Agricultural and Forest Meteorology 150 (2010) 161–165

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Temperature and precipitation effects on canola yields in Saskatchewan, Canada

H.R. Kutcher [a,*], J.S. Warland [b], S.A. Brandt [c]

[a] Agriculture and Agri-Food Canada, Box 1240, Melfort, Saskatchewan, Canada S0E 1A0
[b] Department of Land Resource Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1
[c] Agriculture and Agri-Food Canada, Box 10, Scott, Saskatchewan, Canada S0K 4A0

ARTICLE INFO

Article history:
Received 29 January 2009
Received in revised form 18 September 2009
Accepted 26 September 2009

Keywords:
Brassica species
Heat stress
High temperature
Yield

ABSTRACT

Adverse weather is often associated with yield reduction of canola, also known as oilseed rape. Historical weather and crop yield data from Saskatchewan (SK) crop districts were analyzed with both simple correlation analysis and iterative principal components analysis. The analyses demonstrated the negative impacts of high temperatures and low precipitation, and the positive effects of greater-than-average precipitation, and to a lesser extent, cooler-than-average nocturnal temperatures. Iterative Chi-square analysis and iterative principal components analysis both showed that the beginning of July, which coincides with the early part of the flowering period of the crop in SK, was the critical time in which high temperatures (>30 °C) and low precipitation led to yield loss.

Crown Copyright © 2009 Published by Elsevier B.V. All rights reserved.

1. Introduction

Canola, known as oilseed rape in Europe, is a cool season crop that may be adversely affected by abiotic stresses such as high temperatures (Nuttal et al., 1992; Brandt and McGregor, 1997; Aksouh-Harradj et al., 2001). The effects of high temperature stress on various *Brassica* spp. result in infertility and/or yield loss (Polowick and Sawhney, 1988; Heather et al., 1992; Morrison, 1993; Björkman and Pearson, 1998; Angadi et al., 2000; Gan et al., 2004; McKeown et al., 2005; Warland et al., 2006). A study of canola and condiment mustard (*Brassica* spp.) indicated these species were most susceptible to high temperature stress during flowering, rather than at podding (Angadi et al., 2000). In that study, *Brassica rapa* L. was the most sensitive to high temperature stress, while *B. napus* L. and *B. juncea* L. were both less effected. Morrison and Stewart (2002) reported that for all three of these species the threshold temperature during flowering, which resulted in seed yield losses, was 29.5 °C. Other reports suggest the critical temperature for heat stress in *B. napus* canola is between 30 and 32 °C (Fan and Stefansson, 1986; Polowick and Sawhney, 1988).

Seed yield of canola is determined by the number of pods, seed weight and seeds per pod (McGregor, 1981). Canola has an indeterminate flowering habit, but the number of flower initials that develop is usually limited; as a result, so is the number of pods. The number of pods is influenced most strongly by environment, and has the greatest influence on yield (Olsson, 1960). Due to the pattern of flower and pod development in canola, there is potential for recovery from injuries that occur early in the flowering period (McGregor, 1981). This recovery may be through development of additional flowers, or retention of flowers and pods that would otherwise would be aborted. For example, three *Brassica* spp. responded to heat stress at flowering by continuing to flower after the heat stress was removed (Angadi et al., 2000). Seed yield on the main stem was reduced by 89% due to heat stress, but compensation by pods on branches reduced overall yield loss to 52%. The yield decrease was due to reductions in fertile pods, seed weight, and seeds per pod. Of the three species studied, *B. napus* was least able to recover from severe stress at flowering. Another study of *Brassica* spp. that were stressed by high temperature also showed recovery when the stress was imposed at earlier growth stages (bud formation), but stress imposed during pod development severely reduced most yield components measured (Gan et al., 2004). In that study, the effect of water stress on seed yield was minimal regardless of crop developmental stage when the heat or water stress occurred.

Examination of long-term canola/rapeseed yields revealed that yield increased from 1.01 t ha^{-1}, when production was predominately rapeseed (1960s to the mid-1970s), to 1.29 t ha^{-1} with the development of canola-quality cultivars (late 1970s to 1980s). With improved production technologies and variety improvement, Bérard et al. (2001) suggested that yields in the 1990s should have

* Corresponding author. Tel.: +1 306 752 2776x232; fax: +1 306 752 4911.
E-mail address: Randy.Kutcher@agr.gc.ca (H.R. Kutcher).

0168-1923/$ – see front matter. Crown Copyright © 2009 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.agrformet.2009.09.011

increased to 1.40 t ha^{-1}, but observed yields were almost 10% lower than expected.

Canola is seeded during the month of May in Saskatchewan, with bolting and flowering beginning in late June to early July. The crop usually flowers for a duration of 2–4 weeks depending on environmental and agronomic conditions. Canola is usually swathed mid-August to early September, followed by combining 2–4 weeks later. High temperatures often occur during flowering of the crop. Long-term (1971–2000) climate data indicate that the number of days with temperatures exceeding 30 °C during the month of July varies over the canola production area from 1.6 in the northeast of the province to 4.3 in the southwest (Environment Canada, 2008).

Extreme temperatures coupled with other factors such as water deficits may contribute to high temperature stress. The effects of climatic factors on field crops may be studied through analysis of weather records in combination with long-term yield records. Using this approach, the timing of days with high temperature was shown to have a substantial influence on yield of horticultural *Brassica* crop in southern Ontario (McKeown et al., 2005; Warland et al., 2006). The aim of the current study was to assess the effect of temperature and water stress on canola over the period of canola production in Saskatchewan, and to determine if variation in seasonal climate might be associated with differences in yield observed among years. Knowledge of critical periods of temperature and precipitation stress would be beneficial in the development of strategies to mitigate the impact of these stresses on canola production.

2. Methodology

2.1. Yield and weather data

Saskatchewan is divided administratively into rural municipalities, which are typically about 30 km × 30 km. These are grouped into 20 crop districts, generally composed of 15–20 rural municipalities each. Canola yield records by rural municipality are available from Saskatchewan Agriculture and Food (2005). Canola yields from 1967 to 2001 were averaged by crop district for this study. During this period, the area of canola or oilseed rape harvested varied from a low of 206,800 ha in 1968 to a high of 2,658,800 ha in 1999 (Statistics Canada, 2009). Production has always been greatest in the cooler, more moist areas of the province, which is to the north of a line drawn from the very south-east to the north-west near the city of Lloydminster.

Daily temperature and precipitation data, collected by Environment Canada at standard meteorological stations, are available by station (Environment Canada, 2002). In Saskatchewan, there are generally 1–2 stations per rural municipality. Weather data were averaged, without weighting, on a daily basis across each crop district for the analyses. Data were available to 2001, giving a combined weather-yield record of 35 years. Each crop district within the province was considered as one sample, giving a total of 700 samples for the analysis. Many other relevant variables, such as soil moisture or soil type, are not considered because data do not exist at this level of detail, generally limiting analysis to meteorological station data.

For the correlation analysis, five descriptor variables were defined arbitrarily from the daily temperature and precipitation data for each year in each crop district. These were the growing-season-averaged daily mean (T_{mean}), maximum (T_{max}) and minimum (T_{min}) temperatures, the number of days with maximum temperature greater than 30 °C in the year ($D_{max>30}$) and growing-season total precipitation (*ppc*). For this study, the growing season was defined as days of year 121–273 (1 May to 30 September).

2.2. Correlation

Correlation coefficients for simple linear correlation, represented by *R* and *P*-values were determined for the relationship between yields and the descriptors of the growing-season climate. Correlations were determined for the total dataset using each year from each crop district as one sample.

2.3. Iterative Chi-square

Iterative Chi-square analysis was developed by Caprio (1966), and since then has been applied to wheat yield (Kalma et al., 1992), apples (Caprio and Quamme, 1999), grapes (Caprio and Quamme, 2002) and a variety of vegetable crops (McKeown et al., 2005; Warland et al., 2006). The analysis iteratively examines occurrences of days with temperatures and precipitation above a range of values (which are iteratively stepped through), and determines, via a Chi-square, when significant differences between yield classes exist and at what threshold value. For example, in the analysis below, low-yield years show the most significant Chi-square for excess days with $T_{max} > 31$ °C in the period around the first week of July. The analysis isolates the time of year at which the significant difference occurs, the strength of the difference (through the magnitude of Chi-square), the threshold value above (or below) which the most significant difference occurs, and further defines a positive Chi-square for an excess of days meeting the threshold condition and a negative Chi-square for a deficit of days meeting the threshold condition. The three yield classes are referred to as high, normal and low.

Iterative Chi-square analysis compares the number of days that meet a threshold condition within a moving 3-week period in high- or low-yield years compared to 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 Chi-square value 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-square = 7. In the analysis, a Chi-square value is generated for each week of the growing season and for a range of threshold temperature and precipitation values. The maximum Chi-square value over the threshold range is assigned to that week, while the threshold value of temperature or precipitation that produces the maximum Chi-square 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. For more information on iterative Chi-square analysis, see Caprio (1966), Caprio and Quamme (1999) and McKeown et al. (2005). The Chi-square analysis was coded by the authors using the Matlab™ programming language.

For the analysis presented here, daily weather data were averaged by crop district, and the weather and yield for each year in each crop district was taken as one sample unit. Yield classes were determined based on quartiles of the ranked yields for all crop districts, e.g. 'high' yield years were the top 25% of samples. Each year, each crop district was treated as one sample, resulting in 700 samples for the analysis.

3. Results

3.1. Yield and temperature trends

Analysis of canola yields from each crop district in each year indicated there has been an overall average yield increase of

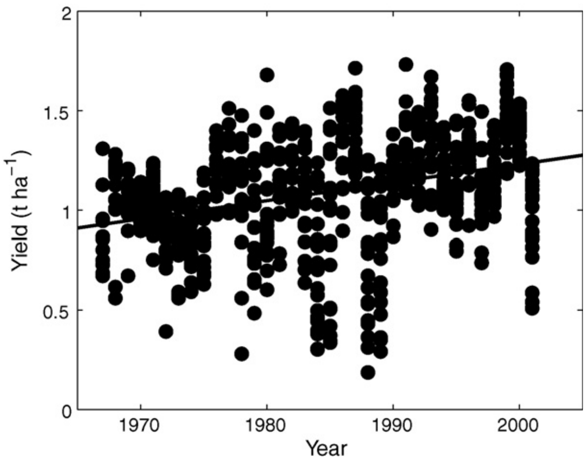

Fig. 1. Historical yields of canola in Saskatchewan from 1967 to 2001. Each point represents the yield from one crop district. The line shows the least-squares linear regression of the data. The slope is 8.97 kg ha^{-1} year^{-1} at $P < 2 \times 10^{-16}$.

approximately 9.0 kg ha^{-1} year^{-1} (Fig. 1), although there was a large amount of scatter across the province, in addition to year-to-year variability. All analyses presented below were performed using the absolute yield data (Fig. 1), as well as with the data from each crop district linearly detrended with time, and each crop district normalized to zero mean and unit standard deviation. The strongest correlations were obtained using the absolute yield data, and so results using detrended or normalized data are not shown.

Historical records of growing-season-mean temperature maximums (Fig. 2) and minimums (Fig. 3) were examined to determine factors that could result in a decrease in correlation after detrending the yield data. T_{max} and T_{min} were correlated (R = 0.63), but exhibited sufficiently different behavior to warrant separate examination. T_{max} shows a weak upward trend of approximately 0.01 °C year^{-1}. T_{min} shows a significant ($P = 1.61 \times 10^{-11}$) upward trend of approximately 0.02 °C year^{-1}. As discussed above, temperature has an impact on canola production. It may be that because temperatures increased with time, detrending or normalizing the yield data removed a portion of the true signal. This result supports the conclusion of a previous report (Bérard et al., 2001), that canola yields in Saskatchewan had not increased as much as expected since the 1970s.

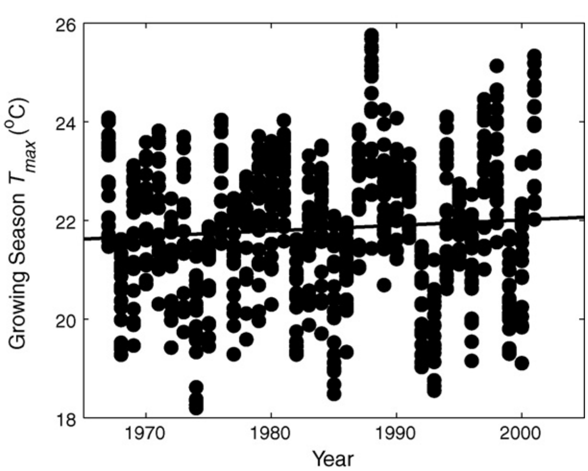

Fig. 2. Historical maximum temperatures in Saskatchewan from 1967 to 2001 (means calculated over each growing season). Each point represents one crop district. The line shows the least-squares linear regression of the data (not significant).

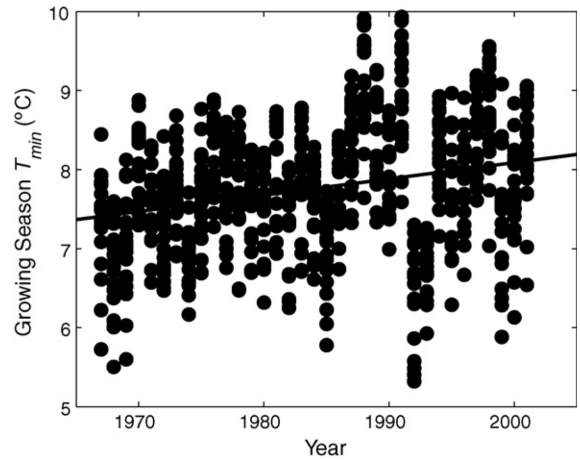

Fig. 3. Historical minimum temperatures in Saskatchewan from 1967 to 2001 (means calculated over each growing season). Each point represents one crop district. The line shows the least-squares linear regression of the data. The slope is 0.021 °C year^{-1} at $P = 1.6 \times 10^{-11}$.

Table 1
Correlations for Saskatchewan canola yields (by crop district) with temperature and precipitation over the growing season (correlations shown are significant at $P < 10^{-12}$).

Variable[a]	R	Slope
T_{mean}	−0.27	−75.5 kg ha^{-1} °C^{-1}
T_{max}	−0.35	−68.2 kg ha^{-1} °C^{-1}
$D_{max>30}$	−0.57	−18.4 kg ha^{-1} day^{-1}
ppc	0.39	1.8 kg ha^{-1} mm^{-1}

[a] T_{mean} = growing-season-averaged daily mean temperature; T_{max} = daily maximum temperature; T_{min} = daily minimum temperatures; $D_{max>30}$ = the number of days with maximum temperature greater than 30 °C in the year; ppc = growing season total precipitation.

3.2. Correlation analysis

The results of the correlation analysis are presented in Table 1. All of the correlations were highly significant ($P \leq 10^{-12}$), except for T_{min} (not shown). $D_{max>30}$ showed the strongest correlation ($R = -0.57$), with ppc second at $R = 0.39$. The slopes of the regression curves show a yield loss of approximately 7% for each degree increase in mean growing-season temperature (based on an overall average yield of 1.09 t ha^{-1}), 12% yield loss for each week (7 days) with maximum temperatures above 30 °C, and gains of 2% for each 10 mm of precipitation over the growing season.

3.3. Iterative Chi-square analysis

Iterative Chi-square analysis was performed using all the data, averaged by crop district. The analysis uses the convention that positive Chi-square values indicate an excess of days meeting the threshold condition, while negative values are used to indicate fewer than expected days meeting the threshold condition. The threshold condition producing the greatest absolute Chi-square value is also returned in the analysis, and shows the temperature or precipitation value at which the most significant difference is seen between high or low-yield years and the median years. Low-yield years had a greater number of days with $T_{max} \geq 31$ °C in July, while high-yield years show no deviation in T_{max} from the normal yield years (Fig. 4). A greater number of days with nocturnal temperatures above 16 °C at the end of June were observed in low-yield years, while high-yield years tended to have fewer warm nocturnal temperatures. High-yield years had precipitation patterns comparable to normal years, while low-yield years had

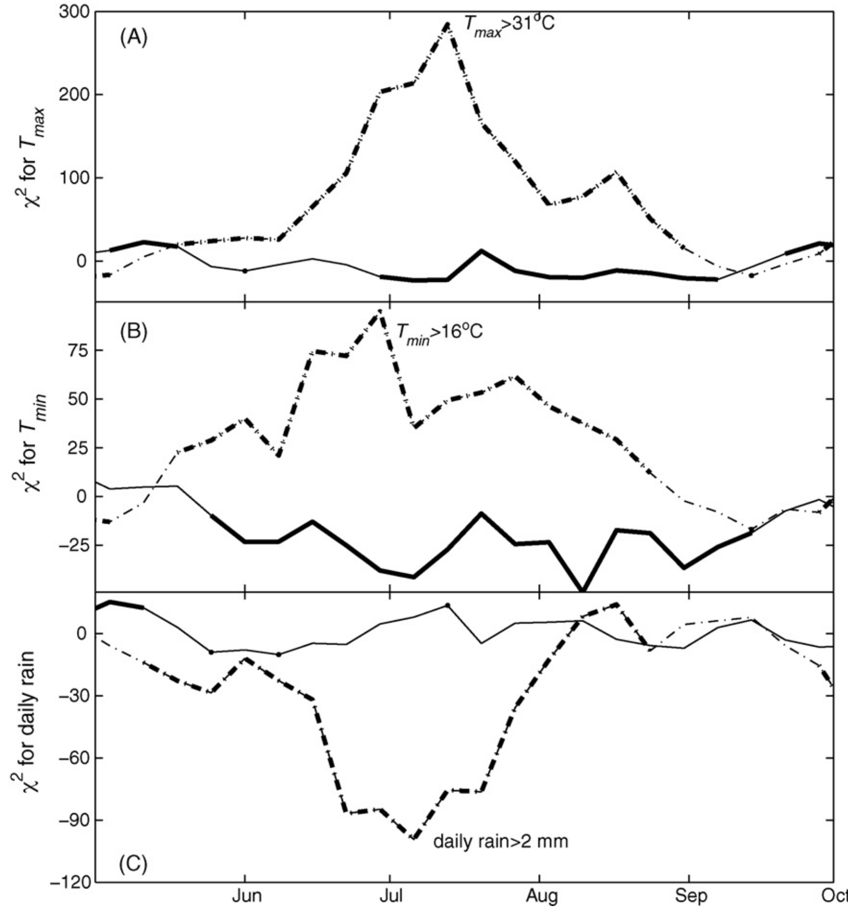

Fig. 4. Results of the iterative Chi-square analysis on all Saskatchewan canola yield data, averaged by crop district: (A) daily maximum temperatures (T_{max}), (B) daily minimum temperatures (T_{min}) and (C) daily precipitation. High-yield years – solid line; low-yield years – dashed line. Bold lines indicate statistically significant Chi-square values at $P \leq 0.01$. Canola in Saskatchewan is usually seeded during the month of May, begins to flower in late June to early July, completes flowering by the end of July and is windrowed in mid to late August.

fewer days with more than 2 mm of rain, with maximum significance at the beginning of July.

4. Discussion

The negative impact of heat stress during flowering on yield components has been reported for many crops. For example, a short period of heat stress increased the frequency of abortion of floral buds and flowers in field pea (Guilioni et al., 1997), and the number of spikelets on the primary inflorescence of wheat was observed to vary with temperature (Halse and Weir, 1974). Unevenly sized flower buds on broccoli inflorescences, as a result of arrested development of certain flower buds, was due to high temperature exposure (>30 °C) during inflorescence production or during the floral initiation process (Björkman and Pearson, 1998). A short period of very high temperature at a sensitive stage of canola development, such as flowering, has been shown to be as critical to yield and quality of canola as mild temperature stress over a longer period (Aksouh-Harradj et al., 2001). It was reported that 75% of *B. napus* pods present at maturity develop from flowers that open within 14 days of the beginning of flowering (Tayo and Morgan, 1975). Therefore the first 14 days of flowering of canola are crucial for seed yield and thus high temperature during this period is expected to have the greatest impact on seed yield.

In this study of weather variables, the number of days with $T_{max} > 30$ °C showed the strongest correlation with yield, followed by growing-season total precipitation. Mean temperatures were less strongly correlated with yield. Chi-square analysis showed that canola yield reduction was associated with daytime temperatures in excess of 31 °C around the first week of July, that high-yield years had lower nocturnal temperatures throughout the growing season, and low-yield years had higher nocturnal temperatures. Low-yield years also had a deficit of precipitation centered on the first week of July. High-yield years generally received normal amounts of precipitation and normal daytime temperatures throughout the growing season.

The results of this study are in general agreement with observations on heat stress in other *Brassica* spp. For example, five vegetable *Brassica* spp. examined in Ontario either benefited from cooler weather or showed damage as a result of hot (>30 °C) weather (Warland et al., 2006). Broccoli, cabbage and radish had reduced marketable yields with increasing number of days with a maximum temperature over 30 °C, and high yields of cauliflower and rutabaga were associated with years that had fewer warm days late in the season. In canola, detrimental effects occurred as a result of a daily maximum temperature of 35 °C at early flowering or pod development (Angadi et al., 2000; Gan et al., 2004). High mean maximum temperature during vegetative development reduced the number of flowers and the number and size of seeds produced per flower, which was responsible for the reduction in seed yield of three *Brassica* spp. (Morrison and Stewart, 2002). The effects of heat stress on male sterility were greater at 30 °C than at 26 °C (Fan and Stefansson, 1986; Polowick and Sawhney, 1988). The current study demonstrates that production is negatively impacted when high air temperatures occur at early flowering, possibly through the effects suggested by these previous studies.

The association of total precipitation during the growing season with moderation of yield reduction may be due to the effect of transpiration cooling (Gates, 1964; Mahan et al., 1995). This has been reported in wheat for example, where leaf temperatures were observed to be higher in water-stressed plants than in non-stressed plants (Gupta et al., 2001). Transpiration cooling depends on evaporation and the supply of water to the leaf from the soil. In years of greater total precipitation, soil moisture would be more readily available to mitigate heat stress. The positive effect of precipitation during the beginning of July to mitigate the yield loss of canola observed in the current study was not detected in the study of *Brassica* spp. by Gan et al. (2004). However, that study of high temperature and water stress was conducted under controlled conditions, which may be quite different from the interaction of high temperature and water stress that occurs under field conditions. In another study of water stress, but not heat stress, under controlled conditions, seed yields, oil concentrations and 1000-seed weights of *B. napus* and *B. rapa* cultivars were reduced by water stress applied either before or after flowering (Mailer and Cornish, 1987). In a field study of *B. napus* canola using rain-out shelters in Colorado it was reported that yield was not significantly reduced by water stress at any particular growth stage (Nielsen, 1997). However, trends in the data indicated lower numbers of pods and seeds with water stress during reproductive development and lower seed weight with water stress during grain-filling. The results of our study support the conclusions of these studies that water stress during the reproductive phase of canola has a negative effect on yield.

5. Conclusions

Without doubt the variations in canola yields in Saskatchewan have been the result of many different factors over the years of this study. This study does not account for variables such as the impact of the various soil types in the province, crop pests and implementation of control measures to combat pests, or changes in management practices, such as production on summerfallow in early years of cultivation, to production in continuous cropping systems under zero or minimum tillage in more recent years. However, the study clearly demonstrated, through use of iterative Chi-square analysis, that the beginning of July was a critical period in the determination of canola yield. High-yield years were associated with greater-than-average precipitation, and to a lesser extent, cooler-than-average nocturnal temperatures. Both simple correlation and iterative Chi-square analysis demonstrated the negative impacts of high temperatures, and the positive effects of greater-than-average precipitation. The reduction in yield associated with high temperatures was the strongest relationship, followed by the impact of precipitation. The importance of temperature and precipitation during this critical period in the determination of canola yield should be useful information to canola breeders in the development of better adapted cultivars, and to canola producers, who may be able to modify management practices to mitigate the impact of these climatic factors on yield.

References

Aksouh-Harradj, N.M., Campbell, L.C., Mailer, R.J., 2001. Canola response to high and moderately high temperature stresses during seed maturation. Canadian Journal of Plant Science 86, 967–980.

Angadi, S.V., Cutforth, H.W., Miller, P.R., McConkey, B.G., Entz, M.H., Brandt, S.A., Volkmar, K.M., 2000. Response of three *Brassica* species to high temperature stress during reproductive growth. Canadian Journal of Plant Science 80, 693–701.

Bérard, R., Brandt, S., McGregor, I., 2001. Determining the Barriers to Higher Canola Yields in Saskatchewan: An Extensive Analysis and a Closer Look at Heat and Water Stress. Final report to the Saskatchewan Canola Development Commission, Saskatoon, SK, 75 pp.

Björkman, T., Pearson, K.J., 1998. High temperature arrest of inflorescence development in broccoli (*Brassica oleracea* var. *italica* L.). Journal of Experimental Botany 49, 101–106.

Brandt, S.A., McGregor, D.I., 1997. Canola response to growing season climatic conditions. In: Proceedings of the Soils and Crops Workshop, Extension Div., University of Saskatchewan, Saskatoon, SK, 20–21 February 1997, pp. 322–328.

Caprio, J.M., 1966. A statistical procedure for determining the association between weather and non-measurement biological data. Agricultural Meteorology 3, 55–72.

Caprio, J.M., Quamme, H.A., 1999. Weather conditions associated with apple production in the Okanagan Valley of British Columbia. Canadian Journal of Plant Science 79, 129–137.

Caprio, J.M., Quamme, H.A., 2002. Weather conditions associated with grape production in the Okanagan Valley of British Columbia and potential impact of climate change. Canadian Journal of Plant Science 82, 755–763.

Environment Canada, 2002. 2002 Canadian Daily Climate Data. CD-ROM. Available from http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html.

Environment Canada, 2008. Canadian Daily Climate Data. Available from: http://www.climate.weatheroffice.ec.gc.ca/prods_servs/index_e.html.

Fan, Z., Stefansson, B.R., 1986. Influence of temperature on sterility of two cytoplasmic male-sterility systems in canola (*Brassica napus* L.). Canadian Journal of Plant Science 66, 221–227.

Gan, Y., Angadi, S.V., Cutforth, H., Potts, D., Angadi, V.V., McDonald, C.L., 2004. Canola and mustard response to short periods of temperature and water stress at different developmental stages. Canadian Journal of Plant Science 84, 697–704.

Gates, D.M., 1964. Leaf temperature and transpiration. Agronomy Journal 56, 273–277.

Guilioni, L., Wery, J., Tardieu, F., 1997. Heat stress-induced abortion of buds and flowers in pea: is sensitivity linked to organ age or to relations between reproductive organs? Annals of Botany 80, 159–168.

Gupta, N.K., Gupta, S., Kumar, A., 2001. Effect of water stress on physiological attributes and their relationship with growth and yield of wheat cultivars at different stages. Journal of Agronomy and Crop Science 186, 55–62.

Halse, N.J., Weir, R.N., 1974. Effects of temperature on spikelet number of wheat. Australian Journal of Agricultural Research 25, 687–695.

Heather, D.W., Sieczka, J.B., Dickson, M.H., Wolfe, D.W., 1992. Heat tolerance and holding ability in broccoli. Journal of the American Society of Horticultural Science 117, 887–892.

Kalma, J.D., Laughlin, G.P., Caprio, J.M., Hamer, P.J., 1992. The Bioclimatology of Frost. Springer-Verlag, New York, NY, 205 pp.

Mahan, J.R., McMichael, B.L., Wanjura, D.F., 1995. Methods of reducing the adverse effects of temperature stress on plants: a review. Environmental and Experimental Botany 35, 251–258.

Mailer, R.J., Cornish, P.S., 1987. Effects of water stress on glucosinolate and oil concentrations in the seeds of rape (*Brassica napus* L.) and turnip rape (*Brassica rapa* L. var. *silvestris* [Lam.] Briggs). Australian Journal of Experimental Agriculture 27, 707–711.

McGregor, D.I., 1981. Pattern of flower and pod development in rapeseed. Canadian Journal of Plant Science 61, 275–282.

McKeown, A., Warland, J., McDonald, M.R., 2005. Long-term marketable yields of horticultural crops in southern Ontario in relation to seasonal climate. Canadian Journal of Plant Science 85, 431–438.

Morrison, M.J., 1993. Heat stress during reproduction in summer rape. Canadian Journal of Botany 71, 303–308.

Morrison, M.J., Stewart, D.W., 2002. Heat stress during flowering in summer Brassica. Crop Science 42, 797–803.

Nielsen, D.C., 1997. Water use and yield of canola under dryland conditions in the central Great Plains. Journal of Production Agriculture 10, 307–313.

Nuttal, W.F., Moulin, A.P., Townley-Smith, L.J., 1992. Yield response of canola to nitrogen, phosphorus, precipitation and temperature. Agronomy Journal 84, 765–768.

Olsson, G., 1960. Some relations between number of seeds per pod, seed size and oil content and the effects of selection for these characters in *Brassica* and *Sinapsis*. Hereditas 46, 27–70.

Polowick, P.L., Sawhney, V.K., 1988. High temperature induced male and sterility in canola (*Brassica napus* L.). Annals of Botony 62, 83–86.

Saskatchewan Agriculture and Food, 2005. Crop yields by rural municipality. Available at http://www.agr.gov.sk.ca/apps/rm_yields/SN_CropsAYP-s.asp.

Statistics Canada, 2009. Table 001–0010 – Estimated areas, yield, production and average farm price of principal field crops, in metric units, annual (table), CANSIM (database). http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm (accessed: September 9, 2009).

Tayo, T.O., Morgan, D.G., 1975. Quantitative analysis of the growth, development and distribution of flowers and pods in oilseed rape (*Brassica napus* L.). Journal of Agricultural Science 85, 103–110.

Warland, J.S., McDonald, M.R., McKeown, A.M., 2006. Annual yields of five crops in the family *Brassicacae* in southern Ontario in relation to weather and climate. Canadian Journal of Plant Science 86, 1209–1215.