# The Thermal Time Concept as a Selection Criterion for Earliness in Peanut[1]

M. J. Vasudeva Rao, S. N. Nigam* and A. K. S. Huda[2]

**ABSTRACT**

Breeding early-maturing cultivars is an important objective of many peanut breeding programs in the world. Most programs use subjective maturity determination methods in selection for earliness. This paper describes a procedure developed at ICRISAT to select early-maturing, high-yielding peanut cultivars based on thermal time accumulation by the crop. In this procedure, cultivars were harvested when the crop was exposed to a predetermined cumulative thermal time (CTT), and selections were made for high yield with acceptable levels of maturity-related traits in a no-stress environment. The predetermined CTT values used in selection for early-maturity represented a 20-day shorter crop duration than for the medium-maturing lines. Based on a 13-year meteorological record, the two predetermined CTTs, (1240 and 1470 °Cd (degree-days) equate to 75- and 90-day durations, respectively, at ICRISAT Center, Patancheru, India in the rainy season (mid June to mid October). It is expected that this procedure could prove useful in peanut breeding to select for earliness.

Key Words: Growing season, early-maturity, heat units, breeding, cultivars, groundnut, degree-days, *Arachis hypogaea L.*

Early-maturing, high-yielding peanut cultivars are needed for many agroecological situations in the semi-arid tropics. These situations include short growing seasons and end-of-season droughts (1) or early frosts. Early-maturing cultivars also can be an important component of a high intensity cropping systems in South and Southeast Asia (4). Many peanut improvement programs around the world, including the one at ICRISAT, have development of early-maturing, high-yielding cultivars as one of their main objectives. The desired crop maturity duration generally varies from 90 to 120 days depending on the agroecological region. Effective differentiation of breeding lines based on their maturity necessitates accurate assessment of their maturity. However, accurate maturity determination in peanut is con-

[1]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ICRISAT Center, Patancheru 502 324 A.P., India. Submitted as ICRISAT Journal Article No. JA 985.

[2]Plant Breeder, ICI India Ltd, Bangalore 560 068, India; Principal Groundnut Breeder, and Agroclimatologist, ICRISAT Center, Patancheru, A.P., 502 324, India.

*Corresponding author.

strained by its indeterminate flowering nature, subterranean pod production, significant maturity x environment interactions and the subjective nature of most maturity determination methods (21).

Ong (15), reviewing the past work on the effect of agroclimatological factors on the phenology of peanut, concluded that temperature is the dominant environmental factor that influences peanut development. Monteith (12) found that the diurnal temperature cycle is more important than either the regular seasonal cycle or the random effects of weather in semi-arid tropics. The concept based on cumulative thermal time (measured in $^0$Cd) has been used in many crops to overcome problems of describing the maturity of cultivars or the stage of optimum harvest (3, 5, 6, 20, 22, 23). In peanut, Mills (9) computed the total heat units necessary from planting to optimum digging for NC 2 cultivar. More recently, Ketring and Wheless (7) used thermal time to determine phenological development in two peanut cultivars, Pronto and OK-FH 15, and concluded that the knowledge of $^0$Cd accumulation can provide estimates of harvest date as well as crop development stage.

This paper describes a procedure developed at ICRISAT using the cumulative thermal time (measured in $^0$Cd units) concept to select early-maturing, high-yielding cultivars.

## Materials and Methods

The present system of yield evaluation of breeding lines at ICRISAT was used to test the usefulness of the thermal time concept in selection for earliness. These breeding lines are derived following pedigree or bulk pedigree methods from crosses between early-maturing source germplasm lines and medium- and late-maturing high-yielding cultivars. In this system, newly identified uniform breeding lines are systematically evaluated at preliminary, advanced, and elite stages in replicated, mostly triple lattice designed, yield trials at one to seven locations in India. As a line is advanced from preliminary to advanced to elite stages, the plot size and the number of locations in which the line is tested increases. At ICRISAT these trials are grown in the rainy (mid June to mid October) and postrainy (mid November to April) seasons representing two distinctly different agroclimatic conditions. Generally, most yield evaluations in peanut adopt physical methods such as hull scrape, stained hull percentage or calendar days to determine the time of digging. In this study, the yield evaluation system was modified by harvesting the trials at predetermined CTTs (cumulative thermal time or growing day-degrees or accumulated heat units, expressed as °Cd) in a staggered harvesting system to select for high-yielding lines with acceptable levels of maturity in early harvests.

Determination of standard CTT: Daily maximum and minimum air temperature measurements taken at the meteorological station at ICRISAT from 1974 to 1986 were used to determine the CTT as follows:

$$CTT\ (^0Cd) = \sum_{P}^{H} \left\{ \frac{T_{max} + T_{min}}{2} - T_{base} \right\}$$

where $T_{max}$ = daily maximum temperature,
$T_{min}$ = daily minimum temperature,
$T_{base}$ = mean base temperature for peanut,
P = planting date, and
H = harvest date.

A mean base temperature of 10°C [10, 11] was used. The daily thermal time was accumulated each day from planting to harvest to arrive at the CTT. June 15 was assumed as the planting date in the rainy season in all years. Thermal time accumulation for 75, 90, 105 and 120 days after planting (DAP), was determined for every year from 1974 to 1986 and a mean CTT over the years was obtained for each of the assumed crop growing periods. The mean CTTs so obtained were referred to as 'standard CTT's. During the same period, i.e., 1974 to 1986, the number of calendar days required by the postrainy season crop to accumulate the standard CTTs, using 15 November as the planting date were calculated.

**Determination of current season harvest date:** The standard CTTs for the 75-and 90-day crop growing periods (1240 and 1470 °Cd, respectively) were used to predict the harvest dates for early-maturity peanut varietal trials in the current season. The 75- and 90-day crop growing periods were selected keeping in mind the requirement of the semi-arid tropical areas of the world and the rice based cropping system of the South and Southeast Asia. A computer program was developed to monitor the progress of thermal time accumulation in the current season and predict the harvest dates by comparing the current accumulated CTTs with the standard CTTs for early harvests. The difference between the current accumulated CTT and the standard CTT for early harvests were divided by the average CTT accumulated for the seven days previous to the date of testing, and the resulting value indicated the remaining number of days until harvest. The program predicted the harvest dates based on a daily updating of the current season's CTT values.

**Selection criteria for earliness:** The yield trials at preliminary stage were harvested when the crop was exposed to 1240 °Cd, the advanced stage trials were harvested when the crop was exposed to 1470 °Cd, and the elite stage trials were harvested twice (staggered-harvesting) when the crop was exposed to 1240 and 1470 °Cds. This combination of staggered-early harvest dates and stage of advancement of cultivars in the yield trials system resulted in the selected lines at the end of the elite trial stage being evaluated twice at both 1240 °Cd and 1470 °Cd. The main criterion for selection of breeding lines for earliness in the yield trial was high pod yield in early harvests. However, to support the selection based on high pod yield, maturity related traits such as shelling percentage, sound mature seed percentage, and 100-seed weight were also monitored. While the pod yield was measured on a plot basis, the maturity related traits were measured on an entry basis. The breeding lines were compared with appropriate control cultivars in the trial. Those which yielded significantly greater than the control cultivars were selected for further evaluation. The staggered harvesting based on standard CTTs was restricted to high input conditions, where insect pests, foliar diseases, and drought were controlled in order to eliminate their influences on maturity.

## Results and Discussion

Thermal time accumulation of a peanut crop in the rainy season at ICRISAT Center, Patancheru, assuming that the crop is planted on 15 June every year (the normal onset of monsoon at ICRISAT is in the second week of June), indicated that about 1240, 1470, 1710 and 1950 $^0$Cd would accumulate on an average in 75, 90, 105, and 120 DAP, respectively (Table 1). The CTT values at the four assumed crop durations ranged even beyond two standard deviations from their respective means over the years indicating that each year could be distinctly different for the thermal regimes experienced by the crop. The number of calendar days required by a peanut crop in the postrainy season to accumulate the standard CTTs of the rainy season crop durations, indicated that for any given standard CTT, the number of days required in the postrainy season also varied considerably (Table 2).

On the basis of thermal time equivalence over the 13-year period, 75, 90, 105, and 120 DAP in the rainy season were approximately equal to 105, 120, 133, and 145 DAP in the postrainy season at ICRISAT, respectively. However, the cumulative thermal regimes to which a crop is exposed over years and seasons appeared to vary considerably and necessitate their accounting while interpreting the realized yield potential of a cultivar in trials and in breeding programs aimed at specific crop maturities.

At ICRISAT, under high input conditions, medium-maturing lines generally mature in 110 to 120 DAP during the rainy season. Vasudeva Rao and Nigam [unpublished data], based on an average of a rainy and a postrainy season estimate, found that the medium maturing cultivars ICGS 11 (13) and ICGV 87128 (14) required about 1760 and 1715 $^0$Cds respectively, to reach their peak seed yields. Therefore, the crop duration for early-maturity trials at ICRISAT was

**Table 1. Thermal time accumulation for 75, 90, 105, and 120 days after planting in the rainy season from 1974 to 1986 at ICRISAT Center, using 15 June every year as the planting date.**

| | Cumulative Thermal Time (°Cd) | | | |
|---|---|---|---|---|
| Year | 75 DAP[1] | 90 DAP | 105 DAP | 120 DAP |
| 1974 | 1248 | 1487 | 1720 | 1951 |
| 1975 | 1215 | 1431 | 1673 | 1901 |
| 1976 | 1234 | 1457 | 1706 | 1962 |
| 1977 | 1248 | 1478 | 1726 | 1967 |
| 1978 | 1159 | 1391 | 1624 | 1866 |
| 1979 | 1297 | 1543 | 1787 | 2024 |
| 1980 | 1234 | 1464 | 1703 | 1946 |
| 1981 | 1235 | 1469 | 1703 | 1937 |
| 1982 | 1259 | 1499 | 1739 | 1972 |
| 1983 | 1276 | 1510 | 1741 | 1968 |
| 1984 | 1234 | 1474 | 1714 | 1954 |
| 1985 | 1232 | 1479 | 1725 | 1960 |
| 1986 | 1210 | 1460 | 1720 | 1976 |
| Range | 1159-1297 | 1391-1543 | 1624-1787 | 1866-2024 |
| Mean | 1237 | 1472 | 1714 | 1952 |
| SD (±) | 33.1 | 36.9 | 37.9 | 37.7 |
| CV (%) | 2.7 | 2.5 | 2.2 | 1.9 |

1. = DAP = Days after planting.

**Table 2. Equivalent number of days in the postrainy season required to accumulate 1240, 1470, 1715, and 1950 °Cd at ICRISAT Center, using 15 November every year as the planting date.**

| | Number of days from planting for accumulation of | | | |
|---|---|---|---|---|
| Year | 1240 °Cd | 1470 °Cd | 1715 °Cd | 1950 °Cd |
| 1974/75 | 112 | 126 | 140 | 151 |
| 1975/76 | 120 | 134 | 147 | 159 |
| 1976/77 | 100 | 115 | 128 | 140 |
| 1977/78 | 101 | 117 | 131 | 143 |
| 1978/79 | 100 | 115 | 130 | 142 |
| 1979/80 | 99 | 113 | 127 | 139 |
| 1980/81 | 104 | 119 | 134 | 145 |
| 1981/82 | 105 | 119 | 132 | 144 |
| 1982/83 | 105 | 118 | 131 | 144 |
| 1983/84 | 105 | 121 | 134 | 146 |
| 1984/85 | 102 | 117 | 129 | 142 |
| 1985/86 | 109 | 123 | 136 | 147 |
| Range | 99-121 | 113-134 | 127-147 | 139-159 |
| Mean | 105 | 120 | 133 | 145 |
| SD (±) | 6.2 | 5.9 | 5.6 | 5.4 |
| CV (%) | 5.9 | 4.9 | 4.2 | 3.7 |

fixed at 90 days. The normal onset of monsoon at this location is in the second week of June and the normal withdrawal is in the second week of October (19) thus giving a growing season of about 120 days for the groundnut crop in a normal year. An earlier harvest at 75 DAP was also included in some trials (preliminary and elite stage trials) to select lines for even shorter growing seasons for multiple cropping situations.

The CTTs corresponding to the early harvest dates, i.e., the 1240 and 1470 °Cds were 520 and 285 °Cd less than the CTT requirement for medium maturing lines at ICRISAT under high input conditions. This represented a reduction in growing season of at least 20 days compared to the medium-maturing lines in the rainy season.

This system of screening peanut cultivars for early-maturity

**Table 3. Performance of selected early-maturing peanut cultivars in staggered harvests under high-input conditions, ICRISAT Center, postrainy season 1986/87[1].**

| | Pod yield (t $ha^{-1}$) | | $SMS^2$ yield (t $ha^{-1}$) | | Shelling (%) | |
|---|---|---|---|---|---|---|
| Genotype | 1240 °Cd[3] | 1470 °Cd | 1240 °Cd | 1470 °Cd | 1240 °Cd | 1470 °Cd |
| ICGV 86016 | 2.62 | 3.52 | 1.55 | 2.55 | 72 | 74 |
| ICGV 86065 | 2.15 | 3.11 | 1.33 | 2.27 | 72 | 76 |
| ICGV 86038 | 2.06 | 3.05 | 1.36 | 2.17 | 73 | 76 |
| ICGV 86061 | 1.99 | 2.90 | 1.34 | 2.10 | 74 | 75 |
| Controls[4] | | | | | | |
| Chico | 1.25 | 1.57 | 0.88 | 1.19 | 76 | 79 |
| ICGS 11 | 1.50 | 2.54 | 0.52 | 1.64 | 54 | 67 |
| SE (±) | 0.12 | 0.18 | 0.13 | 0.15 | 2.3 | 2.8 |
| Trial mean (36 entries) | 1.90 | 2.79 | 1.08 | 1.89 | 67 | 72 |
| CV (%) | 11 | 11 | 21 | 13 | 6 | 7 |

1. Experimental design = 6 x 6 triple lattice; Plot size = 6 $m^2$; High input = 60 kg $P_2O_5$ $ha^{-1}$ with full irrigation and plant protection.
2. SMS = Sound mature seeds.
3. DAP = Days after planting; °Cd = Cumulative thermal time measured in degree-days with 99 and 113 DAP = 1240 °Cd and 1470 °Cd, respectively.
4. Chico = An early-maturing source germplasm line. ICGS 11 = A popular postrainy season spanish cultivar grown in India.

has been used at ICRISAT since 1986. Results of selection using the above procedure in two elite stage yield trials, from the 1986/87 postrainy season and 1988 rainy season at ICRISAT Center (Tables 3 and 4), indicated that the procedure using CTT could be effectively used to select early-maturing cultivars of peanut. In the 1986-87 postrainy season, four cultivars significantly outyielded the highest yielding control cultivar in the 1240 °Cd harvest, and three of them maintained their significant superiority in the 1470 °Cd harvest (Table 3). In the 1988 rainy season trial, two test lines in the 1240 °Cd harvest and three in the 1470 °Cd harvest, significantly outyielded the highest yielding control cultivar (Table 4).

The thermal time requirements for different phenological phases of peanut have been described by Ono (16), Ono and Ozaki (17), Ono *et al.* (18), Emery *et al.* (2), Mills (9), Leong and Ong (8), Mohamed (10), Williams *et al.* (24), and Ketring and Wheless (7). Estimates of total CTT of 2000 °Cd for peanut cultivar Robut 33-1 (15), and 1600 °Cd for cultivar NC 2 (9), are given in the literature.

One practical difficulty encountered in using the CTT concept in selection for a specific maturity group is the need for multiple harvesting to compute the CTT requirements of individual cultivars. In the present procedure this problem is overcome to some extent by harvesting once (or twice) at predetermined CTTs which are based on historical meteorological records and referenced to the medium duration lines. This provides greater assurance than the DAP method of consistent selection pressure for earliness, and facilitates evaluations of potential varieties for targetted growth duration.

With the success in identifying early-maturing advanced breeding lines with this method, it has now been extended to segregating populations where they are dug when the crop accumulates about 1300 °Cd, and lines/plants are selected for high pod yield and early-maturity.

**Table 4. Performance of selected early-maturing peanut cultivars in staggered harvesting under high-input conditions, ICRISAT Center, Rainy season 1988[1].**

| | Pod yield ($t\ ha^{-1}$) | | SMS[2] yield ($t\ ha^{-1}$) | | Shelling (%) | | Seed mass ($g\ 100^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| Genotype | 1240 °Cd[3] | 1470 °Cd | 1240 °Cd | 1470 °Cd | 1240 °Cd | 1470 °Cd | 1240 °Cd | 1470 °Cd |
| ICGV 87882 | 1.68 | 2.15 | 0.91 | 1.21 | 64 | 74 | 26 | 32 |
| ICGV 87922 | 1.60 | 2.07 | 0.93 | 1.35 | 65 | 75 | 24 | 32 |
| ICGV 87910 | 1.30 | 2.16 | 0.77 | 1.52 | 65 | 71 | 25 | 33 |
| Controls[4] | | | | | | | | |
| Chico | 1.12 | 1.23 | 0.71 | 0.81 | 68 | 69 | 20 | 25 |
| TMV 2 | 0.89 | 1.51 | 0.41 | 0.95 | 57 | 68 | 22 | 32 |
| JL 24 | 1.19 | 1.74 | 0.61 | 0.76 | 60 | 64 | 26 | 37 |
| SE (±) | 0.08 | 0.12 | - | - | - | - | - | - |
| Trial Mean (49 entries) | 1.25 | 1.67 | - | - | - | - | - | - |
| CV (%) | 11 | 12 | - | - | - | - | - | - |

1. Experimental design = 7 x 7 triple lattice; Plot size = 6 $m^2$; High input = 60 kg $P_2O_5$ $ha^{-1}$ with full irrigation and plant protection.
2. SMS = Sound mature seeds.
3. DAP = Days after planting; °Cd = Cumulative thermal time measured in degree-days with 78 and 93 DAP = 1240 °Cd and 1470 °Cd, respectively.
4. Chico = An early-maturing source germplasm line. TMV 2, JL 24 = Popular rainy season spanish cultivars grown in India.

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