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Climate change, weather variability and corn yield at a higher latitude locale: Southwestern Quebec

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Abstract Climate change has led to increased temperatures, and simulation models suggest that this should affect crop production in important agricultural regions of the world. Nations at higher latitudes, such as Canada, will be most affected. We studied the relationship between climate variability (temperature and precipitation) and corn yield trends over a period of 33 years for the Monteregie region of south-western Quebec using historical yield and climate records and statistical models. Growing season mean temperature has increased in Monterregie, mainly due to increased September temperature. Precipitation did not show any clear trend over the 33 year period. Yield increased about 118 kg ha^{-1} year^{-1} from 1973 to 2005 (under normal weather conditions) due mainly to changes in technology (genetics and management). Two climate variables were strongly associated with corn yield variability: July temperature and May precipitation. These two variables explain more than a half of yield variability associated with climate. In conclusion, July temperatures below normal and May precipitation above normal have negative effects on corn yield, and the growing seasons have warmed, largely due to increases in the September temperature.

1 Introduction

Global climate is changing, mainly as result of increases in the concentration of atmospheric greenhouse gases (GHGs), with the largest climate changes occurring at higher latitudes (IPCC 2001). In southern Canada the mean annual temperature has increased about 0.5°C to 1.5°C during the last century (Zhang et al. 2000), with the greatest warming during the winter and spring, which is more the result of an increase in the

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minimum temperature than the maximum (Zhang et al. 2000; Bonsal et al. 2001). Annual precipitation in southern Canada has also increased about 5% to 35% during the last century and, seasonally, the greatest increases have been in the winter (Zhang et al. 2000). Predicted climate change scenarios have included warming and changes in precipitation during this century, with expected changes in climate variability and increases in the occurrence of extreme climate events such as drought, heat waves and heavy precipitation (IPCC 2001; Salinger 2005).

One of the sectors more affected by climate change and variability will be agriculture, since crop development depends directly on climate (Salinger 2005; Motha and Baier 2005). Extensive droughts across Canada in 2001 and 2002 showed how sensitive Canadian agriculture can be to extreme climate events (Wheaton et al. 2005). Simulation models have suggested that climate change will bring benefits for some crops but not for others. Growing season length should increase in all agricultural regions of the country (De Jong et al. 2001; Bootsma et al. 2004). Yields of soybean, winter wheat and potato would increase in a warmer and wetter climate, but corn yield would decrease (De Jong et al. 2001). Studies of agro-climatic indices predict increases in corn and soybean yields in those areas of Quebec and Ontario where crop heat units are currently below optimum (Bootsma et al. 2004). Simulation models also predict that the grain yields of C_4 crops grown in Quebec, including corn and sorghum, will increase, but yields of C_3 crops as such soybean will decrease (ElMaayar et al. 1997; Singh et al. 1998). Predictions of yields for future climate scenarios always have some degree of uncertainty and may tend to over estimate them (Changnon and Hollinger 2003).

Part of climate change is increased climate variability and this could have the largest effect on crop yield. Relationships between weather and yield have been widely studied, often to identify critical climate factors for crops, mostly in USA. One of the simplest ways to evaluate how climate change and variability affect crop yield is through historical records, and this approach has been utlilized for several decades (Thompson 1975 and 1986; Changnon and Winstanley 2000). Lobell and Asner (2003), investigated relationships between climate trends (temperature, precipitation and solar radiation) and production of corn and soybean in the USA for the period 1988 to 1998 and found that growing season temperature was the only variable correlated with yield; they observed a 17% decrease in yield of both crops for each degree Celsius increase in temperature. Cooling trends from 1930 to 1972, accompanied by increased rainfall and decreased weather variability, were also associated with corn yield in the US corn belt, but in this case the relationship between temperature and yield was positive (Thompson 1986).

In Canada studies of climate change impacts on crops have been confined to simulation models, but there is a need for empirical data regarding the relationship between climate trends with crop yield variability for major crops, as its high latitude means Canada has experienced more climate change over the last 100 years than most countries (IPCC 2001). Our objective was to study the relationship between key aspects of climate (temperature and precipitation) and corn yield trends in the Monteregie region of southwestern Quebec to identify which variables have been associated with yield variability during the 30 year period 1973 to 2003.

2 Methods

The Monteregie, is an agricultural region located in the southwestern portion of the St. Lawrence River Valley (Fig. 1). It contains 23% of Quebec's farmland and produces about

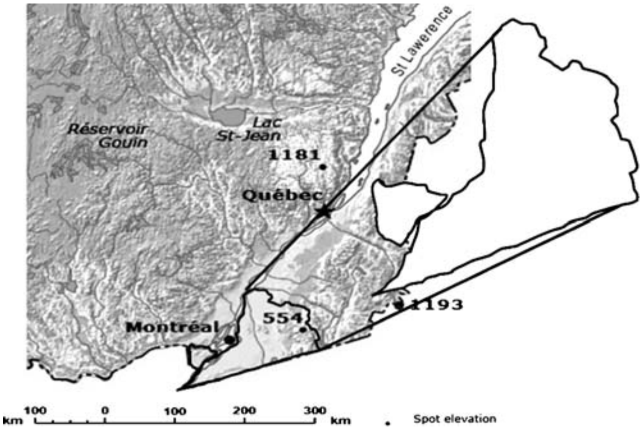

Fig. 1 The Montergie region in the St Lawerence Valley, south-western Quebec

60% of Quebec's total corn grain (Statistics Canada 1998). Most of the area has gradient slopes lower than 4% and gleysolic soils are the dominant type (Jobin et al. 2003). In this area the amount of heat available for the production of corn and soybean are measured in corn heat units (Bootsma et al. 1999). The range of CHU for the region is 2800 to 3300 CHU.

Corn has been grown in Quebec since the early 1900s but continuous yield records extend only back to the 1960s. There is a large gap in available data between the 1940s and 1960s. Corn yields for the Monteregie region over the last 30 years were obtained from bulletins published by Ministère de l'Agriculture du Québec et Bureau de la Statistique du Quebec and from the Institut de la Statistique Quebec (http://www.stat.gouv.qc.ca/donstat/econm_finnc/filr_bioal/culture/culture).

Historical climate data (temperature and precipitation) for the region were obtained from Environment Canada. Nine weather stations were selected across the region, based on their having complete records from 1973 to 2005. The altitude for the selected stations ranged from 31 to 61 m. Monthly temperatures (mean and minimum), and precipitation from May to September, were computed to determine the anomalies (departures from normal) for each month and for the complete growing season, comprised of the 5 months May to September. Accumulated precipitation from August to July was also included. The normal temperature and precipitation was the average of the last 33 years. The separation of weather variables by month and by longer periods was used to determine if weather in some parts of the season has greater effects on corn yield variability than others.

A multiple regression analysis was run using the corn yield historical records and weather variables for the period 1973–2005. In order to process the data a time trend with the effect of no climatic factors (mainly technology – improvements in genetics and production practices), was included, following the method of Thompson (1986); the reason for including only one time trend was because corn yield has maintained a similar rate of increase through the entire 33 year period (Fig. 2). Temperature and precipitation departures from the normal for May, June, July, August and September, and for the entire growing season were also included. Once it was determined that specific variables in the model explained most of the corn yield variability, the model was run again, assuming no deviation from the normal for the weather variables, in order to obtain yield with normal weather, which is the yield trend (Fig. 2). This process allows removal of the technology influence on corn yield and leaves yield variability due to climatic factors (Thompson,

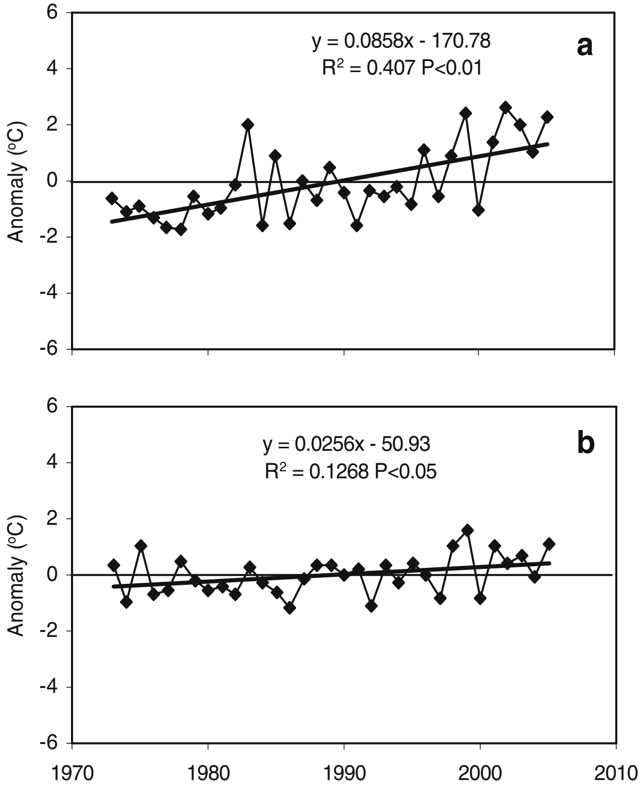

Fig. 2 Temperature trend anomalies, departures from the normal mean temperature, from 1973 to 2005 for **a** September and **b** the entire growing season

1986; Changnon and Winstanley 2000). Yield departures were obtained from the difference between normal yield and observed yield. These departures were used to determine the individual contribution of each weather variable to corn yield variability, due to climatic factors, and to analyze which combination of weather variables explain most of the variability.

3 Results

Mean temperature for the growing season in the Monteregie region of southwestern Quebec has increased approximately 0.8°C from 1973 to 2005, mainly because September temperature has increased about 2.8°C (Fig. 2). May and July temperatures do not show any clear trends, but May was the month with the largest temperature variability (Fig. 3). The growing season and monthly precipitation levels have been quite variable over the last 33 years and show no long-term tendency to increase or decrease (data not shown). With regard to precipitation, particular attention was focused on the amount of rain that occurred in May and July–August, since this may play important roles in corn yield variability. May precipitation ranged from 50 mm below normal up to 62 mm above, with one third of the years being near normal (between −15 and 15 mm of normal; Fig. 4). July–August precipitation ranged from 90 mm below normal to 71 mm above, and tended to be less

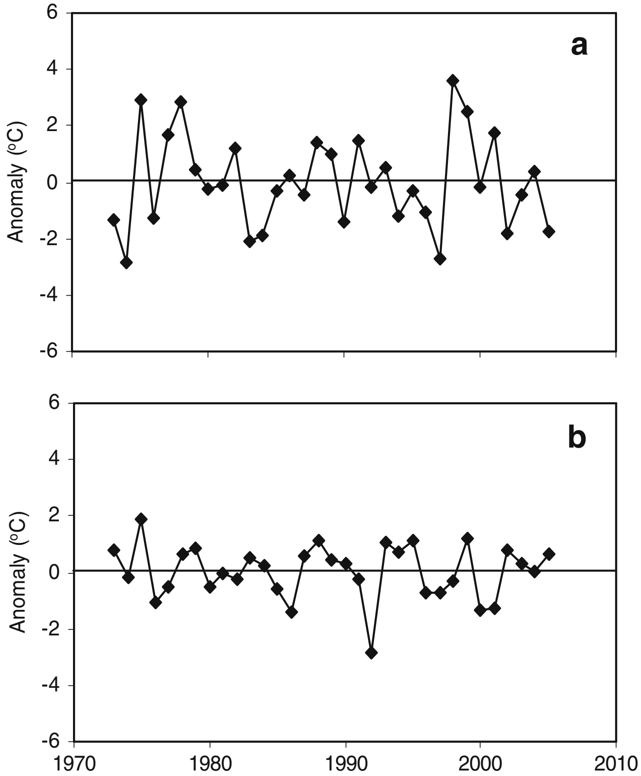

Fig. 3 Temperature trend anomalies, departures from the normal mean temperature, from 1973 to 2005 for **a** May and **b** July

variable between 1990 and 2001, after which the variability increased again (Fig. 4). There was a negative relationship between May precipitation and May temperature (r=−0.52, P< 0.01). In the same way, July temperature and July–August precipitation were negatively correlated (r=−0.39, P<0.05), so that when precipitation increased temperature decreased. July temperature was also positively correlated with August temperature (r=0.35, P<0.05).

After examination of the initial modeling result, three climate variables were retained in the regression model (July temperature, May precipitation and July–August precipitation), plus the background technology trend. July temperature included an exponential (square) effect. July–August precipitation was significant only at P<0.1. Collectively, these variables accounted for 92% of the corn yield variability (Table 1). Under normal weather conditions corn yield has increased 118 kg ha^{-1} annually since 1973 (3.89 t ha^{-1} in 33 years, from an initial baseline yield of 4.6 t ha^{-1}; Table 1, and Fig. 5a).

Technology effect was removed through the differences between yield under normal weather and the observed yield. The corn yield variability due to climatic factors is shown in Fig. 5b. From 1975 to 1991 corn yield variability was relatively low and less than from 1992 to 2005, when it was quite variable. The largest corn yield negative anomalies occurred in 1974, 1992, 2000, 2001 and 2002, and the highest positive anomalies occurred in 1998, 1999, 2003, 2004 and 2005 (Fig. 5b).

The contribution of July temperature anomaly to the effect of climate on corn yield variability was 38%. Yield decreased approximately 377 kg ha^{-1} for each 1°C of

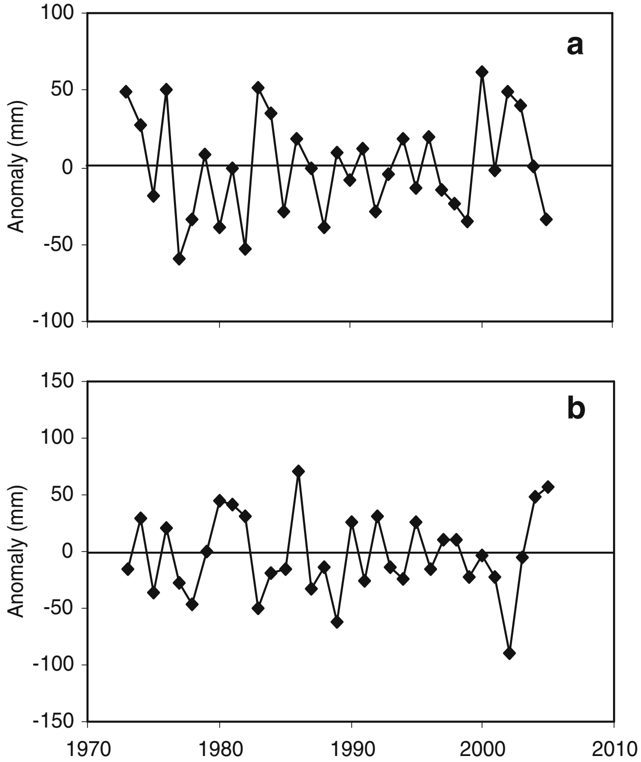

Fig. 4 Precipitation trend anomalies, departures from the normal, from 1975 to 2005 for **a** May and **b** July–August

temperature decrease below normal, but yield increased 126 kg ha^{-1} by each 1°C temperature increase above normal, with an optimum located around 1°C above normal. Thus, temperatures below normal have greater impacts on corn yield than above normal temperatures (Fig. 6a). The normal temperature for July was 20.8°C. The individual contribution of May precipitation to the effect of climate on corn yield variability was 18.8%. Higher yields are obtained when precipitation was below normal; yield decreased approximately 77 kg ha^{-1} for each 10 mm of rain increase (Fig. 6b). The normal May

Table 1 Results of the multiple regression model between yield, year trend (effect of technology), and climate anomalies

Variable	Coefficient	Standard error	*t*(Coef = 0)	*P*
Intercept	4.63812	0.14370	32.27647	0.0000
Technology trend	0.11835	0.00698	16.95084	0.0000
July TA	0.28801	0.08360	3.44503	0.0019
July TA^2	−0.14667	0.04924	−2.97850	0.0061
May PA	−0.00736	0.00215	−3.42733	0.0020
July–August PA	0.00394	0.00204	1.93022	0.0641
R^2=0.923				

TA and *TA^2* Temperature and square of temperature anomalies, *PA* precipitation anomaly.

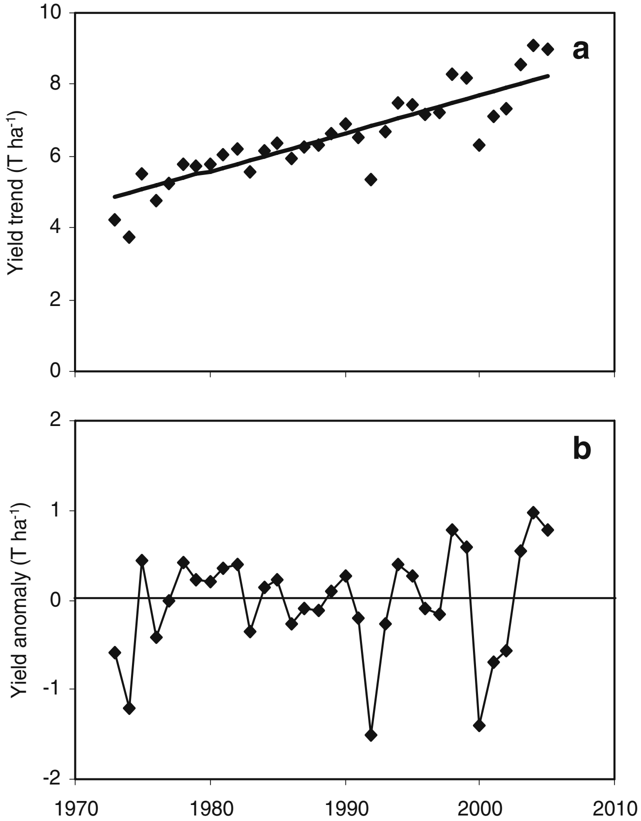

Fig. 5 Corn yield trend from 1975 to 2005 in the Monteregie agricultural region of south-western Quebec. **a** Yield, **b** yield anomaly after normalization. The *bold line* in **a** is the yield trend with normal weather

precipitation is 88.2 mm. The contribution of the July–August precipitation anomaly to the effect of climate on corn yield was small and is not shown here.

Response surface curves were constructed based on the relationship between yield anomalies and the two most important climatic variables: July temperature and May precipitation. Together these variables accounted for up to 62% of corn yield variability. The relationship among the three variables is shown in Fig. 7. Clearly, instances of July temperature below normal and instances of May precipitation above normal have the largest negative impacts on corn yield (Fig. 7). Optimum temperature and precipitation for corn yield are around 1°C above normal and 20 mm below normal, respectively.

4 Discussion

Detectable upward trends in all monthly climatic variables were not anticipated, since the range of years included in this study was relatively short. Growing season temperature increased, largely because the September temperature became warmer. Thus, the autumn temperature is increasing in the Montergie agricultural region. Temperature increases in Canada have been reported as largely due to warmer winter and spring conditions (Zhang et

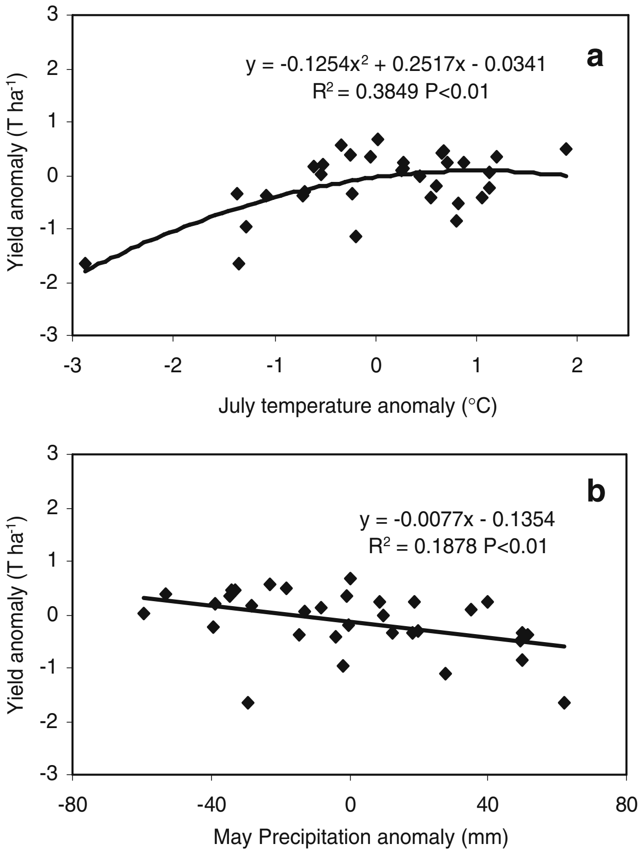

Fig. 6 Regression curve relationships between **a** yield trend anomaly and July temperature anomaly, and **b** yield trend anomaly and May precipitation anomaly

al. 2000); our finding suggest that, at a local level, autumn is getting warmer and this is leading to a longer growing season, as predicted by simulation models which show that growing season length will be extended up to 30–45 days in the main agricultural areas in Ontario and Quebec by the 2070–2099 period, because of warmer spring and fall periods (Bootsma et al. 2004).

Simulation models have predicted warmer temperatures and longer growing seasons, which should lead to improved corn growth and yields in Quebec, but also some limitation in water availability and increased incidences of water stress (Singh et al. 1998; De Jung et al. 2001; and Bootsma et al. 2004). However, how much shifts in weather variability that accompany climate change will affect corn yield in Quebec is not known. We found that yield has increased approximately 3.89 t ha^{-1} over the last 33 years (under normal weather conditions) due mainly to changes in technology. Two major components of technology may be directly involved in these increases, one is the introduction of corn hybrids with lower requirements of CHU, and the other one is the increase in fertilization rates. Since corn has been fertilized at high rates during the last three decades (Agriculture and Agri-Food Canada 1997), probably the main cause of the yield increase in the period examined was steady genetic improvement, including hybrids with lower CHU requirements.

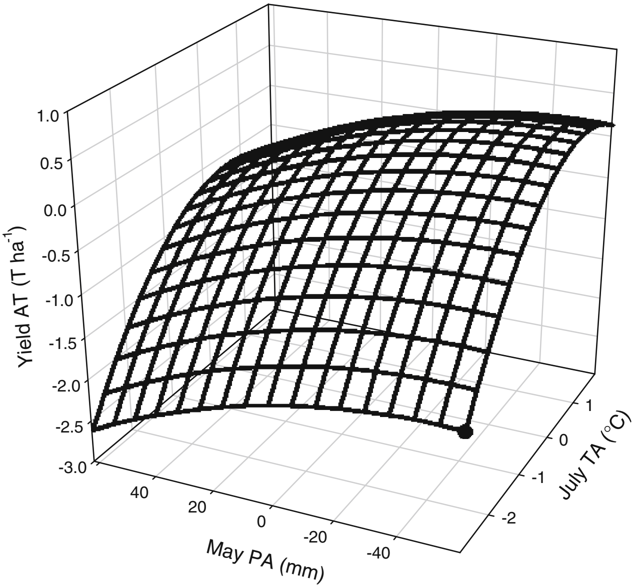

Fig. 7 Regression response surface of relationships among corn yield, July temperature and May precipitation. *PA* Precipitation anomaly, *TA* temperature anomaly and *AT* yield anomaly trend

Once yield trend due to technology was removed, it was observed that two climate variables are strongly associated with corn yield variability: July temperature and May precipitation. These two variables explain 62% of yield variability due to climate. Our study indicates that high May precipitation negatively affects corn yield, probably through delayed planting, possibly increasing early weed establishment, and also decreasing soil temperatures which may delay emergence and early crop development. In the USA high precipitation in May reduces corn yield due to delayed planting date and early weed infestation (Thompson 1986). July temperature alone explained 38% of corn yield variability due to climate. Normal July temperature in the Monteregie region is 20.8°C, and when temperature decreases more than 1°C below normal corn yield is severely affected. Temperature is a critical factor for corn growth and yield; the optimum temperature for this crop is between 20°C to 30°C and any increase above or decrease below this range may negatively affect corn growth or yield (Wilson et al. 1995; Bannayan et al. 2004).

The reproductive stage is very sensitive to temperature; low temperatures may delay anthesis and higher temperatures may shorten the reproductive stage (Bannayan et al. 2004), which could affect final yield. We did not find strong relationships between July–August precipitation and corn yield; however, the lowest yields, in 2001 and 2002, were due to drought in July and August. Those were extreme events that are not common in Quebec, at least at this time, but are more common in Western Canada. This is the first work to show that corn yield in Quebec is affected by variability in July temperature and May precipitation. If growing season temperature increases as has been predicted, probably warmer temperatures in July will improve corn yield, but if spring precipitation increases, this could limit the benefits of a warmer growing season. However, the latter may be offset somewhat by a longer autumn growing period.

5 Conclusions

Growing season temperature has increased in Monterregie, with the largest increase in September. Precipitation did not show any clear trend. Corn yield has increased about 118 kg ha^{-1} year^{-1} from 1973 to 2005 (3.89 t ha^{-1} over the last 33 years), mainly due to changes in technology (the use of better corn hybrids with lower CHU requirements). When the technology factor is removed, the major weather factors affecting corn yield variability are May precipitation and July temperature. July temperature and May precipitation explain more than half of corn yield variability associated with climatic factors. Lower yields were found when May precipitation was above normal and July temperature was below normal. These findings have application for crop producers since we show that there is clear potential for increasingly wet springs to delay planting and unusually hot weather during July to adversely affect corn reproduction and that continued changes in these are probable over the next few decades. An awareness of long term changes in these climatic conditions can allow crop producers to make adaptations to their production systems, such a better drainage and possible mid-season irrigation, to offset changes that will be deleterious to crop yield development. Changes in both May rainfall and July temperature have the potential to adversely affect yield development and are shown to be key factors in examining climate change and climate extreme scenarios as mounting evidence continues to show how sensitive agriculture is to changing climate.

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