Effect of Temperature on Time from Planting to Flowering in Virginia Type Peanuts (**Arachis hypogaea** L.)[1]

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ABSTRACT

Field studies with a planting date variable were utilized to determine an empirical relation between time from planting to first flowering of NC2, NC5, and Florigiant peanuts and minimum and maximum daily temperatures. Two basic types of curvilinear response functions and two heat unit systems, which used linear functions, were compared on the basis of days missed by each prediction. The mathematical expression of the data that gave the least days missed was the daily fraction of time to flowering being the sum of quadratic functions for minimum and maximum temperature. The rate of slope change was greater at the higher end of the temperature range. The relation between time to flowering and minimum temperature was more curvilinear that that for maximum temperature except at higher temperatures. Minimum temperatures below 43° F lengthened the time to flowering for the three varieties. Varietal differences appeared to be expressed more by the relation with daily maximum than with daily minimum temperatures. The expressions calculated should be more accurate for prediction purposes than a linear heat unit system, plus they tend to describe the individual responses to changes in minimum and maximum temperatures. A certain lack of fit for the relation still exists, indicating perhaps some other measure, such as solar radiation, should also be included.

Growth chamber research (Bolhuis and De Groot, 1959; Carlson, 1972; and Wynne, 1974) concerning the period until flowering has demonstrated two points: (1) the effect of temperature differs with variety and (2) the effect of temperature on the rate of development from planting until flowering may be curvilinear.

Field research concerning temperature effects has often been interpreted by the use of heat units. In its simplest form, a daily heat unit may be calculated by averaging the maximum and minimum temperatures. The summation of these units for the period being studied for a given variety is considered to be a constant. This, of course, is a linear relation. Arnold (1959), Went (1953), and Wang (1960) have indicated that such a proportionality could exist only in a very limited range of temperatures.

Attempts have been made to modify the heat unit system to account for different effects of extreme temperatures. Mills (1964), when trying to predict optimum peanut harvesting time, utilized both a lower cardinal temperature (56 F) and an optimum cardinal temperature (76 F). Average temperatures below the lower cardinal temperature were considered to be 56 F. For those above the optimum cardinal temperature, heat units were decreased. The result would be a set of three linear phases.

The approach used by Mills (1964) was compared with several other heat unit systems by Emery, Wynne, and Hexem (1969) when estimating the period from germination to flowering of two peanut varieties. The system they selected was to establish a base temperature (lower cardinal temperature) and to account for the negative effects of lower values. For example, average temperatures below 56 F were detrimental. If, in addition, they limited the heat unit maximum to that attained at 86 F the system did not correlate as well.

Several curvilinear methods of determining the effects of minimum and maximum temperatures on the time from planting to first flowering of Virginia type peanuts were evaluated. A procedure was developed that adjusted the curvilinear relation until the average and the range in days missed for the available data were minimized. This relation was determined for maximum and minimum temperatures separately and for the combination of the two. The results, which should be useful in modeling, are compared with those from two previously reported heat unit studies.

Procedure

Data from two planting date studies were used in this investigation. The first study was conducted by the senior author on Norfolk sandy loam (Type Paleudult; fine-loamy, siliceous, thermic) at the Peanut Belt Research Station near Lewiston, North Carolina. Florigiant peanuts were planted on the following six dates; April 19, April 28, May 7, May 18, May 27, and June 4, 1971. Each planting date was replicated four times. Temperatures were taken from a maximum-minimum thermometer at the Station as prescribed for Weather Bureau records. Also, temperatures were collected in the field from the air and from a 5 cm (2 inch) soil depth with a recording thermometer. Preliminary results with soil temperatures proved less satisfactory than when using air temperatures. Since field air temperature and that at the Research Station headquarters were essentially identical, those from the Research Station were used throughout this study. These findings are in accord with those by Emery et al. (1969). Also, since weather records are maintained in degrees Fahrenheit and prior work with heat unit systems has utilized this scale, all calculations were made using degrees Fahrenheit.

When the Florigiant peanuts began to flower 6.1 m (20 feet) of row was marked off in each plot and the flowers counted twice weekly. The rate of flowering appeared to be linear with time for the first several observations. A regression line was calculated from these points and extrapolated to zero to predict the date of initial flowering for each planting date.

The second set of data used was from experiments conducted by Emery, Wynne, and Hexem (1969). They conducted planting date studies at the Upper Coastal Plain Research Station near Rocky Mount, North Carolina, in 1966, 1967, and 1968. They grew NC2 and NC5 peanuts each year and data on 14 planting dates were collected during the three year period.

Flower counts were collected by flowering position (Gupton, Emery, and Benson, 1968) on these varieties. Their original data indicated that the first flower would appear on the 1/1 position three days prior to the 50% flowering value recorded for that position. Thus, by sub-

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tracting three days, a date of flowering comparable to that used in the first study was determined.

Two mathematical approaches were taken to evaluate the effect of daily maximum and/or minimum temperature on the time to flowering. Such an evaluation is made possible by the natural variation in maximum and minimum temperatures for each growth period for each year. In the first, hereafter called the reciprocal method, days to flowering was set equal to the following quadratic daily temperature function: $Y = aX^2 + bX + c$, where Y is the days to flowering and X is either daily maximum or daily minimum temperature. The reciprocals of these (1/Y) were then summed to unity. The flowering date predicted at unity was then compared with that from the observed flowering date. Utilizing a computer program written by the junior author, the coefficients were allowed to change to minimize the sum of squares of differences between the predicted and observed values. Average days missed and the range in days missed were calculated for comparison.

Since Emery et al. (1969) found that among the heat unit systems they tested the highest correlation with flowering date occurred with one in which negative effects were included, and since the reciprocal approach provided no possible negative effects, a second curvilinear approach using fractions of time to flowering was employed. This method considers both negative and positive effects. In the second approach, a fraction of the time to flowering was set equal to the following quadratic daily temperature function: $Y = aX^2 + bX + c$, where Y is the fraction of time to flowering and X is either daily maximum or daily minimum temperature. The fractions (Y) were summed to unity and the data analyzed as in the first approach.

The effects of maximum and minimum daily temperature were studied separately with both approaches. The predictions using the second or fractional approach were further refined by pooling the results of the maximum and minimum daily temperature equations. Also, more than one equation was used for both maximum and minimum temperature to predict days to flowering more accurately.

Since peanuts flower in the morning, it was considered that the requirement for flowering was fulfilled on the day prior to when the flower was observed. Therefore, the period considered in these studies was from planting to the day prior to that on which the first flower was observed, inclusive.

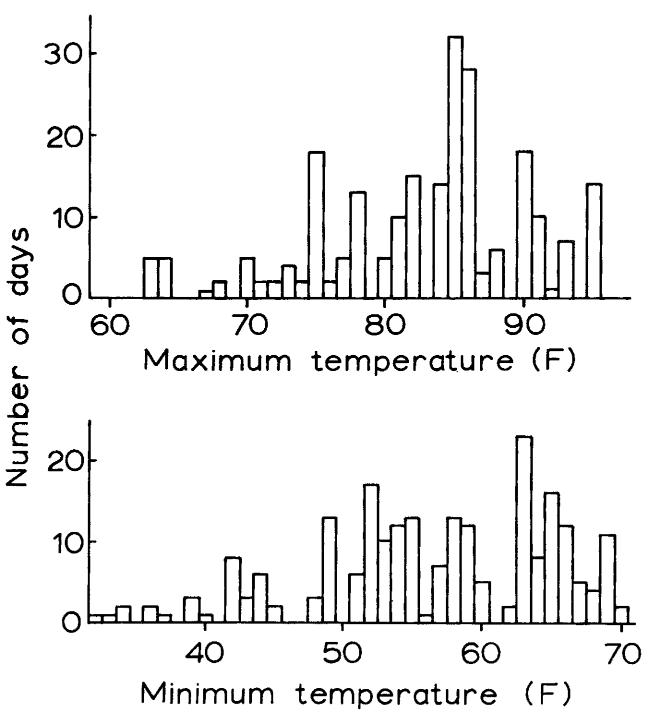

Fig. 1. Frequency distribution of the maximum and minimum temperatures from the six planting-flowering observations with Florigiant peanuts.

Results and Discussion

A summation of the number of days encountered at each maximum and minimum temperature in the six planting-flowering observations with Florigiant peanuts is presented in Figure 1. The range in maximums is from 63 to 95 and the range for minimums is from 32 to 70. The distribution is generally skewed toward the warmer end of the range.

Similar data is shown in Figure 2 for the study involving NC2 peanuts. In this case, however, the summation is for 14 planting-flowering observations. Maximum temperatures range from 59 to 94, slightly lower than occurred in the Florigiant data, while the minimum range was identical to that found in the Florigiant data.

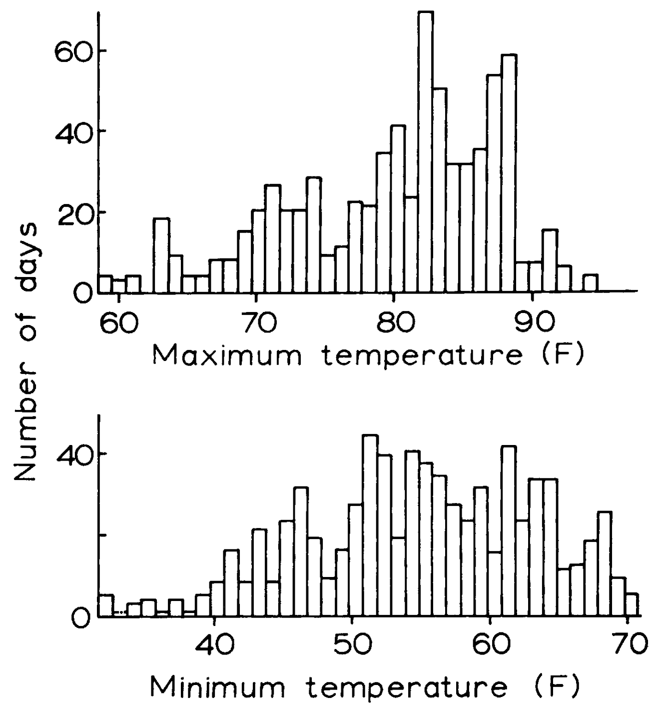

Fig. 2. Frequency distribution of the maximum and minimum temperatures from the 14 planting-flowering observations with NC2 peanuts.

The NC5 peanuts were planted on the same dates as the NC2 variety, so the distribution of temperatures for that variety is nearly the same as that shown in Figure 2. It was felt that these distributions were sufficiently similar such that realistic comparisons could be made among varieties as to temperature effects.

The results from the final equations using the reciprocal method for each of the varieties are given in Table 1, rows 2-3. A comparison is made with the heat unit system used by Mills (1964) since it also would tend to give this relationship (Table 1, row 1). Average days missed when predicting the time to flowering was less with the curvilinear relation developed with either max-

Table 1. Average of absolute number of days missed per planting - flowering observation and range in days missed for three varieties of peanuts as determined by various methods.

Row	Method	NC2	NC5	Florigiant
			Average Range	
1	Heat units, (Mills, 1964)	5.6 -11.2 to 11.7	5.1 -12.7 to 9.9	8.5 -17.9 to 9.0
2	Sum of reciprocals by equation using maximum temperatures	1.1 -2.3 to 2.9	1.3 -2.9 to 4.1	0.5 -1.1 to 1.1
3	Sum of reciprocals by equation using minimum temperatures	2.1 -4.8 to 7.8	2.2 -5.5 to 6.1	0.8 -2.0 to 1.4
4	Heat units (Emery et al., 1969)	1.2 -2.3 to 4.1	1.8 -4.1 to 5.2	0.9 -1.3 to 1.1
5	Sum of fractions by equation using maximum temperatures	1.1 -1.8 to 2.2	1.3 -2.5 to 2.9	1.1 -1.8 to 1.8
6	Sum of fractions by equation using minimum temperatures	1.0 -2.9 to 2.4	1.2 -4.1 to 2.2	0.5 -1.2 to 0.8
7	Sum of fractions by equations using maximum and minimum temperatures	0.8 -2.9 to 1.4	1.1 -3.1 to 1.9	0.5 -0.8 to 1.2
8	Sum of fractions by two equations on maximum and two equations on minimum temperatures	0.7 -2.8 to 1.3	1.1 -3.0 to 1.9	0.3 -0.3 to 0.9

imum or minimum temperature than it was with the heat unit system. Average days missed on either the NC2 or the NC5 peanuts with this approach using maximum and minimum temperatures were 1.2 and 2.2, respectively, while that from the heat unit system was 5.4. For the Florigiant variety these values were 0.5, 0.8, and 8.5, respectively. Similar decreases in the range were also noted.

A plot of the equations calculated with maximum and minimum temperatures for the three varieties is shown in Figure 3. The optimum maximum temperatures indicated by the equations for the NC2, NC5 and Florigiant peanuts were 86.0, 86.1, and 88.6 F, respectively. The optimum minimum temperatures indicated were 59.7, 59.7, and 63.4, respectively, for these varieties. These optimums appear low when considering the results of Bolhuis and De Groot (1959). They studied the time to flowering of three varieties under constant temperature conditions. From their data the optimum constant temperature range to minimize the time to flowering was calculated as 85 to 92 F.

The results with the fractional approach with the three varieties plus the comparison with the heat unit system used by Emery *et al.* (1969) are presented in Table 1, rows 4-6. The maximum average days missed was 1.8 with the NC5 variety using the heat unit system by Emery *et al.* and the minimum was 0.5 with the Florigiant variety using daily fractions calculated from minimum temperatures.

In comparing these methods with the first reported (Table 1, rows 1-3) the greatest improvement occurred when the heat unit system of Emery *et al.* (1969) instead of Mills (1964) was

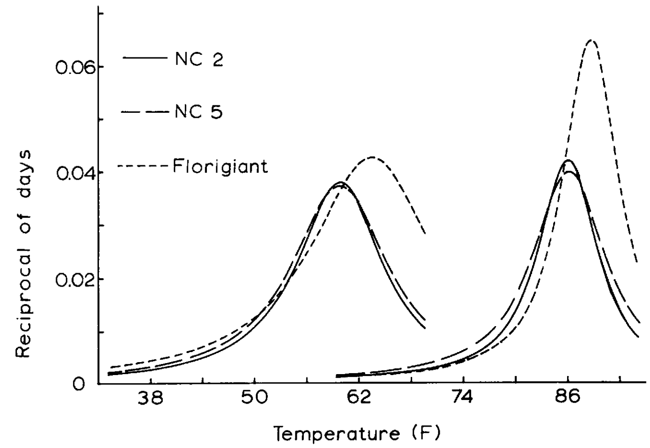

Fig. 3. Relation between the reciprocal of days to flowering and minimum (left) and maximum (right) daily temperatures for three varieties of peanuts.

used. Days missed were much less when using the system that accounted for negative values at low temperatures and did not discount values above a suggested maximum. Except in the case of the NC5 variety, heat units averaging maximum and minimum temperatures by the Emery *et al.* method gave results that were almost as good as the curvilinear approach using either maximum or minimum temperatures separately.

Use of a daily fraction rather than a reciprocal function reduced the average days missed more with minimum temperatures than with maximum temperatures. This indicates that for the conditions of this study, low minimum temperatures were more detrimental than low maximum temperatures.

The relation between the magnitude of the daily fraction and maximum and minimum temperatures for the three varieties using single quadratic equations is shown in Figure 4. Optimum maximum and minimum temperatures indicated by the equations are 122 and 60 F, respectively, for either the NC2 or the NC5 peanuts. These

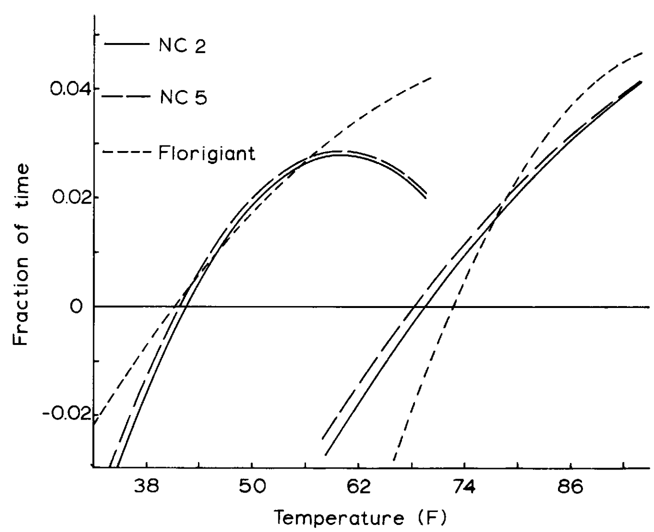

Fig. 4. Relation between fraction of time to flowering and minimum (left) and maximum (right) daily temperatures for three varieties of peanuts.

values for Florigiants were 99 and 85 F. Since the optimum maximum indicated for the NC2 and NC5 varieties and the optimum minimum indicated for the Florigiant variety were well beyond the range of the observed data, the equations may not be applicable in that range.

The temperatures at which the daily fractions become negative have been termed "base" and "lower cardinal" temperatures. For all three varieties the base minimum temperature was near 42 F. The base maximum temperature was about 69 F for the NC2 and NC5 varieties and 72 F for the Florigiant variety. It is noteworthy that the average of the minimum and maximum base temperatures, about 56 F, is the same as determined by Arnold (1959).

Although the temperatures for the Florigiant data (Figure 1) and the NC2 and NC5 data (Figure 2) are similar, the difference presented above may not be due to variety. One season's data with Florigiants may be insufficient to determine the relation accurately. To evaluate this posibility, the best relation between fraction of time to flowering and maximum and minimum temperatures were calculated for each of the three years with the NC2 variety. Five planting-flowering observations were available in 1966 and 1968 and four in 1967. The relation was different in 1966 than that in 1967 or 1968 (Figure 5). This indicates that perhaps other such data on Florigiant peanuts should be compiled. It also indicates, however, that other factors need to be considered. Valli (1965) tried several methods to predict maturity of peanuts and found effective langleys, which is radiation times the daily mean temperature, to be correlated best. Therefore, some measure of radiation possibly should be included when predicting time to flowering.

The present work was conducted to evaluate, as much as possible, the individual effects of maximum and minimum temperatures. It may be advantageous for prediction purposes to use both equations simultaneously. At the same time, each

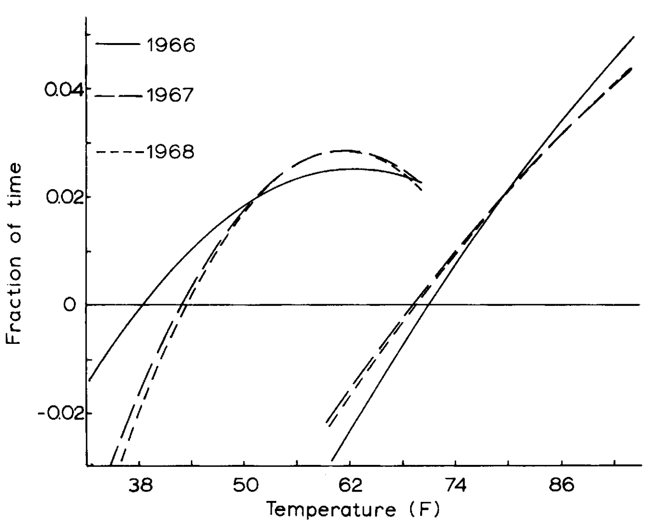

Fig. 5. Relation between fraction of time to flowering and minimum (left) and maximum (right) daily temperatures for NC2 peanuts during three years.

equation would impart the separate effects of maximum and minimum temperatures. This was tested and a slight improvement in the prediction shown. For the three varieties the average days missed ranged from 0.5 to 1.1 (Table 1, row 7).

The quadratic equation used may not be the best form to show the true relation between time to flowering and temperature. The optimum maximum temperatures indicated by the equations for the NC2 and NC5 varieties were quite high. As an alternative, the fraction of time to flowering was set equal to two maximum and two minimum temperature equations. Each equation is operative within a particular temperature range. The equation for the upper temperature range is the sum of the equation for the lower temperature plus an equation which simulates a detrimental effect. A further slight improvement in the predictive ability was shown (Table 1, row 8). The final equations were as follows:

NC2;

$$F = 0.5\ Ymax + 0.5\ Ymin$$

$$Ymax\ (if\ X < 91) = 0.00000407\ X^2 + 0.001237\ X - 0.1064$$

$$Ymax\ (if\ X > 90) = -0.00008536\ X^2 + 0.017359\ X - 0.8329$$

$$Ymin\ (if\ X < 48) = -0.00002227\ X^2 + 0.004592\ X - 0.1555$$

$$Ymin\ (if\ X > 47) = -0.00008563\ X^2 + 0.010574\ X - 0.2967$$

NC5;

$$F = 0.5\ Ymax + 0.5\ Ymin$$

$$Ymax\ (if\ X < 87) = 0.00000735\ X^2 + 0.000723\ X - 0.0856$$

$$Ymax\ (if\ X > 86) = -0.00025369\ X^2 + 0.045841\ X - 2.0352$$

$$Ymin\ (if\ X < 48) = -0.00003339\ X^2 + 0.005601\ X - 0.1753$$

$$Ymin\ (if\ X > 47) = -0.00009564\ X^2 + 0.011521\ X - 0.3161$$

Florigiant;

$$F = 0.5\ Ymax + 0.5\ Ymin$$

$$Ymax\ (if\ X < 86) = -0.00001771\ X^2 + 0.005811\ X - 0.3280$$

$$Ymax\ (if\ X > 85) = -0.00019163\ X^2 + 0.035435\ X - 1.5895$$

$$Ymin\ (if\ X < 57) = -0.00004488\ X^2 + 0.006648\ X - 0.2026$$

$$Ymin\ (if\ X > 56) = -0.00014348\ X^2 + 0.017788\ X - 0.5173$$

where X equals the daily maximum or minimum temperature and F equals the fraction of time to flowering. These relations are shown in Figure 6.

For the NC2, NC5, and Florigiant varieties the optimum minimum temperatures indicated by the equations are 62, 60, and 63 F and the optimum maximum temperatures indicated are 102, 90, and 92 F, respectively. These values appear to be more realistic than those from the single equations. The optimum minimum temperatures indicated are well substantiated by the data but the optimum maximums, since they occur at or beyond the range in the data, may need further verification. Additional equations which would affect the relation at lower temperatures were also evaluated, but no noticeable improvement was shown.

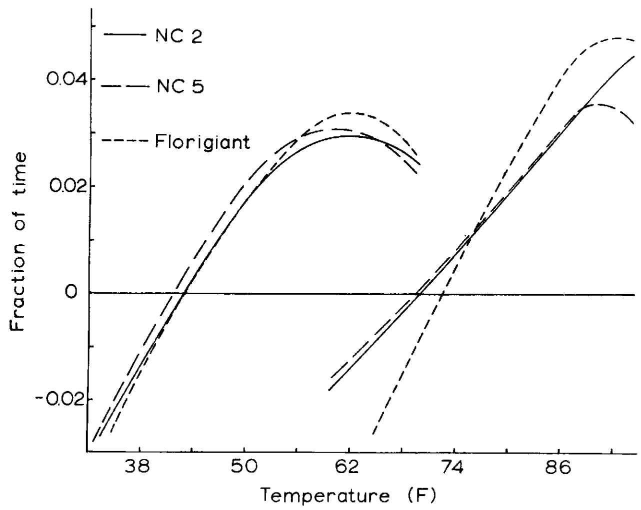

Fig. 6. Relation between fraction of time to flowering and minimum (left) and maximum (right) daily temperatures for three varieties of peanuts when using two equations for each description.

The base minimum temperatures were near 43 F for the three varieties. The base maximum temperatures were 70, 69, and 72 for the NC2, NC5, and Florigiants. Inferences may be drawn from these base temperatures regarding the time to plant these varieties. When the average maximum and minimum temperatures at planting are below 71 and 43 F, detrimental or negative effects on the rate of development would occur. If the growing season is limited, however, the crop should be planted as soon as temperatures average at or above these base levels.

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