JARQ 33, 105-108 (1999)

# Estimation of Flowering Date and Temperature Characteristics of Fruit Trees by DTS Method

**Sukeyuki ONO**[*1] **and Takamitsu KONNO**[*2]

[*1] Department of Citriculture, National Institute of Fruit Tree Science (Kuchinotsu, Nagasaki, 859-2501 Japan)

[*2] Department of Soils and Fertilizers, National Agriculture Research Center (Tsukuba, Ibaraki, 305-8666 Japan)

**Abstract**

A theory and a method were developed for obtaining temperature characteristics for the flowering period of deciduous and citrus fruit trees from the number of days transformed to standard temperature (DTS) based on the Arrhenius law. Three temperature characteristics, i.e. (1) starting date of calculation (ST day), (2) temperature sensitivity (Ea) or temperature coefficient of growth rate (K) and (3) DTS from ST day to flowering time, were determined in a total of 186 cultivars from 11 species on the Main Island of Japan (Honshu) based on the daily mean air temperature and flowering date recorded over a period of at least 10 years. These temperature characteristics differed among cultivated species and may enable to estimate the flowering date.

**Discipline:** Horticulture
**Additional key words:** temperature sensitivity, Arrhenius law, deciduous and citrus fruit trees

## Introduction

The climate of the islands of Japan ranges from subpolar to subtropical. Most of the fruit orchards are located on hillsides and are exposed to extreme weather conditions due to the elevation and topography of the sites. Development of new land for fruit production depends on the accurate estimation of the growing period. Predictive methods for estimating the flowering period could facilitate orchard management practices such as artificial pollination, hormone treatment and cultivation control. A theory was proposed based on the number of days transformed to standard temperature (DTS) derived from the Arrhenius law, and a method (DTS method) was developed by analyzing the relationship between the biological activity and temperature[4]. Although the Arrhenius law has been applied to higher plants[6-8,10], there is no report in which temperature characteristics have been used to improve plant growth. We have shown that temperature characteristics based on the Arrhenius plot can be used effectively to determine the budding and flowering period of Japanese pear trees[10]. Omoto and Aono[9] were able to estimate the flowering date of *Prunus yedoensis* at 21 meteorological stations in Japan by using the DTS method.

An Arrhenius plot of the growth of higher plants has been reported to give a straight line with a negative slope or a line broken into 2 parts, in the range between the temperature of physiological zero and that at which protein denaturation occurs[6,8]. Our experiments have shown that the Arrhenius plot of the flowering period of Japanese pear trees gives linear plots at 7-20°C, and that the Arrhenius law can be effectively applied to the flowering period[10]. Thus, temperature characteristics were calculated assuming that the Arrhenius law could also be applied to fruit trees other than Japanese pear.

This paper is designated as contribution No.1119, from the National Institute of Fruit Tree Science. This work was supported in part by a Grant-in-Aid (Development of Information Management for Agricultural Technique System) from MAFF. Part of this research was carried out in collaboration with the Project Research Team of the National Agriculture Research Center.

Present address:
[*2] Faculty of Agriculture, Niigata University (Niigata, 950-2102 Japan)

## Theory and methods

The relationship between the growth rate constant (k) and temperature can be expressed by equation (1) according to the Arrhenius law. The DTS is defined as the number of days transformed to standard temperature. The equation for the calculation of DTS can be derived as follows:

The ratio of the growth rate constant (k) at arbitrary temperature (T) to (ks) at a standard temperature (Ts) can be represented by equation (4) using equation (1).

$$k = A \cdot \exp(-Ea/RT) \quad (1)$$

$$dk/dT = A \cdot Ea/RT^2 \cdot \exp(-Ea/RT) = k \cdot K \quad (2)$$

$$K = Ea/RT^2 \quad (3)$$

$$m = k/ks = \exp[Ea(T-Ts)/RTTs] \quad (4)$$

where k: growth rate constant ($day^{-1}$),
Ea : apparent activation energy ($Jmol^{-1}$),
R : gas constant (8.314 $JK^{-1}$ $mol^{-1}$),
T : absolute temperature ($deg^{-1}$),
K : temperature coefficient of growth rate ($deg^{-1}$),
A : constant,
ks : growth rate constant at standard temperature Ts,
m : conversion coefficient.

Selecting 20°C as the standard temperature, the daily 20°C DTS can be expressed as follows:

$$\text{Daily } 20°C \text{ DTS} = \exp[Ea(t-293)/586T] \quad (5)$$

where t is the daily mean temperature.

The following 3 temperature characteristics must be obtained for each tree species to estimate the flowering date.

(1) ST day : starting date of calculation,

(2) Ea : temperature sensitivity[10],

(3) DTS : DTS from ST day to the flowering date.

First step was to calculate the mean DTS from arbitrary Ea in each year using the flowering date for at least 10 years. The next step was to compute the residual sum of squares (RSS) for the difference between the estimated and observed flowering period. The optimal temperature characteristics, i.e. ST day, Ea, DTS, gave the minimum RSS.

Calculation was conducted using the personal computer program FLOWER based on the date for full-bloom and the daily mean air temperatures in each year, using 20°C as the standard temperature. Phenological data were recorded for apple, pear, grape, peach, persimmon, chestnut, plum, blueberry, satsuma mandarin and other citrus trees. Data used included the daily mean air temperatures. Data on the date of flowering were kindly provided by 57 public research institutes.

## Results and discussion

Temperature characteristics were obtained with considerable accuracy from the calculation of the observed dates and the estimated dates of flowering in 186 cultivars from 11 fruit tree species in Honshu. Typical dates for apple, pear, peach, plum, grape, persimmon, chestnut, satsuma mandarin and navel orange trees are shown in Fig. 1. In some cases the estimated dates that were different from the actual observed dates were obtained during a year with unusual weather. These results show that temperature characteristics up to the flowering period can be obtained with a good accuracy using the DTS method from Kagoshima to Hokkaido for almost all the cultivated species of fruit trees.

The ST day for navel orange was estimated to be January 10 when RSS was smallest, and that for persimmon February 25 when minimum RSS was observed between February 20 through March 1. Except for some cases, estimation of the ST day was easily obtained. Therefore, it is important to give a physiological interpretation to the ST day, rather than a mathematical interpretation. The estimated ST day in the present study fell in early January for citrus trees, early February for peach trees, mid-February for apple, pear and plum trees, late February to early March for grape, persimmon and chestnut trees. Based on the reports on cold hardiness and dormancy, these periods were found to correspond to those when endodormancy had been terminated[1-3,5].

Fig. 2 shows the relationship between the standard temperature and DTS obtained from temperature sensitivity (Ea) values of various fruit trees in the central part of Honshu Island. Since the Ea value varied among tree species, the change in the rate of DTS was different at various standard temperatures and could be classified into 2 groups (Fig. 2). At 20°C, the first group consisting of apple, pear, peach and plum trees, flowered between 10 and 25 days, the second group consisting of grape, persimmon, chestnut and citrus trees, flowered

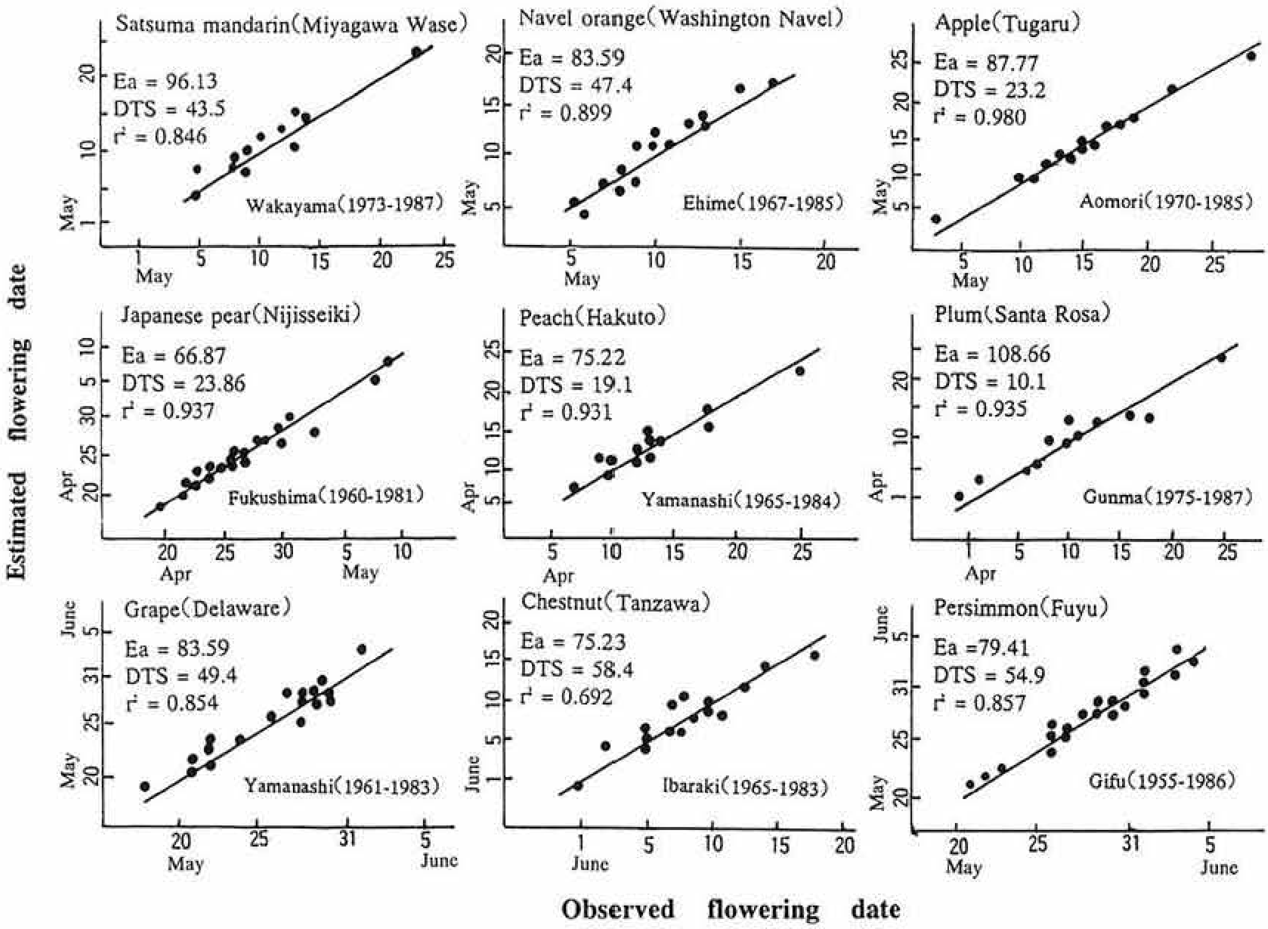


Fig. 1. Relationship between observed and estimated flowering date by DTS method in fruit trees
Ea: kJ $mol^{-1}$, DTS: days with 20°C standard temperature.

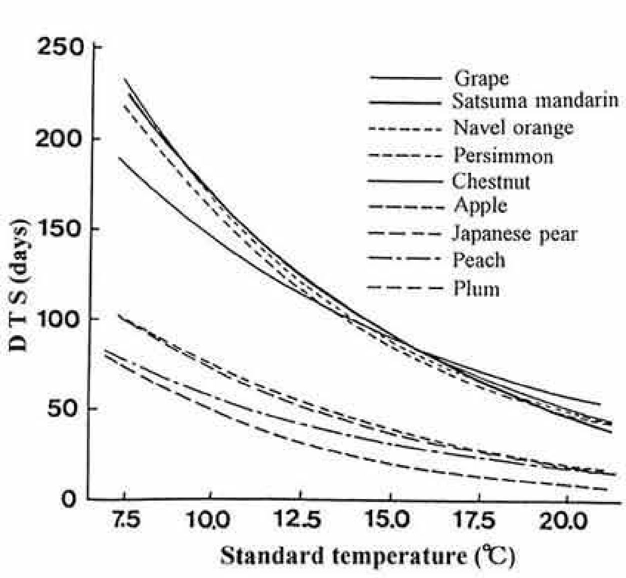


Fig. 2. Relationship between standard temperature and DTS based on temperature sensitivity (Ea) in various fruit trees (Table 1)

between 47 and 58 days. In the central part of Honshu, the first group flowered from late March through mid-April, while the second group flowered from mid-May through early June. In the second group, the ST day for citrus fell early in mid-January while that for grapes, persimmons and chestnuts fell in late February. Interestingly, there was a difference in the growth period from the endodormancy to the flowering period even though the groups showed the same flowering period.

Temperature characteristics of cultivated species in the central part of Honshu are shown in Table 1. Ea values ranged from 75 to 92 kJ $mol^{-1}$ except for plums, the difference being negligible among the cultivated species. The K values calculated from equation (3) were in the range of 0.105–0.129, suggesting that the change of one degree in the air temperature caused a 10.5–12.9% change in the growth rate. Plums had a K value of 0.152 and were the most sensitive to the change in the air temperature among the cultivated species. Such a difference in

**Table 1. Values of temperature characteristics determined by DTS method for fruit tree flowering (central part of Honshu Island)**

| Leading cultivar | Days transformed to the standard temperature (DTS) | | Temperature sensitivity (Ea) | | Starting date for estimating DTS | $r^{2}$ [d] | Number of years used for calculation | Observation site |
|---|---|---|---|---|---|---|---|---|
| | DTS[a] | RSS[b] | Ea[c] | RSS[b] | | | | |
| Apple (Fuji) | 23.3 | 1.03 | 79.41 | 5.43 | Feb. 15 | 0.882 | 16 | Nagano |
| Japanese pear (Kousui) | 21.3 | 1.16 | 83.59 | 8.78 | Feb. 15 | 0.902 | 16 | Tochigi |
| Peach (Hakuto) | 19.1 | 1.18 | 75.23 | 7.10 | Jan. 20 | 0.888 | 19 | Nagano |
| Plum (Santa Rosa) | 10.1 | 0.67 | 108.66 | 10.03 | Feb. 10 | 0.908 | 12 | Gunma |
| Grape (Delaware) | 49.4 | 0.82 | 83.59 | 6.27 | Feb. 20 | 0.868 | 22 | Yamanashi |
| Persimmon (Fuyu) | 54.9 | 0.32 | 79.41 | 7.10 | Feb. 25 | 0.870 | 31 | Gifu |
| Chestnut (Tanzawa) | 58.4 | 0.72 | 75.23 | 18.39 | Mar. 15 | 0.781 | 18 | Ibaraki |
| Satsuma mandarin (Aoshima Unshiu) | 49.7 | 1.22 | 83.59 | 9.19 | Jan. 15 | 0.865 | 14 | Shizuoka |
| Navel orange (Morita Navel) | 47.9 | 1.35 | 91.95 | 7.52 | Jan. 10 | 0.856 | 13 | Shizuoka |

a): DTS; days.
b): RSS; Residual sum of squares, difference between estimated and actual flowering period.
c): Ea; kJ $mol^{-1}$.
d): Correlation coefficient between observed and estimated flowering date.

Ea was reflected in the DTS. For example, chestnuts flowered within approximately 58 days at the standard temperature of 20°C, being the slowest among the tested trees, and yet, below 12.5°C, they showed the shortest flowering period (Fig. 2).

## References


1) Aono, Y. & Omoto, Y. (1990): Estimation of blooming date for *Prunus yedoensis* using DTS combined with chill-unit accumulations. *J. Agric. Meteorol.*, **45**, 243-249.
2) Chandler, W. H. & Tufts, W. P. (1934): Influence of the rest period on opening of buds of fruit trees in spring and on development of flower buds of peach trees. *Proc. Am. Soc. Hort. Sci.*, **30**, 180-186.
3) Fuchigami, L. H. & Cheng-Chu, N. (1987): Degree of growth stage model and rest-breaking mechanisms in temperate woody perennials. *HortScience*, **22**, 836-845.
4) Konno, T. & Sugihara, S. (1986): Temperature index for characterizing biological activity in soil and its application to decomposition of soil organic matter. *Bull. Natl. Inst. Agro-Environ. Sci.*, **1**, 51-68.
5) Lang, G. A. (1987): Dormancy; a new universal terminology. *HortScience*, **22**, 817-820.
6) Lyons, J. M. & Paison, J. K. (1970): Oxidative activity of mitochondria isolated from plant tissues and resistance to chilling injury. *Plant Physiol.*, **45**, 386-389.
7) Minchin, A. & Simon, E. W. (1973): Chilling injury in cucumber leaves in relation to temperature. *J. Exp. Bot.*, **24**, 1231-1235.
8) Nishiyama, I. (1975): A break on the Arrhenius plot of germination activity in rice seeds. *Plant Cell Physiol.*, **16**, 533-536.
9) Omoto, Y. & Aono, Y. (1989): Estimation of blooming date for *Prunus yedoensis* by means of kinetic method. *J. Agric. Meteorol.*, **45**, 25-31.
10) Ono, S. et al. (1988): Effect of temperature on the number of days for budding and flowering of Japanese pear. *J. Agric. Meteorol.*, **44**, 203-208.


(Received for publication, November 2, 1998)