A revised Heat Index (HI) modifier for Canola for climate change studies

A. Bootsma. 2007. Final report for Agriculture and Agri-Food Canada Contract #3000321992.
Prepared Dec. 10, 2007, revised Dec. 18,2007

Background:

The existing canola heat index modifier (HI) developed by W. Pettapiece, et al. (2006) is based on a proxy index which estimates the number of days the daily maximum temperature exceeds 30ºC during the flowering period from 600 to 1100 GDD. Since daily temperatures were not available for gridded normals, the July mean maximum air temperature (Tmax) was used to estimate the number of days. The flowering period was assumed to be between June 15 to July 15. It was assumed that the number of days above 30ºC during that period could be defined by days in June plus ½ days in July, since only monthly statistics on the number of days above 30ºC were available for the 1971-2000 normals from Environment Canada (2002). The relationship between July Tmax and frequency of days >30ºC from June 15 to July 15 used in the existing HI is shown in Figure 1.

The existing HI works well for present day climate conditions in Canada and is presently used in the Land Suitabilty Rating System (version 3.0) as the standard HI for the 1961-1990 time frame (Pettapiece and Tychon, 2007). However, under warmer climate change scenarios, the seeding date of canola would be considerably advanced, and this would advance the flowering period as well. Therefore, it can no longer be assumed that the flowering period is between June 15 to July 15 and using July Tmax as a proxy would not be appropriate. Therefore, the existing HI needs to be modified so that it is more sensitive to climate change scenarios. This new HI modifier will be added to the existing Java program developed under a previous contract (Contract #3000291328) for computing climate indices for small grain cereals that are appropriately sensitive to climate change (EGDD and P-PE). These indices are also used for the climate ratings in the canola Land Suitability Rating System (LSRS), in addition to the new HI modifier.

New HI modifier:

A proxy indicator for estimating the number of days >30ºC during the flowering period of canola was developed as follows. Using monthly climatic normals for the 1971 to 2000 period (Environment Canada, 2002a; Golden Gate Weather Services, 2001), average daily maximum air temperatures were computed using the Brooks sine wave interpolation procedure (Brooks 1943). The average maximum daily air temperature (TmaxEGDD) was then calculated for the period between 600 to 1100 accumulated Effective Growing Degree-Days (EGDD600 and EGDD1100, respectively).. EGDD accounts for the fact that longer daylengths at higher latitudes tend to promote earlier maturity. This period typically begins in mid-June to early July and typically ends in late July to early August for locations in Canada (with some exceptions) when EGDD are accumulated starting from the date when Tmean exceeds 5ºC in spring (Table 1). The variable TmaxEGDD was then related to the average number of days > 30ºC (DAYS>30) for the average period of 600 to 1100 EGDD as shown in Table 1. The average number of days > 30ºC was determined from daily climate data available within the 1971 to 2000 period (Environment Canada 2002b), with adjustment made for missing data. Canadian climate stations used to develop the relationship in Fig. 1 were selected for this purpose, with two northern stations added. Additional stations were selected from warmer climates south of the border in USA to determine how the relationship is likely to look at higher temperatures.

The list of stations used and derived variables are shown in Table 1. A comparison of TmaxEGDD versus DAYS>30 is plotted in Figure 2. The following quadratic regression fit to the data ($R^2 = 0.91$) can be used to estimate days above 30°C for canola:

$$DAYS>30 = 0.11551\ (TmaxEGDD)^2 - 4.37124\ (TmaxEGDD) + 41.54 \qquad \text{(Eq'n 1)}$$

The quadratic regression equation is not reliable beyond the range of the data used in the regression. Consequently, the following conditions need to be applied when using equation (1): If TmaxEGDD is < 19°C, then DAYS>30 = 0.0; if TmaxEGDD is > 32°C, then DAYS>30 = -99, i.e. the relationship is not necessarily valid outside the range of the data. Since under climate warming seeding dates for canola would be advanced, it is unlikely that the maximum of 32°C for TmaxEGDD would be exceeded. However, if this becomes a significant issue under climate change, a new procedure for the HI modifier for canola would need to be developed. Other conditions that need to be applied were as follows: i) if EGDD600 was not reached, then TmaxEGDD = -99 and DAYS>30 = 0.0; ii) if EGDD1100 was not reached then EGDD1100 = -99 and TmaxEGDD = -99 and DAYS>30 = -99. (However, it can be safely assumed that DAYS>30 = 0.0 if EGDD1100 date is not reached).

For the Canadian stations, the number of days >30 °C calculated using the new HI modifier is only slightly different than the values based on the Pettapiece ratings (see Fig. 3 for comparisons). However, it is recommended that no adjustment be made to compensate for this difference, as the comparisons tend to break down in warmer climates (see USA data in Fig. 4).

Conclusion:

It is recommended that equation 1 be used to compute the HI modifier for canola for climate change studies. The modifier can be readily computed from the 30-year monthly climate normals as input. Rather than using the July Tmax as the proxy indicator for computing DAYS>30, the dates on which EGDD600 and EGDD1100 are used to determine the period for which the average Tmax is calculated, since this conforms more closely to the estimated flowering period of canola and is appropriately sensitive to climate change.

Validation test of new program:

The modification to the canola HI as described above was incorporated into a computer program that computes climatic indices for Land Suitability ratings by Steven Zimmer, AAFC Regina. Comparison between canola HI modifier variables computed from 1971-2000 climate normals using Excel spreadsheets with those calculated by the new Java program indicated that these were in agreement within rounding off limits (Table 2). This confirms that the program is working properly.

Running program to compute HI values:

The program (CLIMATE INDICE TOOL for the LAND SUITABILITY RATING SYSTEM (LSRS)Version 1.0.0) can be run on-line at http://ncrxeis4.agr.gc.ca/LSRS/index.jsp . To calculate Canola HI modifier values, only a "standard input" file is required, but the CHU calculations and outputs must be de-selected. If CHU values are not disabled, a "Threshold input" file is also required. The "standard input" file must be an ASCII text file containing longitude (negative decimal degrees), latitude, elevation (metres), 12 monthly Tmax values, 12 monthly Tmin values (°C), and 12 monthly precipitation values (mm). If the input text file is

created using Excel spreadsheet, it needs to be saved as a Tab delimited txt file (*.txt). The output file is saved (downloaded) as a .dbf file which can be converted to a spreadsheet file such as .xls, if the file is not too large. The outputs related to the canola HI modifier are:
EGDD600 (calendar day) (whole numbers)
EGDD1100 (calendar day) (whole numbers)
TmaxEGDD (°C) (2 decimals)
DAYS>30 (days) (1 decimal)

Analyses of revised canola HI on gridded national data:

The revised program was used to compute the canola HI modifier for selected grids across Canada using climate normals for the baseline (1961 to 1990) and 2040 to 2069 period. The climate change scenario was based on the output of the Canadian GCM (CGCMI ga1). Results are presented in Tables 3 and 4. Highest DAYS>30 values (typically 6 to 8 days for the baseline period) were found in southern areas of the prairies, Ontario, Quebec and interior B.C (Table 3). These represent approximately an 18 to 21% deduction in canola Heat Index values (Figure 3 in Pettapiece et al. 2006). DAYS>30 were increased by about 2 days on average for the 2040 to 2069 period. This represents an increase of 3% in the deduction applied to the canola HI. Changes ranged from –0.2 days at Oliver, B.C, to a maximum of +3.9 days at Brandon, MB. The period between EGDD600 and EGDD1100 was typically advanced by 2 to 3 weeks for the 2040 to 2069 period.

Climate Suitability Ratings for Canola:

The climate suitability for canola uses the same moisture and temperature criteria as for small grain cereals (Pettapiece et al. 2006). However, the Heat Index modifier (HI) is applied to either the moisture or temperature rating, depending on which is the most limiting factor. Comparisons between small grains and canola indicate that the climate ratings drop by an average of 5 points for the baseline period and 3 points for the 2040 to 2069 period (Table 5) for the selected locations. This resulted in an increase in the Class limit for only 5 locations for the baseline period and 7 locations for the 2040 to 2069 period. The EGDD and P-PE values used in calculating the climate ratings are presented in Table 6.

References:

Brooks, C.E.P. 1943. Interpolation tables for daily values of meteorological elements. Quart. J. Royal Meteorol. Soc. 69: 160-162.

Environment Canada 2002a. Canadian Climate Normals or Averages 1971-2000. Meteorological Service of Canada, National Archive and Data Management Branch, Downsview, Ontario, Canada. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [18 Apr. 2006].

Environment Canada 2002b. Canadian Daily Climate Data Temperature and Precipitation. Environment Canada, Atmospheric Environment Service, Downsview, Ontario. CD-Rom Database. Available on-line at: http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html [11 Apr. 2005].

Golden Gate Weather Services 2001. Climate Normals (1971-2000). Available on-line at: http://ggweather.com/normals/index.htm [30 Nov. 2001]

Pettapiece, W.W. (Pettapiece Pedology), G. Tychon (Spatial Data Systems Consulting) and Bootsma, A. 2006. Land Suitability Rating System Development: LSRS modifications to accommodate additional crops. Phase II(a) Interim Report submitted to Agriculture and Agri-Food Canada. Edmonton, AB.

Pettapiece, W.W. (Pettapiece Pedology), G. Tychon (Spatial Data Systems Consulting). 2007. Land Suitability Rating System Development: LSRS modifications to accommodate additional crops. Proto-type program developed and prepared in consultation with personnel from Research Branch, Agriculture and Agri-Food Canada, through a contract with the National Land and Water Information Service (NLWIS).

Prepared by:
Andy Bootsma
Agroclimatology Consultant
27 Trimble Crescent
Ottawa, Ontario K2H 7M9

December 10, 2007
Revised December 18, 2007

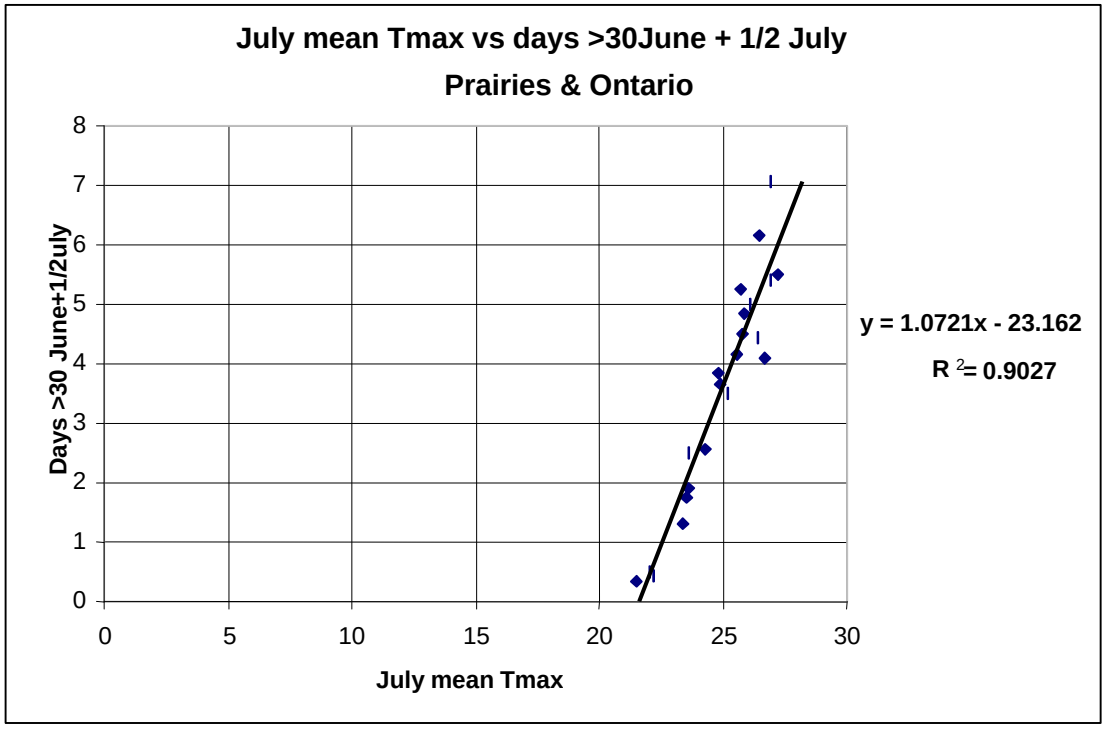

Figure 1. Relationship of July mean maximum temperature and frequency of days >30ºC (from Pettapiece et al. 2006).

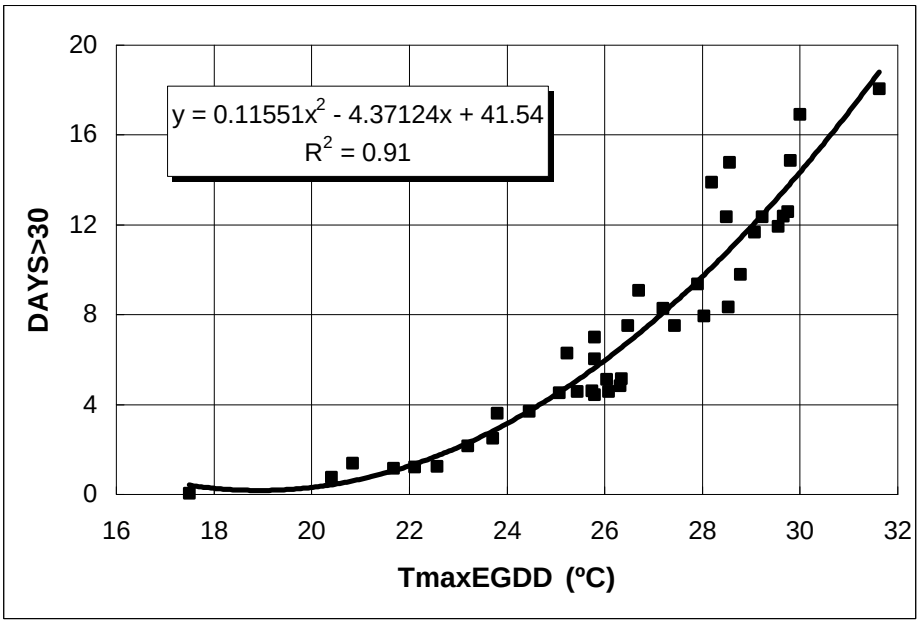

Figure 2. Relationship between average maximum temperature for the period of 600 to 1100 EGDD (TmaxEGDD) and frequency of days >30ºC (DAYS>30).

Table 1: Comparison of average daily maximum temperature for the period from 600 to 1100 accumulated EGDD to frequency of days> 30ºC based on 1971 to 2000 normals for locations shown.

Station	Prov/State	July average Tmax (ºC)	TmaxEGDD (ºC)	# Days > 30ºC				Dates of EGDD	
				July	June	June + 1/2 July	from 600-1100 EGDD	EGDD600	EGDD1100
Slave Lake A	AB	21.2	20.3	0.5	0.1	0.3	0.8	15 July	3 Sept.
Lethbridge CDA	AB	25.6	25.8	5.3	1.5	4.2	7.0	3 July	9 Aug.
Lacombe CDA	AB	22.0	21.7	0.7	0.2	0.5	1.2	14 July	1 Sept.
Edmonton A	AB	22.2	22.1	0.5	0.2	0.5	1.2	11 July	26 Aug.
Beaverlodge CDA	AB	21.5	20.8	0.5	0.1	0.4	1.4	16 July	4 Sept.
Medicine Hat A	AB	26.9	26.7	8.1	3.0	7.1	9.1	26 June	31 July
Regina A	SK	25.7	25.8	4.7	2.9	5.3	6.0	1 July	6 Aug.
Saskatoon A	SK	24.9	25.1	3.3	2.0	3.7	4.5	2 July	8 Aug.
Swift Current CDA	SK	24.8	25.2	4.3	1.7	3.9	6.3	5 July	11 Aug.
Scott CDA	SK	23.6	23.8	1.8	1.0	1.9	3.7	7 July	17 Aug.
Melfort CDA	SK	23.6	23.7	1.6	1.7	2.5	2.6	6 July	15 Aug.
Yorkton	SK	24.3	24.5	2.3	1.4	2.6	3.5	5 July	11 Aug.
Estevan A	SK	26.5	26.5	6.7	2.8	6.2	7.5	29 June	3 Aug.
Deloraine	MB	26.1	26.0	5.2	2.4	5.0	5.1	28 June	1 Aug.
Brandon A	MB	25.2	25.4	3.4	1.8	3.5	4.6	4 July	10 Aug.
Winnipeg A	MB	25.8	25.7	4.0	2.5	4.5	4.1	28 June	31 July
Morden CDA	MB	25.9	25.7	4.5	2.6	4.9	4.6	26 June	29 July
The Pas A	MB	23.4	23.2	1.2	0.7	1.3	2.2	13 July	21 Aug.
Wawa A	ON	20.7	17.5	0.0	0.0	0.1	0.0	30 July	8 Oct.
Ottawa CDA	ON	26.4	26.1	4.3	2.3	4.5	4.6	22 June	24 July
Kapuskasing CDA	ON	23.5	22.6	1.5	1.0	1.8	1.3	16 July	28 Aug.
Harrow CDA	ON	27.2	26.3	5.4	2.8	5.5	4.9	15 June	16 July
Vineland Rittenhouse	ON	26.9	26.2	5.8	2.5	5.4	4.9	19 June	19 July
Pontiac	MI	27.9	27.2	9.5	5.2	10.0	8.3	14 June	14 July
Chester	MT	28.1	28.2	11.9	4.1	10.1	13.9	30 June	4 Aug.
Ann Arbor	MI	28.3	27.4	9.0	5.6	10.1	7.5	12 June	12 July
Chinook	MT	28.9	28.5	12.9	5.5	11.9	12.4	24 June	27 July
Fort Assinniboine	MT	29.1	28.6	15.2	6.9	14.5	14.8	23 June	26 July
Yipsilanti	MI	29.3	28.0	11.1	6.6	12.2	8.0	8 June	7 July
Dearborn	MI	29.8	28.5	10.8	6.4	11.8	8.4	10 June	10 July
Big Sandy	MT	30.4	30.0	16.1	6.5	14.5	16.9	25 June	29 July
Culbertson	MT	30.6	29.8	15.0	6.8	14.3	12.6	19 June	21 July
Methow	WA	30.9	29.2	17.1	6.9	15.4	12.4	16 June	19 July
Fort Peck	MT	31.0	29.7	16.5	7.2	15.4	12.4	16 June	16 July
Hillsboro	IL	32.6	28.8	22.1	15.2	26.2	9.8	19 May	17 June
New Madrid	MO	32.8	27.9	25.4	17.6	30.3	9.4	14 May	12 June
Holly	CO	34.3	31.6	26.2	18.9	32.0	18.1	1 June	29 June
Hudson	KS	34.7	29.6	27.0	19.2	32.7	11.9	19 May	17 June
Alva	OK	35.7	29.8	28.5	22.3	36.5	14.9	18 May	15 June
Okeene	OK	35.8	29.1	29.2	22.6	37.2	11.7	8 May	7 June

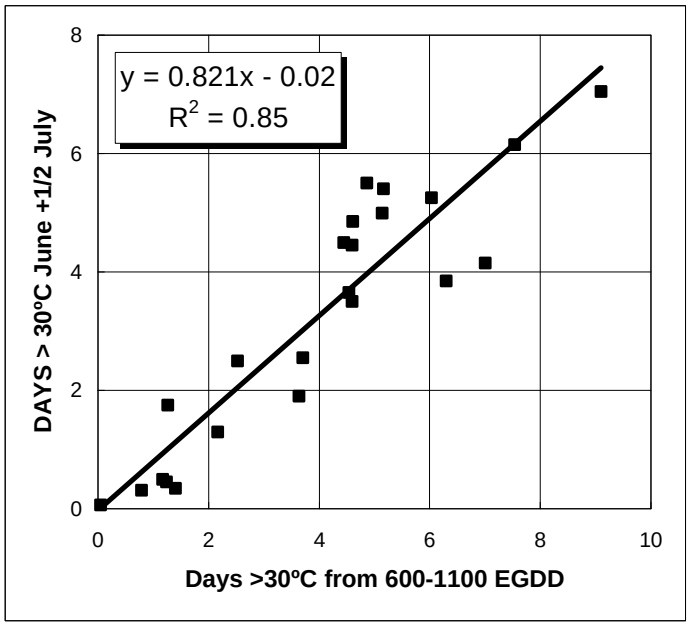

Figure 3. Comparison of the revised HI modifier for canola (days > 30ºC) with the Pettapiece modifier, using Canadian data only.

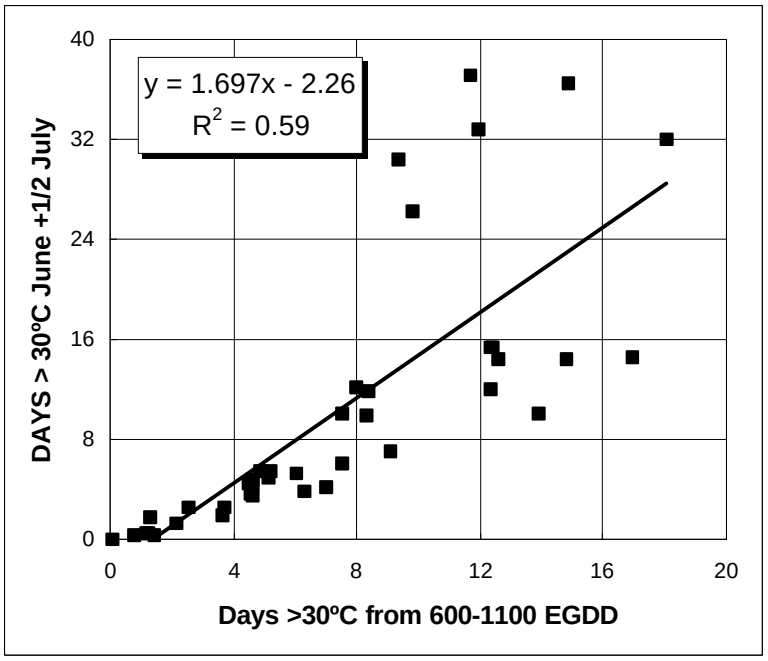

Figure 4. Comparison of the revised HI modifier for canola (days > 30ºC) with the Pettapiece modifier, including data from USA stations.

Table 2. Test of revised canola heat index modifier (HI) using 1971 to 2000 climate normals.

MSC Station #	Station name	Prov	Calculations using Excel spreadsheet				JAVA program results			
			EGDD600	EGDD1100	TmaxEGDD	DAYS>30	EGDD600	EGDD1100	TmaxEGDD	DAYS>30
			Calendar day		ºC		Calendar day		ºC	
3033890	Lethbridge CDA	AB	184	221	25.8	5.6	184	221	25.8	5.6
3023720	Lacombe CDA	AB	195	244	21.7	1.1	195	244	21.7	1.1
3012205	Edmonton A	AB	192	238	22.1	1.4	192	238	22.1	1.4
4016560	Regina A	SK	182	218	25.8	5.6	182	218	25.8	5.6
4057120	Saskatoon A	SK	183	220	25.1	4.6	183	220	25.1	4.5
4047240	Scott CDA	SK	188	228	23.8	2.9	188	228	23.8	2.9
4055085	Melfort CDA	SK	187	226	23.7	2.8	187	226	23.7	2.8
4019080	Yorkton	SK	187	225	24.5	3.7	187	225	24.5	3.7
4012400	Estevan A	SK	180	215	26.5	6.8	181	215	26.5	6.8
5010760	Deloraine	MB	179	213	26.0	6.0	179	213	26.0	6.0
5010480	Brandon A	MB	185	222	25.4	5.1	185	222	25.4	5.1
5021848	Morden CDA	MB	177	210	25.7	5.6	177	210	25.7	5.5
5052880	The Pas A	MB	194	232	23.2	2.3	194	232	23.2	2.3
6105976	Ottawa CDA	ON	173	205	26.1	6.1	173	205	26.1	6.1
6073960	Kapuskasing CDA	ON	197	240	22.6	1.7	197	240	22.6	1.8
6133360	Harrow CDA	ON	166	197	26.3	6.5	166	197	26.3	6.4
6139143	Vineland	ON	172	202	26.3	6.5	172	202	26.3	6.5

Table 3. Results of revised Canola Heat Index modifier for 23 selected grid locations across Canada, using 1961 to 1990 climate normals.

Approx. location		Grid point co-ordinates			1961-1990 data			
	Prov	Latitude	Longitude	Elevation	EGDD600	EGDD1100	TmaxEGDD	DAYS>30
Vancouver	BC	49.264	-123.042	58	169	210	22.07	1.3
Oliver	BC	49.125	-119.569	294	169	204	27.14	8.0
Fort Nelson	BC	58.847	-122.625	339	191	232	22.24	1.5
Lethbridge	AB	49.681	-112.764	909	186	223	26.13	6.2
Edmonton	AB	53.292	-113.597	713	188	231	22.60	1.7
Fort Vermillion	AB	58.431	-116.097	271	188	228	22.89	2.0
Mankota	SK	49.125	-107.069	855	189	226	27.46	8.6
Prince Albert	SK	53.153	-105.681	433	186	226	24.23	3.4
Brandon	MB	49.819	-99.986	396	183	218	26.19	6.3
Flin Flon	MB	54.681	-101.653	302	195	234	23.06	2.2
Churchill	MB	58.708	-94.014	4	-99	-99	-99.00	0.0
Harrow	ON	42.042	-82.903	185	167	197	26.44	6.7
Ottawa	ON	45.514	-75.681	104	180	214	25.91	5.8
Kapuskasing	ON	49.403	-82.486	214	200	247	22.12	1.4
Huntingdon	QC	45.097	-74.153	47	175	207	26.11	6.2
Normandin	QC	48.847	-72.486	120	195	236	22.96	2.1
Deception Bay	QC	62.181	-74.569	290	-99	-99	-99.00	0.0
Fredericton	NB	45.931	-66.653	98	187	222	25.37	5.0
Halifax	NS	44.681	-63.458	12	195	233	23.21	2.3
Sydney	NS	46.208	-60.125	20	206	246	21.94	1.2
Charlottetown	PEI	46.208	-63.181	2	194	230	23.67	2.8
St. John's	NFLD	47.458	-52.764	81	217	277	17.43	0.0
Hopedale	LABR	55.236	-60.264	75	-99	-99	-99.00	0.0

Table 4. Results of Canola Heat Index modifier for 23 selected grid locations across Canada for the 2040-2069 period scenario (CGCMI ga1).

Approx. location		2040 to 2069 scenario (CGCMI ga1)				Difference (2040 to 2069 minus 1961 to 1990)			
	Prov	EGDD600	EGDD1100	TmaxEGDD	DAYS>30	EGDD600	EGDD1100	TmaxEGDD	DAYS>30
Vancouver	BC	142	182	22.38	1.6	-27	-28	0.3	0.3
Oliver	BC	148	181	27.06	7.8	-21	-23	-0.1	-0.2
Fort Nelson	BC	172	205	24.72	4.1	-19	-27	2.5	2.6
Lethbridge	AB	159	194	26.50	6.8	-27	-29	0.4	0.6
Edmonton	AB	162	198	24.28	3.5	-26	-33	1.7	1.8
Fort Vermillion	AB	172	204	25.29	4.9	-16	-24	2.4	2.9
Mankota	SK	164	196	28.32	10.4	-25	-30	0.9	1.8
Prince Albert	SK	170	203	26.48	6.8	-16	-23	2.3	3.4
Brandon	MB	162	192	28.21	10.2	-21	-26	2.0	3.9
Flin Flon	MB	182	213	25.69	5.5	-13	-21	2.6	3.3
Churchill	MB	210	-99	-99.00	0.0	-99	-99	-99	0.0
Harrow	ON	149	179	26.97	7.7	-18	-18	0.5	1.0
Ottawa	ON	168	198	27.40	8.5	-12	-16	1.5	2.7
Kapuskasing	ON	186	221	25.62	5.4	-14	-26	3.5	4.0
Huntingdon	QC	163	192	27.23	8.2	-12	-15	1.1	2.0
Normandin	QC	182	215	25.92	5.8	-13	-21	3.0	3.7
Deception Bay	QC	-99	-99	-99.00	0.0	-99	-99	-99	0.0
Fredericton	NB	174	205	27.04	7.8	-13	-17	1.7	2.8
Halifax	NS	183	216	24.70	4.0	-12	-17	1.5	1.7
Sydney	NS	195	230	23.87	3.0	-11	-16	1.9	1.8
Charlottetown	PEI	182	214	25.42	5.1	-12	-16	1.8	2.3
St. John's	NFLD	209	255	20.09	0.3	-8	-22	2.7	0.3
Hopedale	LABR	-99	-99	-99.00	0.0	-99	-99	-99	0.0
				AVERAGES:		-17	-22	1.7	1.9

Table 5. Comparison between climate LSRS values for small grains and canola at 23 selected grid point locations across Canada.

		1961 to 1990 data				2040 to 2069 scenario (CGCMI ga1)			
		Small Grains		Canola		Small Grains		Canola	
Approx. location	Prov	RATING	CLASS	RATING	CLASS	RATING	CLASS	RATING	CLASS
Vancouver	BC	100	1	99	1	100	1	98	1
Oliver	BC	59	2	47	3	59	2	47	3
Fort Nelson	BC	53	3	52	3	95	1	87	1
Lethbridge	AB	72	2	60	2	74	2	61	2
Edmonton	AB	63	2	61	2	90	1	83	1
Fort Vermillion	AB	56	3	54	3	80	1	71	2
Mankota	SK	63	2	49	3	65	2	47	3
Prince Albert	SK	60	2	56	3	79	2	65	2
Brandon	MB	83	1	69	2	79	2	57	3
Flin Flon	MB	57	3	55	3	92	1	79	2
Churchill	MB	10	6	10	6	30	4	30	4
Harrow	ON	100	1	83	1	100	1	80	1
Ottawa	ON	100	1	86	1	100	1	78	2
Kapuskasing	ON	43	4	42	4	92	1	80	1
Huntingdon	QC	100	1	84	1	100	1	78	2
Normandin	QC	56	3	54	3	100	1	86	1
Deception Bay	QC	10	6	10	6	10	6	10	6
Fredericton	NB	90	1	79	2	100	1	80	1
Halifax	NS	93	1	89	1	100	1	91	1
Sydney	NS	70	2	69	2	100	1	94	1
Charlottetown	PEI	93	1	88	1	100	1	88	1
St. John's	NFLD	43	4	43	4	63	2	63	2
Hopedale	LABR	10	6	10	6	10	6	10	6
AVERAGE:		64		59		79		68	

Table 6. The EGDD and P-PE values used in calculating the climate ratings at 23 selected grid point locations across Canada.

Approx. location		1961 to 1990 period		2040 to 2069 period	
	Prov	EGDD	P-PE (mm)	EGDD	P-PE (mm)
Vancouver	BC	1923	128	2416	280
Oliver	BC	1922	-349	2480	-350
Fort Nelson	BC	1214	-159	1720	-163
Lethbridge	AB	1474	-286	2150	-275
Edmonton	AB	1306	-158	1909	-192
Fort Vermillion	AB	1244	-233	1737	-241
Mankota	SK	1312	-322	1993	-318
Prince Albert	SK	1283	-237	1828	-250
Brandon	MB	1501	-230	2178	-248
Flin Flon	MB	1257	-170	1727	-183
Churchill	MB	495	-56	983	-55
Harrow	ON	2440	-86	3074	-43
Ottawa	ON	1686	-139	2208	-127
Kapuskasing	ON	1115	-130	1556	-132
Huntingdon	QC	1918	-120	2459	-112
Normandin	QC	1245	-107	1686	-124
Deception Bay	QC	25	-3	442	6
Fredericton	NB	1534	-116	2001	-116
Halifax	NS	1559	8	1973	25
Sydney	NS	1366	5	1711	16
Charlottetown	PEI	1563	-70	1985	-50
St. John's	NFLD	1120	97	1309	49
Hopedale	LABR	425	48	498	57