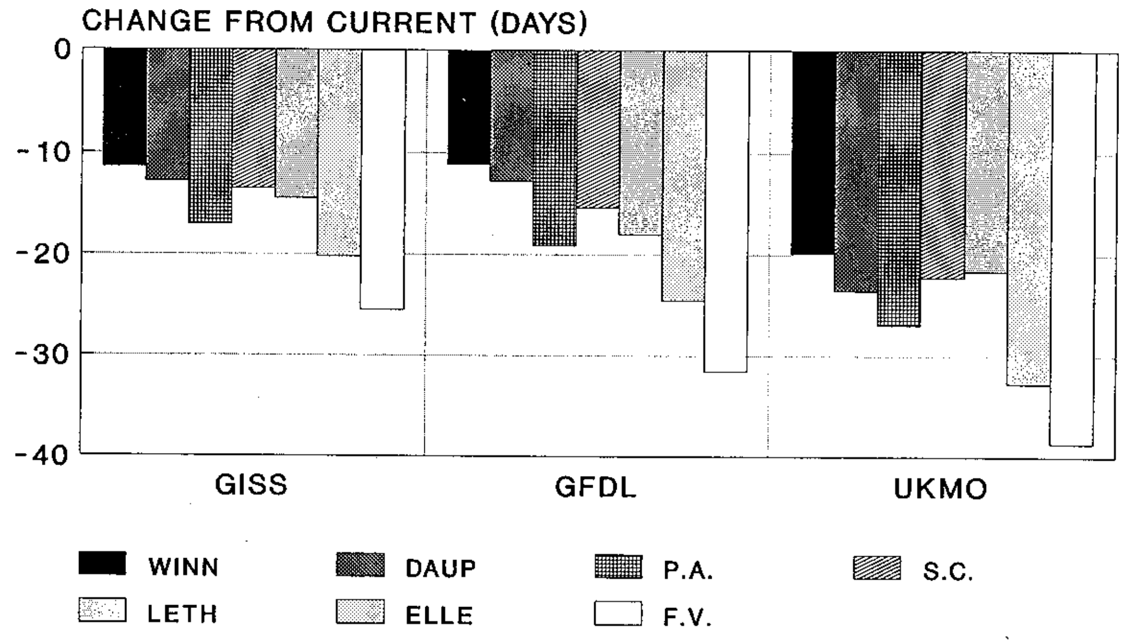


WINNIPEG - PRECIP. CHANGE
2xCO2 / 1xCO2



LETHBRIDGE: PRECIP. CHANGE
2xCO2 / 1xCO2

Fig.3 The precipitation change estimated in Winnipeg and Lethbridge.



CURRENT DAYS TO MATURITY
WINN 87, DAUP 98, P.A. 96, S.C. 98,
LETH 90, ELLE 106, F.V. 119.

Fig.4 Impacts of climatic change on days to maturity.

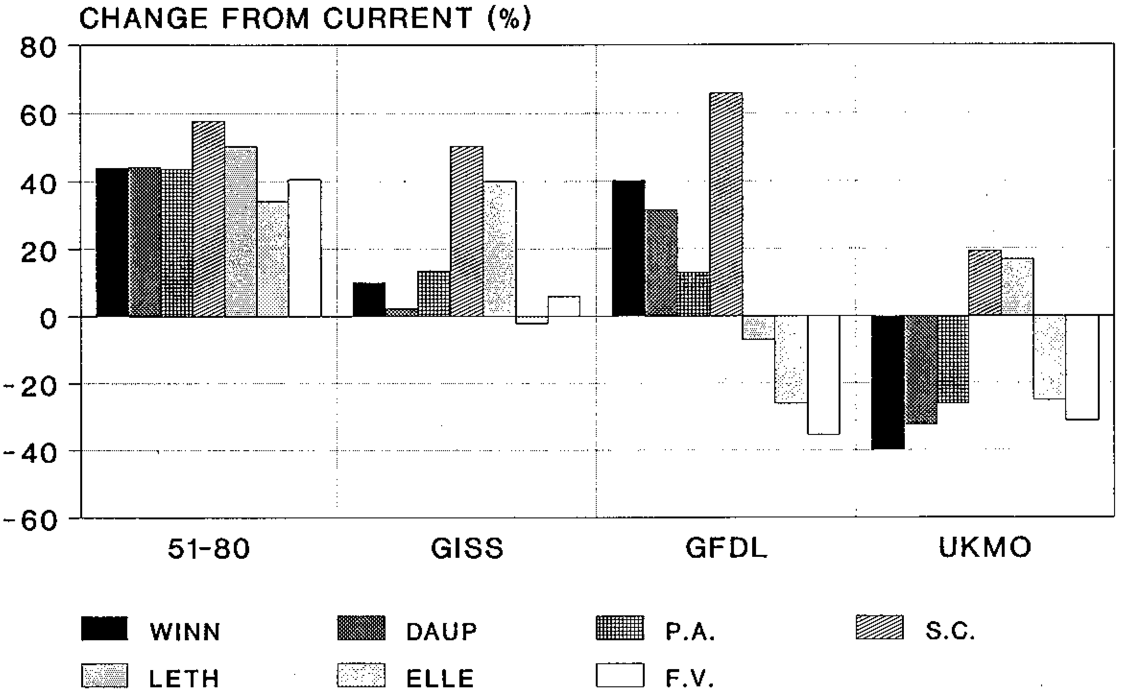
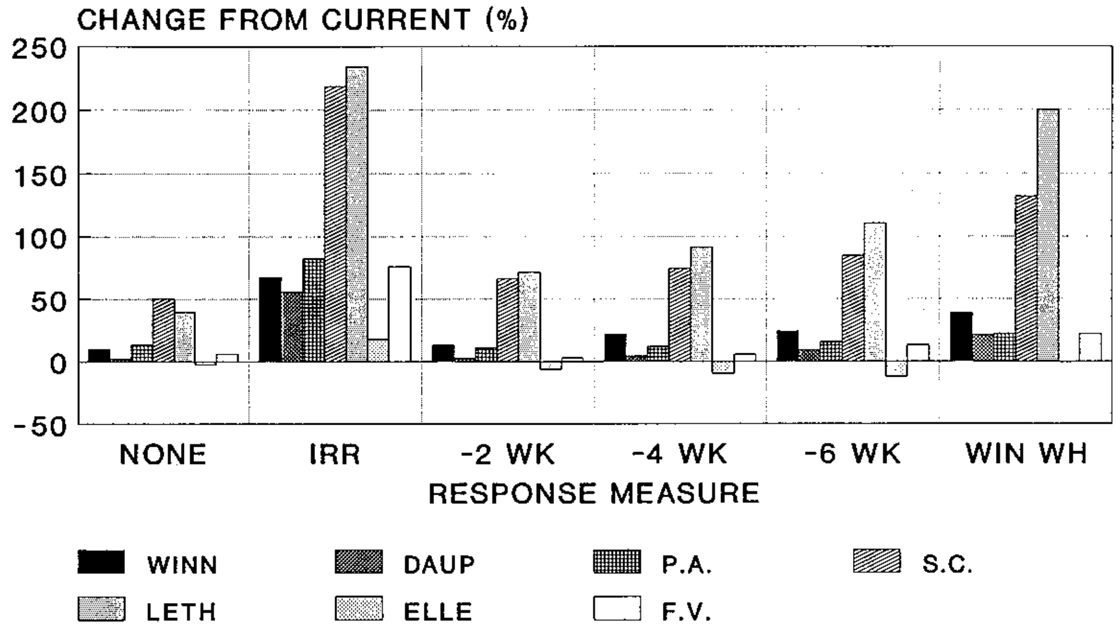


Fig.5 Impacts of elevated CO2 & climatic change on wheat yields.



IRR = IRRIGATE
-2 WK, -4 WK, -6 WK = EARLIER SEEDING
WIN WH = WINTER WHEAT

Fig.6 Responses to the GISS scenario : impacts on wheat yields.

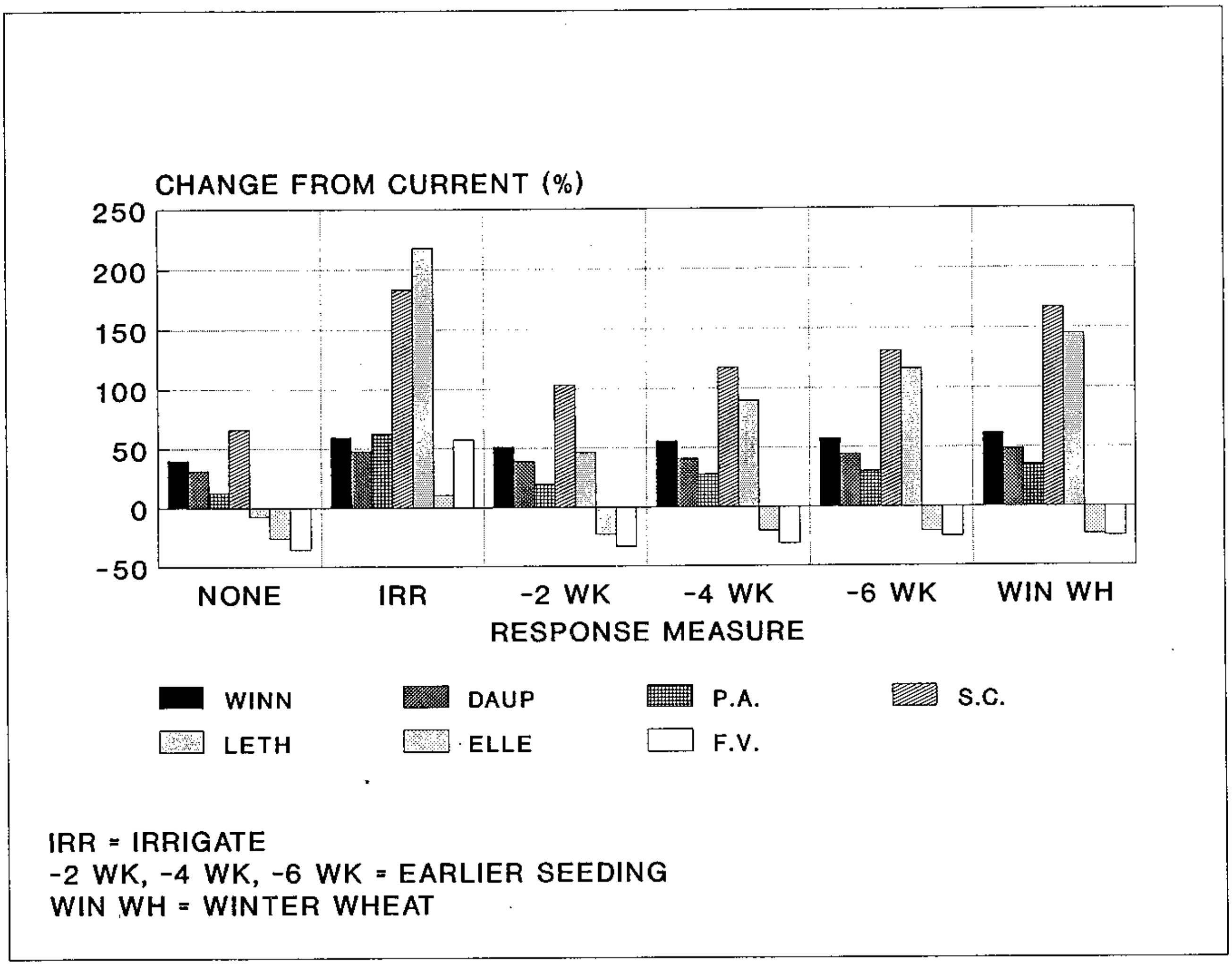
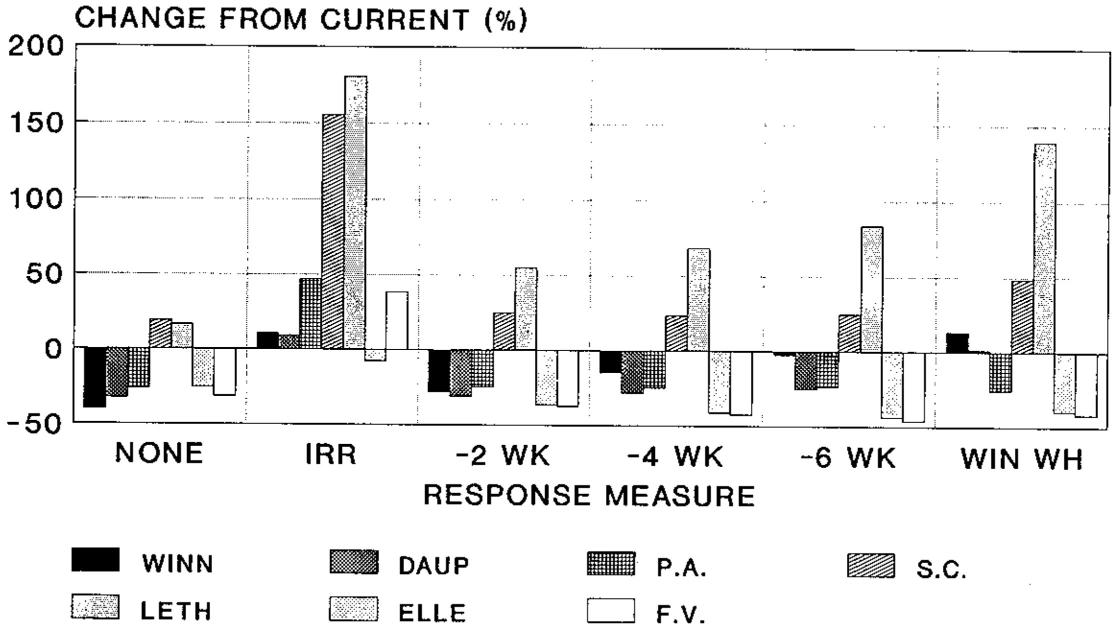


Fig.7 Responses to the GFDL scenario : impacts on wheat yields.



IRR = IRRIGATE
-2 WK, -4 WK, -6 WK = EARLIER SEEDING
WIN WH = WINTER WHEAT

Fig.8 Responses to the UKMO scenario : impacts on wheat yields.

Table 1: COMPARISON OF CERES - WHEAT OUTPUT TO INDEPENDENT ESTIMATES

SITE		SOWING TO MATURITY		YIELD	
		Days	% Diff	kg/ha	% Diff
WINNIPEG	Estimate	87.0[1]		2275[2]	
	CERES[3]	92.5	+6	2682	+18
DAUPHIN	Estimate	90.3		2531	
	CERES	98.1	+9	3210	+21
SWIFT CURRENT	Estimate	97.5		1385	
	CERES	99.7	+2	1612	+16
PRINCE ALBERT	Estimate	96.3		2223	
	CERES	106.1	+10	3020	+36
LETHBRIDGE	Estimate	90.1		1930	
	CERES	101.6	+13	1550	-20
ELLERSLIE	Estimate	106.1		2060	
	CERES	110.5	+4	5450	+164
FORT VERMILLION	Estimate	119.3		1900	
	CERES	118.7	-1	3850	+102

[1] Derived from Bootsma and deJong (1988b).

[2] For Winnipeg, Dauphin, Swift Current and Prince Albert, the independent estimate is derived from a spring wheat model calibrated for the Canadian prairies (Dumanski and Onofrei, 1989). The model employs daily weather data and these estimates represent the average annual yield for the 1964 to 1980 period. The independent estimates for the remaining 3 sites are derived from Alberta Agricultural Statistics and the estimates are the average for 1981 - 1985.

[3] The CERES - WHEAT model was applied using the data described in Section 2. The above estimates have been averaged for the 1951 - 1980 period.