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Determining Heat Unit Requirements for Broccoli Harvest in Coastal South Carolina

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ABSTRACT. **The objective of this research was to determine the least variable method to predict the dates of the first and last broccoli (*Brassica oleracea* L. var *Italica*) harvests based on heat unit summation using coefficients of variation (cv). The method with the lowest cv for predicting first harvest was to sum, over days from planting to harvest, the difference between the growing season mean (GSM) temperature and a base temperature of 7.2 °C. If the GSM maximum (max) temperature, however, was >26.7 °C, an adjusted max temperature was calculated by first subtracting 26.7 °C from the GSM max temperature and then subtracting the GSM mean temperature. Then the growing degree days (GDDs) were summed by subtracting the base temperature of 7.2 °C from the average of the GSM minimum (min) and adjusted max temperatures. This method produced a cv of 3.96 compared to 4.13 for the standard method of summing over the entire growing season, the mean temperature minus the base temperature of 4.4 °C. The method with the lowest cv for predicting last harvest was to sum, over days from planting to harvest, the difference between the GSM max temperature and a base temperature of 7.2 °C. If the GSM max temperature, however, was >29.4 °C, the base temperature was subtracted from 29.4 °C and not the actual GSM max temperature. This method produced a cv of 3.71 compared to 4.10 for the standard method of summing over the growing season, the mean temperature minus the base of 4.4 °C.**

Broccoli has potential as an alternative crop in the southeastern United States. A major barrier to successful production is the inability of growers to predict when sufficient volume of good-quality product can be expected. Accurate prediction of harvest date and developmental stage of a crop has widespread application for improving management of that crop, e.g., scheduling multiple harvests, pest management activities, labor and machinery (Perry et al., 1993). The concept of using heat unit summations or degree days for vegetable production has been used for many years on crops that have a limited life span of quality in the field. Heat unit summations are based on the assumption that there is a direct proportionality between growth and temperature (Reath and Wittwer, 1952). Heat unit summations have been used on many vegetable crops, such as corn (*Zea mays* var. *rugosa* Bonaf) (Arnold, 1959), beans (*Phaseolus vulgaris* L.) (Lorenz and Maynard, 1988), collards (*Brassica oleracea* L. var *acephala*) (Dufault et al., 1989), cucumber (*Cucumis sativus* L.) (Perry et al., 1986, 1990), peppers (*Capsicum annuum* L.) (Perry et al., 1993), and tomatoes (*Lycopersicon esculentum*) (Warnok, 1970; Warnok and Isaacs, 1969; Wilson and Barnett, 1983; Wolf et al., 1986).

Arnold (1959) demonstrated that the appropriate base temperature can be calculated using heat unit summations from a series of plantings by choosing the base temperature giving the smallest coefficient of variation (cv). Hoover (1955) used regression of daily mean temperature on heat unit summations for different environments; Hoover's method correlated closely with that proposed by Arnold (1959).

The concept of a ceiling temperature was initiated by Madariaga and Knott (1951) to control variability caused by high temperatures that exceed a maximum for plant growth. Rates of leaf primordia initiation and leaf tip appearance increased as temperature escalated above a base temperature, up to an optimum (Kiniry et al., 1991). Logan and Boyland (1983) included three considerations in heat unit summations: a minimum temperature that stops growth; a high temperature above which plant growth remains unchanged; and a maximum high temperature above which plant growth is retarded. Perry et al. (1986) incorporated these ideas and also daylength and compared 14 methods for reliability in calculating heat unit requirements for cucumber harvests.

Reliable prediction methods for scheduling planting and harvesting of broccoli would reduce the risk in broccoli production. Dufault et al. (1989) reported that the reduced ceiling method, using a maximum temperature of 23.9 °C and a base temperature of 13.4 °C, produced the lowest cv and was more effective in predicting collard harvest than using the simple method of subtracting a base temperature from mean daily temperatures. To reap the most central heads, broccoli may be sequentially harvested over longer periods of time unlike collards, which tend to be harvested over a few dates. It would be desirable to predict the first harvest date, but predicting the last harvest may also be necessary for scheduling harvest crews and marketing activities. In previous work, Dufault (1996) reported that broccoli head quality is more affected by maximum temperatures than minimum temperatures in the field. A greater emphasis on including maximum temperatures and ceiling temperatures in heat unit summation for broccoli may reduce the variation and error in predicting harvest dates. Therefore, the objective of this study was to determine the least variable method to predict the dates of first and last broccoli harvests in coastal South Carolina.

Materials and Methods

Fifty-six planting dates were chosen for this study from 1990 to 1992 (Table 1). Late winter, spring, summer, and fall planting dates were selected to establish the earliest spring, continuous summer, fall, and early winter production of broccoli in the Charleston, S.C., area. There were 19 planting dates in 1991 and 1992 and 18 in 1990, with each planting date separated by about 2 weeks from mid-February to mid-November. Seeds of four broc-

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coli cultivars—Baccus, Citation, Packman, and Southern Comet—were planted in Speedling cell trays (top, 4 × 4 cm; bottom, 3 × 3 cm; depth, 5.4 cm; cell volume, 65 cm^3) filled with a peat and vermiculite medium (Redi-Earth Terralite mix; W.R. Grace & Co., Allentown, Pa.). The seedlings for all planting dates were grown for 4 weeks in the greenhouse and then transplanted in single rows on raised beds 30 cm apart at the Coastal Research and Education Center in Charleston. Each plot was 4.6 m long and each row was separated by 0.9 m and contained 15 plants. A Latin square experimental design of cultivars was replicated four times. The soil was a Yauhannah loamy fine sand (Aquic Hapludults), and all plantings were made in the same field over all years. Commercially accepted pest management (Cook, 1990) and similar cultural practices were used for all planting dates. Before planting, 70N–32P–58K $kg \cdot ha^{-1}$ were broadcasted and disked into the soil. Trifluralin (a.i.) at 0.6 $kg \cdot ha^{-1}$ was applied and incorporated into the soil after bed preparation. Nitrogen at 46 $kg \cdot ha^{-1}$ was sidedressed about 3 and 5 weeks after transplanting for each planting date treatment.

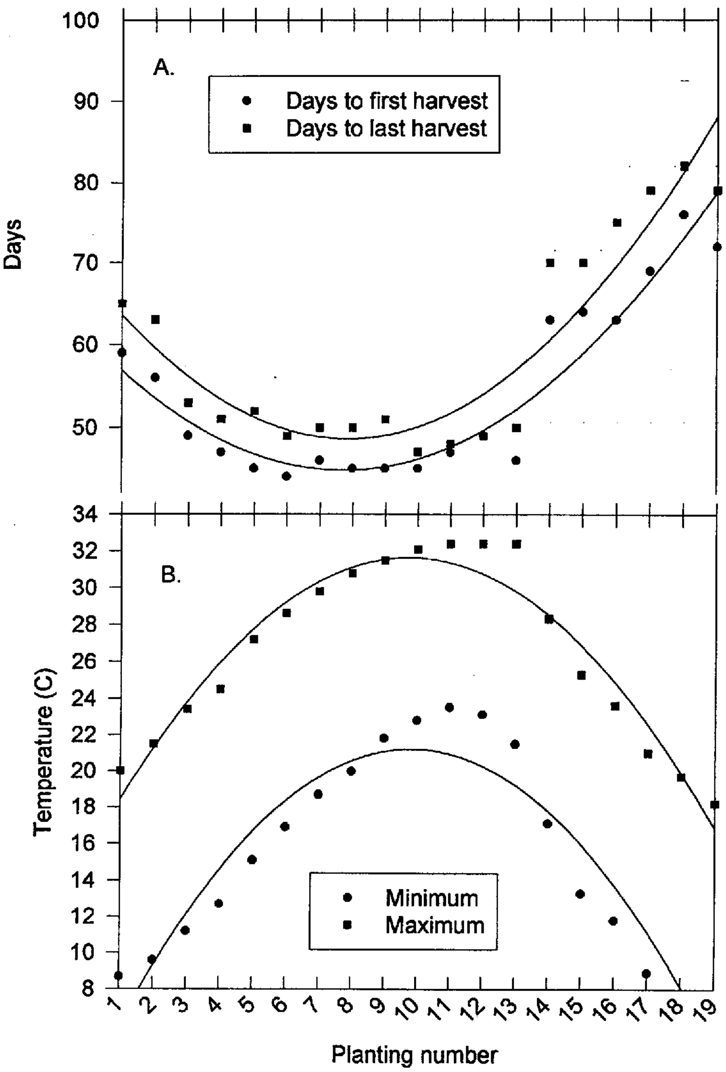

Fig. 1. (**A**) Days to first and last harvests from transplanting for broccoli cultivars planted on 19 planting dates (PD) from 1990–92 (Days to first harvest = 68.3 – (4.99 PD) + (0.317 PD^{-2}) R^2 = 0.87; Days to last harvest = 60.8 – (4.14 PD) + (0.268 PD^{-2}) R^2 = 0.90). (**B**) Growing season mean minimum and maximum temperatures for broccoli cultivars planted on 19 planting dates (PD) from 1990–92 (minimum temperature = 8.88 – (3.60 PD) + (0.184 PD^{-2}) R^2 = 0.92; Maximum temperature = 15.3 – (3.36 PD) + (0.173 PD^{-2}) R^2 = 0.94).

Individual broccoli central heads were harvested at a 10-cm diameter with a 25-cm stem length (measured from the top of the head to stem butt). Head quality was determined using U.S. Dept. of Agriculture (USDA) standards as guidelines (USDA, 1977) and classified either as commercially marketable or unmarketable. Only data from marketable production was included in heat unit summation or growing degree day (GDD) analysis.

Fourteen methods for determining GDDs for cucumbers were described by Perry et al. (1986). Seven of these methods used day length as an additional parameter, yet, in Perry's work, most of these methods did not reduce the cv. In our study, the seven methods not using day length parameters were used; methods 2, 4, 5, and 6 were developed by Perry et al. (1986). In methods 1 and 2, heat unit summations were determined using six base values (0, 1.7, 3.1, 4.4, 5.8, and 7.2 °C); methods 3 to 7 calculated heat unit summations using those base temperatures and six ceiling temperatures (18.3, 21.1, 23.9, 26.7, 29.4, and 32.2 °C). The base temperatures were selected to bracket a standard base of 4.4 °C used in calculating heat units for cruciferous vegetables (Lorenz and Maynard, 1988). The ceiling temperatures were selected to bracket the extreme low and high maximum temperatures possible during the planting date period in Charleston.

GDDs from transplanting to first and last harvests were computed for each day of the planting season for each cultivar using these seven methods:

Method 1

$$GDD = [((T_{max} + T_{min})/2) - B] \quad [1]$$

where T_{max} = maximum daily temperature, T_{min} = minimum daily temperature, and B = base temperature.

Method 2

$$GDD = (T_{max} - B) \quad [2]$$

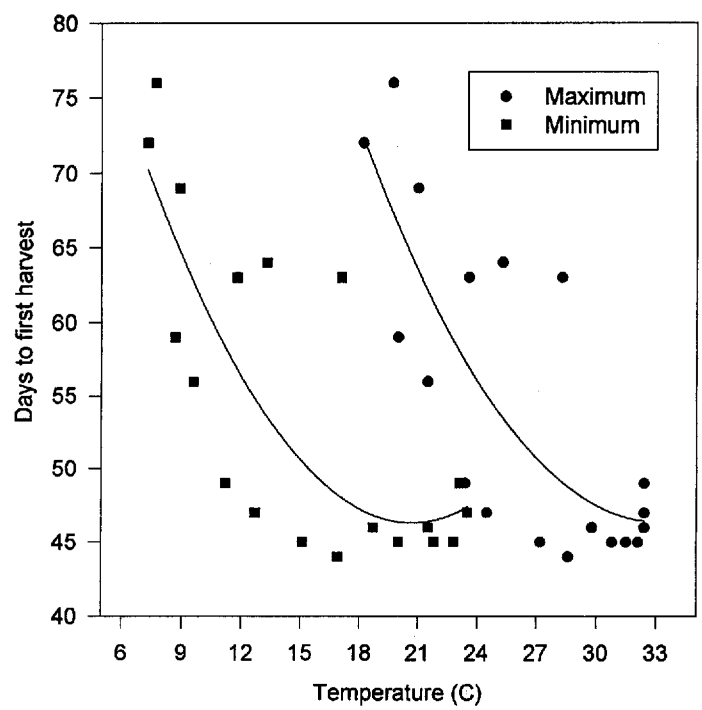

Fig. 2. Relationship between days to first harvest and growing season mean minimum (min) and maximum (max) temperatures for broccoli cultivars planted on 19 planting dates (PD) from 1990–92 (Days to first harvest = 103.5 – (5.54 min) + (0.134 min^{-2}) R^2 = 0.63; Days to last harvest = 174.5 – (7.74 max + (0.164 max^{-2}) R^2 = 0.64).

Table 1. Coefficients of variation for seven methods for calculating heat unit summations for days from planting to first broccoli harvest with varying base and ceiling temperatures.

Base temp (°C)	CV					
	No ceiling temp					
	Method 1					
0	4.22					
1.7	4.17					
3.1	4.15					
4.4	4.13					
5.8	4.14					
7.2	4.17					
	Method 2					
0	4.52					
1.7	4.47					
3.1	4.43					
4.4	4.40					
5.8	4.36					
7.2	4.32					
	Ceiling temp (°C)					
	18.3	21.1	23.9	26.7	29.4	32.2
			Method 3			
0	4.27	4.24	4.22	4.21	4.21	4.22
1.7	4.19	4.17	4.15	4.15	4.16	4.16
3.1	4.13	4.13	4.11	4.11	4.13	4.14
4.4	4.09	4.08	4.08	4.09	4.11	4.13
5.8	4.06	4.06	4.06	4.08	4.11	4.13
7.2	4.07	4.05	4.06	4.09	4.13	4.16
			Method 4			
0	4.90	4.77	4.64	4.56	4.53	4.52
1.7	4.85	4.71	4.59	4.51	4.48	4.47
3.1	4.80	4.66	4.54	4.46	4.43	4.43
4.4	4.75	4.60	4.48	4.41	4.39	4.39
5.8	4.69	4.54	4.42	4.36	4.35	4.35
7.2	4.61	4.47	4.36	4.30	4.30	4.31
			Method 5			
0	4.72	4.41	4.26	4.19	4.22	4.28
1.7	4.71	4.35	4.18	4.12	4.16	4.24
3.1	5.50	4.59	4.21	4.13	4.20	4.28
4.4	4.84	4.29	4.08	4.03	4.10	4.21
5.8	4.93	4.29	4.04	4.00	4.08	4.21
7.2	5.08	4.35	4.02	3.98	4.09	4.23
			Method 6			
0	4.67	5.60	5.02	4.78	4.65	4.65
1.7	4.86	5.63	4.99	4.68	4.57	4.52
3.1	7.15	5.68	4.96	4.64	4.53	4.48
4.4	7.46	5.57	4.94	4.60	4.46	4.45
5.8	7.81	5.87	4.92	4.56	4.46	4.42
7.2	8.20	6.00	4.88	4.51	4.43	4.39
			Method 7			
0	4.28	4.30	4.26	4.18	4.18	4.22
1.7	4.19	4.21	4.17	4.11	4.12	4.16
3.1	4.13	4.16	4.12	4.06	4.08	4.35
4.4	4.10	4.11	4.07	4.01	4.05	4.12
5.8	4.09	4.08	4.04	3.98	4.03	4.12
7.2	4.16	4.08	4.03	3.96	4.04	4.14

Method 3
If $T_{max} > C$, then $T_{max} = C$ and GDD = $[((T_{max} + T_{min})/2) - B]$
or if $T_{max} \le C$, then use Eq. [1] [3]
where C = ceiling temperature.

Method 4
If $T_{max} > C$, then $T_{max} = C$ and GDD = $(T_{max} - B)$ or
if $T_{max} \le C$, then use Eq. [2] [4]

Method 5
If $T_{max} > C$, then $T_{max\,adj} = C - (T_{max} - C)$ and
GDD = $[((T_{max\,adj} + T_{min})/2) - B]$ or
if $T_{max} \le C$, then use Eq. [1] [5]
where $T_{max\,adj}$ = maximum temperature adjusted to equation specifications.

Method 6
If $T_{max} > C$, then $T_{max\,adj} = C - (T_{max} - C)$ and
GDD = $(T_{max\,adj} - B)$ or if $T_{max} \le C$, then use Eq. [2] [6]

Method 7
If $T_{max} > C$ then $T_{max\,adj} = ((T_{max} - C) - (T_{max} + T_{min}))/2$ and
GDD = $[((T_{max\,adj} + T_{min})/2) - B]$ or
if $T_{max} \le C$, then use Eq. [1] [7]

Method 1 was used as the standard for comparing the other methods of heat unit summations. Once a method was identified with the least variation or lowest cv, GDDs were computed for all planting dates and cultivars from spring to fall. It was necessary first to determine the method of least variability for the model combining the effects of planting date, cultivar, and year. PROC GLM procedure of PC SAS (SAS Institute, Cary, N.C.) was used to analyze the change in GDDs for each method as a split-block design with planting date as the main block and cultivar as the sub-block. The absolute lowest mathematical cv value for the model was used to identify the method with the least variation over planting dates and cultivars as outlined by Arnold (1959).

Results and Discussion

Length of the growing seasons from transplanting date to day of first and last harvests were inversely related to increasing growing season mean (GSM) maximum (max) and minimum (min) temperatures and represented a concave second-order polynomial (Fig. 1A). Similarly, the GSM max and min temperatures were alike for some spring and fall growing seasons, and the temperature climate extending from late winter in February to late fall in November was characterized as a convex second-order polynomial (Fig. 1B). Generally, fall planting dates 18 and 19 had the lowest GSM max temperatures and were lower than the first two plantings in late winter in February. GSM min temperatures were lowest and similar in the first two spring plantings and the last planting date in November than any other time. GSM max temperatures were highest and similar from planting dates 8 to 13, and GSM min temperatures were highest from planting dates 9 to 13.

More time was required to reach harvest maturity in late fall plantings than in February plantings, but less time was required for heads to mature in plantings 14 to 19 than in all other plantings (Fig. 1A). Although GSM max and min temperatures were generally similar between late fall growing seasons and late winter and

Table 2. Heat unit summation (C degree days) from transplanting to first and last broccoli harvests in 51 planting dates from 1990 to 1992.

	Days to first harvest[z]					Days to last harvest[y]				
Planting date	Baccus	Citation	Packman	Southern Comet	Mean[x]	Baccus	Citation	Packman	Southern Comet	Mean[x]
16 Feb.	381 b[w]	392 a	376 c	394 a	386 n	768 a[w]	769 a	699 c	741 b	744 n
26 Feb.	394 c	478 a	385 d	404 b	415 m	729 c	833 a	711 d	768 b	760 m
16 Mar.	398 d	476 a	406 c	453 b	433 1	731 c	799 a	718 d	770 b	755 m
30 Mar.	431 c	503 a	435 c	457 b	457 k	729 c	852 a	724 d	824 b	782 1
13 Apr.	456 c	571 a	459 c	479 b	491 j	791 d	991 a	860 c	873 b	879 k
29 Apr.	471 d	677 a	517 c	548 b	553 h	788 c	1070 a	908 b	907 b	918 j
11 May	522 d	632 a	561 c	581 b	572 g	854 d	1252 a	861 b	937 c	976 g
25 May	544 d	586 c	604 b	657 a	598 f	836 d	915 c	941 b	1031 a	931 I
14 June	564 c	---[v]	681 b	710 a	652 a	876 c	---	980 b	1062 a	973 g
29 June	627 c	---	684 b	754 a	688 d	889 c	---	968 b	998 a	952 h
13 July	663 c	---	727 b	787 a	726 c	932 c	---	981 b	1057 a	990 f
27 July	666 c	---	809 b	822 a	766 a	918 c	---	1106 a	1088 b	1037 c
17 Aug.	655 c	---	860 a	692 b	736 c	1012 b	---	1012 b	1053 a	1026 d
6 Sept.	644 c	---	911 a	703 b	753 b	1231 b	---	1419 a	1178 c	1276 a
19 Sept.	603 d	719 a	639 c	668 b	657 e	997 d	1143 a	1043 c	1095 b	1070 b
6 Oct.	575 c	608 a	576 c	601 b	590 f	978 d	1043 a	1007 b	1003 c	1008 e
14 Oct.	484 c	534 a	498 b	501 b	504 I	877 d	980 a	914 c	941 b	928 I
27 Oct.	481 c	511 a	486 b	484 bc	491 j	858 c	916 a	849 d	871 b	874 k
14 Nov.	409 b	427 a	346 d	371 c	388 n	759 b	793 a	647 d	660 c	715 o
Mean[U]	525 d	547 c	577 b	582 a	571	871 d	950 a	913 c	940 b	926

[z]Calculated degree days with method 7 with a base of 7.2 °C and 26.7 °C ceiling temperatures.
[y]Calculated degree days with method 4 with a base of 7.2 °C and 29.4 °C ceiling temperatures.
[x]Mean separation within column for each harvest time by LSD at $P = 0.05$.
[w]Mean separation within row across the four cultivars for each harvest time by LSD at $P = 0.05$.
[v]No marketable production during these planting dates.
[u]Grand mean for each cultivar and mean separation within row for each harvest time by LSD at $P = 0.05$.

Table 3. Coefficients of variation for seven methods for calculating heat unit summations for days from planting to last broccoli harvest with varying base and ceiling temperatures.

Base temp (°C)	CV: No ceiling temp					
	Method 1					
0	4.04					
1.7	4.00					
3.1	4.04					
4.4	4.10					
5.8	4.17					
7.2	4.27					
	Method 2					
0	3.86					
1.7	3.88					
3.1	3.90					
4.4	3.93					
5.8	3.95					
7.2	3.99					
	Ceiling temp (°C)					
	18.3	21.1	23.9	26.7	29.4	32.2
				Method 3		
0	3.94	3.92	3.92	3.91	4.37	4.30
1.7	4.00	3.97	3.96	3.95	4.45	4.37
3.1	4.05	4.02	4.01	3.99	4.57	4.48
4.4	4.14	4.09	4.07	4.05	4.72	4.60
5.8	4.25	4.18	4.15	4.11	4.91	4.77
7.2	4.42	4.31	4.26	4.21	9.31	9.96
				Method 4		
0	4.17	4.08	3.99	3.93	3.90	3.89
1.7	4.12	4.03	3.94	3.88	3.86	3.85
3.1	4.08	3.98	3.90	3.84	3.82	3.82
4.4	4.03	3.94	3.86	3.81	3.79	3.79
5.8	3.98	3.89	3.82	3.76	3.75	3.76
7.2	3.91	3.83	3.76	3.72	3.71	3.72
				Method 5		
0	4.54	4.20	4.02	3.89	5.03	4.82
1.7	4.84	4.34	4.09	3.93	6.51	5.62
3.1	7.88	5.94	4.87	4.13	5.82	5.72
4.4	5.73	4.74	4.29	4.02	5.65	5.31
5.8	6.47	5.08	4.44	4.09	5.97	5.55
7.2	7.64	5.57	4.65	4.18	5.06	6.14
				Method 6		
0	6.64	5.38	4.67	4.13	6.58	5.92
1.7	7.39	5.74	4.86	4.21	6.86	6.16
3.1	8.20	6.14	5.05	4.29	7.15	6.44
4.4	9.20	6.65	5.30	4.40	7.43	6.76
5.8	10.34	7.34	5.62	4.53	7.71	7.12
7.2	11.75	8.28	6.04	4.71	4.20	4.10
				Method 7		
0	4.03	3.96	4.00	3.98	4.50	4.58
1.7	4.12	4.04	4.06	4.04	4.61	4.69
3.1	4.22	4.12	4.13	4.10	4.76	4.84
4.4	4.38	4.22	4.23	4.18	4.95	5.03
5.8	4.61	4.39	4.36	4.29	5.20	5.27
7.2	4.95	4.62	4.54	4.44	8.21	8.23

early spring growing seasons, broccoli matured faster in the spring than fall growing seasons. As planting date extended into late spring, the day and night temperatures progressively increased. Conversely, as planting dates extended into fall, broccoli matured under gradually cooler day and night temperatures. Regression of the length of the growing season length to first harvest with GSM max and min temperatures indicated that, as temperature increased, maturation rate increased curvilinearly and length of harvest season decreased (Fig. 2). In general, at the upper limits of GSM min (>19 °C) and max (>28 °C) temperatures, further increases in GSM minimum temperatures did not affect the days to first harvest.

Days from transplanting to first harvest. The cv values calculated for each of the seven methods ranged from 3.96 to 8.20 (Table 1). The standard method for calculating GDD for broccoli, using method 1 with a 4.4 °C base, produced a cv of 4.13. Other methods that lowered the cv compared to the standard method included methods 5 and 7. Method 5 with a 7.2 °C base and 26.7 °C ceiling lowered the cv by 4% below the standard method to 3.98 and method 7 with a 7.2 °C base and 26.7 °C ceiling lowered the cv by 4% to 3.96. To increase the precision of base temperature selection, additional base temperatures of 8.6, 10.0, 11.4, and 12.8 °C were evaluated. These base temperatures did not decrease the cvs but increased the cv values from 4.06 to 4.24 in method 5 and from 3.98 to 4.11 for method 7 (data not shown). Although the cvs were mathematically very close with methods 5 and 7 with a 7.2 °C base and 26.7 °C ceiling, method 7 produced the absolute lowest cv, making this method the less variable for predicting the first harvest date of broccoli than the standard method 1.

The cv of 3.96 for method 7 with a 7.2 °C base and 26.7 °C ceiling indicated less variation than reported for collards, where the lowest cv was 9.1 for method 6 with 13.4 °C base and 23.9 °C ceiling temperatures (Dufault et al., 1989). The disparity between collards and broccoli is likely due to only uniform-maturing hybrid broccoli cultivars were used in the present study versus some open-pollinated collard cultivars in Dufault's earlier work and to the difference in detecting harvest maturity for each crop. Collards were harvested once over at the 18- to 20-leaf stage, but sequentially harvested broccoli was cut at a uniform 10-cm head diameter. These differences in detecting harvest maturity for collards increased the experimental error, variation in length of growing season, and GDDs. Broccoli heads, in contrast, were harvested at a uniform head diameter that was reproducible and controllable, therefore increasing the precision of determining harvest maturity.

GDDs to first harvest were calculated using method 7 with a 7.2 °C base and 26.7 °C ceiling (Table 2). The cultivar × planting date interaction indicated that each cultivar may have reacted differently over all planting dates evaluated. The magnitude of GDDs for each planting date and cultivar combination provided a relative index for comparing earliness among cultivars. 'Citation' tended to require the most GDDs of all cultivars to reach harvest maturity, which ranged from as few as 392 GDDs in the first February planting and to as many as 719 GDDs in the mid-September planting. Others have reported increased summations in warm compared to cool parts of the season on corn (Gilmore and Rogers, 1958; Lana and Haber, 1952), lettuce (Madariaga and Knott, 1951), and peas (Katz, 1952). 'Citation' had negligible heat tolerance and did not produce any marketable heads from mid-June until mid-September. 'Packman' was the earliest cultivar in the first two February planting dates requiring the fewest GDDs than the other cultivars. 'Baccus' was the earliest of all cultivars from late April to late October plantings. During the summer, from 25 May to 27 July, 'Southern Comet' required the most GDDs. Pooling all cultivars within each planting date indicated that plantings made at about 27 July required the most GDDs of all planting dates. The least GDDs were required in the first planting made in February and the last planting in November.

Days from transplanting to last harvest. The cv values calculated for each of the seven methods ranged from 3.71 to 11.75 (Table 3). The standard method for calculating GDDs for broccoli, using method 1 with a 4.4 °C base without any ceiling temperature, produced a cv of 4.10. Method 4 with a 7.2 °C base and ceiling of 29.4 °C lowered the cv by 10% to 3.71 in contrast to the standard method. Attempts to lower the cv further with additional base temperatures from 8.6 to 12.8 °C increased rather than lowered the cvs (data not shown). Method 4 with a 7.2 °C base and 29.4 °C ceiling was the most appropriate method. Pooling all cultivars within each planting date indicated that plantings made at about 6 Sept. required the most GDDs of all planting dates to complete the harvest season and the least GDDs were required in November.

This study suggested that choice of an appropriate method to determine harvest maturity in broccoli differed by whether the date of the first or last harvest was required. Using an inappropriate method may introduce more variation, thereby reducing the prediction precision. Method 7 with a 7.2 °C base and 26.7 °C ceiling (M1) had the least amount of variation for calculating GDDs for days to first harvest. For days to last harvest, method 4 with a 7.2 °C base and 29.4 °C ceiling (M2) produced the lowest cv of all. If M2 was used to calculate GDDs for days to first harvest, cv values increased by 8% compared to M1. If M1 was used to calculate GDDs for days to last harvest, the cv increased 16% compared to M2. Therefore, to minimize variation and ultimately predict harvest dates, it is important to use different GDD computation methods depending on whether or not the focus is the start or end of the harvest season.

Literature Cited

Arnold, C.Y. 1959. The determination and significance of the base temperature in a linear heat unit system. Proc. Amer. Soc. Hort. Sci. 74:430–445.

Cook, W. 1990. Agricultural chemicals handbook. Clemson Univ. Coop. Ext. Serv. EC 670.

Dufault, R. 1996. Dynamic relationships between field temperatures and broccoli head quality. J. Amer. Soc. Hort. Sci. 121: 705–710.

Dufault, R.J., D.R. Decoteau, J.T. Garrett, R.T. Nagata, K.D. Batal, W.J. McLaurin, D.M. Granberry, K.B. Perry, and D.C. Sanders. 1989. Determination of heat unit requirements for collard harvest in the southeastern United States. J. Amer. Soc. Hort. Sci. 114:898–903.

Gilmore, E. and J. Rogers. 1958. Heat units for measuring maturity in corn. Agron. J. 50:611–615.

Hoover, M.W. 1955. Some effects of temperature on the growth of southern peas. Proc. Amer. Soc. Hort. Sci. 668:308–314.

Katz, Y. 1952. The relationship between heat unit accumulation and the planting and harvesting of canning peas. Agron. J. 44:71–78.

Kiniry, J.R. , W.D. Rosenthal, B.S. Jackson, and G. Hoogenboom. 1991. Predicting leaf development of crop plants, p. 29–42. In: T. Hodges (ed.). Predicting crop phenology. CRC Press, Boca Raton, Fla.

Lana, E. and E. Haber. 1952. Seasonal variability as indicated by cumulative degree hours with sweet corn. Proc. Amer. Soc. Hort. Sci. 59: 389–392.

Logan, S.H. and P.B. Boyland. 1983. Calculating heat units via a sine function. J. Amer. Soc. Hort. Sci. 108:977–980.

Lorenz, O.A. and D.N. Maynard. 1988. Knott's handbook for vegetable growers. 3rd ed. Wiley, New York.

Madariaga, F.J. and J.E. Knott. 1951. Temperature summations in relation to lettuce growth. Proc. Amer. Soc. Hort. Sci. 58:147–152.

Perry, K.B., T.C. Wehner, and G.L. Johnson. 1986. Comparison of 14 methods to determine heat unit requirements for cucumber harvest. HortScience 21:419–423.

Perry, K.B., T.C. Wehner, and G.L. Johnson. 1990. Prediction of cucumber harvest date using a heat unit model. HortScience 25:405–406.

Perry, K.B., D.C. Sanders, D.M. Granberry. J.T. Garrett, D.R. Decoteau, R.T. Nagata, R.J. Dufault, K.D. Batal, and W.J. McLaurin. 1993. Heat units, solar radiation and daylength as pepper harvest predictors. Agr. For. Meteorol. 65: 197–205.

Reath, A.N. and S.H. Wittwer. 1952. The effects of temperature and photoperiod on the development of pea varieties. Proc. Amer. Soc. Hort. Sci. 60:301–310.

U.S. Department of Agriculture. 1977. United States standards for grades of bunched Italian sprouting broccoli. USDA Food Safety and Quality Serv., Washington, D.C.

Warnok, S.J. 1970. Tomato heat accumulation at various locations in California. HortScience 5:670–671.

Warnok, S.J. and R.L. Isaacs. 1969. A linear heat unit system for tomatoes in California. J. Amer. Soc. Hort. Sci 94:677–678.

Wilson, L.T. and W.W. Barnett. 1983. Degree-days: an aid in crop and pest management. Calif. Agr. 37:4–7.

Wolf, S., J. Rudich, A. Marani, and Y. Rekah. 1986. Predicting harvesting date of processing tomatoes by a simulation model. J. Amer. Soc. Hort. Sci. 111:11–16.