TEMPERATURE AS A FACTOR IN NECTARINE PRODUCTION IN THE WESTERN CAPE

Thesis

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DECLARATION

I hereby declare that the research reported in this thesis is original and the result of my own investigations, except where acknowledged. This thesis has not, in its entirety or in part, been previously submitted to any University for degree purposes.

Signed..
Gavin C. Linsley-Noakes

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ABSTRACT

Phenological and climatic data were collected from nectarine orchards containing the cultivars Sunlite, Flavortop and Fantasia, growing in six climatically divergent areas in the Western Cape, South Africa. Shoots were forced at 25°C and bud volumes measured in order to develop an index of when the endodormancy requirement for each cultivar in each area had been satisfied. Flower bud break gave the only consistent indication of when the chilling requirement had been satisfied and 10% flower bud break after 14 days at 25°C was adopted as the best index of end of endodormancy. Unlike vegetative bud break, flower bud break was not influenced by forcing period or gibberellic acid (GA_3) application.

Comparison of winter chilling models using the temperature data for the endodormancy period, showed that the 'dynamic' model (DP) was more accurate than the currently used 'Utah' model (UCU), for estimating the rest requirement of the nectarine cultivars Sunlite, Flavortop and Fantasia. The DP model failed, however, to identify orchards displaying 'delayed foliation' symptoms as a result of insufficient winter chilling. The 'dynamic' model not only takes into account the positive effect of cool temperatures and negative effect of high temperatures on rest completion that the 'Utah' model does, but also the positive effect of moderate temperatures and the fact that chilling negation is subject to time constraints. The nectarine cultivars tested required about 33 ± 5; 46 ± 8 and 46 ± 8 'dynamic' portions of chilling for Sunlite, Flavortop and Fantasia, respectively.

Modification of the UCU model, using principles from the DP model, resulted in a substantial increase in its accuracy. The modification assumes that the negating effect of high temperatures is confined to the diurnal cycle and that there is not a carry-over effect of chilling negation from one day to the next. Coefficients of variation for the estimated chilling requirements of 'Sunlite', 'Flavortop' and 'Fantasia' were reduced from 24.9%, 21.7% and 23.8% to 19.7%, 17.9% and 20.1% respectively. This modification, now called the 'daily positive Utah chill unit model (PCU), is currently used in the Western Cape Province to determine winter chilling efficiency in deciduous fruit orchards. The PCU requirements for 'Sunlite', Flavortop' and 'Fantasia' were 566± 111, 807± 145 and 817± 165 respectively.

Correlations were then made between the heat component during endodormancy (degree hours > 10°C [DH]) and the apparent chilling requirement. The subsequent regressions gave almost parallel slopes regardless of cultivar or chilling requirement, indicating that in milder winter areas, heat accumulation could also play a vital role in endodormancy. As an approximation, an elevation in mean air temperature during the main endodormancy months of May and June, resulted in an apparent reduction in the chilling requirement of 20% for every 1°C increase within the range of 11-14°C. The post-endodormancy heat requirement for bud development in spring was highest in the milder winter areas and lower in areas receiving more winter chilling than their endodormancy requirement.

Although there are already 65 automatic weather stations operating in South Africa's Western Province deciduous fruit industry, the variation in microclimate is much too large to make accurate extrapolations and alternative methods of estimation of chilling are required. Tables for the expeditious determination of daily chill unit accumulation from minimum and maximum temperatures were developed, using the assumption that air temperature follows either a straight line between extremes or that it follows a sine curve during the heating cycle followed by a logarithmic cooling phase. Both tables gave an average accuracy of 95% for determining monthly or total winter chilling in seven divergent locations over three seasons. The sine- logarithmic table appeared to be slightly more accurate under mild winter conditions. Daily positive Utah chill units are now used extensively by the South African deciduous fruit industry and colour maps depicting average PCU chilling values for the region were in the process of being plotted at the time of going to press.

Key words: dormancy; nectarines; *Prunus persica* (L.) Batsch; winter temperature

Abbreviations: DF, delayed foliation; DP, dynamic portions; DH, degree hours > 10°C; PCU, daily positive Utah chill units; UCU, Utah chill units.

GENERAL INTRODUCTION

Winter dormancy in deciduous fruit trees of the temperate zones is a phase of development that occurs naturally and evolved as a means for plants to survive cold winters. Without a comprehensive theory of dormancy it will be extremely difficult to improve the management of dormancy release, be it for the choice of fruit type or cultivar for a specific location, for the promotion or retardation of growth and development, or for the determination of the dormancy intensity, as an important prerequisite for the proper timing of various cultural practices.

Dormancy, which is defined as "a temporary suspension of visible growth of any plant structure containing a meristem" (Lang, Early, Martin & Darnell, 1987), is a term which encompasses a large number of physiologically and ecologically imposed resting phases in meristems. The following terms were initially used by Doorenbos (1953), Samish (1954) and Vegis (1964) to describe these phases:

Summer dormancy (early rest; predormancy) - when extension growth of buds is prevented by physiological processes inside the plant but outside the bud.

Winter dormancy (true dormancy; main rest) - when extension growth of buds is prevented by an inhibitive system within the bud.

Imposed dormancy (late dormancy; after rest) - when extension growth of buds is prevented by external causes, directly and reversibly imposed by environmental conditions, mainly in late winter.

Because of the difficulties with the terminology used in initial dormancy research, many improvements have been proposed, mainly because, in warmer temperate zones, imposed dormancy seldom occurs and because the actual beginning and ending of each phase are not that clearly defined.

Saure (1985) proposed a system in which imposed dormancy can be masked by a prolonged winter dormancy in areas experiencing warm winters (bottom Fig. 0.1.) Under these conditions bud break in spring can be sluggish, even when climatic conditions are conducive to growth and development. The system, however, still fails to adequately delimit the various phases of dormancy.

Kobayashi, Fuchigami & English (1982), have developed an empirical model for predicting rest development in deciduous trees, which describes more clearly the relationship between vegetative maturity, the onset of winter dormancy (Siebel & Fuchigami, 1978) and the first stage of cold acclimation (Nissila & Fuchigami, 1978).

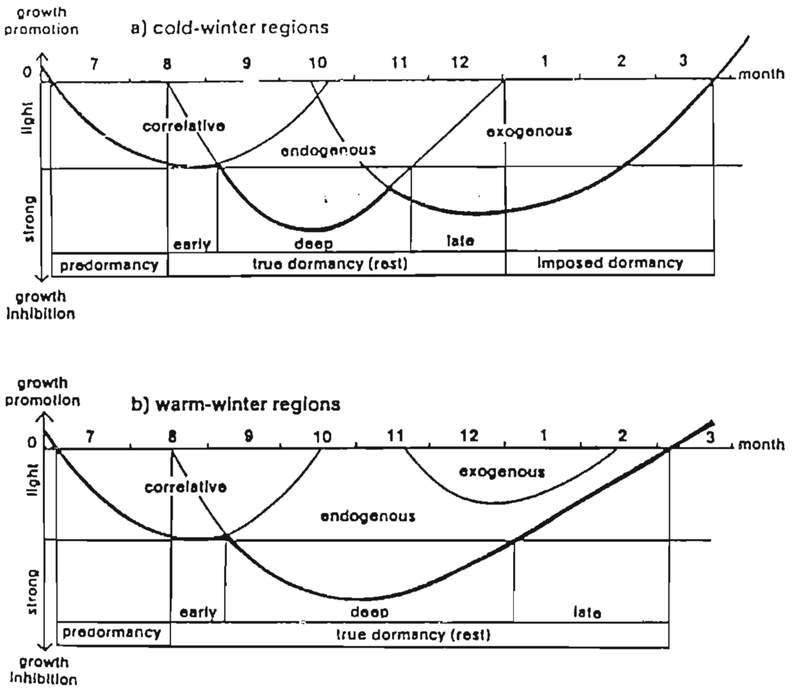


Fig. 0.1 The course of dormancy and its components as influenced by external and internal factors (after Saure, 1985).

Because of the confusion relating to the vast number of terms describing the three phases of dormancy, Lang, *et al.* (1987) have termed the three phases paradormancy, endodormancy and ecodormancy, corresponding to correlative, endogenous and exogenous dormancy as described in Fig 0.1. Using this classification it is possible to expand the notation to describe more fully the controlling factors within the phases of dormancy. e.g. the chilling requirement of winter rest is classified as cryogenic endodormancy.

The main aims of this research were as follows:

1) To identify the endodormancy period of each of the three cultivars chosen in each of the six locations. The hourly temperatures for these periods would then be used to compare the 'Utah' rest completion prediction model then used, with the newly developed 'dynamic portion' model from Israel (Richardson, Seeley & Walker, 1974; Fishman, Erez & Couvillon, 1987a and b).

2) To attempt to develop a model that would be accurate under Western Cape conditions and be easy to use.

3) To develop a method of easy determination of winter chilling using daily minimum and maximum temperatures (Linvill, 1990).

4) To investigate the effect of heat accumulation during endodormancy and during bud development in spring (Sparks, 1993).

5) Once a new model has been developed, a map of winter chilling will be developed for the Western Cape deciduous fruit growing areas.

CHAPTER ONE: DETERMINATION OF THE ENDODORMANCY PERIOD OF NECTARINES

1.1 INTRODUCTION

The identification of the stage of endodormancy is very important because a plant in the state of endodormancy responds quite differently to external influences than a non endodormant plant. Plants enter this stage independently of environmental conditions and consequently will not respond to favourable environments when in this state (Saure, 1985). The entrance into endodormancy is usually preceded by a stage of paradormancy, either brought about by shorter days, cold, heat, drought or other conditions unfavourable to growth, or due to correlative inhibition (Samish, 1954).

With the progression of time between the para- and endodormant state, the range of conditions required to initiate growth becomes narrower and narrower until only the harshest of treatments will stimulate growth. Once this state is achieved, the meristems are considered to be under the control of endodormancy (Vegis, 1964). Gibberellic acid treatment, using a range of concentrations from 0 to 250 $mg.kg^{-1}$ is the standard treatment used for determining when vegetative buds have entered into the endodormant phase (Hatch & Walker, 1969; Couvillon & Hendershott, 1974; Blaine & Allan, 1979; Partridge & Allan, 1980).

Siebel & Fuchigami (1978) showed that the development of vegetative maturity (state of maximum chill injury resistance), the onset of cold acclimation and endodormancy in red-osier dogwood (*Cornus stolonifera* Michx.) are positively related.

The completion of endodormancy has been determined based on the principle that once the bud's endodormancy requirement has been satisfied, environmental conditions conducive to growth result in normal bud development. Forcing temperatures are therefore used and cryogenic endodormancy is complete once forcing temperatures (generally between 20°C and 27°C) result in significant bud break levels after a period of time (14 to 30 days) (Hatch & Walker, 1969; Couvillon & Hendershott, 1974; Mielke & Dennis, 1978; Norvell & Moore, 1982).

The whole question of determination of the endodormant period is complicated by the fact that there are significant differences in the times of entry into, and exit from, endodormancy as well as in the depth of dormancy of individual buds on a tree. Scalabrelli & Couvillon (1985) found that terminal vegetative, lateral vegetative and floral buds of peach showed increased chilling requirements. Shoot length, vigour, position on the tree, orientation, tree complexity, bud age and crop load all affect the physiological stage of buds on the tree (Latimer & Robitaille, 1981; Hauagge & Cummins, 1991a). The duration of paradormancy and external influences during this period also have a profound influence on endodormancy and potential for "delayed foliation". Factors such as juvenility, which extends active growth into autumn and so reduces the start of paradormancy, results in a different endodormancy period when compared with older, more complex trees of the same cultivar (Lloyd & Firth, 1990).

They found that treatments during paradormancy, such as leaf removal and post harvest nutrition (Terblanche, Hesebeck & Strydom, 1979) also have a profound influence on the endodormancy cycle. Dormancy phases can therefore only be accurately determined for individual buds, as trees will have flower and vegetative buds in a range of dormant states throughout the dormant period. This range in physiological status of buds within and between trees manifests itself in "delayed foliation" symptoms in cases where climatic conditions are favorable for growth early in spring without all the bud's endodormancy requirements being met. Where there has been insufficient winter chilling to meet most of the bud's endodormancy requirements, only those buds which have had their requirements met will respond rapidly to favourable environmental conditions, resulting in a long, erratic foliation and flowering period in spring.

This implies that in order to achieve synchronous bud break, a limited period of ecodormancy is required so that as buds exit from endodormancy, ecodormancy prevents them from developing until the endodormancy requirement of the majority of the buds has been satisfied. These buds can then respond to favourable environmental factors simultaneously. Since vegetative and flower buds also tend to have different chilling requirements (Saure, 1985), an imposed ecodormancy will also synchronise vegetative and floral bud break. The "chilling requirement" of a deciduous tree can thus be described as the critical amount of favorable low temperatures required to overcome the cryogenic endodormancy requirement of sufficient vegetative and reproductive buds on a tree to give an acceptable, synchronous bud break under favourable environmental conditions. Ecodormancy therefore acts as a synchronising buffer at the end of the dormancy cycle.

The seasonal bud dormancy pattern in apples resembles a normal curve (Hauagge & Cummins, 1991b). Bud dormancy starts to intensify soon after bud formation and reaches maximum intensity by the time of leaf senescence. Dormancy intensity is directly related to the chilling requirement with high chilling requirement cultivars having an intense bud dormancy.

Most dormancy studies on peaches have used either terminal or lateral vegetative buds to determine endodormancy status (Erez & Lavee, 1971; Erez, Couvillon & Hendershott, 1979a), although flower bud break has also been successfully used (Couvillon & Hendershott, 1974).

The aim of this trial was to evaluate and modify the methods for determining the endodormant period of nectarine buds, as described in the current literature, in order to develop a standard procedure which can be used locally.

1.2 MATERIALS AND METHODS

Climatic and phenological data were collected from nectarine orchards at six locations in the deciduous fruit growing regions of the Western Cape Province of South Africa from 1988 to 1990. These locations were widely divergent in their winter climate and the severity of the winters differed over the three seasons examined. The locations chosen, ranked from coldest to warmest in winter, were Bokkeveld, Ceres, Villiersdorp, Clanwilliam, Paarl and Robertson. The differences in climate were caused by a combination of aspect, altitude, latitude and winter rainfall pattern (Table 1.1).

Table 1.1 Geographical description of locations used in this investigation.

Location	Latitude (°S)	Altitude (m)	Rainfall* (mm)	Sunshine hours* (h/day)	Distance from sea (km)
Bokkeveld	33°10’	1020	501	6.18	100
Ceres	33°23’	960	348	6.33	100
Villiersdorp	34°03	570	431	5.53	40
Paarl	33°50	138	501	6.00	45
Clanwilliam	32°10’	300	137	6.25	30
Robertson	33°49’	156	133	6.45	80

* Long term averages for winter months of May - August.

Three commercially important nectarine cultivars, Sunlite, Flavortop and Fantasia, described locally as having low, medium and medium/high winter chilling requirements respectively, were used for the research. Within each location, orchards in which these cultivars were represented in adjacent blocks and having a uniform microclimate, tree age and training system, were chosen. Within each location a Stevenson screen was erected and air temperature was measured in the screen by means of thermocouples linked to a data logger (M.C. Systems, Steenberg, Cape, South Africa). Casella min/max thermometers were used as a check.

In order to estimate the actual endodormancy requirement of the three cultivars, phenological studies were carried out to separate the endodormancy, ecodormancy and heat requirement components of winter and spring temperatures. Thirty 400 mm shoots from each cultivar at each location were collected at 14 day intervals throughout the winter to examine their phenological status. Only shoots conforming to a set standard were collected. Shoots were collected from a height of between 1.2m and 1.4m (main fruiting area) on the eastern side of the tree (receiving little direct afternoon radiation). Only vertically orientated shoots of just over 400mm were used. The lower 100mm of the shoots was removed and the buds excised to determine bud volumes and for further anatomical and plant growth regulator analysis. Shoots for forcing studies were collected until natural bud break commenced.

In 1988 the shoots were divided into batches of 10 and treated with 0, 100 or 200 $mg.kg^{-1}$ GA_3 made up in distilled water. The shoots were immersed in solutions for 1 min. and then allowed to stand with their bases in the solution for 30 min., before being transferred to jars of distilled water in growth chambers (Couvillon & Hendershott, 1974). In 1989 and 1990 shoots were forced untreated using three replications of 10 shoots per sampling. Flower bud volume was determined in 1989 and 1990 by measuring the displacement volume of 40 flower buds in a 15 ml measuring cylinder. Agral 90 wetting agent [Bayer, (South Africa) P.O. Box 58, Isando, 1600] was used to reduce bud surface tension. In 1991 additional data were collected from the warmest (Robertson) and coldest (Bokkeveld) locations.

The shoots were forced in a growth chamber at $25^{\circ}C$ (± 1) with 350 $\mu mol\ s^{-1}m^{-2}$ of cool-white flourescent light for 16 hr daily. Fresh cuts were made to the bases of the shoots each week. Terminal vegetative, lateral vegetative and reproductive bud development was monitored 14 days after collection and then every two to three days for a period of up to 38 days. These data were plotted graphically and the graphs were then compared to examine the trends shown.

The response curves for each location, cultivar and year were evaluated. The general trend shown by these response curves tended to be similar for each year, and so the averaged response for the six locations and three cultivars were determined and presented in order to keep the chapter concise.

The following descriptions of the months and seasons were used in the discussion of the results:

Month:	November	December	January	February	March	April
Season:	early summer	mid summer	late summer	early autumn	mid autumn	late autumn

Month:	May	June	July	August	September	October
Season:	early winter	mid winter	late winter	early spring	mid spring	late spring

1.3 RESULTS

1.3.1 1988 Season

Gibberellic acid (GA_3) was used to try to define the endodormancy period and intensity in nectarine buds as described in Hatch & Walker (1969). Individual location and cultivar reactions to GA_3 treatments were determined and assessed, but because the responses were very similar, only the averaged responses for the six locations and three cultivars were presented (Fig.1.1). Terminal vegetative buds were the most responsive to GA_3, especially during the early part of endodormancy when the buds were least responsive to forcing temperatures. Terminal bud break during the most sensitive response period was increased from 20 to 30% (Untreated) to 70 to 80% by either 100 or 200 $mg.kg^{-1}$ GA_3. The greatest response to GA_3 application occurred in early winter when endodormancy intensity was high (Fig 1.4).

The averaged response at the inception of the study (5th April 1988) indicated that GA_3 treatment resulted in very little improvement in bud break levels. This lack of response indicates that on average, the period of greatest endodormancy intensity in 1988 was in late autumn. As the endodormancy requirements were satisfied in winter, the response of the untreated shoots to forcing improved, until all terminal buds had broken dormancy by late winter (12th July).

There was very little difference between the forcing action of 100 or 200 mg.kg^{-1} GA$_3$. Gibberellic acid affected the bud break of lateral buds more erratically, with a possible increased bud break in the later part of endodormancy, just before natural bud development took place. The lower response of lateral compared with terminal vegetative bud response to GA$_3$ is well documented (Erez, Couvillon & Hendershott, 1979a). Flower bud break was least affected by GA$_3$, which is in accordance with Hatch & Walker (1969) and Partridge & Allan (1980), although Couvillon & Hendershott (1974) did show difference in cultivar response with reaction to GA$_3$, only just before endodormancy termination.

Terminal vegetative bud break levels were also sensitive to the forcing period (amount of heat accumulation). The number of buds which responded to forcing temperatures increased as the forcing period was lengthened from 14 to ± 30 days (Fig. 1.2).

The response of shoots of the three cultivars to forcing period were similar and so only the averaged cultivar responses are presented. In response to a long forcing regime (30 days), most terminal buds eventually broke dormancy at all sample dates, masking the typical response of terminal buds at different levels of endodormancy to forcing temperatures. This sensitivity of endodormant terminal buds to forcing period reduces the effectiveness of using terminal bud forcing as an accurate index of endodormancy completion. The potential variation in bud break levels in response to small differences in forcing period could be substantial.

Lateral vegetative bud break also increased slightly with longer forcing periods, but much less than the terminal buds. Lateral bud break was also erratic with lateral vegetative buds developing to some small degree at all stages during endodormancy.

Flower bud break was not affected by forcing period or GA$_3$ treatment and appeared to be the most stable index of endodormancy termination (Figs 1.1 and 1.2). The three cultivars examined responded in a similar manner to extended forcing period. The poor averaged response of the 'Flavortop' and 'Fantasia' flower buds to forcing conditions was due to a mild winter, which resulted in severe 'delayed foliation' symptoms at the warmer locations of Robertson and Paarl. At the cooler locations, the 'Flavortop' and 'Fantasia' response was similar to the averaged 'Sunlite' data as in Fig. 1.2.

Flower forcing data for each location and cultivar (Fig 1.3) showed the expected trend of endodormancy completion. Flower buds from the coldest Bokkeveld location completed endodormancy first and from the mildest Robertson location last.

The low chill 'Sunlite' nectarine flower buds developed first and those of the higher chill 'Fantasia' nectarine, last. The 1988 winter was relatively mild and the higher winter chill requiring 'Flavortop' and 'Fantasia' nectarines showed delayed foliation symptoms at Paarl and Robertson. The forcing data for these two locations showed minimal development of the flower buds during late winter and early spring for these locations, while terminal bud development was similar to other locations (not shown).

In dormancy research, rates of bud break rather than absolute levels are important (Saure, 1985). As a measure of rate of flower bud break, the date at which the forcing temperatures gave 10% flower bud break was used as the termination of endodormancy index. The 10% flower bud break was not achieved in the Robertson and Paarl locations, where delayed foliation symptoms were observed, indicating that no ecodormancy occurred or it was masked (Saure, 1985). The small numbers of flowers that did develop early in winter also did not exceed the 10% level. In cases where there was no delayed foliation, the percentage flowering for sample dates following the one giving 10% flower bud break, tended to increase exponentially.

There was very low flower bud break at the milder Paarl and Robertson locations and there were typical delayed foliation symptoms in the orchards. This accounts for the low flower bud break levels in the graph of averaged response. Averaged termination of endodormancy dates, using the 10% flower bud break index, (excluding the delayed foliation data) were the 14th and 29th July and 4th August for 'Sunlite', 'Flavortop' and 'Fantasia' respectively. Termination of endodormancy dates for the years 1988-1991, extrapolated using the proposed 10% flower bud break after 14 days of forcing at 25°C, are presented in Table 1.2.

Nectarine shoot response to 14 days forcing at 25 ±1°C without GA_3 treatment, averaged over the 6 locations in 1988 is presented in Fig. 1.4. The forcing data indicated that the endodormancy intensity reached a peak in during late autumn (mid April) for 'Sunlite' and early winter (mid May) for 'Flavortop' and 'Fantasia', indicating that endodormancy probably started before the onset of winter and associated chilling temperatures. As the bud's endodormancy requirements were satisfied in late winter or early spring, there was a substantial improvement in the response of all bud types to forcing.

As the flower buds on the forced shoots develop synchronously in late endodormancy, the very high rate of transpiration and/or reserve utilisation by the blossoms resulted in a decline in vegetative bud break.

This reduction in the number of vegetative buds that develop when floral bud break occurs is well documented in other forcing studies (Partridge & Allan, 1980; Lloyd & Firth, 1990), and could be the reason for the low lateral vegetative bud break levels measured. The variability in bud break during peak flower bud break response to forcing is reflected in the sharp increase in standard deviations as shown in Appendix 1.

'Sunlite' showed substantial flower and terminal bud break by mid July (Fig. 1.4). Averaged 'Flavortop' and 'Fantasia' forcing data showed only terminal bud break by late July. By the mid August sampling date, there was normal flower and vegetative bud development in the orchards of the cooler locations and so forcing studies were terminated (the endodormancy requirement had been satisfied). The 'Fantasia' and 'Flavortop' trees in the warmer locations showed erratic and delayed foliation and flowering.

Terminal bud break levels gave a good indication of rest intensity (level of forcing required to induce bud development), but the terminal bud's sensitivity to stimuli such as exogenous gibberellic acid or additional heat, made the assay a weak indicator of when the endodormancy requirement was satisfied. Evaluation of the combined forcing data confirmed that flower bud break gave a consistent indication of when the chilling requirement had been satisfied.

Table 1.2 Endodormancy completion dates for the nectarine cultivars Sunlite, Flavortop and Fantasia from six climatically divergent locations in the Western Cape Province of South Africa from 1988 to 1990.

LOCATION/CULTIVAR	SUNLITE			FLAVORTOP			FANTASIA		
	1988	1989	1990	1988	1989	1990	1988	1989	1990
BOKKEVELD	July 3	June 12	June 9	July 12	July 6	July 10	July 25	July 7	July 13
CERES	July 12	July 7	June 23	July 28	July 21	July 29	July 27	July 16	July 26
VILLIERSDORP	July 12	July 5	June 21	Aug 4	Aug 1	July 25	Aug 6	Aug 8	July 28
CLANWILLIAM	July 17	July 12	July 27	Aug 11	Aug 4	Aug 5	Aug 19	Aug 12	July30
PAARL	July 18	July 17	July 13	"DF"*	Aug 11	Aug 10	"DF"	Aug 19	Aug 3
ROBERTSON	July 19	July 17	July 16	"DF"	Aug 13	Aug 12	"DF"	Aug 25	Aug 10
AVERAGE	July 14	July 9	July 2	July29	July 26	July 31	Aug 4	Aug 8	July 29

* Delayed foliation made it impossible to determine endodormancy completion date.

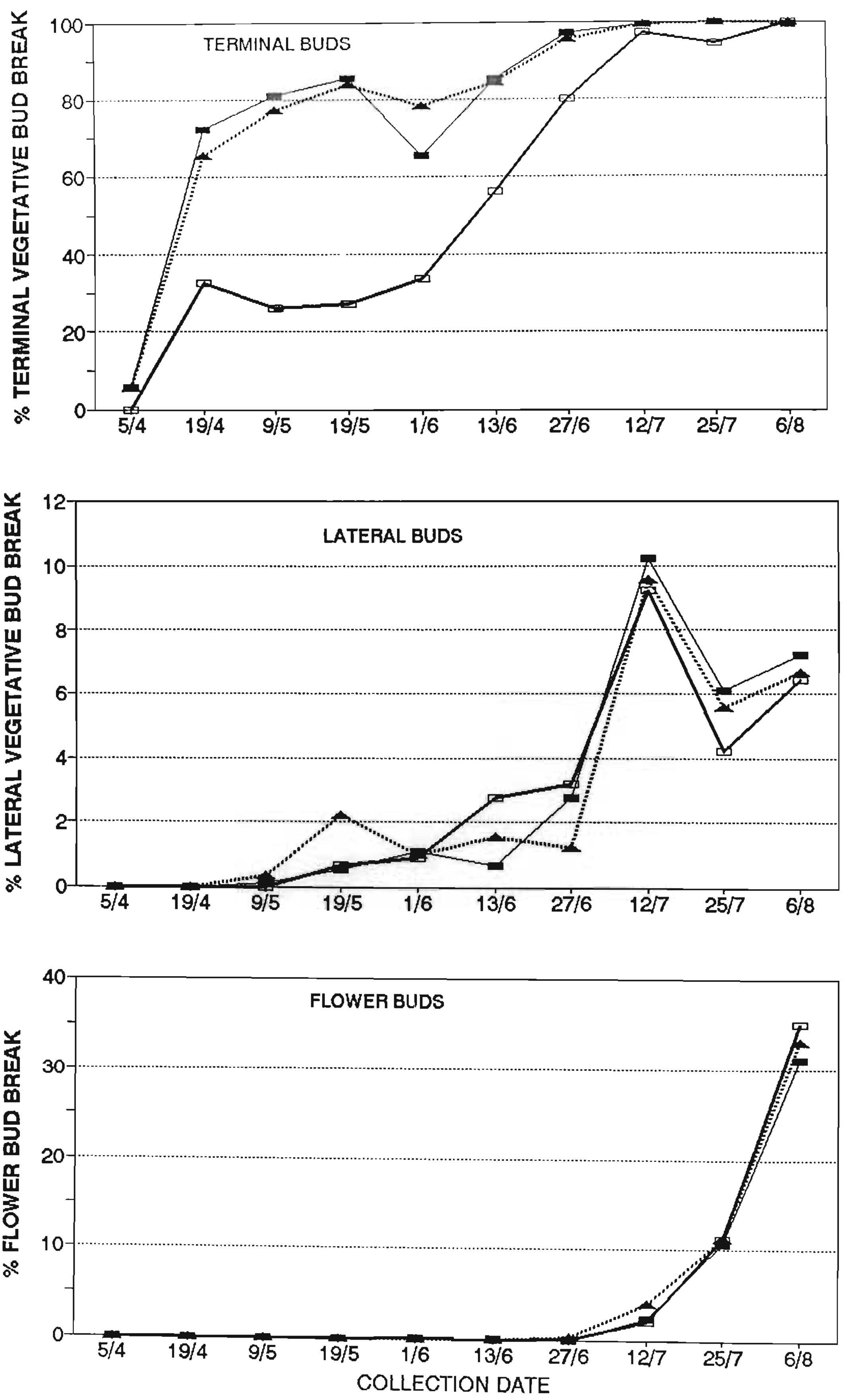


Fig. 1.1 Effect of Gibberellic acid on the forcing of terminal, flower and lateral vegetative buds. Combined response from 'Sunlite', 'Flavortop' and 'Fantasia' nectarines. (□——□, 0mg.kg^{-1} GA$_3$; ■——■, 100mg.kg^{-1} GA$_3$; ▲·····▲, 200mg.kg^{-1} GA$_3$). Standard deviations are presented in Appendix 1.1

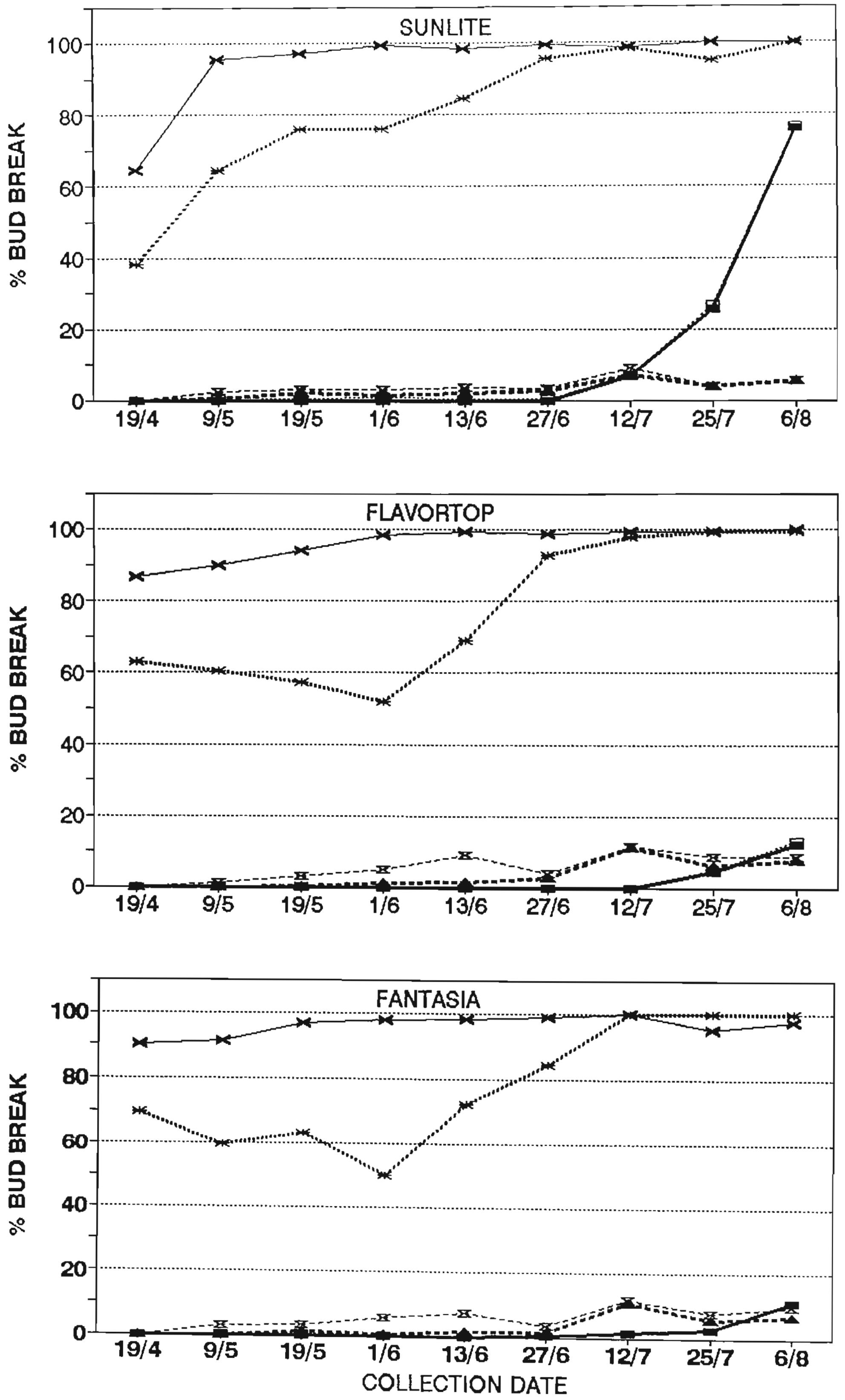


Fig. 1.2 Effect of 14 and 30 day forcing periods on the development of terminal, flower and lateral vegetative buds of 'Sunlite', 'Flavortop' and 'Fantasia' nectarines during the winter of 1988. Terminal vegetative bud development after 14 (*....*) and 30 days forcing (x——x); Lateral vegetative bud break after 14 (▲— — —▲) and 30 days forcing (X- - -X); Flower bud break after 14 (■——■) and 30 days forcing ([]····[]). Standard deviations are presented in Appendix 1.2

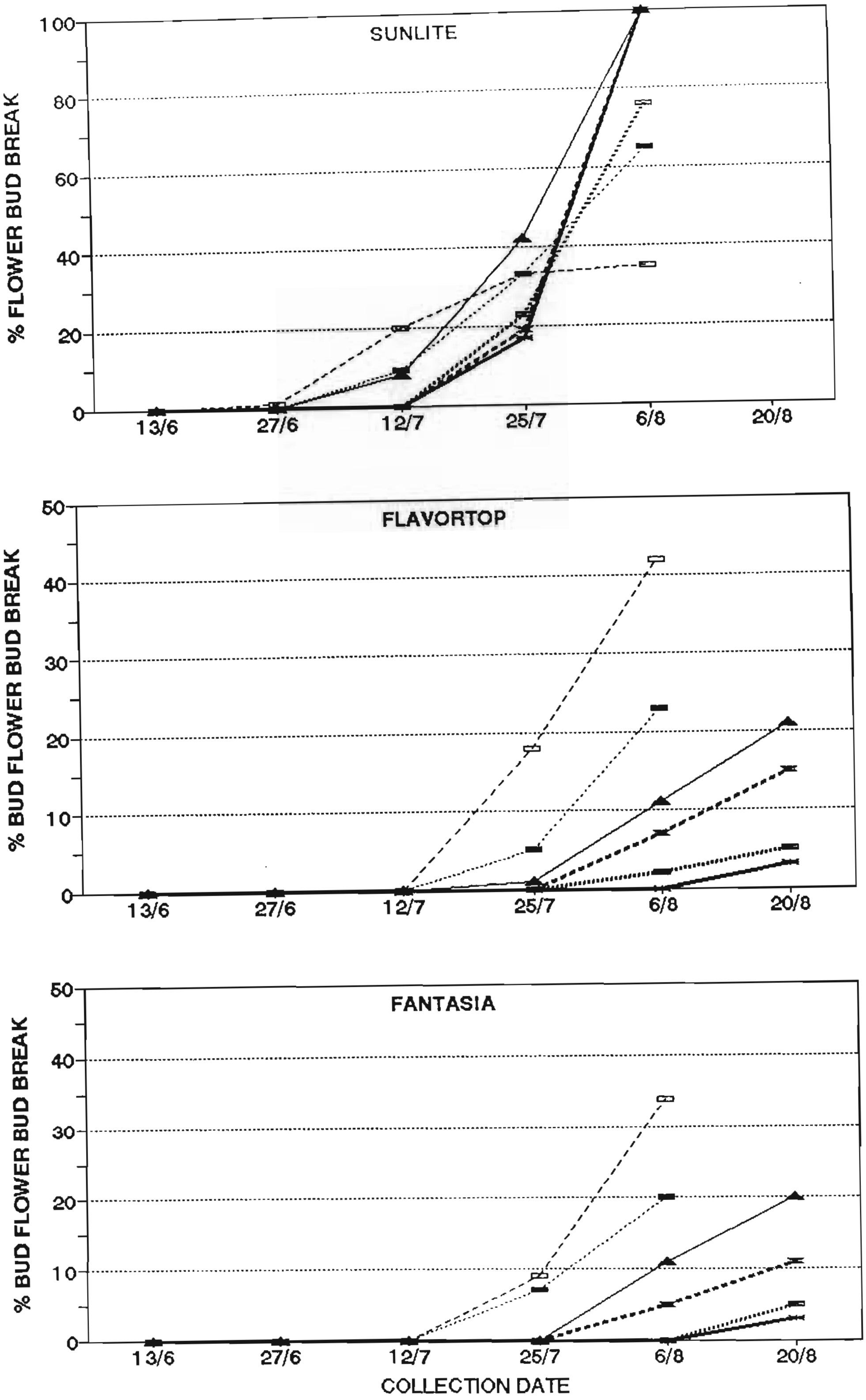


Fig. 1.3 Effect of 14 days forcing at 25 ±1°C on flower bud development in 'Sunlite', 'Flavortop' and 'Fantasia' nectarines from six climatically divergent locations during the winter of 1988. Robertson (*——*); Paarl (☒····☒); Clanwilliam (X— — —X);

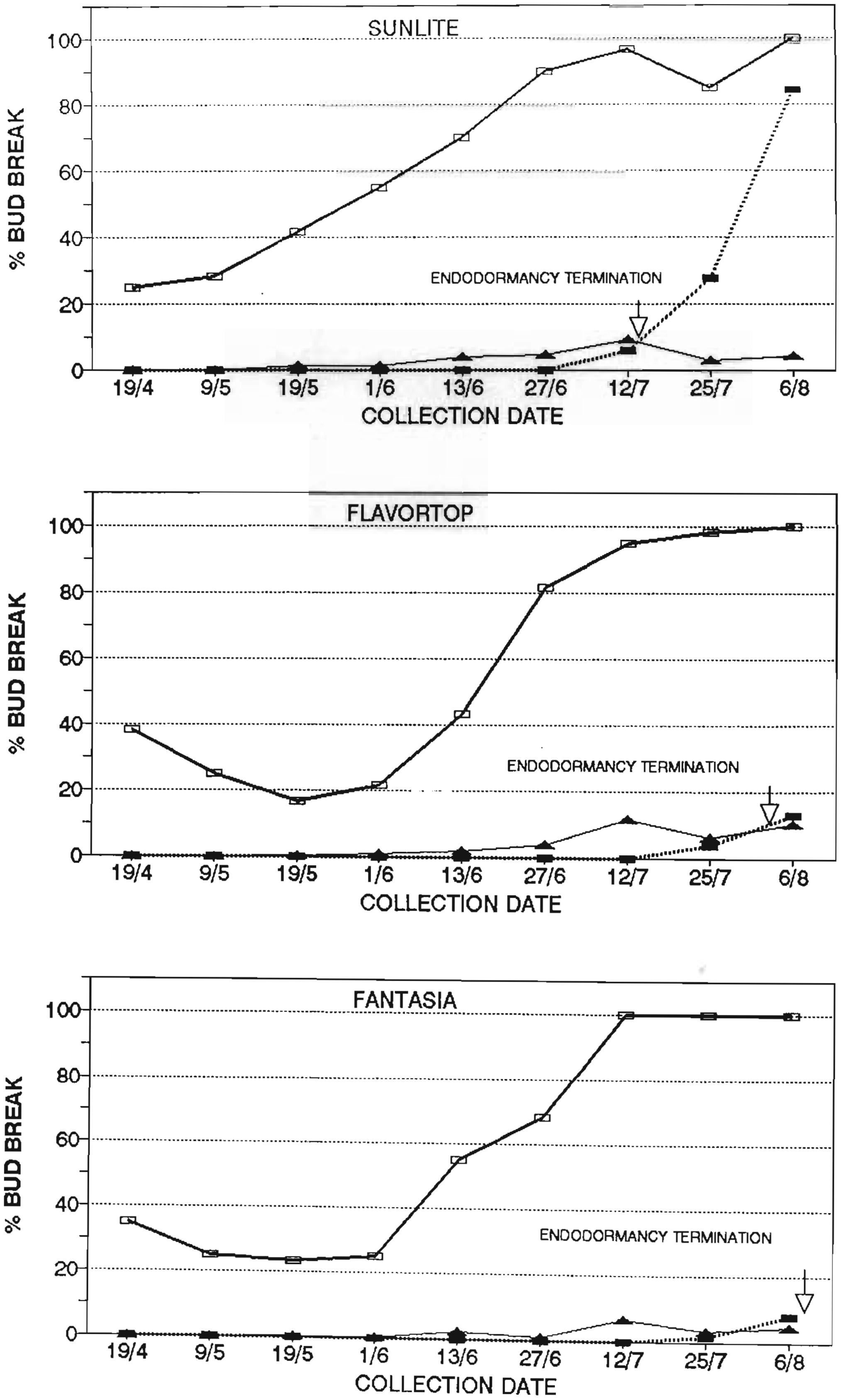


Fig. 1.4 Forcing of terminal ([]——[]), flower (■····· ■) and lateral vegetative (▲ —— ▲) buds of 'Sunlite', 'Flavortop' and 'Fantasia' nectarines. Each line represents the averaged response from six locations during the 1988 winter with termination of endodormancy indicated by arrows. Standard d

1.3.2 1989 Season

Flower forcing patterns gave an accurate account of the differences in climate and bud break performance between the six locations (Fig. 1.5). Ten percent (10%) flower bud break occurred earlier than in 1988 and the levels of flower bud break in the milder locations were higher. No delayed foliation symptoms were recorded in any orchards, although the end of endodormancy and beginning of field bud break were very close (for the higher winter chilling cultivars, Flavortop and Fantasia) in warmer locations. Dates of endodormancy completion for 1989 are shown in Table 1.1.

Averaged data for the six locations, showing vegetative and reproductive bud development as well as bud volume data for the three cultivars are presented in Fig. 1.6. These trends were very similar to those of 1988, as presented in Fig. 1.4 and are fairly representative of the forcing trends in the six locations. Maximum endodormancy intensity in 'Sunlite', as indicated by the least response to forcing, occurred in April, while for 'Flavortop' and 'Fantasia' it occurred in early May. Using the end of endodormancy index as proposed for the 1988 data (10% flower bud break after 14 day at 25°C), 'Sunlite', 'Flavortop' and 'Fantasia' completed endodormancy on about the 9th and 26th of July and the 8th of August respectively, when averaged over the six locations. The 1989 winter was colder than that of 1988 and both maximum endodormancy intensity and endodormancy completion tended to be earlier.

Flower bud volume data supplied additional information on late winter/early spring development (Fig. 1.6) and showed increases in bud volume about 14 days after the forcing index used showed endodormancy completion. 'Flavortop' and 'Fantasia' flower bud volumes in the colder locations followed the same trends as the averaged 'Sunlite' data (not shown), but the average trend was reduced due to delayed flower bud development of these cultivars in the warmer locations.

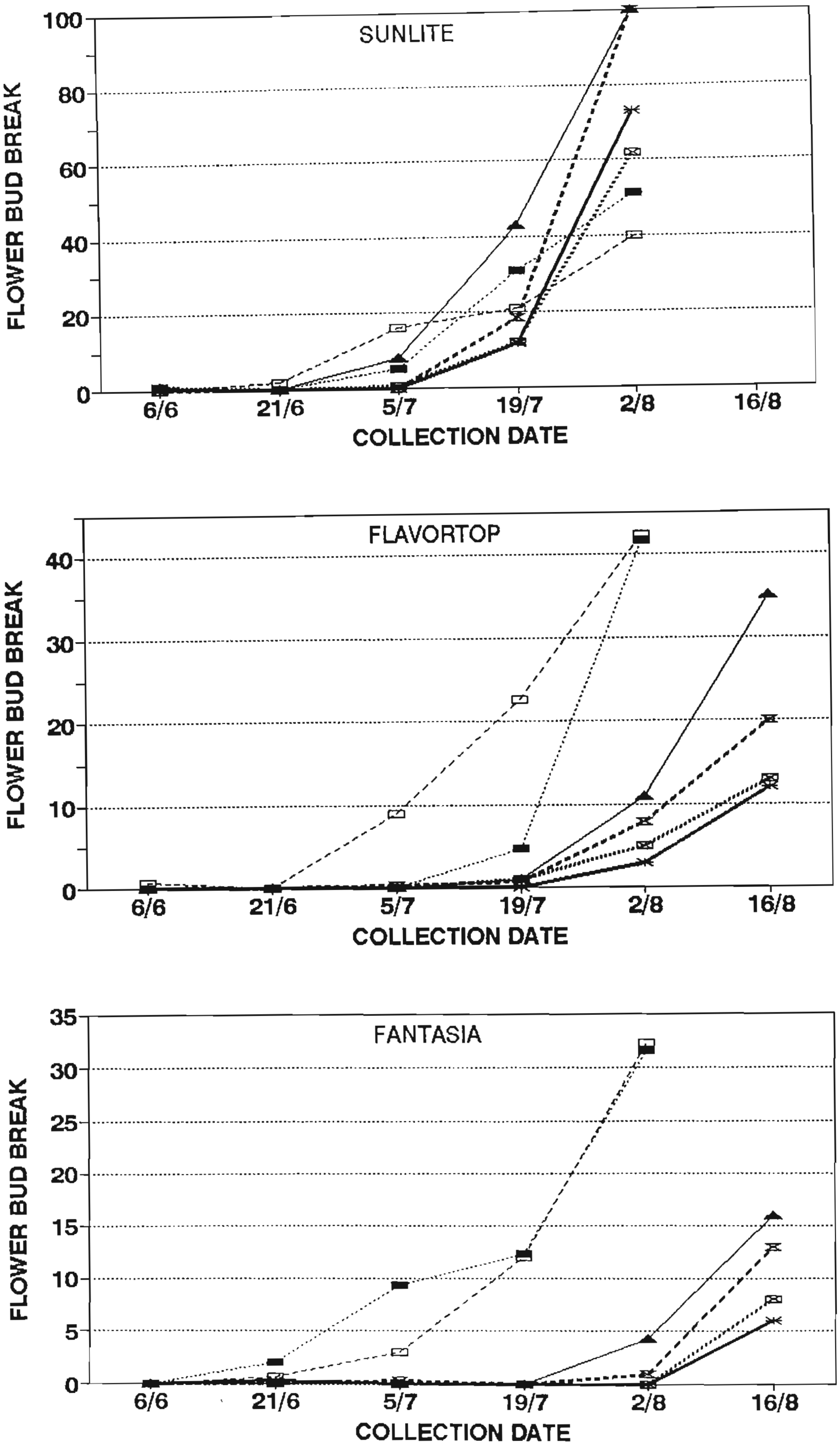


Fig. 1.5 Effect of 14 days forcing at 25 ±1 °C on flower bud development in 'Sunlite', 'Flavortop' and 'Fantasia' nectarines from six climatically divergent locations during the winter of 1989. Robertson (✱——✱); Paarl (☒····☒); Clanwilliam (X– – –X); Villiersdorp (▲——▲); Ceres (■····■); Bokkeveld (□– – –□)

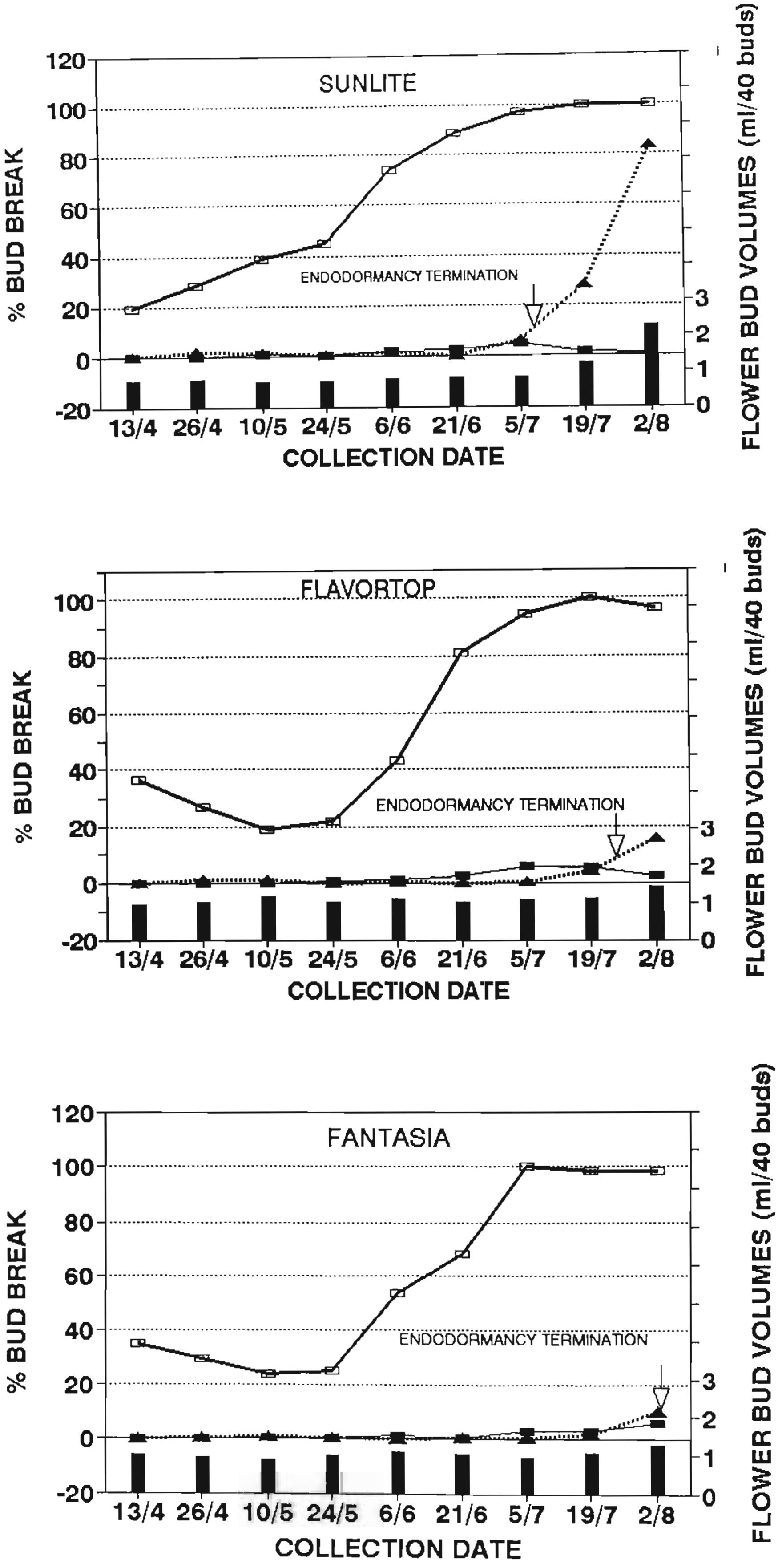


Fig. 1.6 Forcing of terminal vegetative (□——□), lateral vegetative (■——■) and flower (▲·····▲) buds as well as flower bud volumes (▬) of 'Sunlite', 'Flavortop' and 'Fantasia' nectarines. Each line represents the averaged response from six locations during the 1989 winter with termination of endodormancy indicated by arrows. Standard deviations are presented in Appendix 1.4

1.3.3 1990 Season

Individual flower bud break levels showed the same earlier tendencies as the previous season, but the flower development during forcing, for the six locations, occured over a shorter time period (Fig.1.7). Endodormancy completion dates for the three seasons are presented in Table 1.1. Flower bud break trends during endodormancy were more erratic than in the previous seasons, possibly as a result of an apparent earlier endodormancy, followed by fluctuating cold and warm cycles which affected endodormancy intensity. It was, however, still possible to use the 10% flower bud break index to extrapolate endodormancy completion dates.

Following a colder winter than the previous two years, averaged data for 'Sunlite', 'Flavortop' and 'Fantasia' for the six locations indicated that maximum endodormancy intensity in all three cultivars may have occurred before the first sampling (11th May; Fig. 1.8). Termination of endodormancy, using the 10% flower bud break index, was earlier on average, as a result of earlier bud break in the warmer locations. The average for endodormancy completion dates for 'Sunlite', 'Flavortop' and 'Fantasia' were the 2nd, 31st and 29th July respectively.

Bud volumes remained constant after endodormancy completion and began increasing only just before natural bud break in the orchards. Volumes therefore did not give an accurate indication of endodormancy completion.

1.4 DISCUSSION AND CONCLUSION

Of all the phenological attributes examined, only flower forcing data gave an accurate measure of the endodormancy period of nectarines. Using the arguments from the literature reviewed, it is not possible to determine the exact endodormancy period of all the buds on a tree. This is because of the large variation in dormancy status of buds from tree to tree and even within individual trees. From an agronomic point of view, growers, researchers and plant breeders need to be able to quantify the chilling requirement essential to give synchronous and acceptable bud break levels, so as to maximise production potential at the lowest input cost.

Terminal bud break of nectarine shoots did not give an accurate reflection of endodormancy, and the terminal buds sensitivity to forcing period and other exogenous influences makes the assay method very inconsistent.

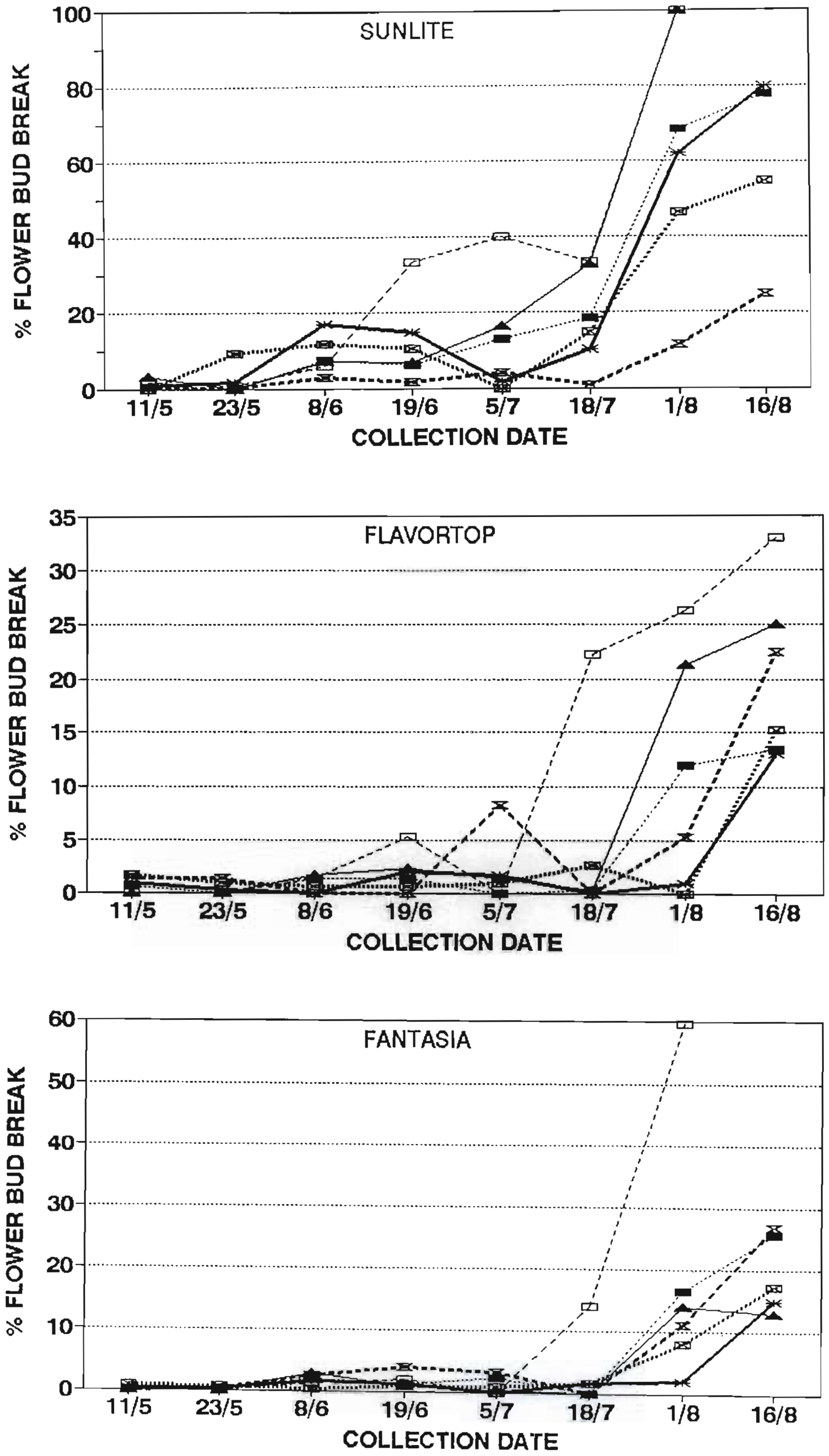


Fig. 1.7 Effect of 14 days forcing at 25 ±1°C on flower bud development in 'Sunlite', 'Flavortop' and 'Fantasia' nectarines from six climatically divergent locations during the winter of 1990. Robertson (✱——✱); Paarl (☒····☒); Clanwilliam (X— — —X); Villiersdorp (▲——▲); Ceres (■·····■); Bokkeveld (

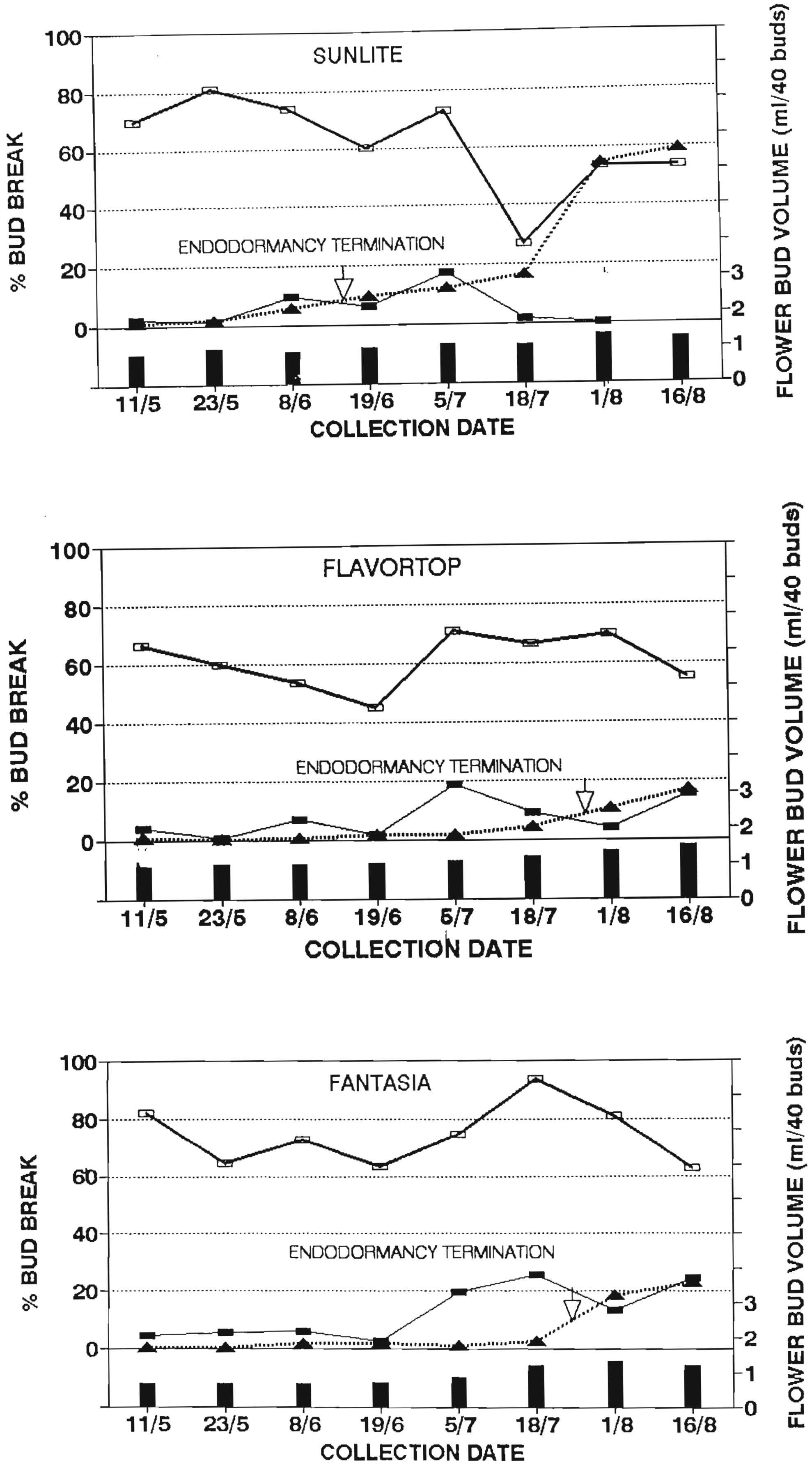


Fig. 1.8 Forcing of terminal vegetative (□——□), lateral vegetative (■——■) and flower (▲·····▲) buds as well as flower bud volumes (▬) of 'Sunlite', 'Flavortop' and 'Fantasia' nectarines. Each line represents the averaged response from six locations during the 1990 winter with termination of endodormancy indicated by arrows. Standard deviations are presented in Appendix 1.5

During the mild winter of 1988 the terminal vegetative bud break levels at the warmer Robertson and Paarl locations showed the same trends as in the cooler locations. These locations showed severe delayed foliation symptoms, indicating that the terminal vegetative bud break levels were not a good indication of endodormancy termination.

Lateral vegetative shoots gave a more accurate account of endodormancy than terminal buds, but bud break levels were not constant or high enough to use as an endodormancy termination index. The rapid decline in the shoots once flowering was intensive may have been a cause of poorer lateral vegetative development. Bud volumes gave a good indication of when natural bud break is about to occur, but this only coincided with termination of endodormancy when there was little or no ecodormancy period. The bud volumes used in this trial may have been too crude to pick up the small changes in bud moisture as indicated in apples and blueberries (Austin and Bondari, 1987; Faust, Liu, Millard & Stutte, 1991).

Flower bud break tended to show an exponential increase once it commenced and the 10% level gave an indication that this rise was part of the exponential increase and not just experimental fluctuation. During the 1990 phenological study, the flower bud break of 'Sunlite' at the warm locations of Paarl and Robertson did rise prematurely above the 10% level prematurely. This is a true reflection of what sometimes occurs in warmer areas during autumn and early winter, where the rest intensity is low and some bud break occurs if there is a spell of hot weather. However, the flower buds showed the normal development pattern in late winter despite some buds opening prematurely.

Thus a 10% flower bud break after forcing nectarine shoots for 14 days at 25°C in mid to late winter appears to give an accurate indication of when sufficient winter chilling has occurred to give acceptable flower bud break. Since flower buds have higher chilling requirements than vegetative buds, an acceptable flower bud break will generally coincide with the synchronous vegetative bud break required to produce economic fruit yields.

Bud maturity and start of endodormancy often occurred before any chilling was recorded in the field (April and May). The climatic data recorded for the period from the commencement of chilling in autumn until the date at which 10% of the flower buds of each cultivar and location, responded to forcing temperatures, was therefore used to determine the endodormancy requirements of the three nectarine cultivars chosen.

CHAPTER TWO: COMPARISON OF REST COMPLETION PREDICTION MODELS FOR NECTARINES

2.1 INTRODUCTION

It is generally accepted that deciduous fruit trees must be subjected to low temperatures for a certain period of time for dormancy release to occur. In 1920 Coville presented evidence that, contrary to the popular belief that the onset of winter cold in autumn brought on dormancy, the following occurred:

i) Dormancy set in before the onset of cold weather.
ii) After dormancy of buds had begun, the exposure of plants to growing temperatures was not sufficient to start growth.
iii) These plants would not resume normal growth in spring unless the plants had been subjected to a period of chilling (Coville, 1920).

It was realised as far back as 1920 that effective temperatures were above 0°C and that freezing temperatures had very little influence on overcoming dormancy. The concept of a chilling requirement in buds had already been proposed for vines by Knight in 1801 (cited by Pollock, 1953). Coville (1920) pointed out that chilling temperatures for blueberries were not necessarily freezing temperatures, but that temperatures a few degrees above freezing for a period of two to three months were required for bud break. Early research concentrated on temperatures in the region of 0°C and it was concluded that temperatures between -1°C and 0°C were fairly effective in overcoming dormancy (Chandler & Tufts, 1934).

Hutchins (1932) reported that 1000 hours of temperatures below 7.2°C (45°F) were sufficient to break the rest period of most of the peach varieties in Fort Valley, Georgia, U.S.A.. This threshold soon became the most widely used criterion for measuring the chilling requirements of cultivars and the suitability of climates for these cultivars. This concept was used successfully by Darrow (1942) to explain why highbush blueberries from central U.S.A. would not perform alongside native rabbiteye blueberries in Florida and was successfully used by Weinberger (1950a) to classify peach varieties.

The adjustment of chilling hours to take into account temperatures of between 0°C and 7.2°C did reduce the disparity between locations and also made comparison from year to year more accurate (Eggert, 1950; Shaltout & Unrath, 1983).

Controlled temperature studies also found that the 7.2°C threshold was too low and that temperatures higher than this threshold have some chilling effect. The threshold for apple buds was found to be below 9°C and almonds 12°C (de Villiers, 1947).

Later experiments proved that temperatures between 0°C and 10°C were most effective. The relative efficiency of low temperatures in releasing buds from endodormancy follows an optimum curve where the maximum efficiency is between 5°C and 10°C (Gilreath & Buchanan, 1981a).

Erez & Lavee (1971) obtained maximum rest breaking efficiency in nectarine lateral vegetative buds at 3°C to 6°C and in terminal buds at 8°C. Ten degrees Celsius (10°C) was only half as effective as 6°C, while 18°C had no chilling effect. Richardson *et al.* (1974) considered 6°C to be the optimum for some peach cultivars, while temperatures above 12.5°C and below 1.4°C had no effect.

Erez & Couvillon (1987) later found that, if constant temperatures were used, 8°C was the most efficient chilling temperature, while some effect was still evident at 0°C and 12°C. Constant 18°C resulted in no chilling effect. Gilreath & Buchanan (1981a) also found maximum chilling efficiency at 8°C for low chill peaches, with decreasing efficiencies up to 14°C and down to 0°C.

In apples, which generally have higher chilling requirements, 2°C was found to be more efficient than 6°C while 6°C was more efficient than 10°C (Thompson, Jones & Nichols, 1975). Shaltout & Unrath (1983), however, found the most efficient chilling temperature to be 7,2°C. They found that some chilling even took place at -0.6°C while the upper limit was as high as 16.5°C.

The optimum chilling temperature for other deciduous fruit crops is similar. Gilreath & Buchanan (1981b) found very little difference between the chilling effect of 3.3°C and 6°C on blueberries and that temperatures of 1°C and 12°C still had some positive effect. Brio (1983) found the most effective chilling temperature for kiwifruit to be 9°C while 12°C still had some chilling effect.

It has long been recognised that high temperatures during winter have a nullifying effect on chilling accumulation (Samish, 1954; Weinberger, 1950b, 1956).

Models for accurately predicting the occurrence of physiological stages of growth and development of fruit crops provide valuable tools for both growers and researchers. Essential to the development of a model to predict breaking of dormancy is an understanding of how it is affected by temperature. Models to predict the bloom time of fruit trees were developed as far back as 1957 (Brown, 1957). In order to develop a model more critical that the summation of chilling hours below 7.2°C, he performed regression analyses on the preceding season's temperature data. His model failed, however, to distinguish between 'delayed foliation' and normal seasons. This research did, however, highlight the different efficiencies of low temperatures on advancing time to bloom.

The assumption that chilling occurred below a certain temperature threshold value was also disputed by Samish, Lavee & Erez (1967). They reasoned that if the process caused by chilling was a chemical one, then such a threshold value would be improbable. They proved that breaking of rest by chilling was an active process with a low thermal optimum, as chilling of 'Early Red' peach buds showed varied responses when chilled at temperatures above or below 7.2°C.

Erez & Lavee (1971) found that, after forcing, lateral leaf bud break of peaches increased with decreasing temperatures from about 11 to a maximum at 6°C. As temperatures dropped below 6°C so too did bud break levels. Using these data they developed the concept of weighted chilling hours. They went on to prove that, by using weighted chill units, they could achieve the same bud break response with continuous or alternating chilling, provided that the sum of the weighted chilling hours was the same. In 'Redhaven' peaches they found that a temperature of 18°C had no effect on chilling but that at 21°C there was a complete disappearance of the chilling effect. This effect appeared to be of limited duration as periods of 11 to 12 days at 20°C resulted in only limited chilling negation. They concluded that a formula to predict the effect of winter temperatures on bud break must take into account low and high temperatures and that the antagonistic effect of high temperatures lasted for a limited period after chilling.

The first adjustment to chilling hours to account for high temperature negation was by Gonzalez-Capeda in 1972 (del Real-Laborde, 1986). He determined chilling hours below 7.2°C but subtracted twice the hours when temperatures exceeded 18°C.

The 'Utah' (UCU) model of Richardson *et al.* (1974), was developed as a more rapid and simple method to estimate the time to end of rest in peaches. This model proposed a weighted chill unit accumulation which assigns one chill unit to an hour of exposure at 6°C, with a lower accumulation as the temperature deviates from the optimum. Once the temperature exceeds 16°C the accumulation becomes progressively more negative, thus negating a portion of the accumulated chilling. They developed a curve which related air temperatures, as measured in a screen, with actual bud temperatures (Lombard & Richardson, 1979). Utah chill units (UCU) were assumed to begin accumulating in autumn the day after the largest negative accumulation.

Together with degree hours after the chilling requirement had been satisfied, this model gave consistent prediction of bloom dates under Utah conditions. The model therefore allowed growers and researchers to:

i) Determine if there was sufficient winter chilling in order to grow specific peach cultivars in the area.
ii) Determine when sufficient chilling has been accumulated and when heat accumulation becomes effective in stimulating bud development.
iii) Determine when cultural practices such as overhead sprinkling to delay bloom, should commence (Richardson *et al.*, 1974).

The UCU model is based on a number of unproved assumptions which open the model to criticism. These assumptions are that the optimum chilling temperature is the same for all fruit species, temperature effects throughout the chilling period remain constant, chilling requirement is not influenced by rootstock and that the negating effect of high temperatures is not limited by time constraints (Aron, 1975; Lombard & Richardson, 1979). Later modification of this model raised the negating threshold temperature from 16 to 18°C to 16 to 19.4°C (Lombard & Richardson 1979), while for cherries numerous modifications were evaluated (Anderson, Richardson & Kesner, 1986). The negating effect of high day temperatures on chilling negation is well documented (Couvillon & Erez, 1985a). Recent investigations into winter chill unit accumulation have shown that it is possible to grow low chill peach cultivars successfully in areas with a negative UCU accumulation in winter (Partridge & Allan, 1980).

Models which accumulate greater negative units for high day temperatures such as the 'North Carolina' model of Shaltout & Unrath (1983) have been found to correlate better with bud break levels of high chill 'Hayward' kiwifruit growing in mild temperate areas (Linsley-Noakes & Allan, 1987).

The dynamic (DP) model adds a further important element viz. timing of exposure to temperatures in a cycle, which appears to have an important influence on rest completion (Fishman *et al.*, 1987a and b). It also incorporates more detailed responses of the bud to temperatures based on experimental data with peach plants (Erez & Lavee, 1971; Couvillon & Erez, 1985a and b; Erez & Couvillon, 1987; Erez *et al.*, 1979a and b):

i) The optimum bell shaped curve for dependence of rest breaking on temperature shows maximum efficiency at 6°C and zero effect at -2°C and 13°C.
ii) Negation of chilling effect by high temperatures depends on their level, duration and cycle length when alternating with lower temperatures.
iii) Moderate temperatures, while having no rest breaking effect, will enhance the chilling effect when occurring alternately with chilling temperatures.

The DP model assumes that the level of rest completion depends on the level of a certain dormancy breaking factor which is accumulated in the bud by a two-step process. The first step is a reversible process of formation and destruction of a thermally labile precursor. When a critical portion of the precursor is amassed, it is transferred irreversibly in the second step, to one portion of a stable factor. The dynamics of this process simulate rest development and agree with the complex effects of temperature on rest completion. Initial investigations have shown that the dynamic model may have particular use in the marginal deciduous fruit growing regions of South Africa (Erez, Fishman, Linsley-Noakes & Allan, 1990).

This chapter reports on the evaluation of rest prediction models in South Africa, for use in the identification of potential deciduous fruit growing areas, determination of chilling requirement of newly bred cultivars and for prediction of the necessity for dormancy breaking sprays following mild winters.

2.2 MATERIALS AND METHODS

Climatic and phenological data were collected as described in Chapter 1. Temperature data for the endodormant periods were converted into UCU and DP. Accumulation of UCU commenced after the last large negative accumulation in May (Richardson *et al.*, 1974) and usually coincided with the first DP accumulation.

Utah chill units and dynamic portions were then calculated for the period from commencement of chilling in late autumn or early winter, until the endodormancy termination index (10% flowering of after 14 days of forcing at 25°C) of each cultivar and location indicated that the endodormancy requirement had been satisfied (Table 1.1).

2.3 RESULTS

2.3.1 1988 Season

The 1988 UCU accumulation (top of Fig. 2.1) shows typical trends of what occurs in warmer locations. UCU accumulation was most rapid in June but leveled off in July. Periods of warm weather resulted in periodic decreases in the UCU accumulation. The endodormancy period of 'Sunlite' ended in mid July, while that of 'Flavortop' and 'Fantasia' ended in mid August. The endodormancy period of 'Flavortop' and 'Fantasia' could not be determined for Robertson or Paarl in 1988, as there was severe delayed foliation (DF) in these orchards. There was therefore insufficient winter chilling to meet the buds endodormancy requirements at these locations.

The UCU model clearly showed the differences in accumulation between the two locations which showed DF symptoms and the cooler Clanwilliam location. These DF locations accumulated less than 500 UCU during the winter period. The DP accumulation (bottom of Fig. 2.1), however, indicated a much closer accumulation pattern for all three warmer locations than the UCU model and failed to distinguish between the DF locations of Robertson and Paarl, and Clanwilliam, where bud break was normal. In these warmer locations, 'Sunlite' required 22 to 27 DP or 275 to 441 UCU (Table 2.1). The requirement of 'Flavortop' and 'Fantasia' could only be determined for Clanwilliam, due to DF in the warmer locations. These cultivars had a similar requirement of 33 DP or 583 UCU.

In the cooler winter locations of Villiersdorp, Ceres and Bokkeveld, much higher UCU and DP accumulation occurred (Fig 2.2), and both models showed the expected differences in total chilling as well as proposed termination of endodormancy dates. The apparent chilling requirement in the colder locations was higher than in the warmer locations. 'Sunlite' required between 31 and 41 DP or 529 and 782 UCU, while 'Flavortop' and 'Fantasia' required between 43 and 54 DP or 709 and 1069 UCU (Table 2.1). The colder the location the higher the apparent chilling requirement to overcome endodormancy.

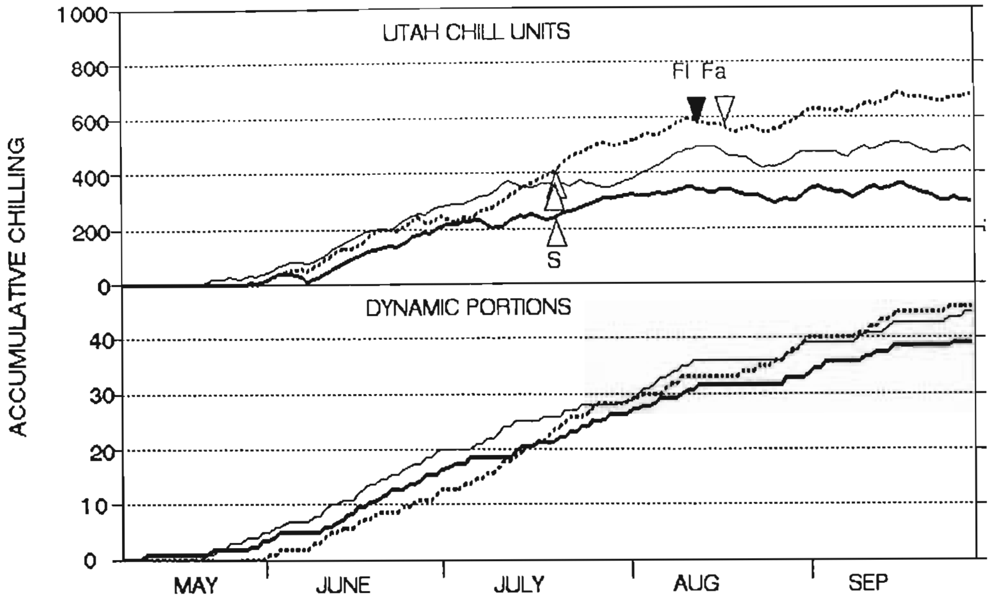


Fig. 2.1 Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam - - - during the 1988 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S△), Flavortop (Fl▼) and Fantasia (Fa▽).

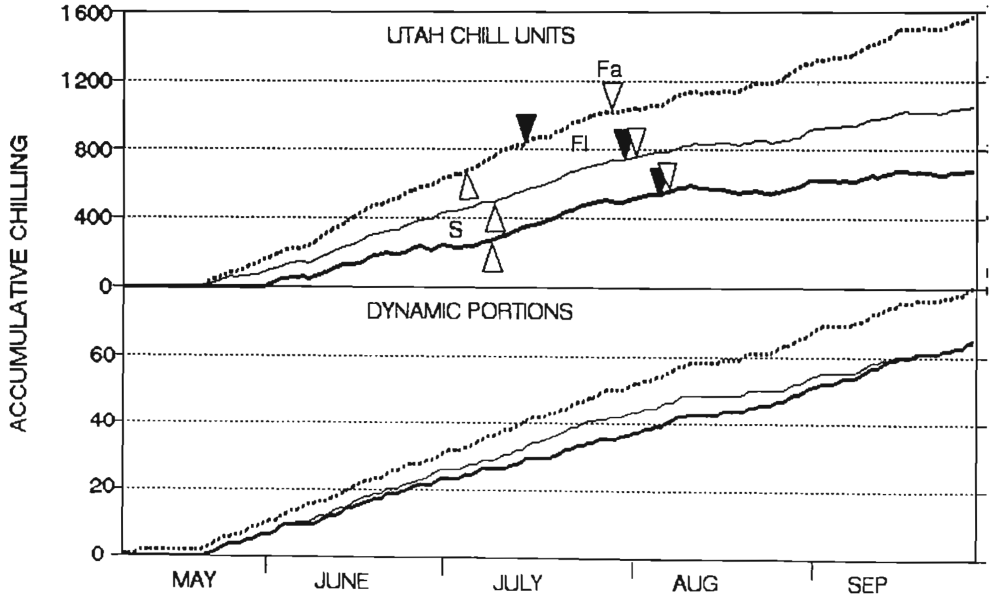


Fig. 2.2 Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld - - - during the 1988 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S△), Flavortop (Fl▼) and Fantasia (Fa▽).

2.3.2 1989 Season

The 1989 winter was colder than in 1988, as is reflected in the approximately 40% higher UCU and ± 30% higher DP accumulations up to the end of September (Figs 2.3 and 2.4). UCU accumulation in the warmer locations (top of Fig. 2.3) showed the expected trend of accumulation and endodormancy completion between the three locations and cultivars tested.

All locations accumulated over 500 UCU by the end of August and delayed foliation symptoms were not evident in any of the trial orchards. DP accumulation (bottom of Fig 2.3) also gave fairly good visual differences in accumulation for the winter period and indicated very little difference in DP accumulation between the individual warmer locations up until the beginning of August. The endodormancy of the 'Sunlite' shoots from the three warmer locations were satisfied at almost the same time in mid July, indicating that these DP accumulation trends were accurate. The endodormancy requirements of 'Flavortop' and 'Fantasia' were satisfied earlier in the cooler of the warm locations and later in the warmest location. This trend was shown by both models. Within each location the difference in chilling requirement between 'Sunlite', 'Flavortop' and 'Fantasia' showed up well. 'Sunlite' required 26 to 27 DP or 369 to 458 UCU and 'Fantasia and 'Flavortop, 39 to 43 DP or 538 to 686 UCU (Table 2.1).

The cooler locations also showed about a 30% higher UCU and DP accumulation than in 1988 (Fig. 2.4). Endodormancy termination dates showed the expected trend with the exception of 'Fantasia', which showed an earlier termination of endodormancy than expected. UCU accumulation showed similar patterns for the Villiersdorp and Ceres locations, but the DP accumulation showed similar trends for Ceres and Bokkeveld. Traditionally, higher chill requiring fruit types such as cherries can be grown in Bokkeveld, but cannot be grown in Ceres because of the high incidence of DF. Generally the UCU graphs gave a more accurate estimation of endodormancy requirement than the DP model. 'Sunlite' required between 34 and 37 DP or 789 to 958 UCU to satisfy the endodormancy requirement, while 'Flavortop' and 'Fantasia' required 41 to 53 DP or 789 to 958 UCU.

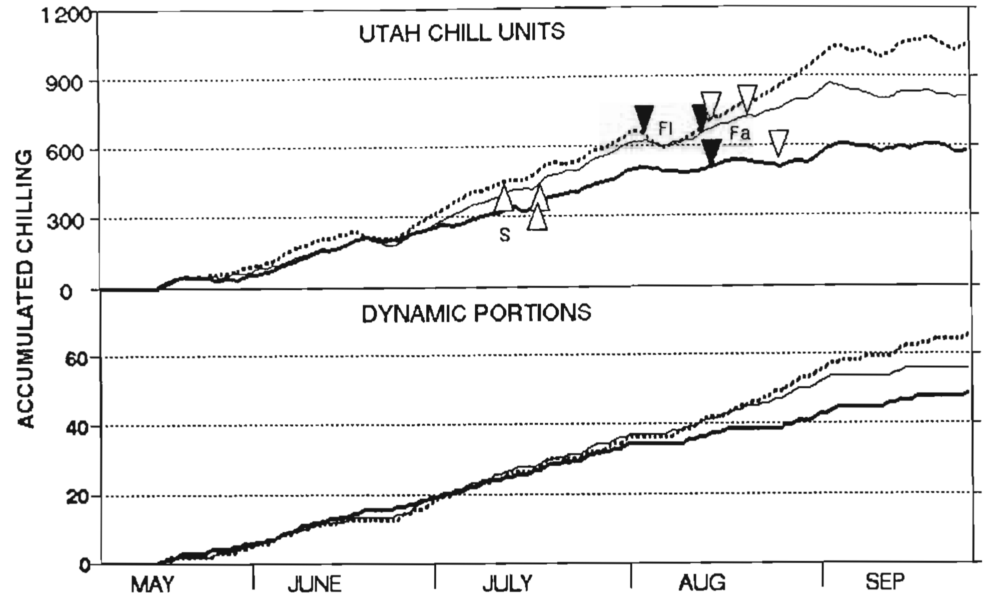


Fig. 2.3 Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam ▬ ▬ ▬ during the 1989 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

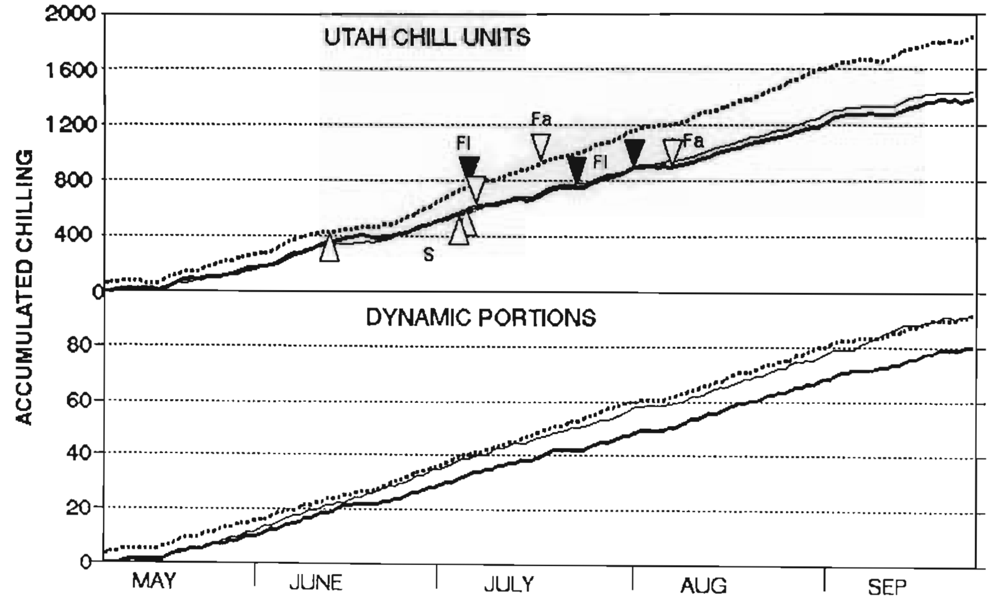


Fig. 2.4 Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld ▬ ▬ ▬ during the 1989 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

2.3.3 1990 Season

The total UCU accumulation in the warmer locations were about 25% lower than in 1989, due mainly to more high temperature negation in spring (Fig.2.5) Dynamic portions, which are not affected by long periods of high temperatures, were only about 5% lower than in 1989. The estimated endodormancy requirement in the warmer locations were 27 to 35 DP or 406 to 632 UCU for 'Sunlite' and 35 to 41 DP or 478 to 705 UCU for 'Flavortop' and 'Fantasia' (Table 2.1). The DP model gave a better estimation of the endodormancy requirement of 'Sunlite' and 'Flavortop' but not 'Fantasia'. Closer examination of the Robertson accumulation line revealed that although there was a difference between endodormancy completion dates of the different cultivars, the actual UCU accumulation remained very similar throughout July, August and September, because of high temperature negation. This appears to be the main reason for UCU model's inaccuracy and the objection to its use in mild winter areas. The DP accumulation failed to produce the differences suggested by the differences in endodormancy termination dates for 'Fantasia'.

In the cooler locations the DP and UCU accumulation generally followed the trends indicated by the endodormancy completion dates (Fig 2.6). The estimated endodormancy termination date for 'Fantasia' in the coldest Bokkeveld location was the only one that did not fit the expected trend. The closeness of the endodormancy completion dates for 'Sunlite' and 'Flavortop' at the Ceres and Villiersdorp locations, indicate that the accumulation patterns for these locations should be very similar. The UCU accumulation for these locations were much closer that those shown by the DP graphs. There was very little high temperature negation in the cooler locations and the total UCU accumulation was about 6% higher and DP accumulation about 5% higher than in 1989. The estimated endodormancy requirement in the cooler locations were 34 to 40 DP or 536 to 670 UCU for 'Sunlite' and 54 to 63 DP or 856 to 1086 UCU for 'Flavortop' and 'Fantasia' (Table 2.1).

2.3.4 Overall trends and statistical analysis

The overall winter chilling accumulation trends for the six locations averaged over the three seasons are presented in Figs 2.7 and 2.8. In the warmer locations (Fig. 2.7) the DP model indicates that the winter chilling in the three locations is on average very similar, with approximately 5% variation in chilling between locations by the end of July.

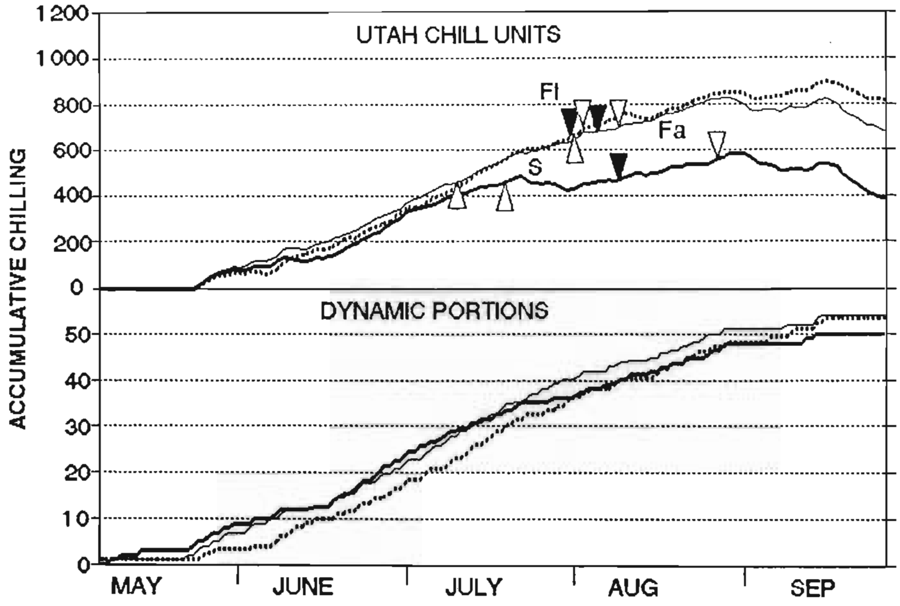


Fig. 2.5 Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam ▪▪▪ during the 1990 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

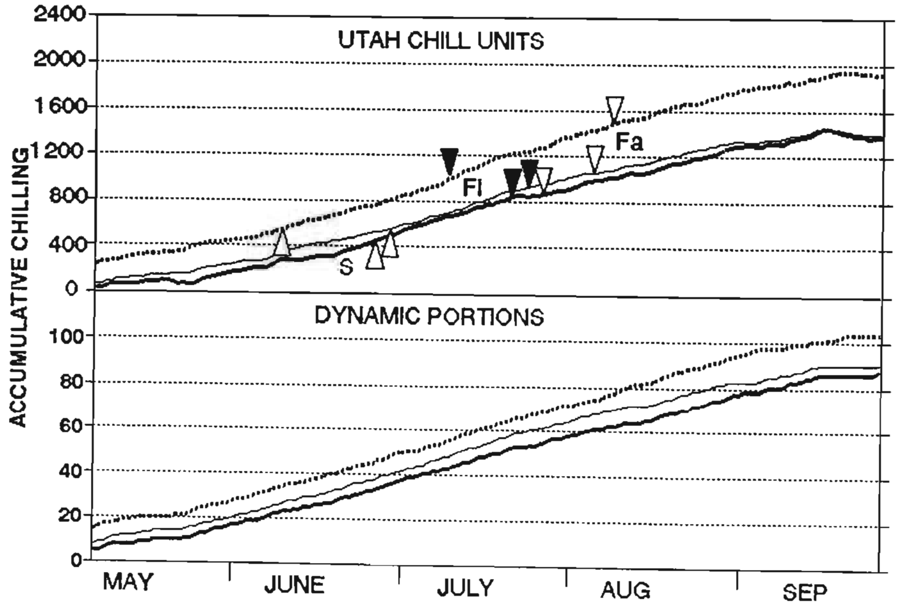


Fig. 2.6 Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld ▪▪▪ during the 1990 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

The UCU average accumulation, however, indicated fairly large differences in winter chilling patterns with about a 40% variation in chilling requirement between locations by the end of July. The close endodormancy completion dates suggest that the DP model is a more accurate predictor of endodormancy than the UCU model. On average, the endodormancy requirement of 'Sunlite' 'Flavortop' and 'Fantasia' in the warmer locations were 29, 40 and 40 DP or 446, 623 and 630 UCU respectively (Table 2.1).

The colder locations accumulated almost twice the winter chilling of the warmer locations. The variation between the models was similar, but the closer endodormancy completion dates for the Ceres and Villiersdorp locations, indicate that the UCU model may give a better indication of the chilling accumulation patterns in colder locations than the DP model. Crops grown in these locations tend to back up this observation, as cherries can be grown at the Bokkeveld location only. The average endodormancy requirements for 'Sunlite', 'Flavortop' and 'Fantasia' were 36, 51 and 52 DP or 602, 878 and 883 UCU respectively.

Analysis of the temperature data for the endodormancy period, showed that the DP model more accurately estimated the rest requirement of the three cultivars tested than the UCU model (Table 2.1). To compare the accuracy of the two prediction models, coefficients of variation were determined for each cultivar using the results from the six areas over three seasons 1988 to 1990. An additional season's data were collected for the warmest Robertson and coldest Bokkeveld locations. The coefficients of variation for the DP model were consistently lower than those for the UCU model. For the 'dynamic' model they were 15.8%, 16.4% and 17.6% for the cultivars Sunlite, Flavortop and Fantasia respectively, while those for the Utah model they were 24.9.%, 21.7% and 23.8% respectively.

Possible reasons for the relatively high coefficients of variation include sampling error, since due to logistics it was not possible to collect shoots for forcing more often than every two weeks. Some of this effect was reduced by the use of the endodormancy completion index, which estimated the date of endodormancy termination based on a straight line drawn between the fortnightly data points. Other factors could include differences in reserve status between locations and small age and vigor differences between orchards. The possibility of heat accumulation affecting endodormancy requirement is discussed in chapter four. The average endodormancy requirement over all areas and seasons, for 'Sunlite', 'Flavortop' and 'Fantasia' were 33, 46 and 46 DP or 526, 764 and 766 UCU respectively. Comparison of the two models for each location indicated a very close correlation between the two models in the colder areas ($r^2=0.997$) while the warmer the location in winter, the more widely divergent the two models ($r^2=0.929$).

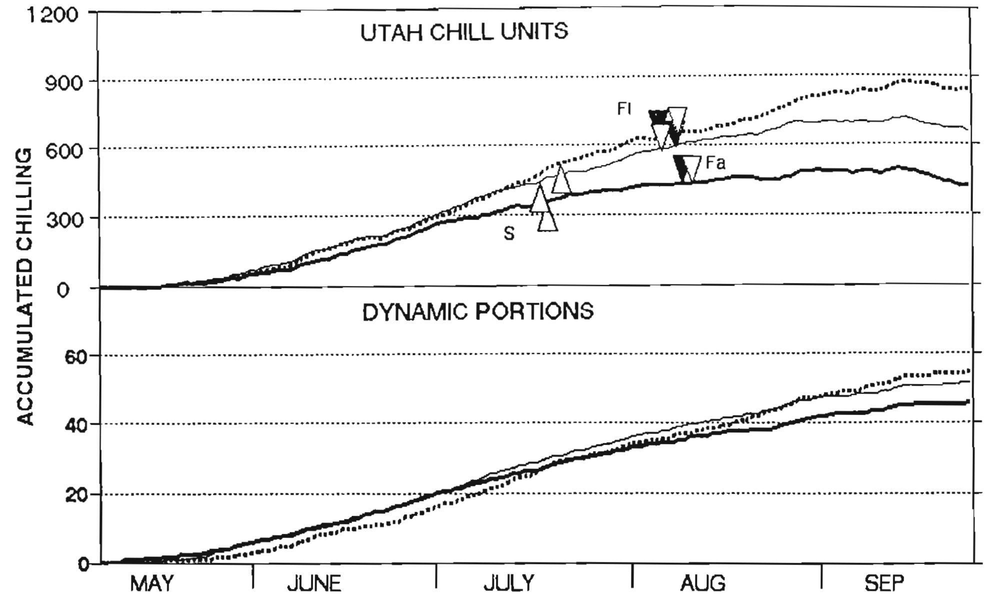


Fig. 2.7 Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ━━, Paarl —— and Clanwilliam ▬ ▬ ▬ averaged over three winters (1988 to 1990). Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

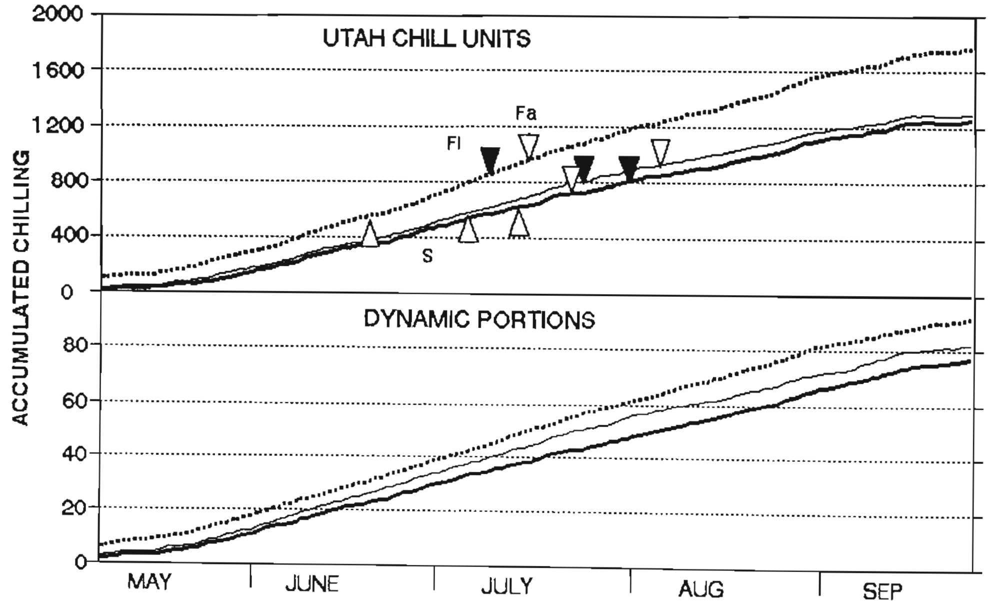


Fig. 2.8 Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ━━, Ceres —— and Bokkeveld ▬ ▬ ▬ averaged over three winters (1988 to 1990). Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

Table 2.1 Accumulation of Utah chill units (UCU) and dynamic portions (DP) chill units, calculated from hourly temperature data, during the endodormancy period of Sunlite, Flavortop and Fantasia nectarines growing at six climatically divergent locations over three or four seasons.

Location	**Year**	**Cultivar/ Model**					
		Sunlite		**Flavortop**		**Fantasia**	
		DP	**UCU**	**DP**	**UCU**	**DP**	**UCU**
Robertson	1988	22	274.5	*	*	*	*
	1989	28	369.0	39	538.0	39	538.0
	1990	34	468.5	41	487.5	40	478.5
	1991	28	406.0	41	538.0	41	548.0
	Mean	**29**	**380**	**40**	**521**	**40**	**522**
Paarl	1988	27	355.0	*	*	*	*
	1989	28	414.0	43	692.5	43	692.5
	1990	35	575.0	42	681.0	42	676.0
	Mean	**30**	**448**	**43**	**687**	**43**	**687**
Clanwilliam	1988	26	441.5	33	583.0	33	583.0
	1989	26	458.0	42	686.5	42	686.5
	1990	35	632.0	38	705.0	35	641.5
	Mean	**29**	**510**	**38**	**660**	**37**	**637**
Villiersdorp	1988	31	528.5	43	709.5	43	709.5
	1989	34	597.5	48	894.5	53	958.0
	1990	34	482.0	54	856.0	56	882.5
	Mean	**32**	**536**	**48**	**820**	**51**	**850**
Ceres	1988	41	719.0	48	817.0	48	817.0
	1989	36	577.5	50	810.5	40	656.0
	1990	40	542.5	63	975.0	59	916.5
	Mean	**39**	**613**	**54**	**867**	**49**	**797**
Bokkeveld	1988	38	782.5	50	1020.5	54	1058.5
	1989	37	679.5	41	789.0	51	927.5
	1990	36	605.5	58	1086.0	61	1125.0
	1991	37	615.0	54	888.0	55	901.0
	Mean	**37**	**670**	**51**	**946**	**55**	**1003**
Mean		33	526.3	46	764.3	46	766.4
Standard deviation		5.2	130.9	7.6	166.0	8.2	182.7
Coefficient of variation		15.8	24.9	16.4	21.7	17.6	23.8

* Insufficient winter chilling for normal bud break and development.

2.4 DISCUSSION AND CONCLUSION

Generally the DP model clearly distinguished between the low chill 'Sunlite' and higher chill requiring 'Flavortop and 'Fantasia'. The high temperature negation in the warmer locations tended to reduce these differences in the UCU accumulation graphs. The close average endodormancy completion dates in the warm locations were also indicative of the close accumulation trend as shown by the averaged DP accumulation graphs. The DP model, however, failed to distinguish between locations showing severe delayed foliation symptoms in 'Flavortop' and 'Fantasia' and those showing normal spring bud break. Unfortunately DF occurred during 1988 only and then only in two locations and so it is difficult to predict if the DP model will consistently not be able to identify DF in orchards. The accuracy of the estimations could be improved by shortening the period between collection of phenological data.

Statistical analysis of the temperature during the endodormancy period confirmed that the DP model gave a more accurate account of the chilling requirement of nectarines than the UCU model. Lower coefficients of variation indicate a better consistency in endodormancy estimation between seasons and locations. This implies that although there is a strong correlation between the two models in cold areas, the DP model, which takes into account the fact that the chilling factor becomes fixed after a certain period of chilling, and so is no longer negatible by high temperatures, gives a much more accurate account of the effectiveness of winter chilling in milder areas than the 'Utah' model.

CHAPTER THREE: DEVELOPMENT OF A REST COMPLETION PREDICTION MODEL FOR WESTERN CAPE CLIMATIC CONDITIONS

3.1 INTRODUCTION

Low chill stone-fruit cultivars are successfully grown in areas which occasionally receive a negative total 'Utah' chill unit accumulation in winter (Allan, Linsley-Noakes, Rufus & Matthee, 1993). Initial investigations have shown that the DP model may have particular use in the marginal deciduous fruit growing regions of South Africa (Erez *et al.*, 1990; Allan *et al.*, 1993; Linsley-Noakes & Allan, 1994).

While the DP model appeared to be better than the UCU model, especially in the warmer areas (Table 2.1 and Fig. 2.7), it failed in one year to distinguish between locations that showed DF symptoms in'Flavortop' and 'Fantasia' and a location that showed normal bud development. Differences in cultivar chilling requirement using the DP model were easily discernable, but it was more difficult to compare locations using the DP model.

Furthermore, calculation of DP requires a complex computer program to calculate the portions of chilling, which makes it less accessible as a management tool for individual fruit growers. Although UCU are also calculated by computer from hourly temperatures, they can be calculated manually or estimated from a table of values, based on daily minimum and maximum temperatures (Linsley-Noakes, 1986). The aim was therefore to attempt to modify the UCU model, in order to develop a more accurate model which is suited to the climatic conditions and technological capabilities of the deciduous fruit grower.

The main points of difference between the DP and UCU models are that the DP model takes into account the effect of moderate temperature enhancement and more importantly the effect of chilling cycle length on negation by high temperature. Under local conditions, moderate temperatures ($\pm 14^\circ$C) in the daily cycle during winter are very common and this is therefore not an important factor. Erez *et al.* (1979b) showed that high temperature negation depends on its level, duration and cycle length and that chilling at 6° to 12°C for a 30 to 38 hour cycle resulted in a fixation of the chilling factor. It follows, therefore, that high temperature negation can only affect the intermediate product of chilling (less than one portion) and that long periods of high temperatures will have a limited negating effect on chilling, other than affecting the current precursor level.

These findings were used in the compilation of the DP model (Fishman *et al.*, 1987a and b). Linsley-Noakes & Allan (1994) also showed that the 'Utah' model consistently underestimated the chilling requirements of the nectarine cultivars Sunlite, Flavortop and Fantasia nectarines in warmer locations.

This chapter reports on the modification of the UCU model, using the latest research findings used to develop the PD model. The local industry is familiar with the UCU model and reluctant to change to a system which they do not fully undertand.

3.2 MATERIALS AND METHODS

Climatic and phenological data were collected as described in Chapter 1. Based on the differences between the DP and UCU models, an assumption was made that the inaccuracy resulting from the assumption that chilling negation by high temperatures is limited to a 24 hours period, would be less than the inaccuracy in the UCU model in warm winter locations, caused by excessive negation resulting from long periods of high temperatures. In an attempt to improve to UCU accuracy, the carry-over effect of chilling negation from one day to the next was cancelled. On days when the UCU totals were negative, therefore, the value was taken as zero. The remaining chill units were then called 'daily positive Utah chill units' (PCU).

3.3 RESULTS

3.3.1 1988 Season

By assuming no negation of chilling by the following day's high temperatures, the chilling accumulation pattern of the PCU more closely followed those of the 'dynamic' model (Figs 3.1 and 3.2). The PCU accumulation continued to increase in these warmer locations (Fig. 3.1) during winter and early spring, compared with the decline showed by the UCU accumulation (Fig 2.1). The main differences between the UCU and PCU accumulations were evident in the milder Robertson, Paarl and Clanwilliam locations, where high day temperatures during the winter period are prevalent.

The PCU model shows more clearly the difference in chilling between the Paarl and Robertson locations, which experienced DF problems, and Clanwilliam which had normal bud development (Fig 3.1, top). The largest change in chill unit accumulation (47%) occurred in Paarl where 521 PCU were accumulated, compared to 355 UCU for 'Sunlite (Table 3.1).

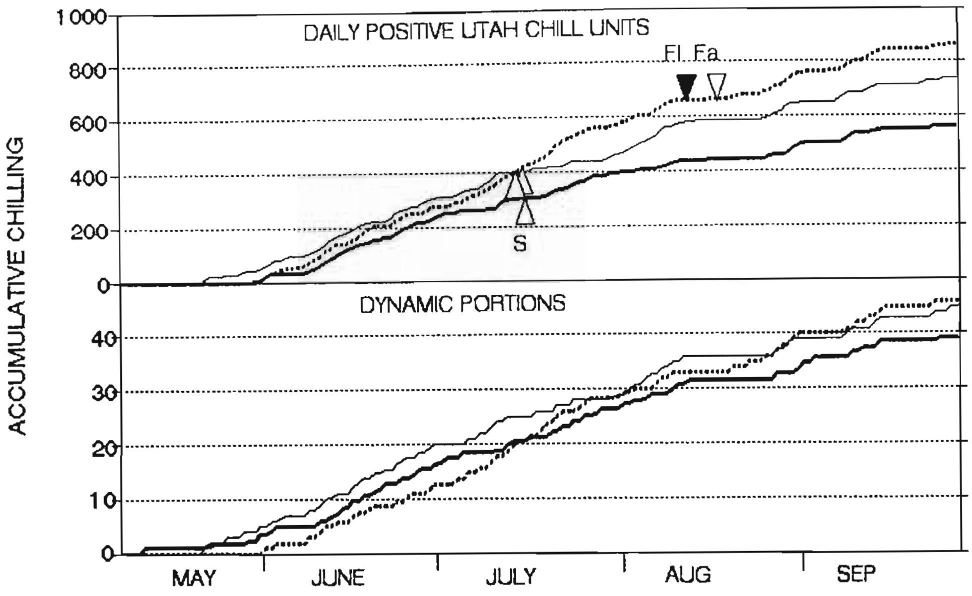


Fig. 3.1 Daily positive Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam ▬ ▬ ▬ during the 1988 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

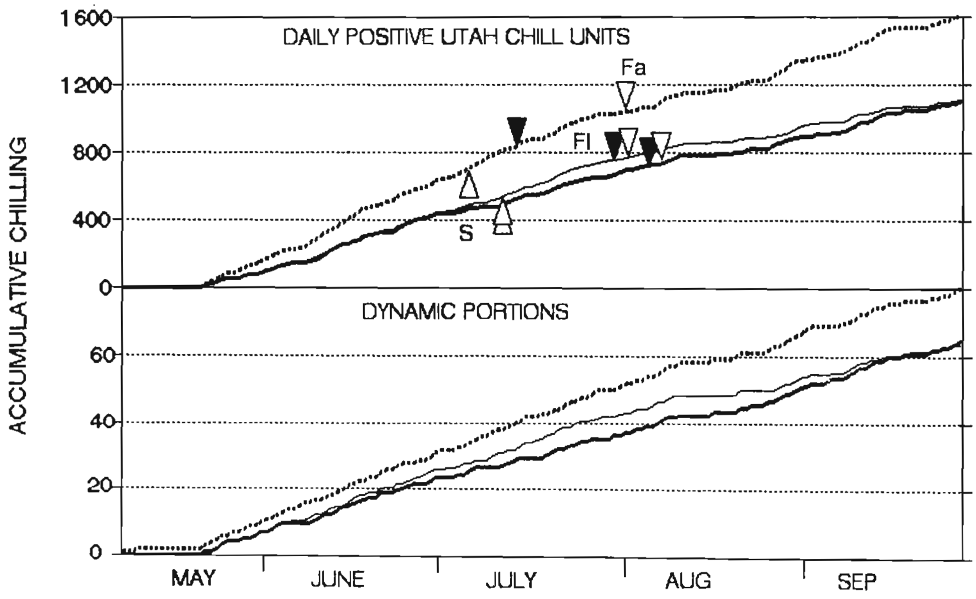


Fig. 3.2 Daily positive Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres ----- and Bokkeveld ▬ ▬ ▬ during the 1988 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

The increase in Robertson, which also showed DF symptoms in 'Flavortop' and 'Fantasia' was also high (30%), but for Clanwilliam it was only 10%. In the cooler locations (Fig. 3.2) the PCU and DP accumulation patterns were very similar. Only the Villiersdorp location showed a higher PCU than UCU accumulation (10% higher for all three cultivars). This indicated that in these locations very little high temperature occurs.

3.3.2 1989 Season

In the warmer locations (Fig 3.3) the PCU model resulted in superior spatial separation of the accumulation trends and the three cultivar's endodormancy termination dates. The largest improvement in chill unit accumulation was at Robertson, where the endodormancy estimation for 'Sunlite', 'Flavortop' and' Fantasia' increased from 369, 487 and 487 UCU to 431, 580 and 571 PCU respectively. In the cooler locations (Fig. 3.4) the PCU accumulation was very similar to that of the UCU accumulation. The PCU trend also gave a better spatial separation of the coldest Bokkeveld location. Severe high temperature negation did not occur at these locations in 1989.

3.3.3 1990 Season

In the warmer locations, the PCU accumulation trends showed a greatly superior spatial separation of chilling requirement estimations for the different cultivars than the those of the UCU model (Fig. 3.5 compared with Fig. 2.5). This was most evident in the warmest Robertson location, where the difference in chilling requirement of 'Sunlite' and 'Flavortop' was improved by over 40% from 70 UCU to 99 PCU. The PCU accumulation patterns in the cooler locations (Fig.3.6) were very similar to those of the UCU trends shown in Fig 2.6.

3.3.4 Overall trends and statistical analyses

The overall accumulation trends for the warmer locations (Fig. 3.7) show only a moderately higher PCU than UCU (Fig. 2.7) accumulation over the year. This is because averaging out of UCU accumulation data tended to mask the periods of high temperature negation clearly shown by the yearly data. The UCU model shows increased accumulation patterns for each of the three locations with time, while the DP model indicates that accumulation at Clanwilliam began later. Although Clanwilliam's chilling was greater over the whole period, the slow commencement resulted in similar accumulations at the time of 'Sunlite' endodormancy completion.

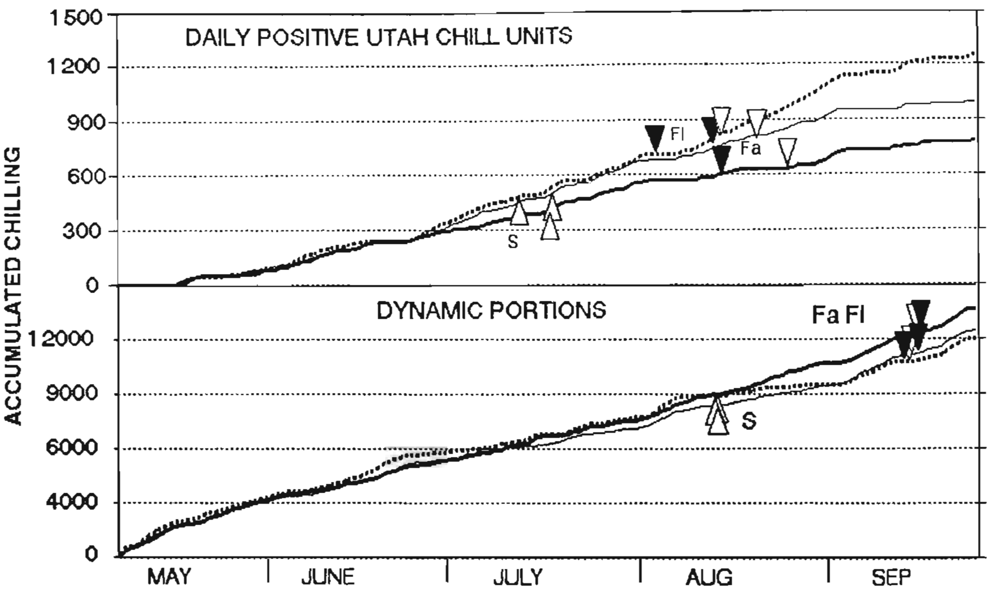


Fig. 3.3 Daily positive Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam - - - during the 1989 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

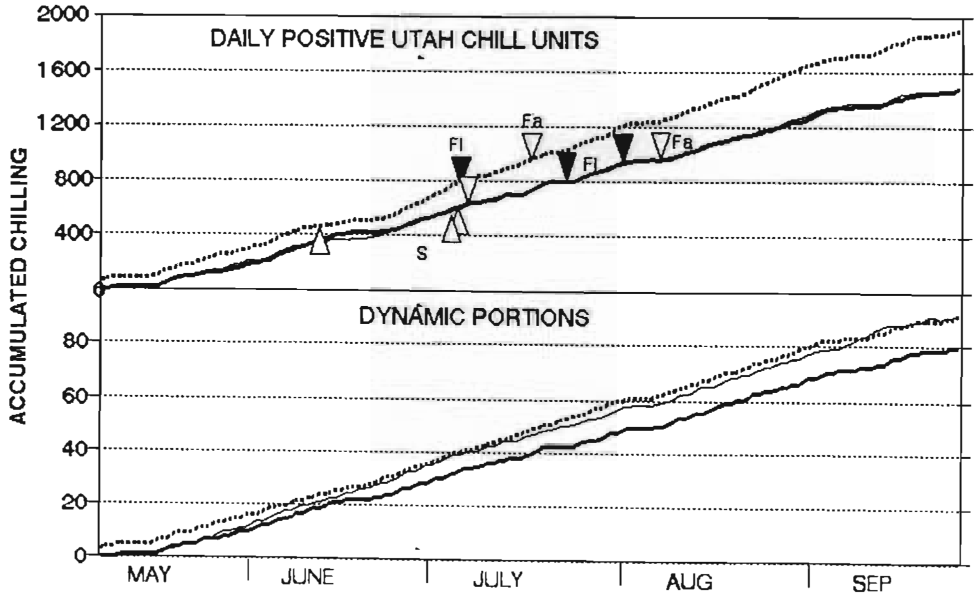


Fig. 3.4 Daily positive Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld - - - during the 1989 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

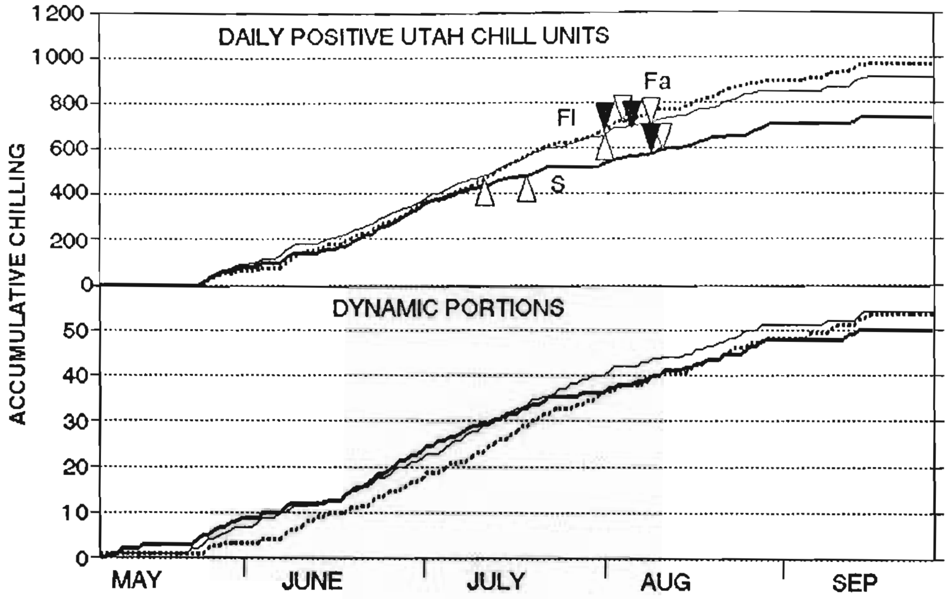


Fig. 3.5 Daily positive Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam ▬ ▬ ▬ during the 1990 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ▽).

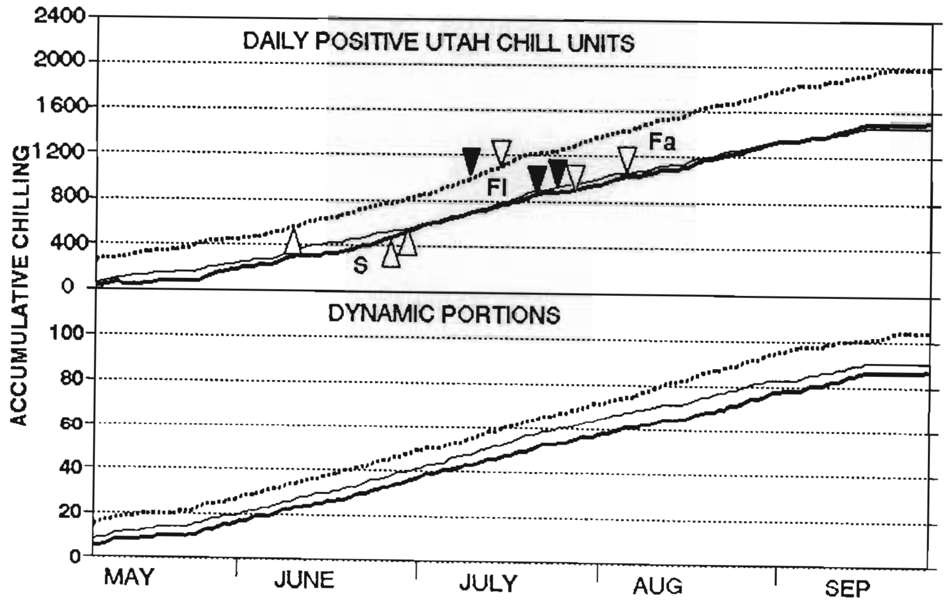


Fig. 3.6 Daily positive Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld ▬ ▬ ▬ during the 1990 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ▽).

The average endodormancy termination dates for 'Sunlite' indicate that the DP model was slightly superior to the PCU model. 'Flavortop' and 'Fantasia' endodormancy termination dates indicate that there was little difference in the PCU and DP models predictions. From the location averages presented in Tables 3.1; 3.2 and 3.3, it is evident that large increases in PCU compared to UCU accummulation occurred in the warmer locations with very little in the colder locations. These inreases in chill units, from warmest to coldest of the six locations were: 13%, 15%, 6%, 6%, 0.5% and 5% for 'Sunlite' and 8%, 7%, 10%, 6%, 1% and 2% for 'Flavortop' and 'Fantasia'. Averaged data for the cooler locations (Fig. 3.8) confirmed that there is very little carry- over of high temperature negation in these locations. The trends were almost identical to those shown in Fig. 2.7.

Analysis of the endodormancy chilling data showed that the modification of the UCU model reduced the coefficients of variation in the cultivar Sunlite from 24.9 to 19.7%, in Flavortop from 21.7 to 17.9% and in Fantasia from 23.8 to 20.1% (Tables 3.1, 3.2 and 3.3). The mean chill unit accumulation for the cultivars Sunlite, Flavortop and Fantasia were 33, 46 and 46 DP and 565, 807 and 817 PCU respectively.

3.4 DISCUSSION AND CONCLUSION

Minor changes to the existing UCU model, then in use by the South African deciduous fruit industry, improved it's accuracy to levels approaching those achieved by the more recently introduced, but less easy to use, DP model. By deleting the carry-over effect of negating temperatures from one day to the next, the effective winter chilling received at a location can be more accurately estimated, especially in warmer locations. Spatial separation of chilling requirements using the PCU model was superior to that of the DP model and the PCU model showed clear differences in accumulation patterns between DF locations and locations with normal bud break.

Using the DPU model, the average chilling requirements for the nectarine cultivars Sunlite, Flavortop and Fantasia for the Western Cape growing areas are 526, 807 and 817 chill units respectively. The chilling requirements of 'Flavortop' and 'Fantasia' are practically identical.

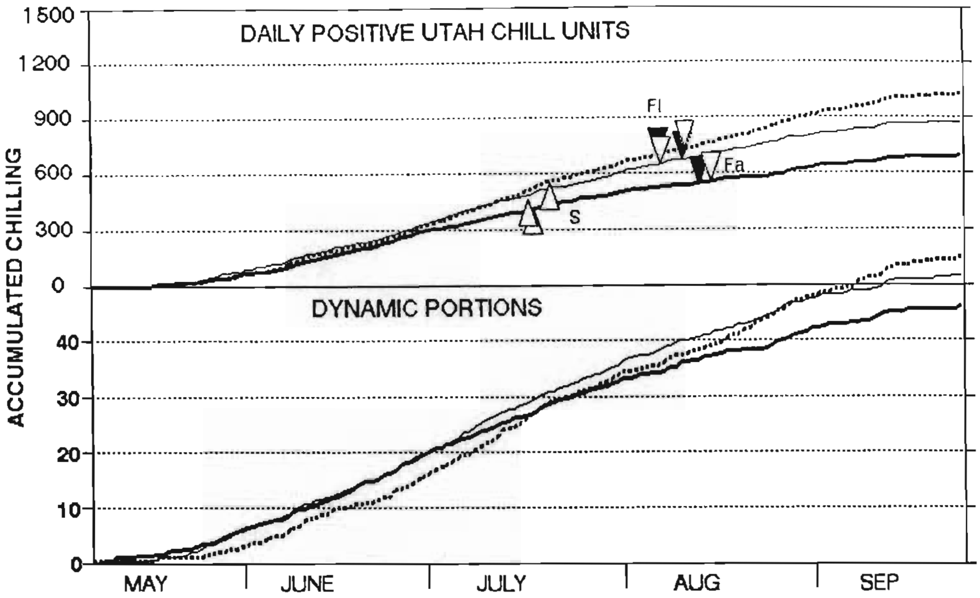


Fig. 3.7 Daily positive Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam - - - averaged over three winters (1988 to 1990). Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ▽).

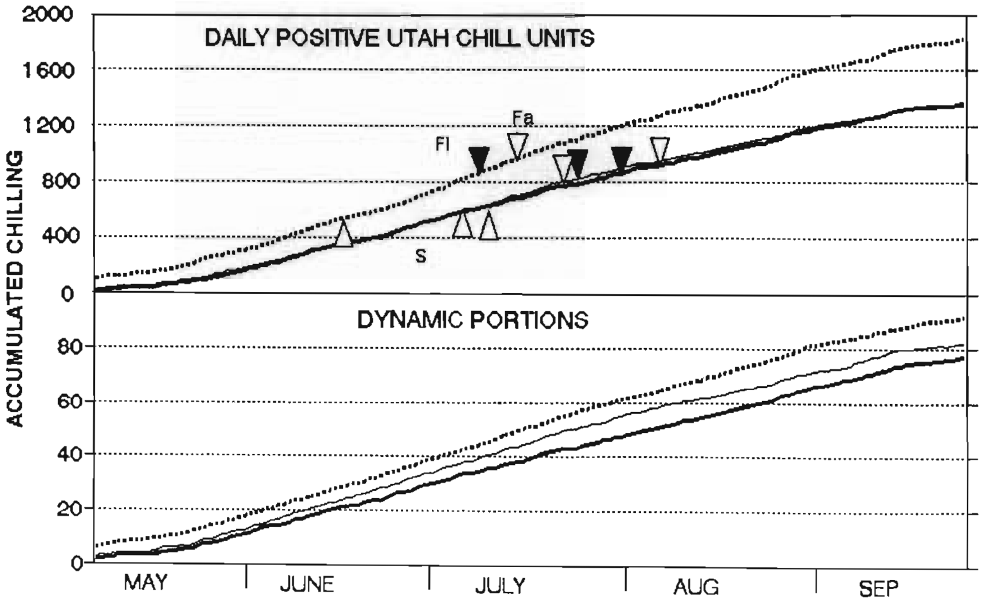


Fig. 3.8 Daily positive Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld - - - averaged over three winters (1988 to 1990). Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ▽).

Table 3.1. Accumulation of 'dynamic portions', 'Utah chill units' and 'daily positive Utah chill units' for the nectarine cultivar Sunlite, from six climatically different locations in the Western Cape, over three or four seasons.

		MODEL		
LOCATION	**SEASON**	**DP**	**UCU**	**PCU**
ROBERTSON	1988	22	247.5	323.5
	1989	28	369.0	431.0
	1990	34	468.5	481.0
	1991	28	406.0	480.0
	Mean	**29**	**380**	**429**
PAARL	1988	27	355.0	521.5
	1989	28	414.0	472.5
	1990	35	575.0	585.5
	Mean	**30**	**448**	**527**
CLANWILLIAM	1988	26	441.5	487.5
	1989	26	458.0	488.0
	1990	35	632.0	648.5
	Mean	**29**	**510**	**541**
VILLIERSDORP	1988	31	528.5	586.0
	1989	34	597.5	624.5
	1990	34	482.0	506.0
	mean	**32**	**536**	**572**
CERES	1988	41	719	719.0
	1989	36	577.5	582.0
	1990	40	542.5	542.5
	Mean	**39**	**613**	**614**
BOKKEVELD	1988	38	782.5	783.5
	1989	37	679.5	717.5
	1990	36	605.5	616.5
	1991	37	615.0	712.0
	Mean	**37**	**671**	**707**
MEAN		33	526.3	565.9
STANDARD DEVIATION		5.2	130.98	111.34
COEFFICIENT OF VARIATION (%)		15.8	24.9	19.7

Table 3.2. Accumulation of 'dynamic portions', 'Utah chill units' and 'daily positive Utah chill units' for the nectarine cultivar Flavortop, from six climatically different locations in the Western Cape, over three or four seasons.

			MODEL	
LOCATION	**SEASON**	**DP**	**UCU**	**PCU**
	1988	delayed	foliation	
ROBERTSON	1989	39	538.0	626.5
	1990	41	487.5	580.0
	1991	418	538.0	590.0
	Mean	**40**	**521**	**598**
	1988	delayed	foliation	
PAARL	1989	43	692.5	778.5
	1990	42	681.0	697.0
	Mean	**43**	**687**	**738**
	1988	33	583.0	641.0
CLANWILLIAM	1989	42	686.5	798.0
	1990	38	705.0	721.5
	Mean	**38**	**660**	**720**
	1988	43	709.5	777.5
VILLIERSDORP	1989	48	894.5	943.0
	1990	54	856.0	890.5
	Mean	**48**	**820**	**870**
	1988	48	817.0	828.5
CERES	1989	50	810.5	818.5
	1990	63	975.0	975.0
	Mean	**54**	**867**	**874**
	1988	50	1020.5	1022.0
BOKKEVELD	1989	41	789.0	827.0
	1990	59	1086.0	1097.0
	1991	54	888.0	920.0
	Mean	**51**	**946**	**967**
MEAN		46	764.3	807.3
STANDARD DEVIATION		7.6	166.0	144.9
COEFFICIENT OF VARIATION (%)		16.4	21.7	17.9

Table 3.3 Accumulation of 'dynamic portions', 'Utah chill units' and 'daily positive Utah chill units' for the nectarine cultivar Fantasia, from six climatically different locations in the Western Cape, over three or four seasons.

		MODEL		
LOCATION	**SEASON**	**DP**	**UCU**	**PCU**
	1988	delayed	foliation	
ROBERTSON	1989	39	538.0	626.5
	1990	40	487.5	571.0
	1991	41	548.0	580.0
	Mean	**40**	**522**	**592**
	1988	delayed	foliation	
PAARL	1989	43	692.5	778.5
	1990	42	676.0	680.0
	Mean	**43**	**687**	**730**
	1988	33	583.0	641.0
CLANWILLIAM	1989	42	686.5	798.0
	1990	35	641.5	658.0
	Mean	**37**	**637**	**699**
	1988	43	709.5	777.5
VILLIERSDORP	1989	53	958.0	1011.0
	1990	56	882.5	917.0
	Mean	**51**	**850**	**902**
	1988	48	817.0	828.5
CERES	1989	40	656.0	664.5
	1990	59	916.5	916.5
	Mean	**49**	**797**	**803**
	1988	54	1058.5	1066.5
BOKKEVELD	1989	51	927.5	1010.5
	1990	61	1125.0	1136.0
	1991	55	901.0	933.0
	Mean	**55**	**1003**	**1037**
MEAN		46	766.4	817.9
STANDARD DEVIATION		8.2	182.7	164.5
COEFFICIENT OF VARIATION (%)		17.6	23.8	20.10

CHAPTER FOUR: EFFECT OF HEAT ACCUMULATION DURING ENDODORMANCY AND BUD DEVELOPMENT

4.1 INTRODUCTION

Moderate to high day temperatures during winter, common in South African deciduous fruit growing regions, are known to have a negative effect on rest development in dormant buds (Erez *et al.*, 1979a), but may also play a positive role in the dormancy process (Couvillon & Erez, 1985b).

Linsley-Noakes and Allan (1994) showed that the UCU model consistently underestimated the chilling requirements of the nectarine cultivars Sunlite, Flavortop and Fantasia in warmer locations within the deciduous fruit growing region or South Africa. These locations experience high temperatures in winter and the effect of these high temperatures during endodormancy has not been fully examined.

Modification of the UCU model improved the accuracy considerably but, like the 'dynamic' model, failed to account for the large differences between the cooler and warmer growing areas (Linsley-Noakes *et al.*, 1994).

The accumulation of heat during the endodormancy period is reported to reduce the apparent chilling requirement in pecan nuts (Sparks, 1993). The endodormancy reaction in pecans is thought to be under the interactive control of heating and chilling. The interrelationship between chilling and thermal time (day degrees above a fixed thermal time) was also discussed by Cannell (1989), but only for the period between commencement of dormancy and full bloom. The effect of thermal time during the endodormant period on its own was not investigated. He concluded that, as the buds are progressively chilled, the thermal time required for them to reach full bloom, should decrease.

Although the effect of heat during endodormancy of nectarines has not been reported on, it is known that low-chill nectarine cultivars grow in parts of Natal adjacent to sub-tropical crops such as papayas and macadamia nuts (Blaine & Allan, 1979; Partridge & Allan, 1980; Allan *et al.*, 1993). These areas receive considerably lower winter chilling and have substantially more heat accumulation during endodormancy than the traditional nectarine growing areas. These areas nevertheless can produce economic low chill nectarine crops without significant delayed foliation symptoms (Allan *et al.*, 1993).

Heat is required for buds to develop once their endodormancy requirement has been met. The amount of heat required to stimulate bud development is a function of the amount of winter chilling received. As buds receive in excess of their chilling requirement, there is an exponential reduction in their heat requirement (Couvillon and Erez, 1985b).

4.2 MATERIALS AND METHODS

Climatic and phenological data were collected as for Chapter 1. Temperature data during the endodormancy period were converted into 'daily positive Utah chill units' (PCU), 'dynamic portions'(DP) and degree hours above a base temperature of 10°C (DH).

DH = Sum of hours $> 10^{\circ}$C in the daily cycle

Correlations were made between estimated chilling requirements of the three nectarine cultivars and the growing degree hour accumulation over the same period. Regressions were then fitted to the data in order to compare the correlations.

Correlations were also made between PCU during endodormancy and DH between end of endodormancy and full bloom.

4.3 RESULTS

4.3 1 1988 Season

The warmer locations (Fig 4.1) had a higher heat unit (DH) accumulation during endodormancy and tended to have a higher DH requirement for natural bud break in spring. Robertson, the warmest location, accumulated 7563 during the endodormancy period of 'Sunlite'. Due to insufficient winter chilling at the Robertson location in 1988, it was not possible to determine the requirement for 'Flavortop' and 'Fantasia'. The coldest Bokkeveld location accumulated only 2978 and about 4000 DH for 'Sunlite and 'Flaavortop/Fantasia' during the same season (Tables 4.1; 4.2 and 4.3). After endodormancy, the 'Sunlite' trees at the Robertson location required 3035 until full bloom respectively, while the Bokkeveld trees required 1229 and 1674 DH respectively. Robertson and Paarl had very similar heat accumulation trends, suggesting that differences in chilling are as a result of more temperatures at the optimal chilling range during Paarl winters.

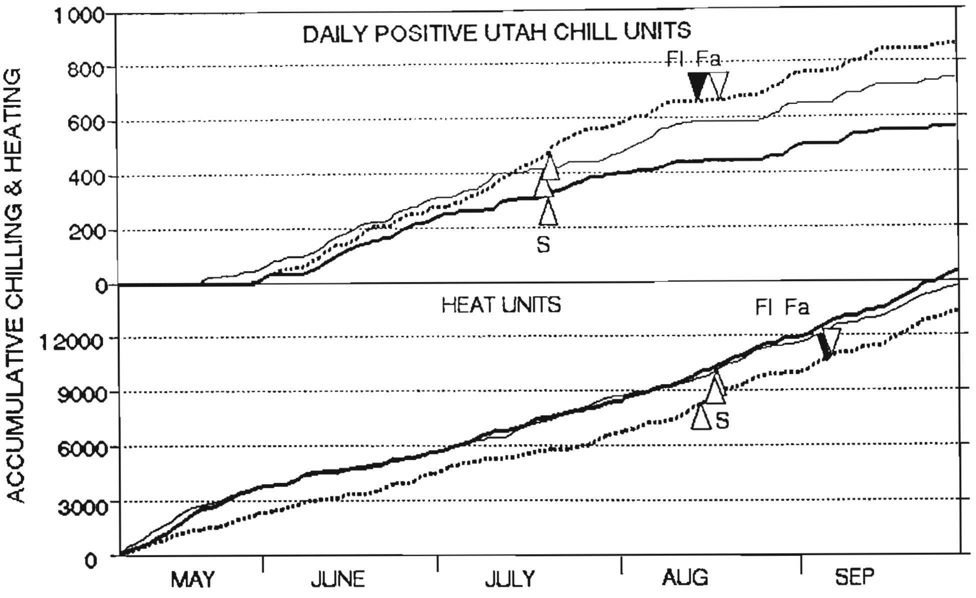


Fig. 4.1 Daily positive Utah chill unit and heat unit (GDH) accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam ▬ ▬ ▬ during the 1988 winter. Arrows in the top graph represent the completion of endodormancy and in the bottom graph the full bloom dates for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

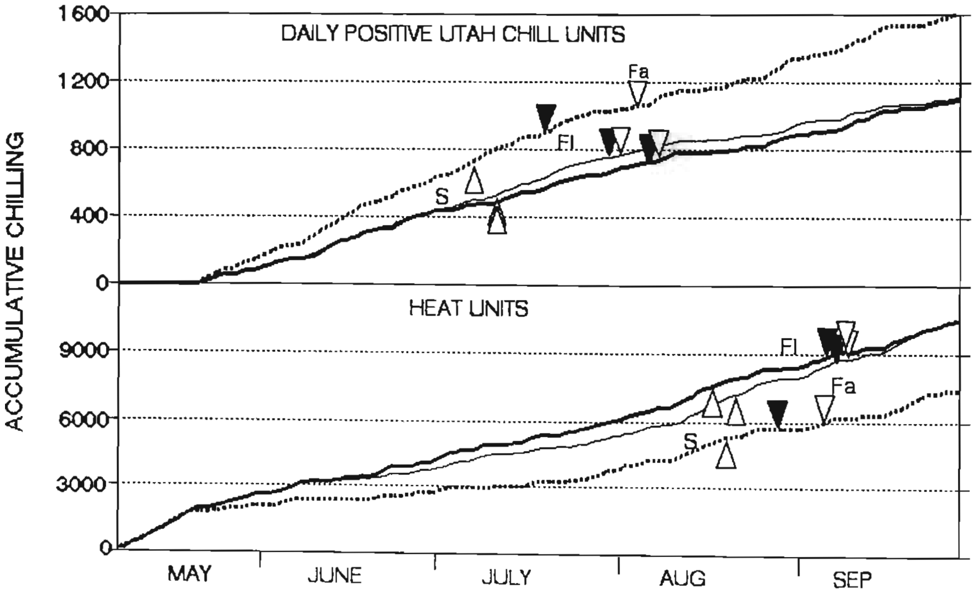


Fig. 4.2 Daily positive Utah chill unit and heat unit (GDH) accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld ▬ ▬ ▬ during the 1988 winter. Arrows in the top graph represent the completion of endodormancy and in the bottom graph the full bloom dates for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

The lower DH requirement for bud break in the cooler locations (Fig. 4.2) resulted in the endodormancy completion and full bloom dates being closer together than in the warmer locations (Tables 4.1: 4.2 and 4.4). In general the full bloom dates corresponded well with the endodormancy completion dates. DH accumulation patterns were almost mirror images of the PCU accumulations, showing that high day temperatures are the main cause of low chill unit accumulation during mild Western Cape winters.

4.3.2 <u>1989 Season</u>

The DH accumulations in the warmer locations (Fig. 4.3) were almost identical to one another, indicating that differences in PCU accumulation between the three locations, as shown on the top of the graph, were due to differences in chilling temperatures rather than high temperatures. The DH accumulation during endodormancy was lower than in 1988, in response to the colder winter (Tables 4.1 to 4.3). 'Fantasia' bloomed at the same time as 'Flavortop' even though it had a longer endodormancy requirement.

In the cooler locations (Fig 4.4) the Villiersdorp location had a higher DH accumulation than Ceres, even though the PCU accumulation was identical. The full bloom dates followed the expected progression beginning with 'Sunlite' and ending with 'Fantasia'. The DH accumulation during endodormancy in the cooler locations, was influenced more by the colder winter of 1989 than the warmer locations (Tables 4.1 to 4.3). For 'Sunlite', this seasonal drop in DH during endodormancy was 12% in Robertson but about 40% in Ceres and Villiersdorp. This indicated that the average temperatures at these colder locations were close to the 10°C base temperature for DH determination, during winter.

4.3.3 <u>1990 Season</u>

The 1990 DH and PCU trends were virtually identical to those of 1989 in both the warn and cool locations (Tables 4.1 to 4.3). The chill unit and DH accumulation data suggest that the main difference between the cooler Villiersdorp and Ceres locations was the higher DH accumulation in Villiersdorp (Fig 4.6).

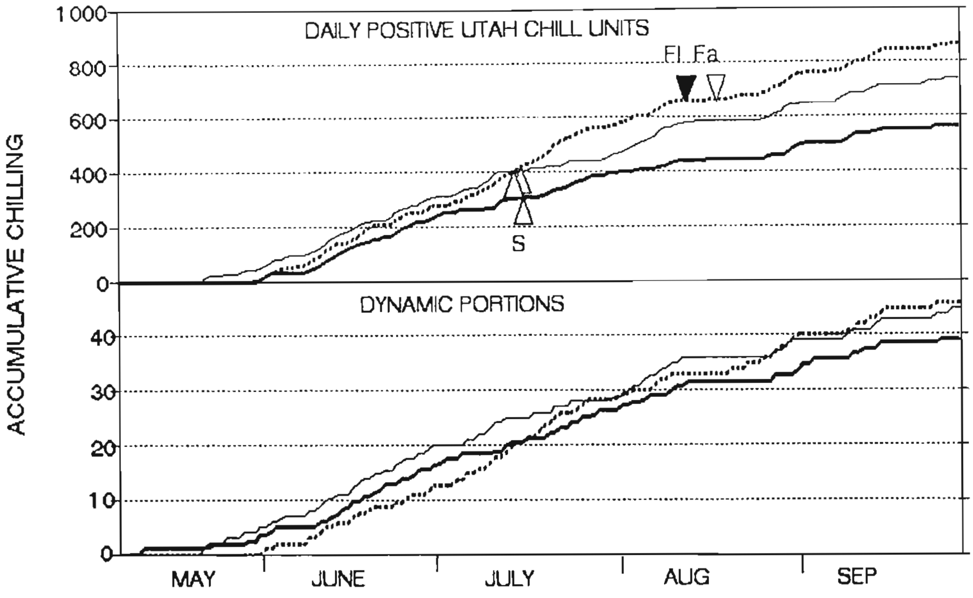


Fig. 3.1 Daily positive Utah chill unit and dynamic portion accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam ▪▪▪ during the 1988 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

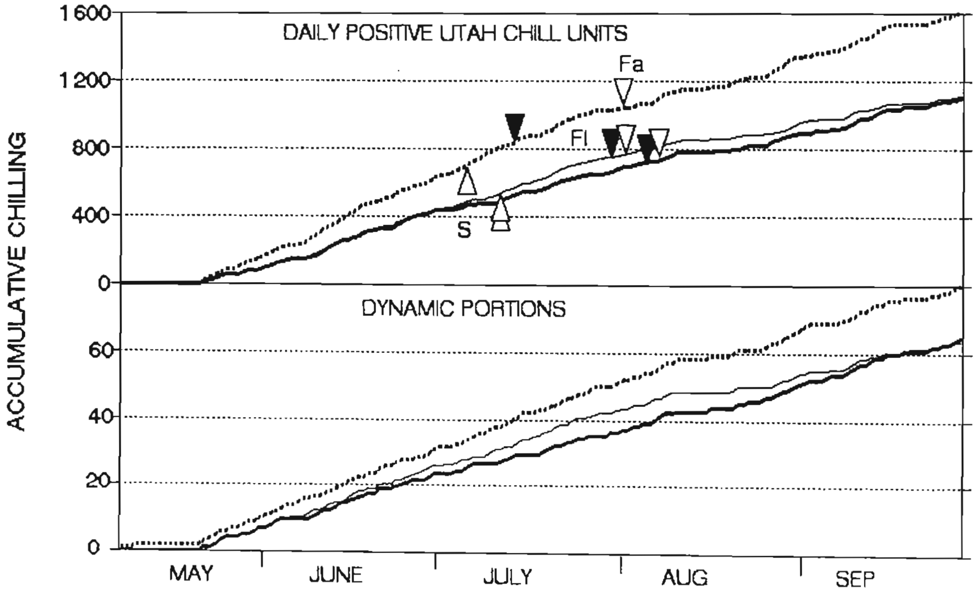


Fig. 3.2 Daily positive Utah chill unit and dynamic portion accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld ▪▪▪ during the 1988 winter. Arrows represent the completion of endodormancy period for the nectarine cultivars Sunlite (S Δ), Flavortop (Fl ▼) and Fantasia (Fa ∇).

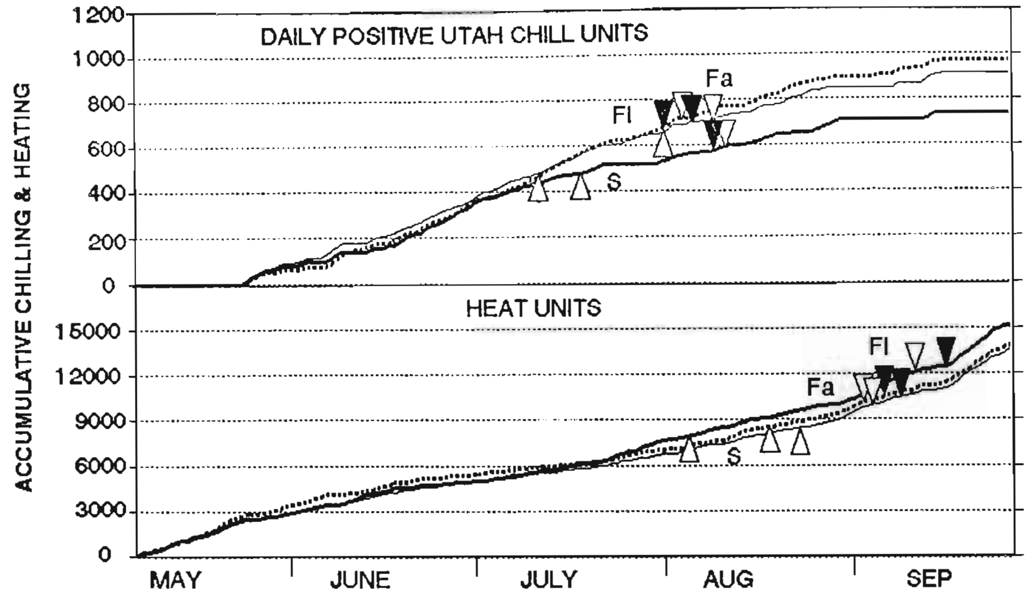


Fig. 4.5 Daily positive Utah chill unit and heat unit (DH) accumulation for the warmer locations of Robertson ▬▬, Paarl — and Clanwilliam - - - during the 1990 winter. Arrows in the top graph represent the completion of endodormancy and in the bottom graph the full bloom dates for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

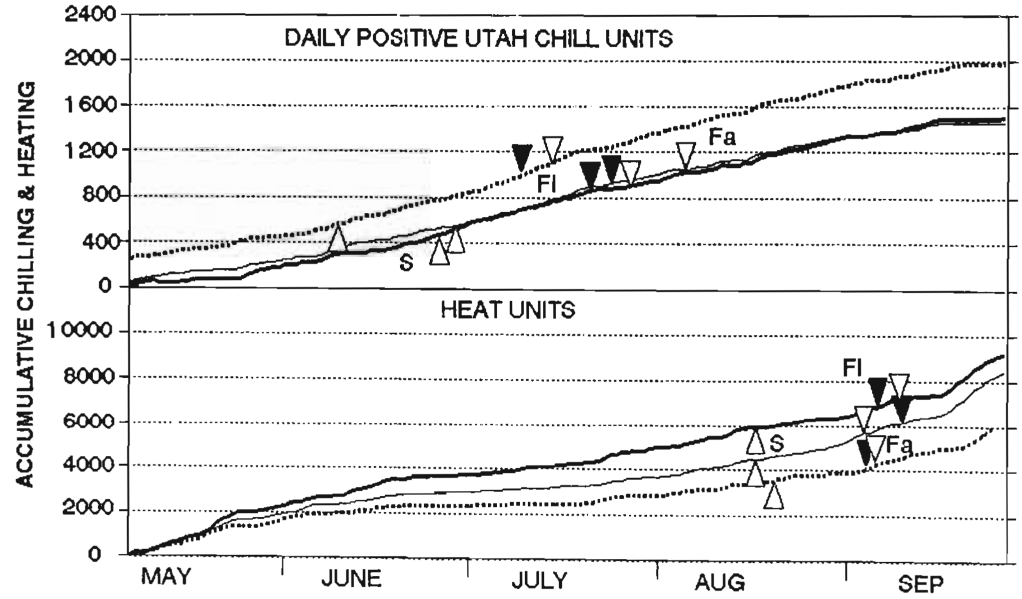


Fig. 4.6 Daily positive Utah chill unit and heat unit (DH) accumulation for the cooler locations of Villiersdorp ▬▬, Ceres — and Bokkeveld - - - during the 1990 winter. Arrows in the top graph represent the completion of endodormancy and in the bottom graph the full bloom dates for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

4.3.4 Overall trends and statistical analyses

The DH accumulations for the six locations, averaged over the three years (1988 to 1990) are presented in Figs 4.7 and 4.8. These graphs suggest that there were small differences in DH accumulation in the warmer locations, but that the larger differences in the cooler locations may play a role in endodormancy completion and bud break.

The statistical analyses of the DH data are presented in Tables 4.1, 4.2 and 4.3. There were large differences in DH during endodormancy with the warmer locations having much higher levels than the cooler locations. In the warmest Robertson location, 'Sunlite' required an average of 454 PCU to overcome endodormancy followed by 2862 DH until full bloom. During endodormancy, however, an average of 6859 DH accumulated. In the coldest Bokkeveld location, an average of 707 PCU was required, followed by 1719 DH until full bloom. During endodormancy, however, only 2533 DH accumulated. The intermediate areas had values evenly spread between these two extremes.

There was a clear trend of apparently lower chilling requirements in areas accumulating high levels if DH during endodormancy. The colder areas, which had higher PCU accumulations during endoddormancy, had lower post endodormancy DH requirements. This phenomenon is well documented in dormancy research (Couvillon & Erez, 1985a).

Although the DH levels followed a constant trend from warm to cold locations, there were large coefficients of variation for both the DH accumulation during or after endodormancy. For 'Sunlite', 'Flavortop' and 'Fantasia' the average endodormancy DH were 5116, 5827 and 6086, with coefficients of variation of 31.6, 44.6 and 45.1% respectively. For 'Sunlite', 'Flavortop' and 'Fantasia' the post endodormancy DH requirements were 2005, 2098 and 2214, with coefficients of variation of 32.3, 34.0 and 32.7% respectively.

By using the average PCU and post endodormancy DH requirement for 'Sunlite', 'Flavortop' and 'Fantasia' (566PCU + 2005 DH; 807 PCU + 2098 DH and 818 PCU + 2214 DH respectively), it was possible to test the PCU model's ability to predict actual full bloom dates using the data available. For 'Sunlite' the PCU model overestimated the full bloom dates by an average of 6.65 ± 11.2 days, while for Flavortop and Fantasia the overestimation was 0.2 ± 11.1 days and 1.6 ± 9.9 days respectively.

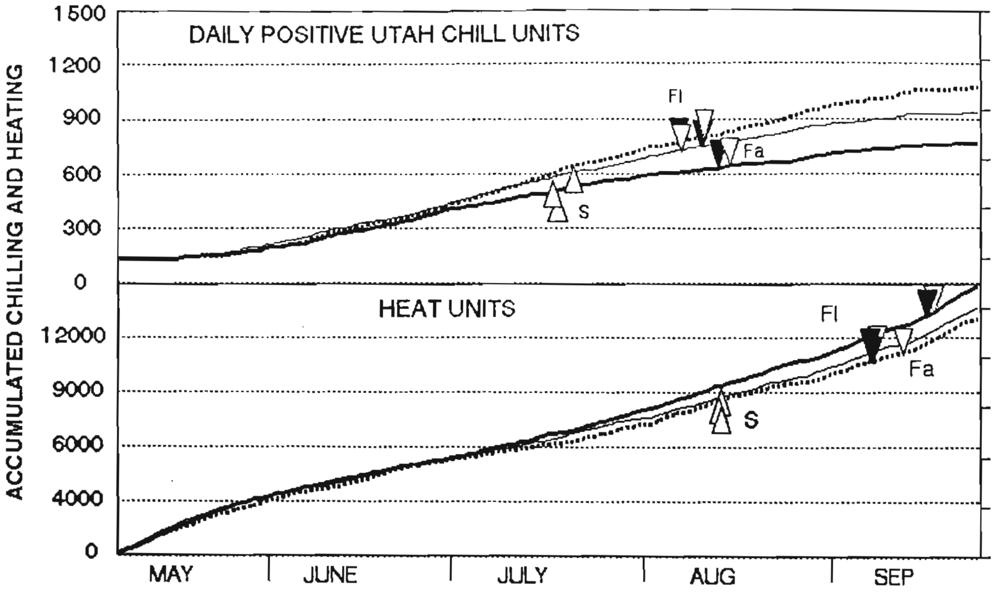


Fig. 4.7 Daily positive Utah chill unit and heat unit (DH) accumulation for the warmer locations of Robertson ▬▬, Paarl —— and Clanwilliam ▪▪▪ averaged over three winters (1988 to 1990). Arrows in the top graph represent the completion of endodormancy and in the bottom graph the full bloom dates for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

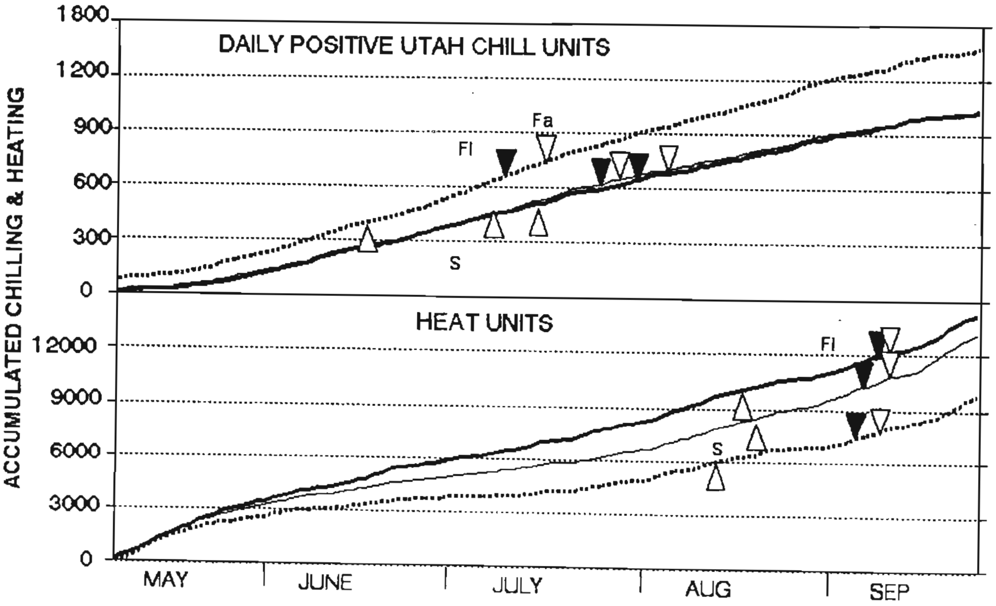


Fig. 4.8 Daily positive Utah chill unit and heat unit (DH) accumulation for the cooler locations of Villiersdorp ▬▬, Ceres —— and Bokkeveld ▪▪▪ averaged over three winters (1988 to 1990). Arrows in the top graph represent the completion of endodormancy and in the bottom graph the full bloom dates for the nectarine cultivars Sunlite (S △), Flavortop (Fl ▼) and Fantasia (Fa ▽).

Table 4.1 Accumulation of daily positive Utah chill units (PCU) and degree hours >10°C (DH) during the endodormancy period as well as the period from endodormancy to full bloom, for the nectarine cultivar Sunlite, from six climatically different locations in the Western Cape over three to four seasons.

LOCATION	**SEASON**	**PCU**	**ENDODORMANCY**		**FULL BLOOM**	
			DH	**DATE**	**DH**	**DATE**
ROBERTSON	1988	323.5	7563	19/7	3035	19/8
	1989	431.0	6746	17/7	2261	16/8
	1990	481.0	6216	16/7	3078	10/8
	1991	480.0	6912	16/7	3100	12/8
	Mean	**429**	**6859**	**17/7**	**2862**	**14/8**
PAARL	1988	521.5	7640	18/7	2560	18/8
	1989	472.5	6213	17/7	2189	16/8
	1990	585.5	5873	13/7	2274	10/8
	Mean	**527**	**6575**	**16/7**	**2341**	**15/8**
CLANWILLIAM	1988	487.5	6195	17/7	2136	16/7
	1989	488.0	6604	12/7	2334	14/7
	1990	648.5	6901	21/7	1455	16/7
	Mean	**541**	**6567**	**15/7**	**1975**	**15/7**
VILLIERSDORP	1988	586.0	5362	12/7	2201	15/8
	1989	624.5	3790	5/7	2324	16/8
	1990	506.0	4840	21/7	1050	15/8
	Mean	**572**	**4664**	**13/7**	**1858**	**15/8**
CERES	1988	719.0	4978	12/7	2136	19/8
	1989	582.0	2983	7/7	1754	15/8
	1990	542.5	3387	23/6	1066	16/8
	Mean	**614**	**3783**	**4/7**	**1652**	**17/8**
BOKKEVELD	1988	783.5	2978	3/7	1229	17/8
	1989	717.5	2367	12/6	1285	15/8
	1990	616.5	2072	9/6	1343	5/8
	1991	712.0	2713	5/6	1299	7/8
	Mean	**707**	**2533**	**20/6**	**1719**	**11/8**
MEAN		565.9	5116.1		2005.4	
STANDARD DEVIATION		111.3	2261.1		647.7	
COEFFICIENT OF VARIATION (%)		19.7	31.6		32.3	

Table 4.2 Accumulation of daily positive Utah chill units (PCU) and degree hours $>10^{\circ}C$ (DH) during the endodormancy period as welll as the period from endodormancy to full bloom, for the nectarine cultivar Flavortop, from six climatically different locations in the Western Cape over three to four seasons.

LOCATION	SEASON	PCU	ENDODORMANCY		FULL BLOOM	
			DH	DATE	DH	DATE
ROBERTSON	1988	DF				
	1989	626.5	9263	13/8	2623	15/9
	1990	580.0	10578	12/8	3600	14/9
	1991	590.0	9979	11/8	3561	14/9
	Mean	**589**	**9440**	**12/8**	**3261**	**14/9**
PAARL	1988	DF				
	1989	778.5	8503	11/8	1875	12/9
	1990	697.0	7074	10/8	2774	5/9
	Mean	**738**	**7789**	**11/8**	**2325**	**9/9**
CLANWILLIAM	1988	641.0	8331	11/8	2163	7/9
	1989	798.0	8938	4/8	1221	6/9
	1990	721.5	7424	5/7	3071	7/9
	Mean	**720**	**8231**	**7/8**	**2157**	**7/9**
VILLIERSDORP	1988	777.5	6747	4/8	2172	5/9
	1989	943.0	5221	1/8	1630	15/9
	1990	890.5	4770	25/7	2020	5/9
	Mean	**870**	**5579**	**4/8**	**1941**	**6/9**
CERES	1988	828.5	5873	28/7	2797	8/9
	1989	818.5	3727	21/7	1653	3/9
	1990	975.0	3643	29/7	2170	4/9
	Mean	**874**	**4414**	**26/7**	**2207**	**5/9**
BOKKEVELD	1988	1022.0	3977	12/7	1764	29/8
	1989	827.0	2468	6/7	1628	6/9
	1990	1097.0	2462	10/7	1519	5/9
	1991	920.0	2405	6/7	1635	6/9
	Mean	**976**	**2828**	**8/7**	**1637**	**4/9**
MEAN		817.3	5852.7		2098.7	
STANDARD DEVIATION		164.5	2638.6		685.4	
COEFFICIENT OF VARIATION (%)		20.1	45.1		32.7	

Table 4.3 Accumulation of daily positive Utah chill units (PCU) and degree hours $>10^{\circ}$C (DH) during the endodormancy period as well as the period from endodormancy to full bloom, for the nectarine cultivar Fantasia, from six climatically different locations in the Western Cape over three to four seasons.

LOCATION	SEASON	PCU	ENDODORMANCY		FULL BLOOM	
			DH	DATE	DH	DATE
ROBERTSON	1988	DF				
	1989	626.0	9263	25/8	2623	15/9
	1990	571.0	10578	10/8	3600	14/9
	1991	580.0	9979	24/8	3561	14/9
	Mean	**592**	**9440**	**20/8**	**3261**	**14/9**
PAARL	1988	DF				
	1989	778.5	8503	19/8	1875	14/9
	1990	680.0	6860	3/8	2988	14/9
	Mean	**730**	**7682**	**11/8**	**2431**	**9/9**
CLANWILLIAM	1988	641.0	8331	19/8	2163	9/9
	1989	798.0	8938	12/8	1221	10/9
	1990	658.0	6937	30/7	3108	9/9
	Mean	**699**	**8067**	**10/8**	**2164**	**9/9**
VILLIERSDORP	1988	777.5	6747	6/8	2397	5/9
	1989	1011.0	6064	8/8	1108	12/9
	1990	917.0	3700	28/7	3200	7/9
	Mean	**902**	**5504**	**4/8**	**2235**	**8/9**
CERES	1988	828.5	5874	27/7	2797	8/9
	1989	664.5	3106	16/7	2318	7/9
	1990	916.5	2937	26/7	2570	8/9
	Mean	**803**	**3972**	**23/7**	**2562**	**8/9**
BOKKEVELD	1988	1066.5	4155	25/7	1764	5/9
	1989	1010.5	2717	7/7	1628	10/9
	1990	1136.0	2462	13/7	1519	5/9
	1991	933.0	2405	12/7	1635	7/9
	Mean	**1037**	**2935**	**14/7**	**1637**	**7/9**
MEAN		817.9	6086.4		2214.3	
STANDARD DEVIATION		164.5	2713.1		753.1	
COEFFICIENT OF VARIATION (%)		20.1	44.6		34.0	

4.3.5 Field bud break data

The percent vegetative and reproductive bud break measured about two weeks after the full bloom stage of each cultivar for the six locations over the three year period are presented in Figs 4.9 and 4.10 respectively. There was an improvement in vegetative and reproductive bud break levels from 1988 (warm winter) to 1989 and 1990 (colder winters) especially in vegetative bud break in the higher chill cultivars, 'Flavortop' and 'Fantasia'. It was difficult to correlate these data with field chilling results. The measurement of rates of bud break would have been a more accurate measure of bud development in spring but due to logistical limitations this was not possible.

4.3.6 Interaction of heat and chilling during dormancy

A comparison between warm and cold areas as well as between warmer and colder winters indicated a possible correlation between the winter chilling and heat units accumulated during endodormancy. The relationship between PCU requirement and DH accumulation during endodormancy for the nectarine cultivars Sunlite, Flavortop and Fantasia is presented in Fig. 4.11.

The more heat that a location received during endodormancy the lower was the apparent chilling requirement. This ties in with the perception that in cooler locations the depth of endodormancy is greater than in warmer areas and as such the chilling requirement to release these buds from endodormancy is greater. Estimates of the chilling requirement of Sunlite, Flavortop and Fantasia nectarines for areas receiving different heat levels during endodormancy were estimated from Fig 4.11 and are presented in Table 4.4.

The correlations indicate that in locations with high DH levels during endodormancy (6000 to 8000), the chilling requirement of 'Sunlite' could be as low as 26 DP or 480 PCU and that of 'Flavortop/ Fantasia' 36 DP or 600 PCU. In the colder locations (200 to 5000 DH) the chilling requirement could be as high as 41 DP or 720 PCU for 'Sunlite' and 54 DP or 1000 PCU for 'Flavortop' and 'Fantasia'.

There appears to be a lower limit to the amount of chilling required for normal bud break regardless of heat accumulation. For 'Fantasia' and 'Flavortop' less than 550 PCU resulted in typical delayed foliation symptoms (Tables 3.2 and 3.3; Fig 3.1). 'Sunlite', however, could possibly be grown in locations receiving less than 323 DPU (the lowest in this study) provided that DH accumulation during endodormancy is high.

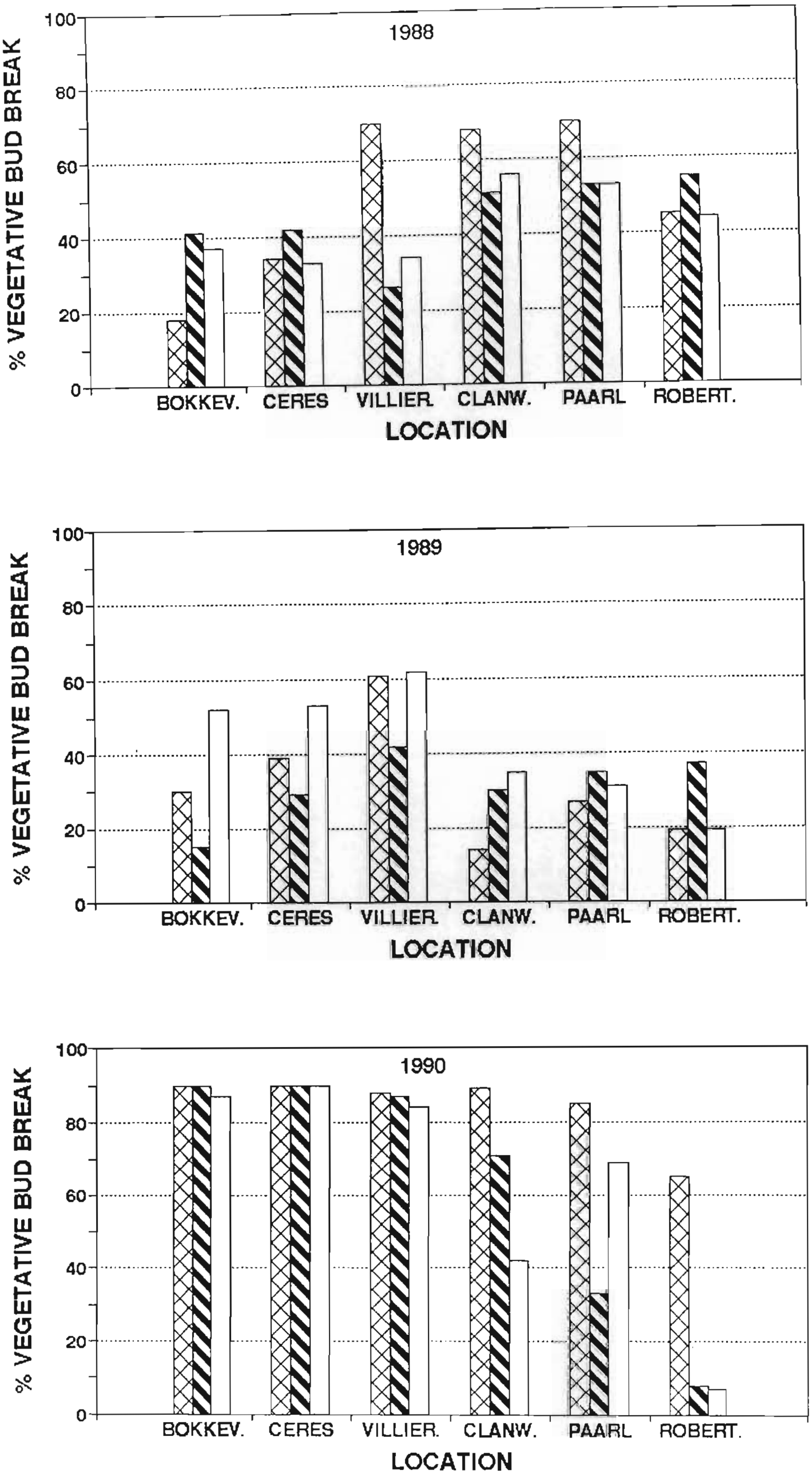
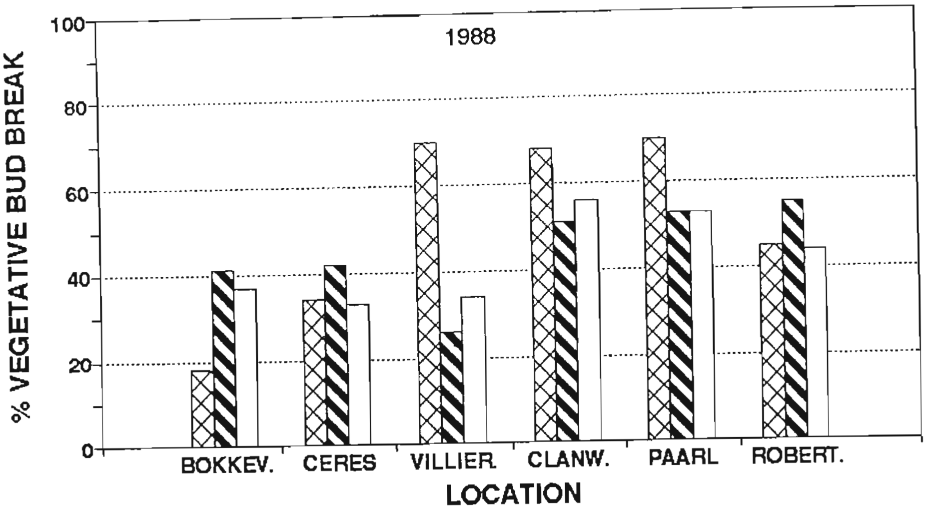
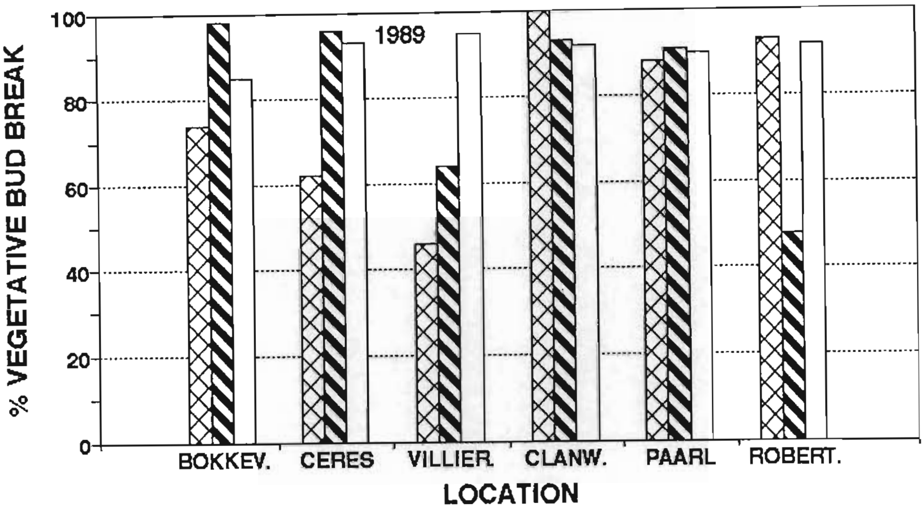


Fig. 4.9 Field vegetative bud break levels measured two weeks after full bloom for the nectarine cultivars, Sunlite (cross hatch bars), Flavortop (hatched bars) and Fantasia (clear bars), from six climatically divergent locations over three seasons.





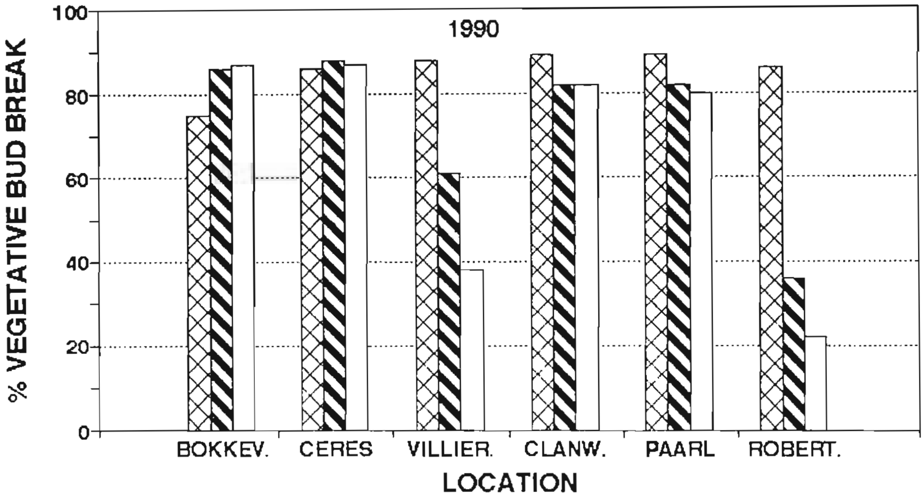


Fig. 4.10 Field reproductive bud break levels measured two weeks after full bloom for the nectarine cultivars, Sunlite (cross hatch bars), Flavortop (hatched bars) and Fantasia (clear bars), from six climatically divergent locations over three seasons.

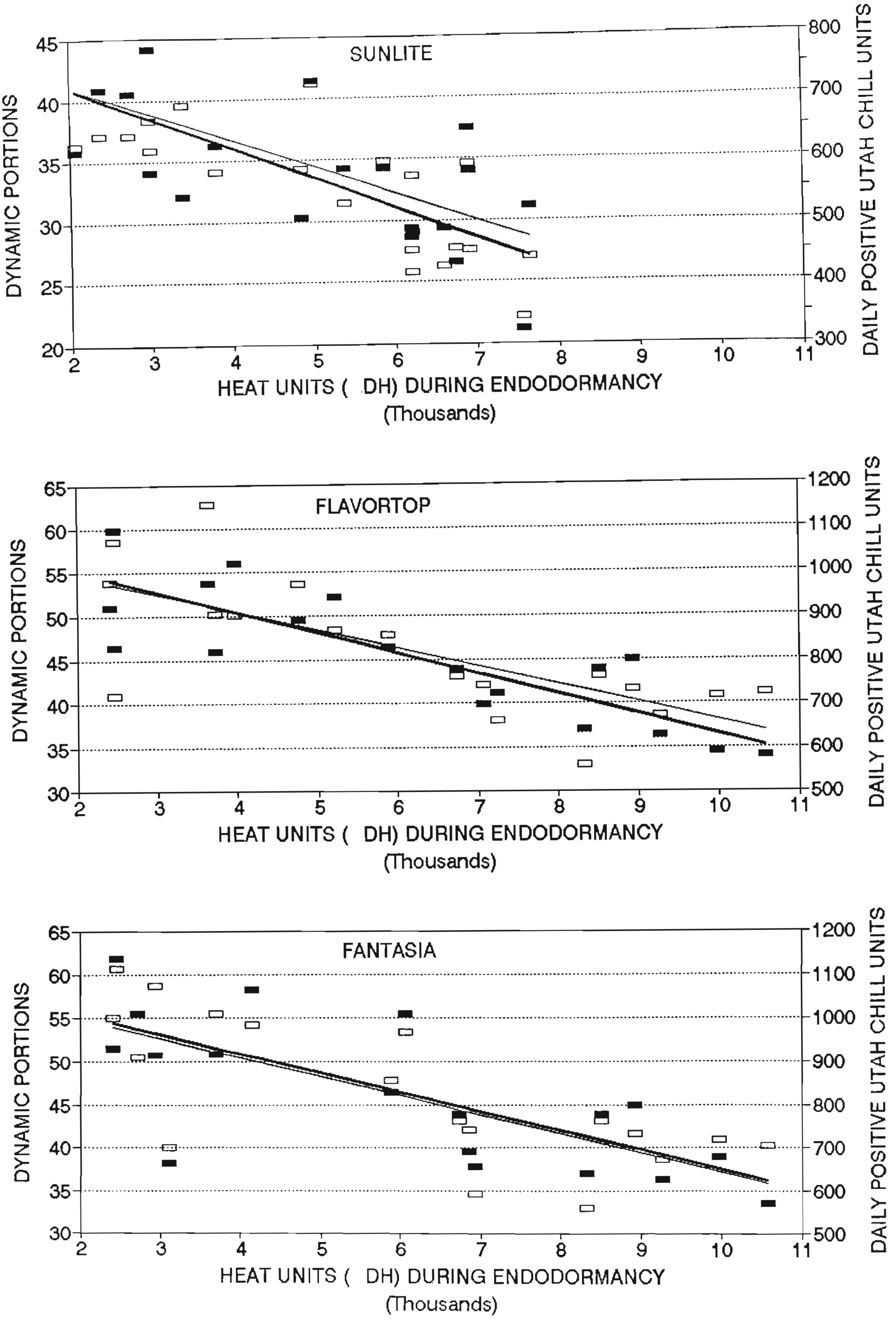


Fig. 4.11 Interaction between degree hours >10°C (DH) and dynamic portion (▯, ▬) or daily positive Utah chill units (▮, —) chill units measured during the endodormant period of the nectarine cultivars Sunlite, Flavortop and Fantasia.

Table 4.4 Tentative dynamic portion (DP) and daily positive Utah chill unit (PCU) requirement for the nectarine cultivars Sunlite, Flavortop and Fantasia based on the heat accumulation during the endodormant period.

Cultivar	Model	Warm[z] locations	Mild[y] locations	Cold[x] locations
Sunlite	DP PCU	26-31 480-550	31-36 550-620	36-41 620-720
Flavortop & Fantasia	DP PCU	36-42 600-730	42-48 730-860	48-54 860-1000

[z] 6000-8000 DH for Sunlite; 8000-11000 DH for Flavortop and Fantasia. (Average May and June temperature of 13-14 °C).

[y] 4000-6000 DH for Sunlite; 5000-8000 DH for Flavortop and Fantasia. (Average May and June temperature of 12-13 °C).

[x] 2000-4000 DH for Sunlite; 2000-5000 DH for Flavortop and Fantasia. (Average May and June temperature of 11-12 °C).

Table 4.5. Linear regressions for the correlation between dynamic portions (DP) as well as daily positive Utah chill units (PCU), and heat accumulation >10°C (DH) during endodormancy, for the nectarine cultivars Sunlite, Flavortop and Fantasia.

Cultivar	Model	Linear regression	r^2
Sunlite	DP PCU	= 45.86821 + (-0.00246 X DH) = 810.0923 + (-0.04411 X DH)	0.483 0.305
Flavortop	DP PCU	= 58.65595 + (-0.00205 X DH) = 1092.892 + (-0.04623 X DH)	0.521 0.709
Fantasia	DP PCU	= 59.84810 + (-0.00223 X DH) = 1086.383 + (-0.04411 X DH)	0.551 0.533

The slope of the correlation between PCU or DP and DH was similar but the base chilling level for the cultivars Fantasia and Flavortop was higher than that for cultivar Sunlite. The linear regressions of the correlation data are presented in Table 4.5. Correlation coefficients (r^2) for PCU were 0.305 for the cultivar Sunlite, 0.709 for Flavortop and 0.533 for Fantasia. Correlation coefficients (r^2) for DP were 0.483 for the cultivar Sunlite, 0.521 for Flavortop and 0.551 for Fantasia. The DP model showed slightly better correlations with DH, indicating lower variability when using this model. The linear regression lines for 'Flavortop' and 'Fantasia' were almost identical, confirming that these two cultivars have almost identical endodormancy requirements (Table 4.5).

4.4 DISCUSSION AND CONCLUSION

It is apparent that, like pecans (Sparks, 1993), nectarines may also be under some sort of interactive control of heating and chilling temperatures during the endodormancy period. The most conceivable consequence of high temperatures during endodormancy is in regulating the intensity of endodormancy as reported in apples (Hauagge & Cummins, 1991), *Carya* spp. (Amling & Amling, 1980; Sparks, 1993) and *Cornus sericea* (Kobayashi *et al.*, 1982). The model of Saure (1985) suggests a shifting efficiency of chilling and negating temperatures depending on the endodormancy intensity. This model suggests that in colder locations, where intensity is high, the effective chilling temperature range would be smaller and the resulant chill unit accumulation lower than where endodormancy intensity is low. The converse would apply for inhibition by high temperatures, with a greater negating effect of high temperatures where endodormancy intensity is high. Such a model could account for the differences in apparent chilling requirement between warmer and cooler locations as determined using the DP, UCU and PCU models.

At high temperatures there will be other chemical reactions occurring in the buds which may affect endodormancy. Powel & Haung (1982) reported that a few of hours at 39°C could replace the chilling requirement in apples. In this study the temperatures never exceeded 35°C in winter, and the warmest, Robertson location, accumulated only 39, 33 and 101 hours above 25°C during the winter months of May to August for 1988, 1989 and 1990 respectively.

This high temperature influence could explain the apparent differences in chilling requirement for the same cultivar when determined in climatically divergent locations, and the observation that chilling appears to be more efficient in warmer locations (Weinberger, 1967). The apparent influence of high temperatures on endodormancy intensity could also be part of the reason why an experimental chilling regime of constant 6°, interrupted by 11 to 12 days of 20°C, had an enhancing effect over uninterrupted 6°C (Erez & Lavee, 1971).

The enhancing effect of moderate temperatures on chilling by may also be linked to endodormancy intensity. Temperatures of 6°/15°C were found to be more efficient than constant 4°C for peaches (Erez *et al.*, 1979b) and 7°/15°C was more efficient than constant 7°C in blueberries (Gilreath & Bucannan, 1981b).

The fairly parallel regression slopes regardless of cultivar or chilling requirement suggests that these data can be extrapolated for other nectarine and peach cultivars as well. The slightly superior correlation between DP and DH than PCU during endodormancy, confirms that the DP model fairly accurately describes the endodormancy process. There are few other studies that have investigated dormancy over such a wide climatic spectrum and which have included an investigation into the effect of heat accumulation during endodormancy. The concept of heat accumulation affecting the chilling requirement is new and controversial. It does, however, warrant further research and an attempt should be made to incorporate the concept of high temperature influence during endodormancy into the DP model.

The choice of a base temperature >10°C rather than >4.5°C for calculating DH or GDH was chosen for practical rather than scientific reasons. The South African deciduous fruit industry has traditionally been supplied with heat units in the form of DH >10°C. The aim therefore was to use the unit currently used by the industry for easier application in the industry. In retrospect, both base temperatures should have been compared in this study. A scientific publication based on this chapter will be prepared and the comparison between heat unit models will be made using hourly temperatures. The thermal base temperature of 4.5°C was based on a study in Utah where no growth occurred in peach buds when held at 4.5°C after the dormancy requirement had been satisfied (Richardson, Seeley, Walker, Anderson & Ashcroft, 1975). Buchanan, Bartholic & Biggs (1977) found, however, that using a base temperature of 4.5°C resulted in too rapid an accumulation of heat units under warmer, Florida conditions. They found that a base temperature of 10°C gave better results. The literature cites various base temperatures, indicating a need for a comprehensive study of thermal base temperatures throughout the development period of deciduous fruit trees.

CHAPTER FIVE: ESTIMATING DAILY POSITIVE UTAH CHILL UNITS USING DAILY MINIMUM AND MAXIMUM TEMPERATURES

5.1 INTRODUCTION

Following the initial research by Linsley-Noakes, Allan & Matthee (1994), the Western Cape fruit industry stopped using the UCU model and adopted the PCU model for assessing winter chilling. The current availability of 'daily positive Utah chill units' (PCU) in the fruit growing regions of the Western Cape Province is limited to about 65 sites, distributed throughout the industry and the different growing regions. These data give a fair indication of the year to year fluctuation in the winter chilling but cannot be used to assess the potentially large differences in microclimate over short distances, caused by differences in aspect, altitude, cloud cover, wind and rainfall (Aron, 1983).

Good correlations between mean temperature and the occurrence of delayed foliation symptoms have been reported. In south-east U.S.A., Weinberger (1956) studied the mean monthly temperatures and delayed foliation over 18 seasons and 30 locations and found a correlation coefficient of 0.93. Based on these and further analyses, a relationship between mean monthly temperature in winter and chilling hours was determined and tabulated. Sharpe (1966) produced a similar table for the milder blueberry production areas of Florida. In other Florida areas, these correlations with monthly temperatures underestimated chilling considerably, indicating that mean temperatures can be used only in areas where the correlation is known.

Mean monthly temperature has been used as the basis for models to predict winter chilling in milder winter location of Rio Granda do Sol of Brazil (del Real-Laborde, 1986). The monthly chilling hours for May to August (H_C) = 485.1 - 28.52 x mean monthly temperature. Maximum and minimum temperatures have been used to estimate chill units in Tunisia (Crossa Raynaud, 1955) and California (Aron, 1974).

The major problem with this type of determination is that it is applicable only in the region in which it was developed and attempts to apply these models in other areas have shown marked decreases in accuracy (Munzo, 1969; Lombard & Richardson, 1979; Chandler & Brown, 1953; Shaltout & Unrath, 1983; Weinberger, 1967).

The concept of using daily minimum and maximum temperatures to estimate chilling is not new. As far back as 1955 minimum and maximum temperatures had been used to estimate chilling hours below 7.2°C (Ruck, 1975).

As the concept of weighted chill units developed, so too did the development of equations to estimate daily accumulation of chill units (Richardson *et al.*, 1974; Aron, 1975; Saunders, 1975; Lombard & Richardson, 1979.; Parton & Logan, 1981; Wann, Yen & Gold, 1985; del Real-Laborde, 1986; Linvill, 1990).

These authors are in agreement that a mathematical formulation using only minimum and maximum temperatures could never be developed to duplicate the infinite number of variations possible on a thermal trace or those logged electronically. Nevertheless, the information generated by these estimations still represented a useful tool for growers and researchers alike (Saunders, 1975).

This chapter reports on the estimation of PCU from daily minimum and maximum temperatures and the formulation of tables from which PCU can be estimated using the intersection of minimum and maximum temperature coordinates in an estimation table.

5.2 MATERIALS AND METHODS

Climatic data were collected from seven climatically divergent fruit growing regions throughout the Western Cape Province using electronic recorders housed within Stevenson screens (M.C. Systems, Steenberg, Cape, South Africa). Air shade temperatures were logged hourly for three seasons, 1992, 1993 and 1994. The hourly data for the winter months of May, June, July and August were then converted to PCU using a personal computer (Data supplied by M. Louw, Infuitec Institute for Fruit Research, P. Bag X5013, Stellenbosch, 7600, South Africa).

Two tables of estimated chill units, using different methods of hourly temperature estimation, were developed. The first table ('Straight line') was developed using the assumption that the daily temperature fluctuation follows straight lines between the minimum and maximum temperatures in order to estimate hourly temperatures from which PCU were calculated (Table 5.1). This table has been used with reasonable success in South Africa for the past eight years (Linsley-Noakes, 1986).

The second table ('Sine log'; Table 5.2) was developed to estimate hourly temperatures based on the observation that the daytime solar cycle followes a sine curve from sunrise to sunset as described by Eq [1]:

$$T(t) = (T_{max} - T_{min}) \times \sin[(\pi \times t)/DL + 4)] + T_{min} \qquad [1]$$

Where T(t) is the temperature at time t after sunrise; T_{max} is maximum temperature; T_{min} is minimum temperature and DL is daylength (in hours).

A second logarithmic equation is used to describe the night time cooling (Eq [2]):

$$T(t) = Ts - [(Ts - T_{min})/ \ln (24 - DL] \times \ln(t) \qquad [2]$$

Where T(t) is the temperature at time $t > 1$hr after sunset; Ts is the sunset temperature obtained from Eq. [1] and other terms as described in Eq. [1] (Linvill, 1990). The calculations were based on the 34° 30'S latitude's day length data for the winter period in the Western Cape. The latitudes of the locations used ranged between 33°S (Bokkeveld) and 34°S (Ceres).

Daily minimum and maximum temperatures for the six locations over the three seasons were used to estimate PCU from the tables using the @INDEX function in a Quatro Pro5 program. The daily minimum and maximum temperatures were rounded off to exclude decimals for easier estimation from the tables. The daily, monthly and total PCU accumulations, based on the actual hourly recorded temperatures, were then compared with DPU obtained from the calculated hourly values.

5.3 RESULTS

PCU accumulations, as estimated using either a straight line or sine-logarithmic estimation between daily maximum and minimum temperatures are presented in Tables 5.1 and 5.2 respectively. These tables on their own give additional insight into the effective chilling temperatures, as it can be clearly seen which temperature variables result in maximum chilling and which result in no chilling. From these tables it is clearly evident that the main cause of low PCU in many of the fruit growing regions of the Western Cape Province of South Africa is not a lack of low night temperatures, but rather occurrence of high day temperatures which cancel the positive chill units accumulated during the cooler period of the daily cycle.

Table 5.1 Daily positive Utah chill unit (PCU) estimation table I. Chill units for all possible minimum and maximum temperatures in the Western Cape Province of South Africa were determined on the assumption that diurnal temperatures follow straight lines between minimum and maximum temperatures.

MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE (C)																		
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
-5	12	12	12	13	12	11.5	11.5	10.5	9	8.5	8.5	7.5	4.5	4.5	3.5	2.5	2.5	3	3.5
-4	12	12.5	13.5	12.5	13.5	12.5	11.5	11	10.5	9.5	8	8	6	4.5	3.5	2.5	2.5	3	3.5
-3	13	13	14	14	13	13.5	13	11.5	10	11	9	7	6	4.5	3.5	3	1.5	2	2.5
-2	15	15	15	15.5	14.5	14	13.5	12.5	11	10.5	9.5	7.5	6	5	3.5	3	2	2.5	3
-1	16.5	16.5	16.5	16	16	15	14.5	13	12.5	11	10	8	6.5	6	4.5	2.5	1.5	2	2.5
0	18	18	18	18	17.5	16.5	15.5	14.5	13.5	11.5	11	9	7	5.5	4	2.5	1.5	2	2.5
1	21	21	20.5	19	19	17.5	17	15	14	12.5	11.5	9	8	5	3.5	2.5	2	2.5	3
2	22	22	22	21	20.5	19	17.5	15.5	14	12.5	11	8.5	7.5	5.5	3.5	3	2	2.5	3
3	23	23	23	21.5	20	19.5	17	15.5	14.5	12.5	9.5	8.5	6.5	5	3.5	1	1.5	2	2.5
4	23	23	22.5	21	20	18.5	16	15.5	13.5	11.5	8.5	7	6	3.5	3	0	0	0.5	1
5	23	22	22	20	19.5	17.5	15.5	14	12	10.5	7	7	4.5	2	1	0	0	0	0.5
6	22	21.5	21.5	19.5	18.5	16.5	14	13.5	12	10	7	5.5	2.5	1.5	0	0	0	0	0
7	21.5	21	21	18.5	17.5	15.5	13.5	11	10.5	8	5.5	4	1	0	0	0	0	0	0
8	20.5	20	19.5	16.5	16	14	11.5	9.5	8.5	6.5	4.5	1.5	0	0	0	0	0	0	0
9	20	18	14.5	13	13	11	8.5	7.5	6	4.5	2.5	0	0	0	0	0	0	0	0
10	19.5	14.5	12	12	12	10	7.5	6	4.5	2.5	1	0	0	0	0	0	0	0	0
11	16.5	13	12	12	12	9	6	4.5	3.5	1	0	0	0	0	0	0	0	0	0
12	16	13	12	12	12	6	3	2	1	0	0	0	0	0	0	0	0	0	0

Table 5.2 Daily positive Utah chill unit (PCU) estimation table II. Chill units for all possible minimum and maximum temperatures in the Western Cape Province of South Africa were determined on the assumption that diurnal temperatures follow a sine curve for the heating cycle, followed by a logarithmic cooling cycle.

		MAXIMUM TEMPERATURE (C)																		
		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
M	-5	8	6.5	6.5	5	5	4	2.5	2	2.5	0	0	0	0	0	0	0	0	0	0
I	-4	12	11	11	10	10	11	9.5	8	8	6	4.5	4.5	1.5	0.5	0	0	0	0	0
N	-3	13	12	12	11	11	11	10	9	8.5	7	5	3.5	2.5	1.5	0	0	0	0	0
I	-2	14	12	13	12	12	12	11	8.5	8.5	7.5	5	4.5	2	2	0	0	0	0	0
M	-1	15	15	14	14	14	14	12	10	8.5	8.5	6	5.5	3	1.5	1	0	0	0	0
U	0	15	15	15	14	14	14	12	12	9.5	9.5	7	6.5	3.5	1.5	1.5	0	0	0	0
M	1	17	17	17	16	16	16	14	13	12	11	8	7	4	2.5	1.5	0.5	0.5	0	0
	2	21	20	20	19	19	19	17	15	13	12	10	8.5	6	4	3	2	1	1	0
T	3	22	22	22	21	21	20	18	16	15	13	12	9.5	7.5	5	4	3	1.5	1.5	0.5
E	4	22	22	21	21	21	19	18	16	15	13	11	9.5	6.5	4	2.5	2.5	1	0	0
M	5	22	22	21	20	20	19	17	15	14	13	10	8	5	3.5	2.5	2	0.5	0	0
P	6	23	22	21	19	19	19	16	15	13	12	10	8	4.5	2.5	2	0	0	0	0
E	7	21	21	20	19	19	18	15	14	12	11	8.5	6.5	3	1.5	0	0	0	0	0
R	8	20	20	20	19	19	16	13	12	11	10	6.5	6	1.5	0.5	0	0	0	0	0
A	9	20	18	17	15	15	14	11	9	8	6.5	4	2.5	0	0	0	0	0	0	0
T	10	20	17	12	12	12	12	9	7.5	6.5	5	2	0.5	0	0	0	0	0	0	0
U	11	19	15	12	12	12	12	8.5	6.5	5.5	4.5	1.5	0.5	0	0	0	0	0	0	0
R	12	19	15	12	12	12	12	7.5	4	3.5	2	0	0	0	0	0	0	0	0	0
E																				

The monthly and total winter PCU accumulations for the six locations, as estimated from hourly data, 'straight line' and 'sine log' tables are presented in Table 5.3. The 'straight line' table tended to underestimate the chill units in all locations. The 'sine log' table tended to slightly underestimate chilling in the cooler areas, while slightly overestimating chilling in the warmer locations when compared to hourly computed values.

Graphs of the extreme warmest (Robertson in 1993) and extreme coldest (Bokkeveld in 1992) location and season's data are presented in Figs. 5.1 and 5.2. There was very little difference between estimated and hourly computed PCU in the cool Bokkeveld location. In the warmer location, however, the sine log estimations gave a similar trend and accumulation level, while the straight line, although it had a similar trend, tended to underestimate PCU.

The statistical analysis of the chilling data indicates very similar correlation coefficients for both tables in comparison to actual hourly recorded data (Table 5.4). Coefficients of $r^2 = 0.95$ for the monthly and total winter chilling estimations for both the 'straight line' and 'sine log' models, were higher than expected, considering the large variation in winter chilling as indicated in Table 5.4. The correlation coefficients were slightly better in the cooler locations ($r^2 = 0.961$) compared to the warmer locations ($r^2 = 0.882$), but virtually the same for both the 'straight line' or 'sine log' tables.

Comparison of the differences between the hourly and daily table estimations indicated that although the differences between the 'straight line' and actual hourly recorded values showed a lower standard deviation and variance than the 'sine log' values, it underestimated the chill units by about 13% (Table 5.2). Adjustment of the straight line estimations by 13%, so as to make the estimations more directly comparable, increased the standard deviations level to those of the sine log estimations. Based on the better adaptability of the 'sine-log' model in other countries (Linvill, 1990), the 'Sine log' table for estimation of PCU from minimum and maximum temperatures, has the potential to estimate chilling reasonably accurately where hourly temperature data are not available.

5.4 DISCUSSION AND CONCLUSIONS

The use of tables from which winter chilling can be estimated using daily minimum and maximum temperatures, allows for the rapid estimation of PCU in winter, where hourly data are unavailable. The sine-logarithmic table gave a better estimation of chilling than the straight line table in the warmer areas, but both gave reasonable approximations in the cooler areas.

Table 5.3. Monthly and total winter PCU accumulation of seven fruit producing regions of the Western Cape Province of South Africa over three years. PCU were calculated from hourly temperature recordings and estimations of hourly temperatures from daily minimum and maximum temperatures, based on straight line and sine logarithmic models.

			1992			1993			1994	
Location	**Month/ Method**	**Hourly record**	**Straight line**	**Sine log**	**Hourly record**	**Straight line**	**Sine log**	**Hourly record**	**Straight line**	**Sine log**
Bokkeveld area	May	392	392	370	398	338	367	250	219	211
	June	458	395	405	463	406	397	475	415	425
	July	494	480	453	422	388	402	490	477	443
	August	445	427	404	409	364	362	446	392	338
	Total	**1782**	**1693**	**1632**	**1691**	**1495**	**1528**	**1660**	**1503**	**1467**
Langkloof area	May	182	156	181	153	129	166	174	146	165
	June	267	249	275	238	193	233	294	287	310
	July	236	223	239	188	167	190	323	291	321
	August	292	266	275	239	222	241	351	322	343
	Total	**976**	**893**	**969**	**818**	**710**	**830**	**1138**	**1045**	**1137**
Villiersdorp area	May	107	118	149	84	72	111	135	118	147
	June	261	265	297	201	145	195	293	279	317
	July	250	227	280	202	176	211	288	272	307
	August	291	250	290	214	191	240	315	266	316
	Total	**909**	**859**	**1016**	**700**	**583**	**755**	**1031**	**943**	**1087**
Elgin area	May	179	199	208	113	88	128	154	136	146
	June	253	249	266	247	185	218	176	257	286
	July	269	205	294	192	153	180	279	185	254
	August	311	275	310	233	199	230	274	242	278
	Total	**1011**	**927**	**1078**	**785**	**624**	**755**	**982**	**819**	**963**
Mean	Cold	1222	1148	1206	1070	923	1038	1276	1165	1230
Franschhoek area	May	162	140	184	112	62	95	112	105	126
	June	277	287	326	157	136	177	274	259	291
	July	250	227	280	202	136	165	255	207	257
	August	291	243	280	178	151	188	189	153	197
	Total	**979**	**896**	**1070**	**648**	**485**	**624**	**830**	**723**	**869**
Paarl area	May	165	127	142	97	84	115	153	146	154
	June	316	208	237	233	208	237	279	247	281
	July	308	263	292	147	125	162	274	262	277
	August	278	193	223	137	118	145	171	162	191
	Total	**1066**	**790**	**893**	**613**	**534**	**659**	**877**	**816**	**903**
Robertson area	May	58	76	82	34	31	45	99	86	87
	June	232	193	212	186	145	163	188	170	194
	July	212	188	212	133	100	127	211	187	197
	August	204	194	210	115	95	118	164	145	187
	Total	**705**	**651**	**716**	**467**	**370**	**452**	**661**	**587**	**664**
Mean	Warm	1019	809	939	831	503	623	837	736	850

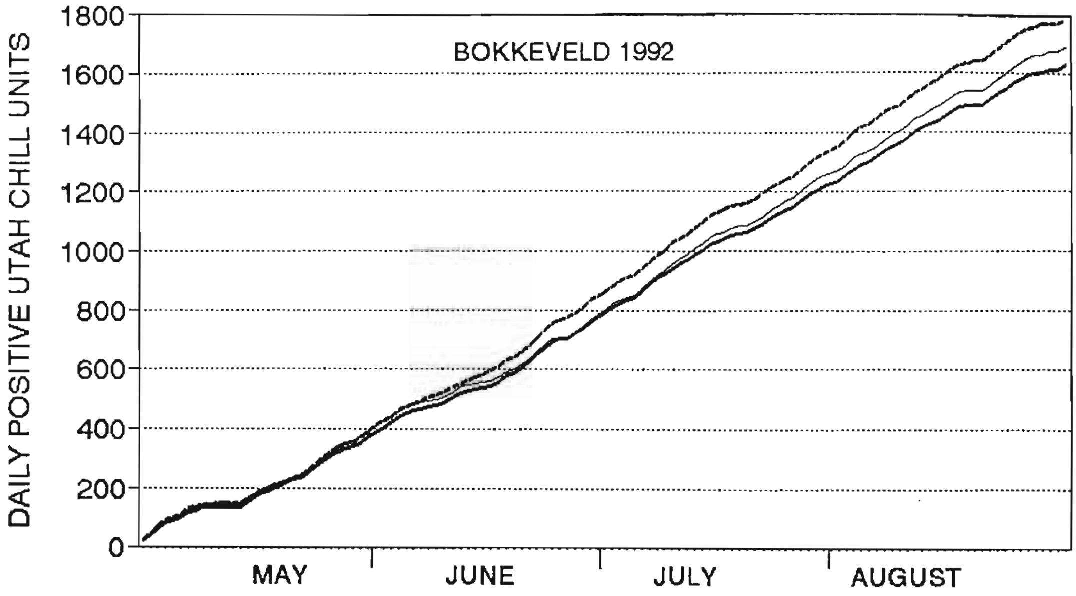


Fig. 5.3 Daily positive Utah chill unit accumulation in the cooler Bokkeveld in 1993. Chill units were calculated from hourly recorded temperatures (▬▬) and these were compared with estimates of hourly temperatures by straight line (——) and sine-log (▬ ▬ ▬) models using daily minimum and maximum temperatures.

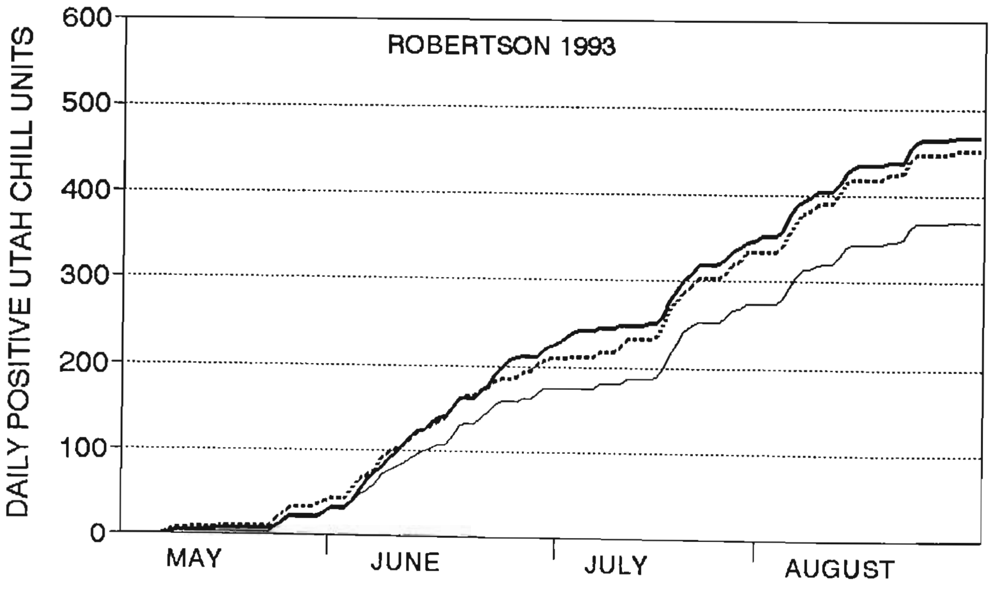


Fig. 5.4 Daily positive Utah chill unit accumulation in the warmer Robertson in 1993. Chill units were calculated from hourly recorded temperatures (▬▬) and these were compared with estimates of hourly temperatures by straight line (——) and sine-log (▬ ▬ ▬) models using daily minimum and maximum temperatures.

Table 5.4 Statistical evaluation of two methods of estimating PCU from daily minimum and maximum temperatures: Monthly totals using the daily accumulation determined from the 'straight line' and 'sine log' tables were correlated with the conventional hourly computed values.

		Straight line			Sine log		
Attribute	DF[v]	Coefficient of Variation	Standard deviation	r^2	Coeficient of variation	Standard deviation	r^2
Total chilling[z]	19	6.14	37.64	0.953	7.29	53.14	0.955
Monthly chilling[y]	82	10.23	104.8	0.953	12.18	148.4	0.948
Monthly-cooler areas[x]	49	9.37	87.97	0.962	10.96	120.22	0.961
Monthly-warmer areas[w]	31	11.38	129.47	0.889	13.8	190.52	0.882

[z] Total winter chill unit accumulation for each location and season.

[y] Monthly chill unit accumulation totals (monthly totals for all locations and seasons analysed).

[x] Monthly chill unit accumulation for the cool Bokkeveld, Villiersdorp, Langkloof and Elgin locations.

[w] Monthly chill unit accumulation for the warmer Franschhoek, Paarl and Robertson locations.

[v] Degrees of freedom in analysis

By using a 'sine log' model to estimate hourly temperatures from minimum and maximum temperatures, for conversion to PCU, it was possible to calculate PCU values for all possible minimum and maximum temperature combinations inherent during Western Cape winters. These data were used to construct a chill unit estimation table, which allows for the easy estimation of daily PCU values. An average accuracy of 95% in the diverse locations was achieved despite the wide range of climates measured. The accuracy of the estimations tended to be better in the cooler locations where higher chill unit accumulation took place. The sine-logarithmic table can be used in areas of similar latitudes and tables can be constructed for higher and lower latitudes, where day lengths differ in winter. The tables also give an excellent insight into how chilling is influenced by different temperature ranges. The 'Sine log' table has been compared with the 'straight line' table in Pietermaritzburg, Natal, South Africa (approximately 30°S latitude), but without the day length adjustment it was not as accurate.

OVERALL CONCLUSIONS

At the commencement of this research, the South African deciduous fruit industry was making extensive use of the Utah dormancy completion prediction model of Richardson *et al.* (1974). This model effectively estimated the winter chilling of the cooler locations , but caused a great deal of confusion and resulted in many bad management decisions in warmer locations.

Critical to the correct evaluation of the Utah and other models was the accurate determination of the endodormancy period. Endodormancy, as shown by forcing response, had commenced in all cases before the first chilling accumulated. The standard method used to determine endodormancy completion, *viz.* forcing with high temperatures, was used. The standard practice of gibberellic acid application before forcing, was an aid to determining maximum dormancy intensity, but gave no clear indication of endodormancy completion. The common forcing assay of measuring the time to 50% vegetative bud break (Erez *et al.*, 1979a and b), could not be determined in this study, because extensive flowering often occurred before many lateral vegetative buds had sprouted. The intensive flowering resulted in desiccation of the shoots due to moisture and/or reserve depletion, even though the shoots were treated as suggested in the appropriate publications. A possible reason for the differences in response to forcing is the type of material used in this investigation. Most dormancy research has made use of two year old trees on their own roots or fruit types with mixed buds. The shoots on more juvenile trees tend to have a lower flower to vegetative bud ratio than mature trees. Under local conditions up to four flower buds per node were observed.

The stage at which forced shoots produced 10% bud break after 14 days of forcing at 25°C generally coincided with optimal terminal bud break and an increased trend in lateral vegetative development. Once 10% flower bud break had occurred, the flower bud break levels tended to increase exponentially in subsequent samples. Flower bud break levels after forcing of excised shoots for 14 days at 25°C, not only gave an indication of when the endodormancy requirement of the buds was satisfied, but also an indication that sufficient chilling had occurred for a rapid and synchronous bud break. This 14 day forcing period results in a DH accumulation of about 5000 which was in excess of the bud's requirement in the field (Tables 4.2 and 4.3). Longer forcing periods tend to obscure the response pattern that would occur naturally. The superior response curves of flower buds to forcing temperatures, as a means for determining endodormancy completion, has been shown in other warm temperate fruit growing regions (Blaine & Allan, 1979; Partridge & Allan, 1980).

In locations with DF symptoms, normal terminal bud development was shown by the forcing studies, but flower bud break levels were seriously affected. The stage at which forced shoots produced 10% bud break after 14 days of forcing at 25°C coincided with optimal terminal bud break and an increased trend in lateral vegetative development. Once 10% flower bud break had occurred, the flower bud break levels tended to increase exponentially in subsequent samples.

Under local conditions the use of the 10% flower bud break index as a measure of the buds endodormancy requirement being satisfied, gave a satisfactory indication of when sufficient winter chilling had occurred to give an acceptable, synchronous vegetative and flower bud break. Recent literature indicates that if forced shoots were enclosed in perforated plastic sleeves to reduce desiccation, superior results could be achieved. This technique would certainly have improved the amount of data available, particularly during the final period of endodormancy termination.

Evaluation of the temperature over the endodormancy period using the UCU and DP models, confirmed suspicions that the UCU is less suitable for local conditions, particularly in the warmer locations. The DP model gave a more reproducible estimation of the cultivar's winter chilling requirement over a large range of climates and seasons and generally gave trends which coincided with endodormany completion dates. The DP model failed, however, to distinguished between locations showing DF symptoms and normal bud break patterns, although DF only occurred in two locations and during one season only. This investigation revealed that both models were equally accurate in the cooler fruit growing locations but that it was in the warmer locations and during the warmer seasons that both models gave less accurate results.

Based on the differences between the UCU and DP models, a modification was made to the UCU model whereby the negation by high temperatures was limited to the diurnal cycle. This modification resulted in a substantial improvement in the accuracy of the model. The benefits of this modification outweigh the inaccuracy caused by excessive high temperature negation in warm locations. Although DP are available to the deciduous fruit industry, it has opted to use the PCU model, as growers understand the concept well, the units are easy to calculate an they can relate to the values of the different locations.

The post endodormancy heat requirement for bud break is well documented and this investigation confirmed the response of buds to heat accumulation following different intensities of winter chilling. The effect of heat accumulation during endodormancy suggests that, like pecans (Sparks, 1993), other deciduous trees may also be under the interactive effect of chilling and heating in winter. There was a fair correlation between chilling requirement and heat accumulation during endodormancy, indicating lower chilling requirements in areas with substantial DH acumulation during endodormancy. This concept may also explain the large differences in apparent chilling requirement of the same cultivar grown at different locations, which is well documented in the literature. The nature of this response may be through affecting endodormancy intensity, with some evidence in the literature suggesting that the lower temperatures in cooler locations induces a more intense dormancy. This more intense dormancy may result in a higher chilling requirement or result in a smaller range and lower efficacy of chilling temperatures. This concept is controversial and requires further research before it can be generally accepted.

The availability of chill units to the deciduous fruit industry is dependent on strategically placed automatic weather stations run mainly by the South African Weather Bureau and the Stellenbosch Institute for Fruit Research. This network of weather stations, however, cannot supply accurate chilling data for all locations. The development of accurate PCU estimation tables, which estimate chilling from daily minimum and maximum temperatures, has therefore meant that growers can determine the winter chilling in any orchard or location not served by the network of weather stations. The use of the sine curve for estimating the heating cycle and a logarithmic cooling cycle gave the best results in warmer locations. Tables of chilling can be produced for any latitude where deciduous fruit are grown.

The sine log, PCU estimation table will enable the determination of PCU where only daily minimum and maximum temperatures are recorded. It will also enable growers with more sophisticated weather stations to estimate daily chilling accumulation, since the network of weather stations are downloaded weekly, resulting in at least a week's lag before the station's chilling data are available.

This main goals of this investigation have been achieved and the Infruitec Institute for Fruit Research, P. Bag X5013, Stellenbosch, South Africa were in the process of compiling PCU contour maps for the industry at the time of going to press. The 1994 monthly and total PCU accumulation is presented in Appendix I.

LIST OF PUBLICATIONS ARISING FROM THIS RESEARCH

ALLAN, P., LINSLEY-NOAKES G.C., MATTHEE, G. & RUFUS, G., 1993. Winter chilling models in a mild subtropical area and the effects of constant 6°C chilling on peach bud break. Paper presented at the ISHS Symposium on Temperate Zone Fruits in the Tropics and Subtropics, Cairo, 22-26 May 1993, Acta Hort., In Press.

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LINSLEY-NOAKES, G.C., LOUW, M. & ALLAN, P., 1995. Estimating 'daily positive Utah chill units' using minimum and maximum temperatures. Submitted to *J. S. Afr. Soc. Hort. Sci.*

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APPENDIX 1: Standard deviations for the composite graphs in Chapter 1

Appendix 1.1: Fig. 1.1 (DF = 17)

SAMPLING DATE	GIBBERELLIC ACID 3 CONCENTRATION								
	0mg/kg			100mg/kg			200mg/kg		
	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD
5/4	0.0	0.0	0.0	0.0	2.3	0.0	0.0	2.3	0.0
19/4	2.7	1.7	0.0	4.4	2.3	0.0	4.0	2.7	0.0
9/5	1.8	2.2	0.0	3.9	4.0	0.2	3.8	4.1	0.7
19/5	2.3	2.8	0.7	4.2	4.4	0.5	4.0	4.2	1.4
1/6	2.3	3.1	0.7	2.4	3.9	0.6	3.9	4.3	0.6
13/6	3.5	3.7	1.4	4.2	4.2	0.7	3.9	4.4	0.5
27/6	3.4	4.2	1.7	4.5	4.5	1.3	4.5	4.6	1.2
12/7	5.9	4.2	3.4	6.9	5.2	2.8	7.1	4.3	6.6
25/7	12.0	4.2	2.0	13.3	4.7	2.0	12.2	4.3	6.9
6/8	39.5	4.5	7.8	32.8	4.7	7.3	37.3	4.2	15.6

Appendix 1.2: Fig. 1.2 (DF = 17)

FORCING PERIOD	SAMPLING DATE	FANTASIA			FLAVORTOP			SUNLITE		
		TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD
14days	5/4	0.2	0.2	0.2	0.2	0.2	0.2	2.6	0.2	0.2
	19/4	4.3	1.2	1.2	4.0	2.1	2.1	2.9	2.3	2.3
	9/5	3.9	1.1	1.1	4.0	2.2	2.2	4.0	2.3	2.2
	19/5	4.2	2.1	2.1	4.0	2.4	2.4	4.0	3.0	3.0
	1/6	3.5	2.1	2.1	3.8	2.6	2.6	3.9	3.0	3.1
	13/6	3.9	2.3	2.3	3.7	2.9	2.9	4.0	3.2	3.2
	27/6	3.7	3.2	3.2	3.8	3.2	3.4	3.6	3.3	3.2
	12/7	3.0	3.9	6.1	3.3	4.6	3.5	3.4	4.3	8.0
	25/7	7.4	8.1	9.7	7.5	8.2	10.8	7.6	8.3	14.4
	6/8	17.8	18.7	22.5	17.8	18.6	22.0	17.9	18.9	42.9
30days	5/4	0.8	0.2	0.2	0.8	0.2	0.2	1.9	0.2	0.2
	19/4	3.9	2.4	2.4	4.1	2.8	2.8	3.5	3.0	3.0
	9/5	3.8	2.9	2.7	3.9	3.0	2.9	4.0	3.2	3.3
	19/5	4.0	2.8	2.9	3.9	3.4	3.3	4.1	3.4	3.2
	1/6	3.9	3.4	2.4	4.0	3.8	2.9	4.0	2.8	2.8
	13/6	4.0	4.5	2.6	4.0	5.3	2.7	4.0	3.4	3.1
	27/6	3.9	3.6	3.5	3.9	3.4	3.4	3.9	3.4	3.3
	12/7	3.4	4.1	6.2	3.6	4.8	3.6	3.9	4.5	8.1
	25/7	7.0	7.6	9.3	7.0	7.6	10.4	7.1	7.8	14.3
	6/8	21.6	22.4	25.6	21.7	22.4	25.2	21.8	22.7	44.2

Appendix 1.3: Fig. 1.4 (DF = 5)

SAMPLING DATE	FANTASIA			FLAVORTOP			SUNLITE		
	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD	TERMINAL VEGETATIVE	LATERAL VEGETATIVE	FLOWER BUD
19/4	36.4	0.0	0.0	33.4	0.0	0.0	22.2	0.0	0.0
9/5	22.9	0.0	0.0	38.2	0.0	0.0	30.2	0.0	0.0
19/5	35.9	0.7	0.0	24.3	0.7	0.0	35.3	2.2	0.0
1/6	34.0	0.7	0.0	31.8	1.5	0.0	29.3	2.2	0.4
13/6	39.5	3.7	0.0	28.1	3.1	0.0	31.6	3.7	0.0
27/6	21.9	1.5	0.0	14.6	3.5	0.0	8.2	4.7	0.4
12/7	0.0	4.3	0.0	7.6	10.1	0.0	7.5	8.8	7.3
25/7	0.0	2.2	2.7	3.7	4.8	6.5	33.5	3.4	8.9
6/8	0.0	4.4	12.0	0.0	6.5	15.3	0.0	3.7	30.1

Appendix 1.4: Fig. 1.6 (DF = 5)

	FANTASIA				FLAVORTOP				SUNLITE			
SAMPLIN DATE	TERMINAL VEGETATIVE	LATERAL VEGETATIV	FLOWE BUD	FLOWER BU VOLUME	TERMINAL VEGETATIV	LATERAL VEGETATIV	FLOWER BUD	FLOWER B VOLUME	TERMINAL VEGETATIV	LATERAL VEGETAT	FLOWER BUD	FLOWER B VOLUME
13/4	36.1	0.0	0.0	0.2	33.5	0.0	0.0	0.2	19.5	0.0	0.0	0.1
26/4	24.6	0.0	0.4	0.2	37.5	0.0	1.2	0.1	30.2	0.0	2.0	0.2
10/5	35.4	0.5	1.9	0.2	23.1	0.3	1.5	0.2	37.1	1.2	2.0	0.2
24/5	34.0	0.3	0.4	0.1	31.8	0.8	0.0	0.2	31.9	1.1	1.1	0.1
6/6	38.5	2.2	0.0	0.1	28.1	2.2	0.7	0.2	31.2	1.8	1.3	0.2
21/6	21.9	0.7	0.5	0.2	14.1	1.6	0.0	0.1	6.9	2.4	0.4	0.2
5/7	0.0	2.2	0.4	0.2	7.4	5.1	0.4	0.2	6.3	4.5	7.3	0.2
19/7	3.7	3.7	2.7	0.1	0.0	6.1	6.4	0.2	0.0	2.4	9.0	0.2
2/8	3.7	11.3	11.0	0.3	7.5	2.6	16.0	0.5	0.0	1.4	30.5	0.7

Appendix 1.5: Fig. 1.8 (DF = 5)

SAMPLIN	FANTASIA				FLAVORTOP				SUNLITE			
SAMPLIN DATE	TERMINAL VEGETATIVE	LATERAL VEGETATIV	FLOWE BUD	FLOWER BU VOLUME	TERMINAL VEGETATIV	LATERAL VEGETATIV	FLOWER BUD	FLOWER B VOLUME	TERMINAL VEGETATIV	LATERAL VEGETAT	FLOWER BUD	FLOWER B VOLUME
11/5	15.60	2.72	0.37	0.09	30.85	5.80	0.68	0.11	34.00	2.23	1.19	0.15
23/5	23.85	9.03	0.25	0.07	36.44	0.74	0.56	0.03	36.34	2.43	3.52	0.16
8/6	12.46	6.81	0.88	0.11	29.85	9.54	0.66	0.14	34.56	12.45	3.78	0.16
19/6	20.38	1.90	1.05	0.18	29.03	2.55	1.85	0.10	29.58	6.45	11.04	0.20
5/7	22.19	21.79	1.26	0.13	33.43	22.52	2.98	0.21	33.65	15.74	13.84	0.16
18/7	5.59	20.19	5.02	0.25	40.60	7.23	8.13	0.15	13.25	2.19	13.31	0.17
1/8	33.96	7.25	18.96	0.23	36.51	5.77	10.14	0.17	31.45	0.75	39.22	0.20
16/8	25.78	11.22	9.51	0.57	27.94	11.67	9.93	0.21	41.50	16.30	39.62	0.59

APPENDIX 2: 1994 daily positive Utah chill unit values for the fruit producing regions of the Western Cape Province of South Africa. Chill units were calculated from hourly temperature values.

LOCATION	STATION NAME	LATITUDS	ALTITUD (m)	APRIL	MAY	JUNE	JULY	AUG.	TOTAL
ASHTON	HERBERG	33 51	170	8	125	234	266	204	837
BARRYDALE	LENTELUS	33 55	410	33	134	245	272		684
BONNIEVALE	MERWESPUNT	33 58	110	10	115	209	251	219	804
BONNIEVALE	MORGENSTOND	33 56	140	21	148	269	307	297	1042
CERES	BRONAAR	33 00	945	66	203	439	445	394	1547
CERES	DE KEUR	32 59	945	100	250	475	490	446	1761
CERES	DIE EIKE	33 13	880	87	252	453	482	413	1687
CERES	DISSELFONTEIN	32 53	960	70	211	434	457	363	1535
CERES	ESPERANTO	33 10	1020	134	243	461	447	429	1714
CERES	GROOT VLAKTE	33 19	1155	151	268	441	456	440	1756
CERES	LANGRIVIER	32 51	960	39	98	308	192	236	873
CERES	LINDESHOF	32 57	930	26	230	445	452	386	1539
CERES	M FULENI	33 18	600	43	199	346	340	306	1234
CERES	QUARTA	33 23	480	23	172	332	269	269	1065
CERES	WAKKERSTROOM	33 18	820	76	226	447	435	407	1591
CERES	WELTEVREDE	32 58	960	118	229	424	418	406	1595
CITRUSDAL	CITRUSDAL EXP. FM	32 32	198	0	86	262	298	149	795
DARLING	ALEXANDERFONTEIN	33 22	230			169	221	203	593
DE DOORNS	DE VLEI	33 26	490	26	164	304	324	278	1096
DE DOORNS	JOLETTE	33 30	370	8	100	257	218	214	797
FICKSBURG	FICKSBURG EXP. FM	28 50		93	175	293	259	224	1044
FRANSCHHOEK	CLOS CABRRIERE	33 55	250	0	176	359	352	239	1126
FRANSCHHOEK	PATRYSFONTEIN	33 55	350	0	112	274	252	189	827
GEORGE	HOPS	33 57	230	26	124	184	334	288	956
GRABOUW	APPELTHWAITE	34 19	275	37	180	358	318	338	1231
GRABOUW	DE RUST	34 10	330			249	281	275	805
GRABOUW	ELGIN EXP. FM	34 08	305	14	154	176	292	275	911
GRABOUW	GRABOUW FARMS	34 13	200	9	143	276	242	227	897
GRABOUW	KRABBELFONTEIN	34 14	170	16	159	305	290	307	1077
KAKAMAS	BLOUPUTS	28 50		0	46	174	149		
MISGUND	LANGKLOOF EXP. FM	33 46	722	84	174	294	322	351	1225
MONTAGU	GOEDEMOED	33 42	360	15	115	181	244	203	758
PAARL	BACKSBERG 1	33 50	260	0	115	268	223	143	749
PAARL	BACKSBERG 2	33 50	340	27	130	339	257	207	960
PAARL	BIEN DONNE	33 50	138	0	136	279	274	171	860
PAARL	LANQUEDOC	33 43	191			234	262	134	630
PAARL	MERLE 1	33 43	380			307	261	186	754
PAARL	MERLE 2	33 51	180			201	206	107	514
PAARL	NEDEBURG	33 40	183	0	107	209	253	137	706
PAARL	WESTLAND	33 07	240	1	94	268	210	145	718
PORTERVILLE	DE TUIN	33 08	80	0	113	233	298	157	801
PORTERVILLE	ROOIHOOGDE	33 04	70	0	78	171	250	195	694
PRIESKA	GREENVALLEY NUTS	29 40		10	59	196	174	93	532
ROBERTSON	ROBERTSON EXP. FM	33 49	156	5	99	188	211	164	667
SOMERSET WEST	NOOTGEDACHT	34 02	380	7	104	276	245	194	826
SOMERSET WEST	VERGELEGEN 1	34 06	3260	7	108	243	232		
SOMERSET WEST	VERGELEGEN 2	33 04	80	4	142	210	227	195	778
STELLENBOSCH	GROENHOF 1	33 52	280				252		
STELLENBOSCH	GROENHOF 2	33 52	180	0	193	340	364	304	1201
STELLENBOSCH	HELDERFONTEIN	33 55	140	2	130	234	265	188	819
SWELLENDAM	ROTTERDAM	33 03	70				250	223	473
TULBAGH	OPSTAL	33 11	340	11	139	256	341	238	985
TULBAGH	VINDOUX	33 15	170	0	131	260	1317	184	1892
TULBAGH	WINTERHOEK 2	33 10	520	18	122	270	280	244	934
VILLIERSDORP	BOSKLOOF	34 02	730	95	205	411	414	466	1591
VILLIERSDORP	THEWATERSKLOOF	34 03	570	44	154	327	322	378	1225
VYEBOOM	LONGDOWN	34 03	340	18	135	293	288	319	1053
WELLINGTON	ERNITS	33 40	190					124	124
WOLSELEY	PLATVLEI	33 27	260	2	168	321	333	277	1101