Field Response of Peas to Excess Heat during the Reproductive Stage of Growth

Floyd V. Pumphrey

Columbia Basin Agricultural Research Center, Oregon State University, Pendleton, OR 97801

Robert E. Ramig

U.S. Department of Agriculture, Agricultural Research Service, Columbia Plateau Conservation Research Center, P. O. Box 370, Pendleton, OR 97801

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Abstract. Regression analysis was used to establish the effect of maximum daily temperatures on fresh pea (*Pisum sativum* L.) yield during the reproductive stage of growth. Maximum daily temperatures below 25.6°C had little influence on pea yield. Temperatures above 25.6°C depressed yield; this adverse effect increased exponentially as maximum daily temperature increased linearly. Predicted decrease in fresh pea yield ranged from 16 kg/ha per heat degree day above 27°C to 67 kg/ha per heat degree day above 35°C.

Literature describing the relationship between pea production and air temperature during the later stages of growth is relatively consistent on two points. The most critical time when high temperatures adversely affect pea yield is from flowering through pod filling (Boswell, 1929; Karr et al., 1959; Lambert and Linck, 1958; McWilliams, 1980; Stanfield et al., 1966). These authors also agree that the yield component primarily affected by temperatures above the optimum is reduction in the number of pods per plant.

Information available on heat-pea yield relationships is confusing as to the upper optimum temperature. Lambert and Linck (1958) and Nonnecke et al. (1971) suggested 27°C as a critical level for maximum daily temperatures (dt_{max}). Wang (1962) gave 25 to 26°C as an upper optimum during blooming and 36°C as the upper threshold where growth ceased. A seasonal mean maximum of 20 to 21°C was considered optimum for peas by Fletcher et al. (1966). Bowell (1929) concluded a daily mean of 20°C to be near the critical heat point, with higher temperatures being adverse to pea growth. Stanfield et al. (1966) reported pea yields decreased as day temperatures increased above 16°C and night temperatures increased above 10°C. Wang (1962) attributed 75% of the yearly pea yield variations in Wisconsin to the difference in minimum temperatures during the seedling stage and the reproductive stage of growth. Warm springs and cool summers produced higher yields; cool springs and warm summers produced lower yields. Ridge and Rye (1985) stated that frosts near first bloom and high temperatures during flowering explained 68% of the variation in seed yield of peas near Horsham, Australia. They concluded that a 1°C lowering of mean daily temperature during flowering should increase yield by 600 kg·ha⁻¹. A review of the literature does not reveal information on the extent of yield reduction resulting from different temperature levels above the optimum.

Air temperatures vary considerably from day-to-day and year-to-year in the pea-growing area of northeastern Oregon, southeastern Washington, and northern Idaho (NOAA, 1944–1977).

In some years, dt_{max} for short periods during blooming and pod filling (mid-May into July) greatly exceed the suggested optimum temperature. These high temperatures are observed to stress the pea plant and to be adverse to pea yields.

Step-wise multiple regression analysis of yields of fresh peas, precipitation, and temperatures indicated that precipitation and dt_{max} above 26°C from flower initiation to harvest accounted for 65% of the year-to-year variation in pea yields (Pumphrey et al., 1979). We analyzed air temperatures and pea yield data to determine the influence of dt_{max} above 10 base temperatures on fresh pea yields.

Materials and Methods

Data for this study were compiled from 62 location-years of weather records and fresh pea yields near Pendleton, Ore. Measurements were made from 1945 through 1977, except in 1947 and 1966, when late spring frosts severely damaged the pea plants.

Peas were grown in a rotation of peas and winter wheat and were planted between 1 and 15 Apr. Blooming started after 10 May; harvest was generally in the last half of June but occasionally as late as early July. The pea cultivar grown was 'Dark Skinned Perfection', except for a few early years, when the cultivar Perfection was grown.

Maximum daily air temperatures were recorded at the Columbia Basin Agricultural Research Center, Pendleton. The farthest field location from the temperature observations was 16 km. The range in elevation among all locations did not exceed 150 m.

Pea yields were adjusted to mean October through June precipitation to remove variation on yield due to year-to-year variability in water supply (Snedecor and Cochran, 1967). This allowed the effect of excess heat to be analyzed per se. Adjusted mean yield was 2615 ± 880 kg·ha⁻¹; range of yields was 400 to 4600 kg·ha⁻¹.

Heat stress degree-day sums (HSDDS) were calculated from before bloom initiation to harvest for fresh peas, which was the reproductive growth stage. An HSDDS for each base temperature and location year was obtained as:

$$HSDDS = \sum_{i=1}^n (T_i - B), \quad [1]$$

where: i indexes each day from 10 May (before bloom initiation)

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to harvest for fresh peas; n is the number of days from 10 May to harvest; T_i is dt_{max} in °C measured in a standard weather instrument shelter; and B is a base temperature. Only positive values of $(T_i - B)$ were summed. "

HSDDS were calculated for each of 10 base temperatures—20.6, 22.2, 23.9, 25.6, 27.2, 28.9, 30.6, 32.2, 33.9, and 35.6C (69, 72, 75, 81, 84, 87, 90, 93, and 96F)—for each location year. Simple regression analysis was used to obtain a regression equation expressing the relationship between the HSDDS above each base temperature and fresh pea yields. The model used was:

$$\hat{y} = a + b x, \quad [2]$$

where: $\hat{y}$ is the estimated yield of fresh peas; a is the intercept; b is the regression coefficient; and x is the heat stress degree day sum (HSDDS). The regression coefficients from the 10 regression equations calculated using Eq. [2] were fit to the exponential equation $\hat{y}_d = a_d x e^{b_d x}$ to describe the effect of increasing heat during the reproductive stage of growth on yield of fresh peas, where: $\hat{y}_d$ is estimated yield depression from dt_{max} above the base temperature; a_d is the intercept; e is the base of natural log; b_d is the regression coefficient; and x is the HSDDS above the temperature base.

Results and Discussion

Heat stress degree day sums. Mean HSDDS declined as base temperatures increased (Table 1), indicating that many dt_{max} exceeded the lower base temperature and few dt_{max} exceeded the higher base temperatures. The ranges and standard deviations of the HSDDS express the variability in dt_{max} during the reproductive stage of growth between years. Maximum daily temperatures considered to be adversely warm for pea production ($> 25.6C$) occurred in all years.

Optimum temperature. The negative regression coefficients (Table 2), which are an expression of the influence of the average heat stress degree day above the base temperature on yield of fresh peas, became progressively larger with each increase in the base temperature. All were significant at $P = 0.01$. The small changes in the size of the regression coefficients from base temperatures 20.6 through 25.6C indicate minimal adverse effect on pea yield of dt_{max} slightly exceeding these lower base temperatures (Table 1). Further raising the base temperature increased the regression coefficients exponentially, showing the greater expression of the higher dt_{max} on yield reduction.

The decline in intercepts as the base temperatures increased

Table 1. Means, ranges, and standard deviations of heat stress degree-day sums above 10 base temperatures in northeastern Oregon, 1945-1977.¹

Base temp (°C)	Heat stress degree-day sums		
	Mean	Range	SD
20.6	253	124-398	64
22.2	194	82-321	57
23.9	140	50-244	48
25.6	96	30-186	41
27.2	64	16-137	33
28.9	39	3-105	25
30.6	22	1-77	18
32.2	11	0-53	13
33.9	5	0-33	8
35.6	2	0-16	4

¹1947 and 1966 not included due to freezes.

Table 2. Regression equations for yields of fresh peas (adjusted to mean precipitation) vs. excess heat (x = heat stress degree-day sums) above base temperatures and standard deviations of regression coefficients, 1945-1977.¹

Base temp (°C)	Regression equation (kg·ha ⁻¹)	Standard deviation of regression coefficient
20.6	4095 - 5.85x	1.60
22.2	3961 - 6.94x	1.76
23.9	3878 - 9.01x	2.03
25.6	3743 - 11.7x	2.31
27.2	3599 - 15.3x	2.87
28.9	3428 - 20.8x	3.66
30.6	3242 - 29.1x	4.94
32.2	3084 - 40.9x	7.59
33.9	2928 - 61.6x	12.42
35.6	2347 - 76.4x	24.45

¹1947 and 1966 not included due to freezes.

Fig. 1. Reduction in fresh pea yield (kg·ha⁻¹) from an average heat stress degree day above the base temperature during the reproductive stage of growth.

above 25.6C and the rapid increase in the size of the regression coefficients with temperatures above 25.6C (Table 2) indicate the temperature level at which dt_{max} became unfavorable for peas. There was little effect between 20.5 and 26C on yield, so that this broad range can be considered the upper temperature optimum. This result concurs with the findings of Wang (1960), who suggested an upper maximum range of 25 to 26C.

Critical temperature. Regression coefficients (Table 2) increased rapidly when the base temperature was higher than 27.2C. Regression coefficients plotted against base temperatures (Fig. 1) show the exponentially adverse effect of high temperatures during the reproductive growth period on fresh pea yields. Excellent fit of the data to the exponential equation is indicated by the large r^2 and the small error of estimate. The critical level of dt_{max} of 27C suggested by Lambert and Linck (1958) and Nonnecke et al. (1971) is supported.

The significant finding of the analysis reported in this paper is the exponentially increasing adverse effect on fresh pea yield of a linear increase in dt_{max} above that of the optimum temperature range for pea reproduction. A strong negative correlation of heat degree-day sum and pea yield reported by Pumphrey et al. (1979) showed that peas were sensitive to and adversely affected by air temperatures above 25.6C during blooming and pod filling. The predicted linear effect on yield was -12.9 kg/ha per heat degree day of temperature higher than 25.6C. The exponentially adverse effect of excess heat on the yield of fresh peas in this study ranged from -16.6 kg/ha per heat degree day of air temperature above 27.2C to -74.0 kg/ha per heat degree day of air temperature above 35.6C during blooming and pod filling (Fig. 1). These data are in agreement with peas being C_3 plants; increasing temperature above the optimum increases photorespiration (Fritter and Hay, 1981; McWilliams, 1980) and, thus, explains the increasing negative effect as dt_{max} increased above 26C.

This information should encourage pea producers to grow early maturing cultivars and to use the earlier, lower temperatures of the growing season where late pea-growing-season temperatures exceed 26C. Processors can use this model to estimate crop yields using weather records. These data aid in interpreting variations among years in research results attributable to dt_{max} during flowering and pod filling.

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