Heat units, solar radiation and daylength as pepper harvest predictors

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Abstract

Daily maximum and minimum air temperature, total solar radiation and daylength data from seven locations during three seasons of 3 years were used to compare 52 heat unit accumulation models with counting days as a harvest prediction method for pepper. The best model was defined as the one with the least variation, i.e. smallest coefficient of variation (CV). CV's were calculated for each method over all seasons and locations, for each method over all locations for each season, and for each method in each season at each location. In all cases heat unit accumulation methods were better than counting days. The location and season specific model was the most accurate, but the analysis over all seasons and locations did result in smaller CV's than counting days, so improved harvest prediction can be achieved by using regionally developed models.

Introduction

The tristate vegetable project 'Agricultural Adjustment in the Southeast through Alternative Cropping Systems' involves cooperators in North and South Carolina and Georgia (Bauer et al., 1989). The basic objective of the project is to analyze the feasibility of regional vegetable production providing alternatives and/or supplements to current enterprises. The work described herein was conducted to contribute to this objective.

Accurate prediction of harvest date and developmental stage of a crop

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has widespread application for improving management of that crop, e.g. scheduling multiple harvests, pest management activities, labor and machinery. Previous results (Boswell, 1929, Magoon and Culpepper, 1932, Madariaga and Knott, 1951, Katz, 1952, Guyer and Kramer, 1952, Reath and Wittwer, 1952, Gilmore and Rogers, 1958, Dufault et al., 1989, Perry and Wehner, 1990, Carlson and Hancock, 1991) have shown that heat unit modelling for harvest date prediction has potential for operational applications. Several recent publications (Perry et al., 1986, Dufault et al., 1989, Hodges, 1990) include comprehensive literature reviews of heat unit modelling. The objective of this study was to determine if a method of heat unit summation could be developed to improve the accuracy of pepper (*Capsicum annuum* L.) harvest prediction over the standard method of counting days from planting.

Materials and methods

Seven locations were chosen for this study (Table 1). Spring, summer and fall planting dates were selected with the goal of establishing earliest spring and latest fall production for the tristate region (Table 2). Four cultivars of bell pepper, 'Keystone Resistant Giant No. 3', 'Skipper', 'Gator Belle' and 'Hybelle' were evaluated in each location. Cultivar selection was based on commercial standards and previous yield trials. Uniform plot size, experiment design, grading standards and data collection were used in all locations. Individual plots were 6.1 m long and 1.5 m wide. Two rows of 6 week old transplants were planted 30 cm in row and 30 cm between rows on 1.5 m centers. A latin square experiment design of cultivars was replicated four times. Commercially accepted fertilization based on soil tests, plastic mulch and pest management practices were used in all locations. Half of N and K and all P materials were applied preplant. The remaining N and K were applied weekly. Sufficient irrigation was supplied to maintain available soil moisture near the plants at 80% of field capacity. Row middles were treated with 2 kg ha⁻¹ napromamide, and all beds were fumigated with 200 kg ha⁻¹ of 98% methyl bromide. Peppers were harvested weekly, for 4–6 weeks depending on the location, when fruits were firm and mature. Cultivars did not differ significantly in harvest date and therefore cultivar differences were not given further consideration for calculation of heat unit accumulations. Daily maximum and minimum air temperatures were recorded by alcohol-in-glass thermometers in standard National Weather Service wooden, double-roofed, side-louvered shelters at 1.5 m above the surface. Daily total solar radiation was measured only at Lewiston and Fletcher by a Radiometer 8-48 (Eppley Laboratory, Newport, RI). The number of days from planting to first harvest was used as the standard of comparison for summations of heat units.

Table 1
Locations of Tristate plantings from spring 1985 to fall 1987

Location (state)	Geographic region	Elev (m)	North Latitude	West Longitude	Soil type	Ave growing season (days)
<i>Georgia</i> Attapulgus	Lower SW Coastal Plain	85	30°42"	84°23"	Norfolk loamy sand fine loamy siliceous thermic Typic Kandudult	279
Plains	Central Western Coastal Plain	152	32°3"	84°22"	Greenville series, clayey, kaolinitic, thermic Rhodic Kandudult	280
Tifton	Lower SW Coastal Plain	110	31°28"	83°31"	Tifton sandy loam fine sandy, siliceous thermic Plinthic Paleudult	296
<i>North Carolina</i> Fletcher	S Appalachian Mountains	631	35°26"	82°34"	Delanco loam, Aquic Hapludult	200
Lewiston	Tidewater Coastal Plain	15	36°8"	77°10"	Norfolk sandy loam fine sandy, siliceous thermic Plinthic Paleudult	210
<i>South Carolina</i> Charleston	Lower Eastern Coastal Plain	3	32°47"	79°56"	Yauhannah fine loamy sand, siliceous thermic Aquic Hapludult	290
Clemson	Upper Piedmont	250	34°41"	82°49"	Congaree silt loam fine loamy, mixed nonacid thermic Typic Udfluvient	205

Table 2

Locations and planting dates of peppers from Spring 1985 through Spring 1987

Planting time ^a		Georgia			North Carolina		South Carolina	
		ATTA ^b	PLNS	TIFT	FLET	LEWI	CHAS	CLEM
SP1	1985				15 May	30 Apr		
SP 2	1985					16 May		
SU 1	1985			28 June	3 June			
SU 2	1985				18 June			
FL 1	1985	15 Aug					31 July	1 Aug
SP1	1986	19 Mar	24 Mar		23 May	5 May	1 Apr	18 Apr
SP2	1986		9 Apr			20 May		1 May
SU 1	1986				4 June			
SU2	1986				16 June			
FL1	1986	18 Aug	12 Aug			14 July	6 Aug	
SP1	1987		17 Apr			4 May	7 Apr	23 Apr
SP2	1987					18 May		8 May
FL1	1987		13 Aug			23 July		

^a ATTA, Attapulcus, CHAS Charleston CLEM Clemson FLET Fletcher LEWI Lewiston PLNS, Plains TIFT, Tifton

^b SP, spring SU, summer FL, fall, 1 and 2 indicate first and second plantings, respectively

Heat unit summations were determined using 26 methods with 20 base/ceiling temperature combinations, where base temperatures were 0, 10, 14, 18 and 21°C and ceiling temperatures were 28, 30, 32 and 34°C Base temperatures were selected to be a range around a previously determined base of 10°C (Sanders et al, 1980) Ceiling temperatures were selected to be a range above the optimum temperature for peppers, 24°C (Lorenz and Maynard, 1980)

Thirteen of the methods used for determining heat unit accumulation were described by Perry et al (1986) In addition, these 13 methods were multiplied by daylength These 26 methods plus the standard of counting days from planting to first harvest resulted in a total of 27 methods

Method 1

Standard growing degree day (GDD) computation

$$\text{GDD} = \Sigma[(T_x + T_n)/2 - \text{Base}] \quad (1)$$

where T_x is the daily maximum and T_n is the daily minimum air temperature

Method 2

Use daily maximum instead of mean air temperature

$$\text{GDD} = \Sigma(T_x - \text{Base}) \quad (2)$$

Method 3

If maximum is greater than the ceiling, then set maximum equal to ceiling and use Eq (1)

Method 4

Same as Method 3, but use Eq (2)

Method 5

If maximum is greater than the ceiling, set maximum equal to the ceiling minus the difference between the maximum and ceiling, then use Eq (1)

Method 6

If maximum is greater than the ceiling, set maximum equal to the ceiling minus the difference between the maximum and ceiling, then use Eq (2)

Method 7

If maximum is greater than the ceiling, subtract the difference between the maximum and ceiling from the daily mean, then use Eq (1)

Method 8

Sum growing degree hours (GDH) by using Eq (1) for each hourly mean. The hourly means used in this method were derived from the daily maximum and minimum values by the method of Perry et al (1986)

Method 9

Same as Method 8, but reset maximum as in Method 3

Method 10

Same as Method 8, but reset maximum as in Method 6

Method 11

Sum GDH accumulated during daytime only

Method 12

Same as Method 11, but reset maximum as in Method 3

Method 13

Same as Method 11, but reset maximum as in Method 5

Methods 14 through 26 are Methods 1 through 13 multiplied by daylength

Method 27

Number of days from planting through first harvest

The following additional methods were applied only to the Fletcher and Lewiston locations

Method 28 through 53 are Methods 1 through 26 multiplied by total daily solar radiation

The coefficient of variation (CV) was used as recommended by Arnold (1959) to identify the best method for predicting first harvest. The CV is the sample standard deviation expressed as a percentage of the sample mean. CV's were calculated for each method over all seasons and locations, for each method over all locations for each season, and for each method in each season at each location.

Results and discussion

Analysis of methods 1–27

Determination of the stability of Methods 1 through 27 with the 20 base/ceiling combinations resulted in 540 CV's, representing 32 environments. These CV's ranged from –275% to 140%. Method 19 with base = 10°C and ceiling = 30°C had the smallest CV = 13.5%. Method 27, counting days, had a CV of 15.6%. However, Method 19 showed minimal improvement over the same model without daylength, Method 6, which had a CV of 13.6% with base = 14°C and ceiling = 30°C. Accuracy of prediction of harvest date was improved when data were analyzed on a regional basis. Twenty of the remaining methods also had smaller CV's than Method 27. The five methods that did not have CV's smaller than Method 27 were Methods 1, 8, 10, 24 and 26.

CV's were also determined for all methods/base/ceiling combinations over the environments grouped into each of the three seasons. Fall CV's (nine environments) ranged from the lowest of 5.2% for Method 25 base = 21°C/

Table 3

Number of environments (*N*), heat unit accumulation method number base and ceiling for smallest CV and CV for Method 27, counting days, for six locations and 3 seasons during 1985, 1986 and 1987

Location	Season	N	Method with smallest CV				CV Method 27 Counting days
			No	Base	Ceiling	CV	
Attapulugus	Fall	2	25	0	30	6.4	14.1
Charleston	Fall	2	19	18	30	0.04	4.6
	Spring	2	15	21	28	0.16	1.9
Clemson	Spring	4	12	18	28	1.6	16.1
Fletcher	Spring	2	2	0	34	0.02	6.7
	Summer	4	14	0	30	6.0	7.9
Lewiston	Fall	2	17	10	32	0.0004	1.1
	Spring	6	12	21	28	2.4	7.5
Plains	Fall	2	12	21	32	0.07	17.3
	Spring	3	6	0	28	6.8	5.7

ceiling = 30°C to 535%. Method 27, number of days, had a CV of 18.6%. All methods with one or more base/ceiling combinations had smaller CV's than Method 27. Thus, certain heat unit summations were much less variable than counting days during the fall season. The spring CV's (18 environments) ranged from -107% to 239%. Method 19 base = 18°C/ceiling = 30°C had a CV = 9.3% compared with Method 27 CV = 12.7%, i.e. heat unit summation again improved harvest date prediction accuracy over counting days. The methods that did not have CV's smaller than Method 27 were Methods 1, 10, 14, 21, 23, 24 and 26. The summer CV's (five environments) ranged from -437% to 187% with Method 25 CV = 9.5% relative to Method 27 CV = 20.1%. Methods 6, 9, 12, 15, 17, 19, 22, 24, 25 and 26 also had lower CV's than Method 27 for summer.

Heat unit summations showed more improvement (less variability) relative to counting days when analyzed for each season rather than over all seasons. The seasonal analyses also suggest that the greater number of spring environments, i.e. 18 spring environments versus nine fall and five summer environments, likely skewed the results of the over-all-seasons analysis.

Analysis for each location in each season was not possible owing to missing data where no plantings were made (Table 2). However, data were available to carry out ten of the 21 possible location/season combinations. These showed great improvement, i.e. smaller CV's representing less variability, over counting days in all cases except spring in Plains, Georgia (Table 3). Thus, using the heat unit accumulation methods at these locations during the given season should provide more accurate predictions of harvest date than using the historical average number of days from planting to first harvest.

Table 4

Number of environments (*N*) and heat unit accumulation method number base and ceiling for smallest CV for three seasons at two locations during 1985–1986 and 1987

Location	Season	<i>N</i>	Method with smallest CV			
			No	Base	Ceiling	CV
Fletcher	Spring	2	28	10	28	0.11
	Summer	4	32	14	30	6.8
Lewiston	Fall	2	43	14	32	0.007
	Spring	6	36	0	30	2.0

Analysis of Methods 28–53

The addition of radiation did not improve model prediction accuracy. Analysis for each location for the available seasons showed that the smallest CV's determined from Methods 1–27 (Table 3) were not reduced by the addition of radiation to the models (Table 4). On the contrary, the CV's were increased in three of the four location/season combinations (Tables 3 and 4).

The limitation of radiation data from only two stations requires these results to be deemed preliminary. Our results do, however, support the results of a recent study which looked at solar radiation in phenology models (Caprio and Snyder, 1991).

Conclusions

The improved model accuracy for location and season specific analysis demonstrated that a large part of the variation between locations and seasons is addressed implicitly in the location/season-specific model. This is a serious weakness in heat unit modelling. It means that to achieve the greatest accuracy with peppers, models must be developed for a specific site and season. This would be a very costly and time consuming task. However, the analyses of the methods over all seasons and locations and over all locations for each season did result in smaller CV's than merely counting days, so improved harvest prediction accuracy can be achieved by using regionally developed models. Further, the potential for improved harvest prediction using more complex models certainly exists as well.

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