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Long-term Yield of Horticultural Crops in Wisconsin in Relation to Seasonal Climate in Comparison with Southern Ontario, Canada

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***Abstract*. The relationship between long-term weather and yield of 11 horticultural crops and one field crop in Wisconsin was determined for a 55-year period (1950–2005). The relationships among weather parameters and yield in Wisconsin were also compared with associations between weather and yields in Ontario, Canada, from a previous study. The number of days in a growing season with maximum temperatures 30 °C or greater (hot days) was negatively correlated with yields of beet for canning (r^2 = 0.15), green pea (r^2 = 0.16), onion (r^2 = 0.08), and sweet corn for processing (r^2 = 0.16) in Wisconsin. Hot days were also negatively correlated with yield of green pea (r^2 = 0.16) in Ontario, Canada. Growing season precipitation in Wisconsin was positively correlated with yields of beet for canning (r^2 = 0.18) and green pea (r^2 = 0.09). An increase in yields of beet for canning in Wisconsin and green pea from Ontario was also observed with an increase in number of days with rainfall during the growing season (r^2 = 0.12 and 0.15, respectively). Monthly minimum and maximum temperatures and hot days had an effect on vegetable yields in Wisconsin. A high number of days with precipitation in May and July was associated with yields of most vegetables and grain corn in Wisconsin. These results indicated the importance of the total and frequency of seasonal precipitation and the negative effect of exposure of crops to extreme temperatures on yields of vegetable crops.**

Vegetable crops play a significant role in the economy of Wisconsin and thereby impact both state-level and national agricultural and manufacturing industries (Keene and Mitchell, 2010). In the United States, Wisconsin ranks seventh for farm gate vegetable sales (Keene and Mitchell, 2010), second for both harvested area and total production of processing vegetables, and third for production value (Keene and Mitchell, 2010; USDA NASS, 2008). Among the main processing vegetable crops are potato (*Solanum tuberosom* L.), sweet corn (*Zea mays* L.), green bean (*Phaseolus vulgaris* L.), green pea (*Pisum sativum* L. subsp. *sativum*), cucumber (*Cucumus sativus* L.), and onion (*Allium cepa* L.) with a total value of U.S. $549 million per year in economic activity in production and processing industries, which provide more than 4300 jobs (Keene and Mitchell, 2010). Similarly, Ontario has more than 50% of the cultivated area for vegetables in Canada with a farm gate value of more than Canadian $245 million per year from the major vegetable crops bean, beet, cabbage, carrot, cucumber, onion, pea, and potato (Statistics Canada, 2011).

A number of investigations have been conducted to determine the impact of weather on crop yield. Most of these studies analyzed the relationship between weather parameters for extended periods and field crop yields such as wheat (Chmielewski and Potts, 1995; Robertson, 1974), corn (Anderson et al., 2001; Kucharik and Ramankutty, 2005), and legumes (Anderson et al., 2001). The yield of several of the major vegetable crops in Ontario, Canada (McKeown et al., 2005, 2006; Warland et al., 2006) and yields of sugar beets (Dubez and Oosterveld, 1976) was shown to be associated with long-term weather patterns. The most important weather factor for cool-season vegetable crops in Ontario was the number of days during the growing season with temperatures that exceeded 30 °C. Yields decreased as the number of hot days increased (Warland et al., 2006). Other climatic factors such as air temperature, total rainfall, and frequency of precipitation are also known to be important factors that affect crop yields (Alexandrove and Hoogenboom, 2001). These environmental factors, for instance high temperatures, may also result in disorders that affect vegetable crop quality (Warland et al., 2006).

The trend in yields of some field and vegetable crops in Wisconsin and the United States was studied by Tiefenthaler et al. (2003). An increase in yield of vegetable crops was identified and was attributed to improved production, irrigation, application of supplemental fertilizers, and better management of insect pests, diseases, and weeds. They considered the introduction of synthetic nitrogen fertilizer following World War II to be the biggest factor in improving yields. We observed that their data showed variations in yield from 1980 onward that resembled the variation in yields in Ontario.

The vegetable production areas of the state of Wisconsin are within the same latitude as those regions of Ontario and there are similarities in agricultural practices and several of the vegetable crops grown. Thus, Wisconsin is an ideal state to compare the long-term effect of climate on vegetable crop yield with that of southern Ontario and to determine if the associations identified in Ontario were relevant to other regions. The length of the growing season should be similar in the two locations, so growing conditions and yields could be similar also. However, the weather in Wisconsin could be quite different from that in Ontario in any year. To study the effects of weather, yield data of the major vegetable crops by county and county weather data for a 55-year period from Wisconsin were examined. The objectives of this study were 1) to determine the associations between long-term weather and yield of 11 horticultural crops and one field crop in Wisconsin; and 2) to determine if the relationships between weather and yields identified in Ontario, Canada, were similar for vegetable crops in Wisconsin.

Materials and Methods

Yield data (Figs. 1, 2, and 3) were obtained from the U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), Wisconsin. Crops examined from Wisconsin were 11 horticultural crops: beet (*Beta vulgaris* L.), cabbage (for fresh market and kraut) (*Brassica oleracea* var. *capitata* L.), carrot [*Daucus carota* subsp. *sativus* (Hoffm.) Arcang.], cucumber (*Cucumus sativus* L.), green pea (*Pisum sativum* L. subsp. *sativum*), onion (*Allium cepa* L.), potato (*Solanum tuberosom* L.), snap bean (*Phaseolus vulgaris* L.), and sweet corn (for processing and fresh market) (*Zea mays* L.) and one field crop: grain corn (*Zea mays* L.). The Wisconsin weather data were collected from weather stations in seven counties: Door, Grant, Sauk, Taylor, Washburn, Waushara, and Wood. The weather data (Fig. 4) were averaged by latitude/longitude across the state between 42 and 44.5° N. This area covers the majority of horticultural production in Wisconsin. Each day's data were averaged from every station to obtain the regional daily averages. From these regionally averaged data, mean temperatures, number of days with temperatures 30 °C or greater (hot days), total precipitation, and number of days with rainfall 2.5 mm or greater were calculated

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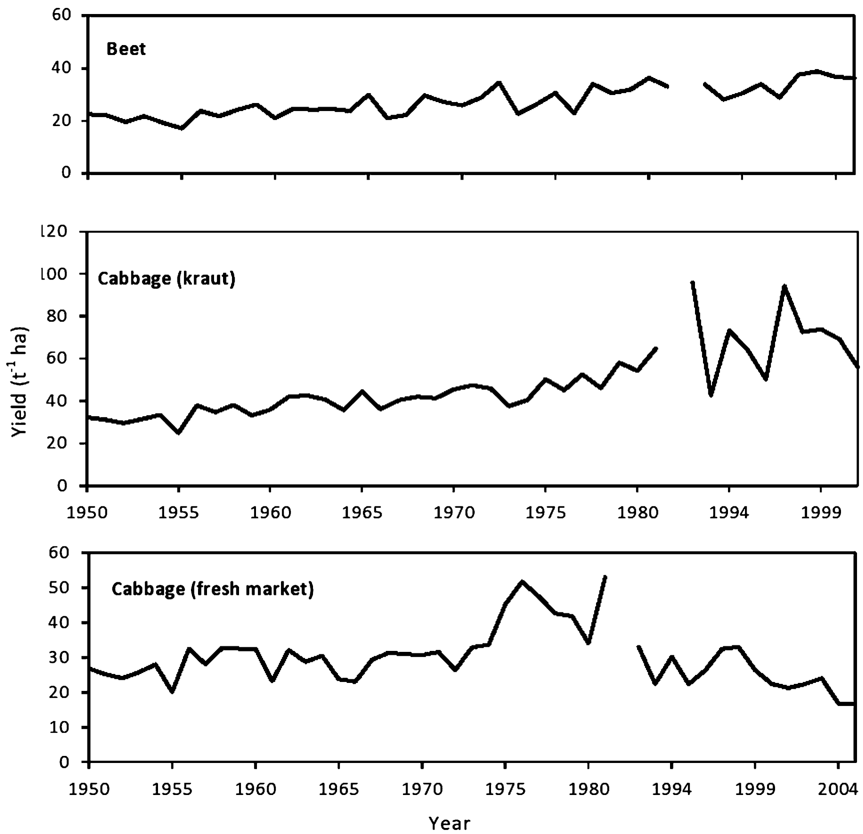

Fig. 1. Yield of beet (1950–1981; 1992–2000), cabbage for kraut (1950–81, 1983–92) and fresh market cabbage (1950–81, 1992–2005) in Wisconsin. Broken line indicates data were not available.

for the growing season, defined as 1 May to 30 Sept. (day of year 121 to 273). Weather data for Ontario were obtained from the Meteorological Service of Canada (Environment Canada, 2002). The portion of the province of Ontario where weather data were collected is a strip running diagonally from long. 79° W lat. 43° N to long. 83° W lat. 42° N and covers the majority of horticultural production in the province. Yield data for Ontario were obtained from the Ontario Ministry of Agriculture, Food and Rural Affairs (2002).

The data analysis consisted of calculating the coefficients of determination (r^2) between yield and the growing season and monthly weather variables. Yield was the dependent variable and weather measurements were the independent variables. The monthly and growing season weather variables were: mean temperature, number of days with temperatures 30 °C or greater, total rainfall, and number of days with 2.5 mm or greater rainfall. Correlation analysis was used to determine the relations between weather variables of Wisconsin and southern Ontario. Data were analyzed using Proc Corr, Proc Reg, and Proc GLM in SAS Version 9.1.3 (SAS Institute Inc., Cary, NC).

The iterative χ^2 analysis (Caprio, 1966) was applied to the yield data of onion and snap bean. The method has been used for yield analyses of wheat (Kalma et al., 1992), apple (Caprio and Quamme, 1999), grape (Caprio and Quamme, 2002), cabbage, onion, and rutabaga (McKeown et al., 2005), and broccoli and cauliflower (Warland et al., 2006). Iterative χ^2 analysis compares the number of days that meet a threshold condition within a moving 3-week period in high or low yield years compared with normal years. The number of days meeting the threshold for years in each yield class is expected to be proportionally distributed; if not, the returned χ^2 departs from 0. A significant difference in the number of days exceeding the threshold value between yield classes exists at the 1% confidence level for $\chi^2 = 7$. In the analysis, a χ^2 is generated for each week of the growing season and for a range of threshold temperature and precipitation values. The maximum χ^2 over the threshold range is assigned to that week, whereas the threshold value of temperature or precipitation that produces the maximum χ^2 is recorded. In previous studies (Caprio and Quamme, 1999, 2002), the threshold value has been called the cardinal value, but this was renamed in this study to avoid confusion with cardinal temperature for optimal growth. Temperature ranges are searched in steps of 1 °C from –10 to 35 °C, and daily precipitation is searched in steps of 0.2 mm from 0 to 50 mm. Thresholds can be sought either above or below each value, referred to as high-to-low or low-to-high scans, respectively. All analyses reported in this study used high-to-low scans.

Results

Relations between Wisconsin and Ontario weather conditions. Several similarities were observed between the long-term weather in Wisconsin and Ontario. Although there were significant positive correlations among all of the weather parameters in Wisconsin [total seasonal rainfall, number of days with rainfall, mean season temperatures, and number of hot days (r^2 = 0.1, 0.59, 0.71, and 0.32, respectively)] and southern Ontario, some of the relationships were weak. The number of days with rainfall and the mean season temperatures showed the strongest relationships.

Temperature. There were significant correlations between yields of several vegetable crops in Wisconsin and weather variables. The number of hot days was more important than the mean seasonal temperatures in determining yield (Table 1). A decrease in yield was observed in beet, green pea, onion, and sweet corn for processing with an increase in the number of days (4–48 d/growing season) with maximum temperatures 30 °C or greater. Similarly, yield of green pea in Ontario was negatively correlated (r^2 = 0.16) with the number of hot days/growing season (0–35 d/growing season).

The effect of high temperatures was even more evident when the data were examined by month. Yields of most of the crops evaluated in this study were affected by the number of hot days in June, July, and August (Table 2). Yield reduction of green pea and onion was associated (r^2 = 0.24 and 0.15, respectively) with increasing number of hot days in June (1–13 d). Yield of green pea, snap bean, cucumber, grain corn, onion, beet, and sweet corn for processing decreased (r^2 = 0.28, 0.23, 0.19, 0.18, 0.17, 0.14, and 0.11, respectively) with increasing number of hot days in July (1–14 d). Many of the crops that were affected by hot days in July were also affected negatively by an increasing number of hot days in August (1–13 d). Although the total number of hot days in the growing season was not related to yield reductions in cabbage, the number of hot days in August was correlated (r^2 = 0.24) to lower yields in cabbage for kraut (Table 2).

Yield was also related to the average maximum and minimum temperatures in June and August for potato and grain corn (Table 2). An increase in yield of potato was associated (r^2 = 0.20) with increasing average minimum temperature in June (10 to 16 °C) but decreased (r^2 = 0.16) with increasing average minimum temperature in August (12 to 19 °C). Similarly, yield reduction of grain corn was correlated with increasing average maximum temperature in August (24 to 30 °C). Yields of fresh market cabbage, fresh market sweet corn, and carrot were not correlated with monthly minimum or maximum mean temperatures or the number of hot days. There were positive correlations between the number of hot days in the growing season and the number of hot days in July or August (data not shown). A negative correlation was found between the number of hot days and the entire growing season total rainfall or the number of days with rainfall (data not shown).

The iterative χ^2 analysis identified relationships between poor and good years for yields of onion and snap bean and climate

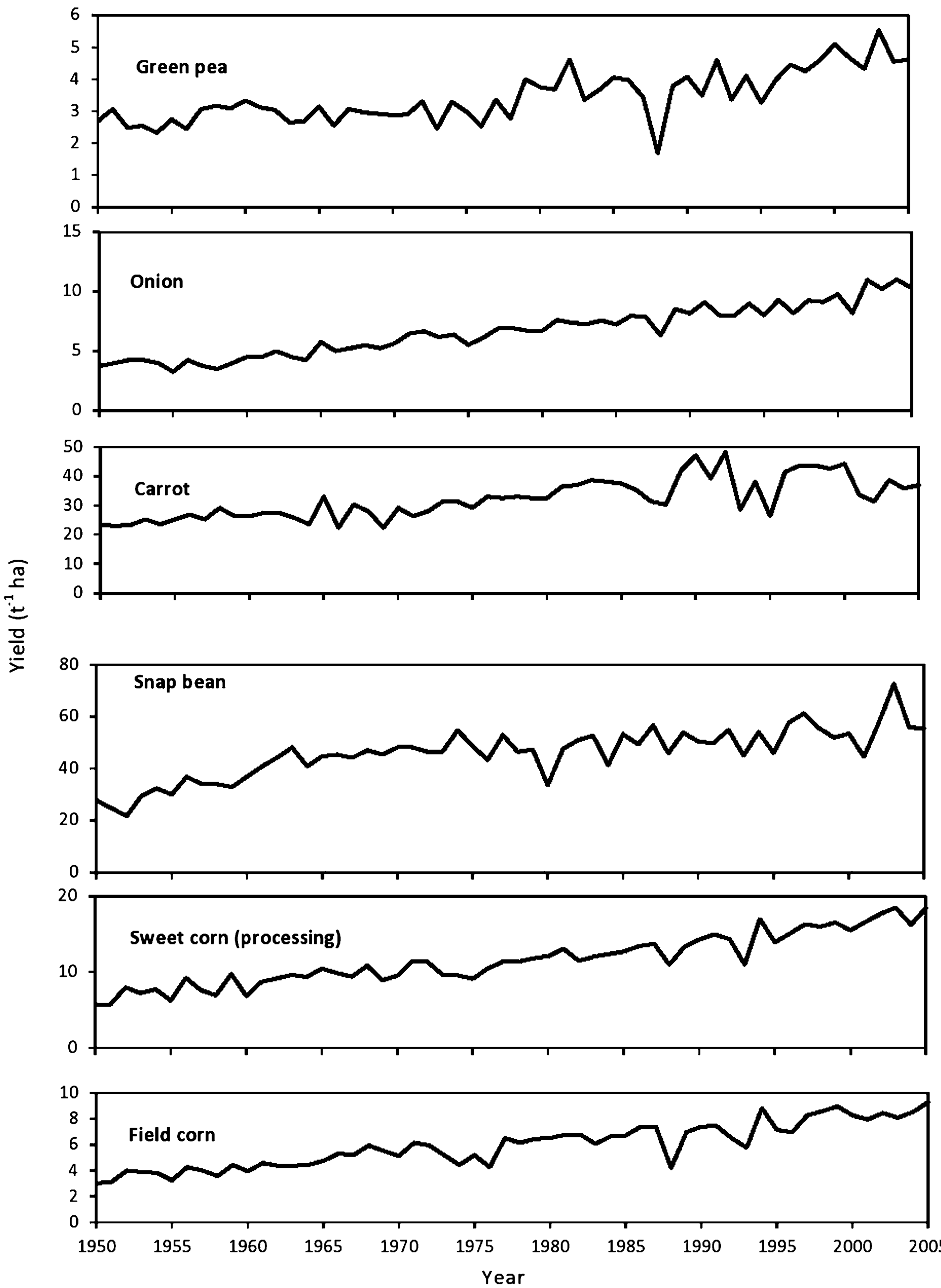

Fig. 2. Yield of green pea, onion, carrot, snap bean, and sweet corn for processing and field corn in Wisconsin (1950–2005).

variables (Figs. 5 and 6). Onions and snap beans show clear peaks in the first week of August. Decreased yields were correlated with the number of hot days with temperatures greater than 30 or 32 °C. In the linear correlation analysis, yields of onion and snap bean were negatively correlated with temperatures. Yields of onion decreased with increasing number of hot days during the growing season and in August. Similarly, snap bean yield decreased as the number of hot days in August increased.

Precipitation. Total seasonal rainfall and number of days with rainfall during the growing season showed some relationships to yields of beet for canning and green pea (Table 1). Yield of beet and green pea in Wisconsin increased with increasing total rainfall during the growing season. Similarly, an increase in yield ($r^2 = 0.15$) of green pea was also observed in Ontario with increasing total seasonal rainfall. No correlations were observed between number of days with rainfall and yield of most vegetable crops in Wisconsin, with the exception of beet ($r^2 = 0.12$) in which yield increased with increasing number of days with rainfall during the growing season (Table 1).

When monthly data were examined, the number of days with rainfall was more important than the total monthly rainfall in influencing the yield of the vegetable crops in this study (Table 2). Higher total rainfall during June (32–201 mm) was associated with higher yield of carrot ($r^2 = 0.15$). Similarly, the number of days with rainfall in July (7–15 d) was related to higher yield of beet ($r^2 = 0.15$), cucumber ($r^2 = 0.15$), snap bean ($r^2 = 0.14$), grain corn ($r^2 = 0.14$), and green pea ($r^2 = 0.12$). However, increasing number of days with rainfall in May (8–15 d) was related to lower yield of beet ($r^2 = 0.15$), cabbage for kraut ($r^2 = 0.19$), and grain corn ($r^2 = 0.14$) (Table 2).

Discussion

Among the weather parameters that were examined to determine their impact on vegetable crop yield in Wisconsin, the number of hot days during the growing season was the most important factor. The importance of the number of hot days on vegetable yield in southern Ontario was reported previously

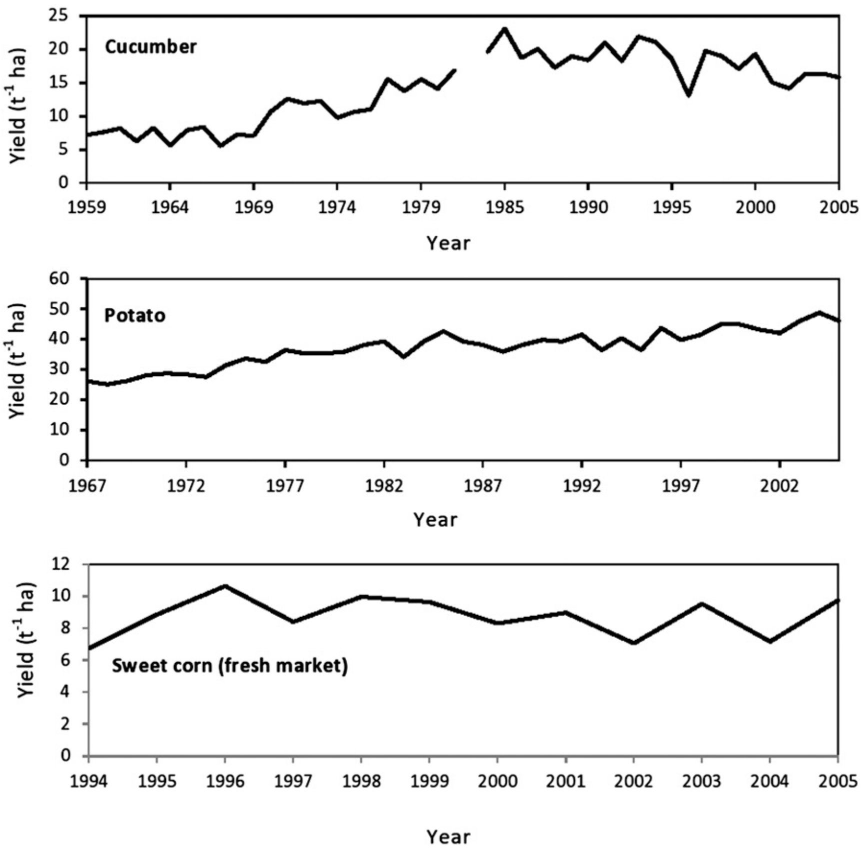

Fig. 3. Yield of cucumber (1959–81, 1984–2005), potato (1967–2005) and sweet corn for fresh market (1994–2005) in Wisconsin. Broken line indicates data were not available.

(McKeown et al., 2005). Temperatures greater than 30 °C may induce stress in vegetables, especially cool-season vegetables (Farnham and Björkman, 2011). Crops that were affected by the number of hot days per growing season in this study were green pea, beet, onion, and sweet corn for processing. Olivier and Annandale (1998) reported the importance of high temperatures in determining the development of pea, which could certainly affect yield. They noted a reduction in germination and development rates in pea at temperatures greater than 30 °C. A controlled environment study showed reduced fresh weight and number and pea seed size after exposure to increasing temperatures from 27 to 32 °C and exposure periods from 1 to 5 days (Lambert and Linck, 1958). In the current study, an increase in the number of hot days during the growing season was associated with reduced yield of green pea in Wisconsin (7–48 d) and in Ontario (1–28 d). The yield of green pea in Wisconsin was also reduced with an increasing number of hot days in June and July. Green pea in Wisconsin is planted mid-April to early May reaches maturity June to July (Delahaut and Newenhouse, 1997) and harvested during July (USDA NASS, 2008). Thus, the results of the present study are consistent with the earlier controlled environment studies showing negative effects of high temperatures as the plants reach maturity.

In this study, the number hot days during the growing season, particularly during June, July, and August, were related to a reduction in onion yield. Yield of onion grown on organic (muck) soil in Ontario (lat. 44°5′ N and long. 79°35′ W) also decreased as the number of hot days increased during the growing season, particularly hot days in June and August (Tesfaendrias et al., 2010). The optimum temperature range for onion is between 12 and 24 °C (Ware and McCollum, 1980) and temperatures above the optimum slow bulb formation (Brewster, 1997), which consequently reduces the marketable yield of the crop.

It was both the number of hot days during the growing season and the number of hot days in July that had a negative effect on beet yield. Beet for canning needs to be a deep red in color (Shoemaker, 1953). High temperatures result in poor color development of the root (Ware and McCollum, 1980). High temperatures can also cause rapid development and white interior rings of the beet root (Schrader and Mayberry, 2003). The exposure of beets to higher temperatures may have reduced the quality of the beets in addition to reducing yields.

Sweet corn is a warm-season crop and is planted throughout May and June in Wisconsin (Delahaut and Thiede, 1999). However, despite the classification as a warm-season vegetable, the optimum temperatures for growth are relatively cool; 16 to 24 °C is best for growth and quality (Maynard and Hochmuth, 1997) and temperatures above 31 °C result in inferior quality sweet corn (Delahaut and Thiede, 1999). In this study the number of days with temperatures 30 °C or greater was associated with a reduction in yield of sweet corn for processing. The most important periods were July and August. A similar trend was seen for grain corn in Wisconsin. In Africa, Lobell et al. (2011) reported that for every day corn is exposed to temperature greater than 30 °C, yield is reduced by 1.0% under optimal rainfed conditions and by 1.7% under drought.

For the cool-season crop, cabbage for kraut, and the warm-season vegetable crops, snap bean and cucumber, the number of days with hot temperatures in August (cabbage) or July and August (snap bean and cucumber) had the greatest effect on yield rather than the total number of hot days during the growing season. Wszelaki and Kleinhenz (2003) reported weight loss of processing cabbage cultivars that were planted in May in Ohio when they were exposed to temperatures greater than 20 °C for 7 d of the last 2 weeks before harvest (98 to 149 d after planting). Similarly, a negative effect of high temperatures, mainly number of days during the growing season, was observed on Brassica crops in southern Ontario (McKeown et al., 2005, 2006; Warland et al., 2006). Warland et al. (2006) also noted reduced marketable yields of Brassicaceae vegetables in Ontario when the plants were exposed to an increasing number of hot days during the critical stages of plant development. Although not significant, the data suggested that yield of fresh market cabbage in Wisconsin was also negatively affected by the number of hot days.

High temperatures result in abscission of reproductive units of snap beans resulting in low pod production (Kigel et al., 1991), which leads to lower yield. Konsens et al. (1991) also reported abscission of flower buds, flowers, and young pods as a result of exposure of snap bean to temperatures of 32/27 °C, which resulted in reduced pod setting. Yield reduction of snap bean in Wisconsin was associated with the number of hot days in July and August, most likely as a result of the effect of heat stress. Yield of cucumber was also reduced as the number hot days in July and August increased. The growth rate of cucumber is slower at temperatures greater than 30 °C and fewer female flowers develop in gynoecious cucumber cultivars exposed to stress associated with high temperatures (Valenzuela et al., 2011). Both of these effects would contribute to lower cucumber yields. In general, of all the weather parameters that affected vegetable yield, growers are least able to mitigate high temperature.

With the exception of beets, the yield of crops in this study was unaffected by the total number of days with rain during the growing season. The yields of beets in Wisconsin and green pea in both Wisconsin and Ontario increased with increasing total growing season rainfall. To maintain yield and quality of their crops, Wisconsin growers irrigate ≈100,000 ha of potato, vegetable, field, turf, and nursery

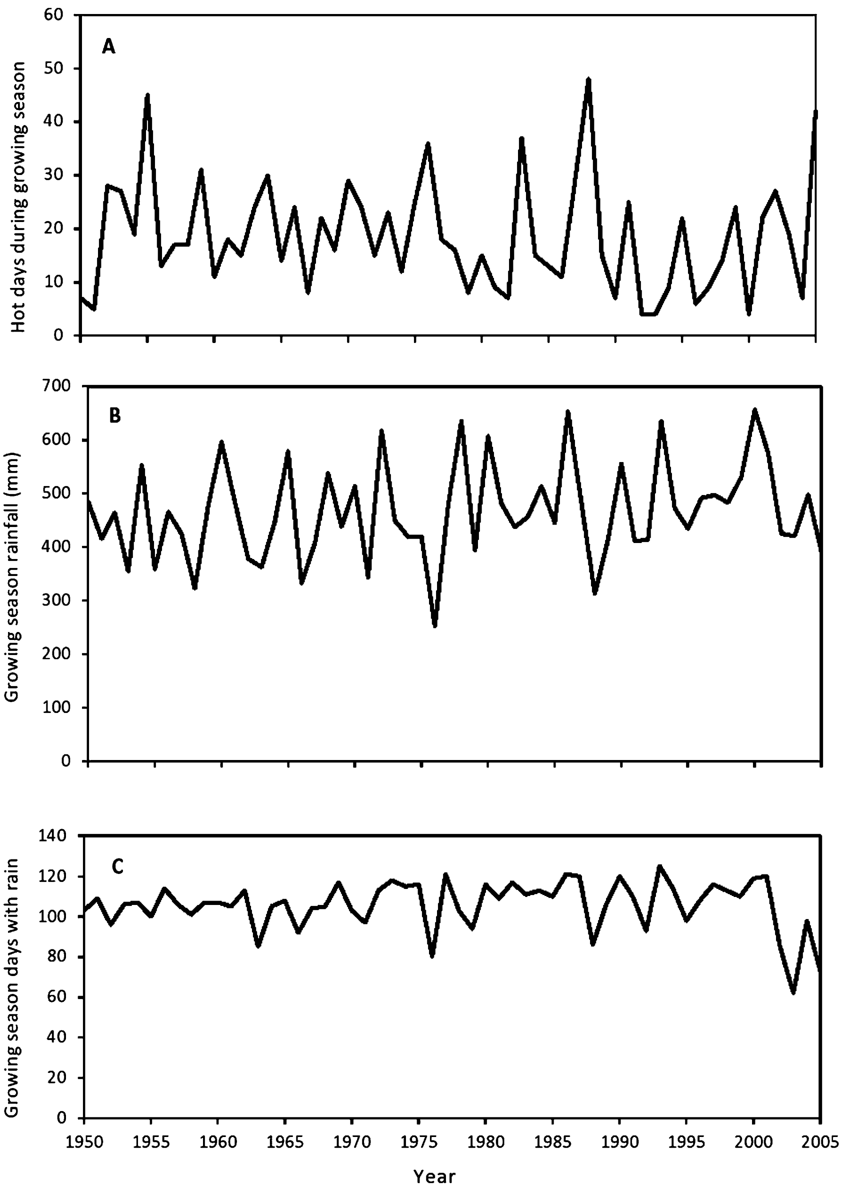

Fig. 4. (**A**) Hot days (days with temperature 30 °C or greater) during growing season; (**B**) total growing season rainfall (mm); and (**C**) days with rainfall (2.5 mm or greater) during the growing season in Wisconsin (1950–2005).

Table 1. Coefficient of determination (r^2) analyses of annual crop yield ($t \cdot ha^{-1}$) of vegetable crops in Wisconsin State versus growing season precipitation, number of days with rain during the growing season, and number of days with temperatures 30 °C or greater.

Crop[z]	Mean temperature	Days with 30 °C or greater	Growing season precipitation	Days with rain
Beet (Canning)	0.001	0.15** (-)[y]	0.18**	0.12*
Cabbage (Fresh market)	0.01	0.03	0.02	0.02
Cabbage (kraut)	0.01	0.01	0.001	0.005
Carrot	0.004	0.01	0.002	0.02
Cucumber	0.01	0.05	0.04	0.02
Grain corn	0.01	0.06	0.07	0.02
Green pea	0.03	0.16**(-)	0.09*	0.00
Onion	0.02	0.08* (-)	0.05	0.01
Potato	0.005	0.01	0.004	0.06
Snap bean	0.002	0.03	0.06	0.003
Sweet corn (processing)	0.02	0.08* (-)	0.05	0.01
Sweet corn (Fresh market)	0.04	0.04	0.002	0.01

[z]Beet 1950–81; 1992–2000 (n = 41 years); cabbage (fresh) 1950–81, 1992–2005 (n = 46 years); cabbage (kraut) 1950–81, 1983–92 (n = 42 years); carrot, grain corn, green pea, onion, snap bean, and sweet corn (processing) 1950–2005 (n = 56 years); cucumber 1959–81, 1984–2005 (n = 45 years); potato 1967–2005 (n = 39 years). All are vegetable crops with the exception of grain corn, a field crop.
[y]Sign of slope of correlation indicated; * and ** significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

crops annually (Curwen and Massie, 1994). Irrigation can compensate for low rainfall and protect the yield of vegetable crops. Thus, the data on rainfall may not be as relevant for irrigated crops. Irrigation of many vegetable crops such as onion and potato began in Ontario in 1989 after a season of very low rainfall in 1988 (M.R. McDonald, personal communication), and ≈70% of the potato crop in Ontario is irrigated (E. Banks, personal communication). In Ontario, processing pea is not irrigated and pea for the fresh market receive some irrigation, but this accounts for less than 20% of the total area of pea fields (M. Paibomesai, personal communication).

The number of days with rain in each month during the growing season was more important for most crops than the total growing season rainfall or total monthly rainfall. The number of days with rain in May, which may result in excessive moisture, had a negative effect on the yields of beet, cabbage for kraut, grain corn, and snap bean. In Wisconsin, these crops are planted between mid-April and early June (Delahaut and Newenhouse, 1997). Depending on planting date or growth stage of the crop, excess moisture may result in delayed field work, germination failure (Heydecker and Orphanos, 1968), and development of seedling diseases caused by soilborne pathogens (Koike et al., 2007), all of which can affect yield.

Increased carrot yield was associated with increasing total monthly rainfall in June. Carrots are more sensitive to drought stress during early growth stages, which results in reduced yield, compared with drought stress occurring closer to harvest (Sørensen et al., 1997). Thus, the amount of rain in June may have affected germination and uniformity of emergence and early establishment of carrot in Wisconsin, which in turn affected yield. The number of days with rainfall in July was associated with increased yield of beet, cucumber, grain corn, green pea, and snap bean. Anderson et al. (2001) reported the importance of water and its availability in determining yield of corn, soybean, and alfalfa in the Great Lakes Region during the period 1895 to 1996. They noted an increase in regional yield as a result of adequate rainfall and less stressful growing season weather. The need for moisture in rainfed crops and the sensitivity of different crops to moisture deficit at certain growth stages may have led to the stronger correlation of yield with the frequency of rainfall in July (McKeown et al., 2005).

The combination of linear correlation analysis and the iterative χ^2 analysis was useful in determining the timing of the weather events and the impact they have on crop yields. The iterative χ^2 analysis indicated that both snap bean and onion are very sensitive to daily maximum temperatures at the very end of July/beginning of August. High temperatures at this time significantly decreased yield over years without many hot days. Little correlation was seen with precipitation, as previously reported in Ontario. Other crops in Wisconsin did not exhibit clear trends from the iterative χ^2 analysis. Generally, the results of this study

Table 2. Coefficients of determination (r^2) of annual crop yield (t·ha^{-1}) of 11 crops in Wisconsin versus mean monthly temperatures, number of days with maximum temperature of 30 °C or greater, total monthly rainfall and number of days with rain 2.5 mm or greater.

	Minimum temperature		Maximum temperature	Number of days with temperature 30 °C or greater			Total monthly rainfall	Number of days with rainfall	
Crop[z]	June	August	August	June	July	August	June	May	July
Beet					0.14*(-)[y]			0.15*(-)	0.15*
Cabbage (kraut)						0.24**(-)		0.19*(-)	
Carrot							0.15*		
Cucumber					0.19**(-)	0.22**(-)			0.15*
Grain corn			0.18**(-)		0.18**(-)	0.24**(-)		0.14*(-)	0.14*
Green pea				0.24**(-)	0.28**(-)				0.12*
Onion				0.15*(-)	0.17*(-)	0.30**(-)			
Potato	0.20**	0.16*(-)							
Snap bean					0.23**(-)	0.31**(-)			0.14*
Sweet corn (processing)					0.11*(-)	0.15*(-)			

[z]Beet 1950–81; 92–2000 (n = 41 years); cabbage (fresh) 1950–81, 1992–2005 (n = 46 years); cabbage (kraut) 1950–81, 1983–92 (n = 42 years); carrot, grain corn, green pea, onion, snap bean, and sweet corn (processing) 1950–2005 (n = 56 years); cucumber 1959–81, 1984–2005 (n = 45 years); potato 1967–2005 (n = 39 years). All are vegetable crops with the exception of grain corn, a field crop.

[y]Sign of slope of correlation indicated; * and ** significant at $P \leq 0.05$ and $P \leq 0.01$, respectively. Blank spaces indicate no significant correlation.

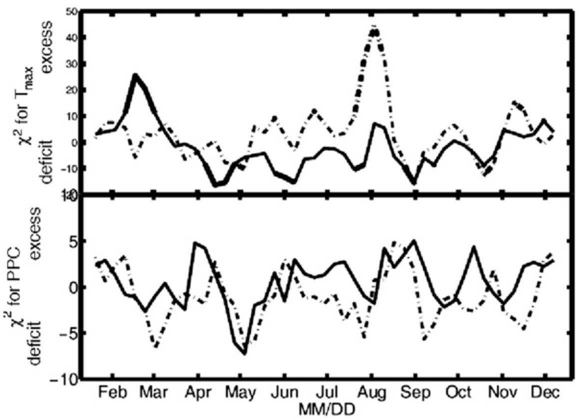

Fig. 5. Chi-square analysis for onion, daily maximum temperature, on top, and precipitation on the bottom. The solid line shows the χ^2 for high-yield years and the dashed line for low-yield years. The thicker line indicates significant correlation at $P < 0.01$. The peak for maximum temperature at the beginning of August indicates a strong correlation between poor yields and daily maximum temperatures greater than 30 °C.

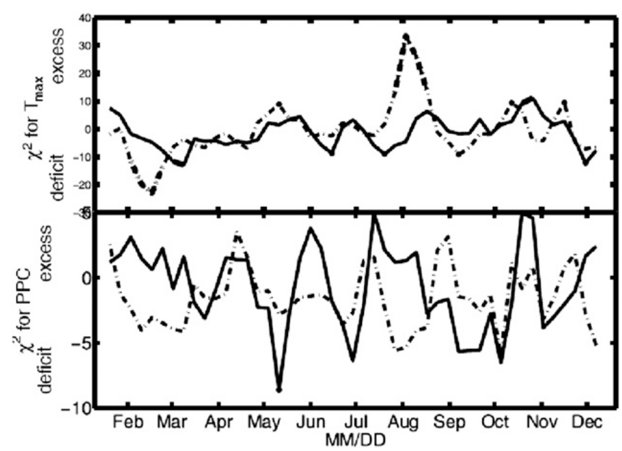

Fig. 6. Chi-square analysis for snap bean, daily maximum temperature, on top, and precipitation on the bottom. The solid line shows the χ^2 for high-yield years and the dashed line for low-yield years. The thicker line indicates significant correlation at $P < 0.01$. The peak for maximum temperature at the beginning of August indicates a strong correlation between poor yields and daily maximum temperatures greater than 30 °C.

were consistent with the previous studies conducted in Ontario (McKeown et al., 2005; Tesfaendrias et al., 2010; Warland et al., 2006), which investigated trends in long-term weather conditions in relation to the yield of vegetable crops.

In conclusion, this study showed the impact of weather on vegetable crop yield and the use of long-term weather parameters in determining crop yield. The study also showed that there was a number of similarities between weather parameters of Wisconsin and southern Ontario. Although rainfall and temperature were somewhat related, the greatest similarities between the two regions were growing season temperatures and the number of hot days. However, the results demonstrated that they were different enough to be reasonably independent samples. This could be the result of local practices or other non-weather factors. The crop that showed the most consistent response in both Wisconsin and Ontario was green pea. The most important weather variables that determined yield of green pea were total growing season precipitation, which increased yield, and the number of hot days, which decreased yield. The results of this study substantiate the observations from previous studies that temperatures 30 °C or greater have a negative effect on yield of several vegetable crops. Thus, the number of days with hot temperatures, especially during July and August, emerges as the most important environmental factor that should be measured to estimate yields of vegetable crops. Yield estimates are important for vegetable processors who must plan for a constant flow of produce to a processing plant as well as for growers and retailers of fresh produce. High temperatures can be the most difficult weather parameter to modify, unlike cool temperatures, which can be more easily modified by mulches or rowcovers. For the crops that need irrigation, growers may reduce the irrigation interval during hot days to prevent heat stress. Thus, this work emphasizes the importance of breeding vegetable crops for heat tolerance.

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