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An Apple Phenology Study: Design of a Predictive Model of Shoot Growth, Flower Development and Fruit Growth

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An Apple Phenology Study: Design of a Predictive Model of Shoot Growth, Flower Development and Fruit Growth

By

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ABSTRACT

AN APPLE PHENOLOGY STUDY: DESIGN OF A PREDICTIVE MODEL OF SHOOT GROWTH, FLOWER DEVELOPMENT AND FRUIT GROWTH

By

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A phenology study in apple was conducted in 7 orchards using 10 varieties. The major goal was development of a predictive model of apple tree growth. Shoot growth and selected environmental parameters were monitored at 1 to 7 day intervals. There were 3 phases of model development: 1) Phenophases (morphological stages of development) were numerically indexed (Phenocode) and a detailed description of apple shoot growth developed. 2) Phenocodes for 'Red Delicious' apple (*Malus domestica* Borkh.), 'Golden Delicious' apple (*Malus domestica* Borkh.), and spur type 'Golden Delicious' were fit to an asymptotic non-linear Logistic equation: $Y=B(1)/(1+EXP(B(2)-B(3)*X+B(4)*X^2-B(5)*X^3))$ using degree-day accumulation as the independent variable. A system initializing the model for use in alternate years and locations, based on Biofix values was designed. In trials the model predicted stage of development within 0 to 2 phenophases up to 4 months in advance. 3) An interactive computer program 'PHENOTE' utilizes the predictive equations and monitored Biofix data to generate predictions of phenophase, as related to degree-day accumulation.

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

Section I

Section II

Table		Page

Table Page

Section III

Appendix A

LIST OF FIGURES

Figure | Page

Figure Page

Introduction

An apple orchard ecosystem is composed of many complex interactions between the environment and organisms with the apple tree as the integrating component. The other major components of interest to the orchardist are insects, diseases, weeds, and the abiotic environment, which interact to influence the growth of the apple tree. Each of these components and its interactions comprise a subsystem of the orchard ecosystem. For instance, vegetative and reproductive shoot development are closely related to disease and insect subsystems. The environment has a major influence on all subsystems and their interactions.

Quality apples are a high value crop. A greater understanding of the tree and how it responds to its environment should contribute to more efficient insect and disease control and application of growth regulators by improved timing for implementation of management strategies. The apple tree is a dynamic organism whose growth can be subdivided into many components, such as canopy development (shoot, leaf, and fruit growth), canopy photosynthesis, allocation of photosynthates, uptake of nutrients, translocation of growth substances, etc. (3,14). Complex energy interactions between the tree and its environment exist (1,4,14). Research has been conducted on many of the physiological components of growth and resulted in subcomponent models for tree fruits (9,10,12,15).

Models with predictive capabilities have the potential to contribute information on which to base orchard management decisions. Predictive models of tree fruit canopy development have been designed using dry weight measurements to characterize growth (5,8,10). This technique is destructive to plant material, and while useful to basic researchers, is unsuited for use in orchard production systems. A non-destructive method of data collection to monitor growth would be preferred.

More recently, phenometric stages of development and associate environmental parameters have been used to model growth components of canopy development (2,6,16). Lombard and Richardson (1979), descibe phenology as the relationship between the appearance of a periodic event (development) of the plant and climate. A good overview of the historical use of phenology in agriculture has been written by Frans-Emil Wielgolaski (1974). Tracking spring bud development and heat unit accumulation has been used in peaches to predict bloom (13), in cherry to identify late blooming cultivars to decrease probability of crop loss due to spring freeze (7), in cherry to predict leaf emergence (2), and in apple to predict phenophase (stage of development) for use in planning orchard management decisions (16).

In 1982 a project was undertaken at Michigan State University, to study the phenology of both the vegetative and reproductive components of canopy development in apple.

The main objective of the study was to develop a predictive model for shoot growth that would have field applications for growers, researchers, and pest consultants. The model would be 'driven' by weather inputs which are easily accessed by users. The goal would be improved timing and more efficient planning of management strategies for the apple orchard.

Monitoring spring bud development and environmental parameters would be key elements of both model design and subsequent field use. Three phases were used in designing the phenology model. The first phase involved the specification of a precise phenocode for indexing morphological development. This resulted in a detailed description of the phenophases selected (Section I). Secondly, mathematical functions relating observations of phenophase to environmental variables were fitted (Section II), and the relationships between years and between sites were determined to test the model (Section II). Finally, a computer adaptation of the prediction equations was developed to be applied for field use.

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Section I

A Morphological Description of Apple Tree Growth: Vegetative and Reproductive Functions Partitioned by Stage of Development

Abstract: A non-destructive method of monitoring shoot growth and development was utilized during Phase I of the apple phenology study. Observable stages of morphological development (Phenophases) were numerically indexed (Phenocode) using seperate coding systems for vegetative and reproductive shoots . Observations were made from 1982 through 1985 in 7 orchards using 10 varieties at 1 to 7 day intervals. A detailed description of apple growth by phenophase is presented. Inter and intra-varietal differences in morphological development are discussed. Accompanying photos detail each stage of development.

Introduction

To be successful an apple grower must be aware of the overall growth and vigor and the stage of development of his/her trees. In a sense, good growers actually conduct ongoing phenological observations, though not in a 'data collection mode'. The trees must be well trained and pruned, and must be maintained in a good healthy condition. In order to keep trees healthy, a program of insect and disease control is essential.

Michigan apple growers use growth stages to help time cultural and pest control activities. The Commercial Fruit Growers Pesticide Handbook (E 154, Cooperative Extension Service, Michigan State University) and handbooks from other states recommend the timing of pesticide application according to developmental stages of the reproductive shoots.

In 1982 a study was undertaken at Michigan State University to develop a predictive model of apple tree growth. Phase I of developing an empirical model was to observe and classify the incremental changes in morphology that occur throughout the growing season. The objectives of Phase I of model design were: 1) standardize and precisely describe the phenophases to be used in developing the predictive model, and 2) develop a numerical indexing code (Phenocode) for tracking morphological development in apple.

Researchers have historically used morphological stages of development to help describe apple growth (2,5,6,7,30,31,32,36). In New York, Chapman proposed standard names for key apple bud stages and discussed intervarietal variations in appearance at several stages (6,7). Although Chapman indicated that these variations were of minor importance, they could be important in the context of a modeling study.

The stages proposed by Chapman are useful as general benchmarks of development, but are too imprecise for modeling. Recognizing this, Seem and Cullinan have expanded the classic staging system to more precisely describe the phenophases of McIntosh apples (32).

An adaptation of Seem's coding system was developed by Edson and Flore for use in designing an empirical model of apple growth (12). The staging divisions were chosen to be reasonably consistent with those commonly used by Michigan apple growers (J.A. Flore, C. Kesner, F.G. Dennis, personal communication), and other researchers (3,28,30,32,33). Coding increments were chosen to reflect the relative amount of physiological time (based on degree-day accumulation) spent within each phenophase. The goal was to arbitrarily achieve linearity, relative to degree-day accumulation early in the season. A linear response could simplify modeling and calculations using prediction equations. The description of growth that follows is part of Phase I of the phenology study conducted from 1982-1985.

Materials and Methods

Plant Material Culture

Three orchards at the Michigan State University Horticultural Research Center (HRC), at East Lansing, Michigan were chosen as the primary observational sites. 'Red Delicious'/Std (age=16 years in 1982), 'Golden Delicious'/Std (age=16 years in 1982), and spur type 'Golden Delicious'/MM111 (age=9 years in 1982) were observed.

The trees were trained to a modified central leader system and were pruned annually to maintain form and adequate light penetration into the canopy. The trees were not irrigated, but rainfall is normally sufficient at these orchard sites. Pesticide applications maintained the trees free of serious insect and disease problems. Fertilizer was applied as needed to maintain the nutitional status of the orchards. The orchard floor management system was sod aisles with herbicide strips.

Observations and Experimental Design

Shoot growth was partitioned by function and location into 4 categories: vegetative spur, reproductive spur, vegetative terminal, and reproductive terminal growth. Partitioning was necessary to develop precise descriptions of the different types of shoot growth and subsequently a predictive model of canopy development. Observations were made at 1 to 7 day intervals, depending on the stage of development and weather (eg. higher temperatures require more frequent observation). The experimental design was a completely randomized design, replicated by tree. Four shoots of each component class (vegetative spur, vegetative terminal reproductive spur, reproductive terminal), on each of 5-6 trees/site, were chosen at random and the phenophase recorded at each time of observation. McIntosh trees at the Michigan State University Plant Pathology Orchard were also observed in 1982. In 1983 the study was expanded to include additional locations and varieties. Fifteen year old trees of 'Red Delicious', 'Red Spur', 'Golden Delicious', 'Jonathon', and 'Ida Red', on MM111 and MM106 rootstocks, were observed every 5-8 days at the Graham Research Station in Grand Rapids, Michigan. Younger trees (5 years) of 'Jonathon'/M7A, 'Smoothee Golden Delicious'/M7A, and 'Ida Red'/M1X/MM111 were observed at 5-8 day intervals at the Clarksville Horticultural Experiment Station in 1983. Observations were continued during 1984 in the primary orchard sites at HRC, but were also made on on 'Paula Red', 'Empire', 'Mutsu', and 'Jonathon' during early growth (bud break - petal fall). In 1985 observations were made only on spur type 'Golden Delicious' at HRC. The discussion that follows details morphological development in apple based primarily on observations made on 'Golden Delicious' and 'Red Delicious'. Some notes on varietal differences are included, based on the expanded observations of 1983-84.

Discussion

Classifying growth - Development of stages

The growth description and accompanying photos closely depict the major morphological stages that can be visually quantified in apple during one season of growth (12). The stages referred to in this description represent an adaptation of the stage classifications developed by Seem and Szkolnik (31) (Table 1,2). Classic growth stages have been incremented (eg. 'silver tip' is subdivided into 'early silver' and 'silver tip') to provide a more precise system for phenology tracking. Photos are included to help standardize and define each stage (Figure 4-6).

Apple shoots can be classified as either reproductive (flowering and fruiting) or vegetative (non-fruiting). Buds are mixed, containing both leaf and flower tissue in the same buds, or simple, containing only vegetative tissue. Shoots may be classified as an extension shoot (referred to as terminal growth) or as a spur shoot (lateral growth on a 2 year or older extension shoot).

A terminal shoot (Figure 4I) is usually characterized by relatively long internodes and occurs at the distal end of a branch or strong lateral.

Spur shoots (Figure 4G) are short lateral shoots with characteristic short internodes. Normal spurs flower in alternate years, with the inflorescence arising in the terminal position. Each inflorescence usually contains from 1-6 flowers. Vegetative growth must continue from a lateral leaf bud subtending a spur leaf. This leads to a crooked growth pattern for these shoots.

Several types of vegetative shoot growth occur in apple in addition to extension shoot growth and spur shoot growth. Watersprouts are vegetative shoots that originate on the trunk and major scaffold branches (Figure 6M). They have an upright growth habit, generally characterized by long internodes. Suckers are analogous to watersprouts, but are outgrowths of the root system (Figure 6N). Bourse shoots are vegetative shoots that develop from a bud in the leaf axil of a flower cluster (Figure 5O). Morphological development of these shoot types closely approximates normal vegetative shoot devlopment, so precise descriptions are not given.

Table 1: Reproductive Phenocodes: Used to numerically code morphological development of reproductive shoot growth in apple

STAGE NAME	CODE	FIGURE
Dormant	1.0	4A
Early Silver Tip	3.0	4B
Silver Tip	5.0	4C
Green Tip: 0 - 0.4 cm	7.0	4D
: 0.5 - 0.9 cm	8.0	4E
: 1.0 - 1.4 cm	9.0	4F
: 1.5+ cm	10.0	---
Pre-cluster Leaf	10.0	4G
Early Tight Cluster	11.0	4H
Tight Cluster	12.0	4I
Early Bud Expansion	13.0	4J
Bud Expansion	14.0	4K
Early Pink	15.0	4L
Pink	16.0	4M
Full Pink	17.0	4N
1 Blossom	18.0	4O
2-3 Blossoms	19.0	5A
4+ Blossoms	20.0	5B
Full Bloom	20.5	5C
Early Petal Fall	22.0	5D
Mid Petal Fall	23.0	5E
Late Petal Fall	24.0	5F
Early Fruit Set	25.0	5G
Mid (2-3) Fruit Set	26.0	5H
Late (4+) Fruit Set	27.0	5H
Fruit Diameter:		
<0.5 cm	28.0	---
0.5 - 0.9 cm	29.0	---
1.0 - 1.4 cm	30.0	5I
1.5 - 1.9 cm	31.0	---
2.0 - 2.4 cm	32.0	---
2.5 - 2.9 cm	33.0	5J
3.0 - 3.4 cm	34.0	---
3.5 - 3.9 cm	35.0	---
4.0 - 4.4 cm	36.0	---
4.5 - 4.9 cm	37.0	5K
5.0 - 5.4 cm	38.0	---
5.5 - 5.9 cm	39.0	5L
6.0 - 6.4 cm	40.0	---
6.5 - 6.9 cm	41.0	---
7.0 - 7.4 cm	42.0	5M
7.5 - 7.9 cm	43.0	---
8.0 - 8.4 cm	44.0	---

Table 2: Vegetative Phenocodes: Used to numerically code morphological development of vegetative shoot growth in apple.

STAGE NAME			CODE	FIGURE
Dormant			1	4A
Early Silver Tip			3	6A
Silver Tip			5	6B
Green Tip:	0 - 0.4 cm		7	6C
:	0.5 - 0.9 cm		8	--
:	1.0 - 1.4 cm		9	6D
:	1.5+ cm		10	--
Shoot Growth:				
1 Leaf			11	6E
2 Leaves			12	--
3 Leaves			13	6F
4 Leaves			14	--
5 Leaves			15	6G[y]
6 Leaves			16	6H[yx]
7 Leaves			17	--
8 Leaves			18	--
9 Leaves			19	6I[z]
10 Leaves			20	--
11 Leaves			21	--
12 Leaves			22	--
13 Leaves			23	--
14 Leaves			24	--
15+ Leaves			CODE = leaf number + 10	--
Terminal Bud Set:				
Dwarfing Rootstocks				
and Spur Types:		Spur	25	6L
		Terminal	30	6L
Standard Rootstocks:		Spur	30	6L
		Terminal	32	6L

[y] This photo also shows how far the leaf margins must be unfurled to be counted (see text).

[x] Example of SPUR growth

[z] Example of TERMINAL growth

Description of Shoot Growth (Refer to Table 1,2;Figure 4-6)

Early Growth: Vegetative and Reproductive

Early season growth is very similar for both reproductive and vegetative buds. A general description of early growth stages follows, and the differences between the two types of growth within each stage are discussed.

When apple buds are dormant it is very difficult to reliably differentiate between reproductive and vegetative buds. Generally, it is believed that reproductive buds are plumper, while vegetative buds have a more slender appearance. This is not necessarily the case, as bud size and bud type (mixed or simple) are influenced by a number of environmental and cultural factors (1,25), as well as the age of the bud (eg. time from initiation) (1). Spurs flower in alternate years, so a more reliable decision may be made by looking for stem scars from the previous year's fruit; if the stem scar is present, the bud will probably be simple (vegetative).

Stage: Dormant

Like many deciduous trees, the apple must enter a dormant state to survive cold winter temperatures. The bud scales harden, helping to protect and nourish the tender tissue they enclose (1), and take on a necrotic, lifeless appearance. In some cultivars, a grayish-silvery pubesence developes as dormancy progresses. This pubesence may appear on the tips of the bud scale or may occur as a general covering of the bud.

Stage: Early Silver

As the temperatures warm in the spring, the buds break rest and begin growth, which cannot be detected visually (23,24). As this growth proceeds, the buds begin to swell. As swelling progresses the bud scales will crack apart, revealing a small wedge of silvery tissue at the apex (Figures 4B, 6A). The exposure of this small wedge of tissue is the major identifying character of 'early silver' and is normally visible on only one side of the bud apex during this stage . 'Early silver' represents the first evidence of growth that we can visually quantify. It is difficult in some cultivars with heavily pubescent buds to determine the initial occurence of 'early silver'.

Stage: Silver Tip

Bud swelling continues, exposing more silvery tissue from the apex along the side of the bud (Figures 4C, 6B). The silvery wedge of tissue may also expand to be visible on more than one side of the bud (although this is not a necessary criterion for classification). The major criteria for classification into the 'silver tip' stage is expansion of the silvery wedge of tissue along the side of the bud (from the apex) associated with a widening scale crack. No green tissue is exposed at this stage. 'Silver tip' is more readily identifiable than 'early silver' and hence more suitable as a first biofix selection (11).

Stage: Green Tip

The 'green tip' stage is reached when the bud expands to reveal green tissue (Figure 4D, 6C). This tissue is first evident as a small point of green that can be seen by looking down into the bud from the apex. This small point of green tissue may not be clearly visible from a side view and is easily missed, with the bud still appearing to be in the 'silver tip' stage. The buds are sub-classed in the 'green tip' stage according to the length of green tissue extending beyond the distal tip of the external bud scales. The sub-classes are: 0.0 - 0.4cm (Figure 4D, 6C); 0.5 - 0.9cm (Figure 4E); 1.0 - 1.4cm (Figure 4F, 6D); 1.5+ cm . The first green tissue to appear is largely undefineable. Both vegetative and reproductive buds usually grow in the same fashion through the 0.5-0.9cm green tip stages (although vegetative buds tend to appear more slender in growth). As extension continues, vegetative and reproductive buds begin to diverge in their outward visual appearances. The difference normally becomes evident by the time buds reach the 1.0 - 1.4cm stage. (Note that the 1.0-1.4cm stage is equivalent to the classic 1/2 inch green stage.) Vegetative buds may continue to expand in 'green tip', up to the 1.5+ extension class prior to unfurling the first leaf. Emergence of the first leaf can also occur directly from the previous class (1.0-1.4cm). Floral buds rarely extend to the 1.5+cm class. Rather, once reaching approximately 1.0 - 1.2cm they begin to swell in diameter as the flower buds (not quite visible yet) begin to push out. Usually the floral buds will grow into the 'pre-cluster leaf' or 'early tight cluster' stage before extension can reach the 1.5+ extension class. It should be noted, the differences in appearance between vegetative and reproductive buds in the early green tip stages vary with variety. 'Golden Delicious' and 'Northern Spy' have comparatively small and slender reproductive buds, while 'Empire' ,'Mutsu', and some strains of 'Red Delicious' have relatively larger, plumper reproductive buds.

Vegetative Growth (Refer to Table 2;Figure 6,7)

Stage: Shoot Extension

The vegetative bud passes into the shoot extension stages when the first leaf is unfurled from the expanding bud. The first leaves (1-2) which emerge, termed transition leaves by Abbott (1), are small and oval in shape. In contrast, leaves that appear later are larger and more ovate in shape. The first leaves often abcise before the end of the growing season. 'Shoot extension growth' stages are classed according to the number of leaves emerged (Figure 6E-6I). When a leaf emerges, it is usually curled from the leaf margins inward. As the leaf unfolds the margins are the last to uncurl. A leaf is not classified as emerged (added to the leaf number total) until the edges have uncurled (Figure 6O: leaf on left is not counted, leaf on right is ;Figure 6H: this spur is classified as having 6 leaves, although #7 is nearly expanded). Patterns of growth for terminal and spur shoots are similar, but terminal shoots generally have longer internodes and a greater total leaf number (compare shoots in Figures 6G and 6I). Many times terminal shoots also have larger leaves than spur shoots. Spur shoots commence growth earlier and set terminal bud earlier than terminal extension shoots (Figure 3).

<u>Stage: Terminal Bud Set</u>

When the current season's flush of growth stops, a bud is formed at the apex of the shoot. This is called 'terminal bud set'. It is from this bud that next season's growth (or another flush of growth during the current season) will originate. The growth rate decreases as the vegetative shoot approaches bud set. The last leaves to emerge are smaller and internodes are shortened. Leaves may emerge somewhat hooked at the tip (Figure 6J). The final leaf to emerge just prior to 'terminal bud set' may be very small. Frequently the leaf margins never completely unfurl during expansion. Many times this last rudimentary leaf abcises as the terminal bud swells during its development (Figure 6K). As the bud matures, bud scales harden, with a gradual color change from green to brown.

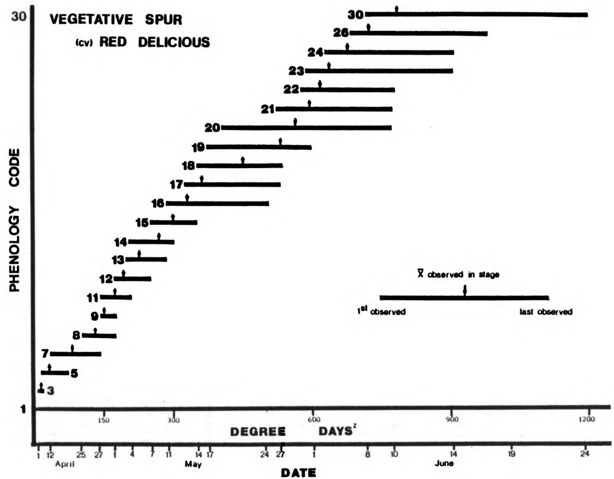
Stage: Regrowth

Under certain environmental conditions regrowth occurs after terminal bud set. The newly set terminal bud breaks and begins a new cycle of vegetative growth during the current summer season. Regrowth shoots can arise from terminal buds set either on terminal or spur shoots. Regrowth progresses sequentially much like early season growth, except that the silver tip stage is eliminated. Growth proceeds from terminal bud break right into green tip, first leaf, etc. (Figure 7A-F). Shoot extension is rapid and continues until a new terminal bud is set at the apex of the regrowth shoot. Internodes of regrowth shoots occuring on extension shoots are usually shorter than those on regular first growth. Late in the season (usually following terminal bud set on regrowth shoots) it can be difficult to determine whether or not regrowth has occurred. To determine if terminal bud set occured earlier, observe shoots for the presence of bud scales or scars at the suspected point of origin for the regrowth shoot (Figure 7G, 7H). This can be determined by looking along the shoot (working towards the base of the shoot) for an area of smaller leaves followed by a subsequent area with larger leaves. The more mature smaller leaves may be darker in color than the relatively younger, larger leaves. This represents the area where leaf size began to decrease just prior to first terminal bud set and then increased again as new leaves (regrowth) began to emerge. This change in leaf size may not be dramatic if sufficient time has elapsed, as the first flush leaves continue to expand. Observation of an extra long internode at this point, appearing as if a leaf is missing, may also help identify regrowth shoots.

Stage: Regrowth Bud Set

This stage is analogous to 'Terminal Bud Set' but occurs when the regrowth shoot has completed its current flush of growth.

Figure 1: Comparative distribution of phenophase (stages of development) as a function of degree-day accumulation (base 40) and date, for vegetative spur growth in apple:(cv) Red Delicious (HRC, 1983).



z Degree-day accumulation calculated at Base 40 °F using the Baskerville and Emin method (4). Start date for degree-day accumulation: April 1. Orchard site: HRC, 1983.

Reproductive Growth (Refer to Table 1; Figures 4,5)

Previous Stage: Green Tip

Stage: Pre-Cluster Leaf

Not all reproductive buds express the 'pre-cluster leaf' stage. Both inter and intra-varietal variation occurs. This variability in development occurs as the buds grow thru the late 'green tip' stage into the 'tight cluster' stage. When the 'pre-cluster leaf' stage is present, one or two small leaves subtending the cluster of flower buds will unfold before the cluster completely outgrows the bud (Figure 4G). If the 'pre-cluster leaf' stage is not present, then the cluster of flower buds starts to become visible, but remains sheathed by the subtending leaves, which do not unfurl.

Three different variations for development exist: 1) within year - same variety, 2) between years - same variety, and 3) between varieties. 'Golden Delicious' seems prone to both within year and between year variation.

1) In 1983, almost all flower buds passed directly from the 'green tip' stage into the 'early tight cluster' stage without clearly exhibiting the 'pre-cluster leaf' stage. Some flower buds did display the 'pre-cluster leaf' stage. It is probable that this represents variances in growth rates, with those clusters showing pre-cluster leaves having slower rates. This could be attributed to bud to bud

variation in chilling hour accumulation (8,13,21,26,35) or carbohydrate reserve status (1). Landsberg discussed a study conducted by Abbott showing that when winter chilling was delayed buds continued to grow (swell in size) but did not break until after chilling, opening directly to the 'green cluster' stage (23).

2) In 1984, flower buds exhibited the 'pre-cluster leaf' stage with greater frequency.

3) In contrast to 'Golden Delicious', varieties such as 'Mutsu', 'McIntosh', and 'Northern Spy' all tend to exhibit the 'pre-cluster leaf' phase in all years.

Adjustments to the phenocode were made based on the variations in development observed in the latter green tip stages through the early tight cluster stage (eg. both 1.5+cm green tip and pre-cluster leaf = 10).

<u>Stage: Early Tight Cluster</u>

The 'early tight cluster' stage is reached when the cluster of flower buds is clearly visible, but the number of individual buds is not yet descernible. The leaves subtending the cluster will have begun to unfurl by this time. (Figure 4H).

<u>Stage: Tight Cluster</u>

The stage 'tight cluster' is reached when the cluster leaves begin to unfold and the individual buds start to become recognizable. The buds are still tightly appressed (Figure 4I).

Stage: Early Bud Expansion

As the flower cluster continues to grow, the individual flower buds begin to swell and separate. The 'early bud expansion' stage is reached when it is clear that one or two buds are beginning to show swelling and separation (Figure 4J). A number of cluster leaves generally will have unfolded and begun expansion during this phase.

Stage: Bud Expansion

As the flower buds swell and separate, the pedicels also begin to grow up and out. The flower buds are all clearly decernible at this stage, the pedicels are extended, and many cluster leaves are now out. The flower buds have not yet cracked to show pink (except possibly the king bloom in the latter occurence of this stage).

Stage: Early Pink - Full Pink

After the clustered flower buds have separated (although some clusters may occasionally remain tightly bunched) they continue to swell, revealing petal tissue when the buds crack open at their apex. The 'pink' stage is subclassed into three categories, ranked according to the amount of pink petal tissue visible. The subclasses are 'Early Pink' (Figure 4L), 'Pink'(Figure 4M), and 'Full Pink' (Figure 4N). Flower buds are considered to be in the 'early pink' stage when only a few buds are initially showing pink, or all buds are showing very little pink. A cluster with a full compliment of flowers has up to 5 - 6 flowers / cluster. Normally, the king bloom (center blossom) is more advanced than the other blossoms in the cluster, and frequently 1 or 2 buds lag behind in development. This variation makes averaging of the stages of all the buds within a cluster and subjective judgement important in determining bud/bloom class in the flowering stages. It is during the 'pink' stages that the variation of growth among flower buds within a cluster first becomes apparent. As the flower buds expand, more pink petal tissue is exposed and the buds are classified into the 'pink' and 'full pink' stages, respectively.

Stage: Blossom Classes

Following the 'pink' stages the flower buds continue to expand until they fully open. They open in order of relative maturity within the cluster, with the king bloom usually opening first. There are three bloom classes, with each ranking dependent upon the number of blossoms which have opened. A blossom is classed as being open if all of the petals have unfurled. The bloom classes are '1 blossom'(Figure 4D); '2-3 blossoms'(Figure 5A); '4+ blossoms'(Figure 5B).

Stage: Full Bloom

'Full bloom' is a frequently used development marker.

It is really an averaged classification that occurs when 70 - 80% of the blossoms on a tree are open (F.G. Dennis, personal communication). Hence, there can be some overlap with the '4+ blossom' stage and the 'early petal fall' class. Once apple blossoms open they may remain on the tree for a number of days before dropping their petals. When clusters are first observed to have 4 or more blossoms open then the '4+ blossom' stage is the most appropriate. If all the flowers in a cluster are open or the blossoms appear aged (the pollen darkens from a bright yellow to dark yellow/tan) the use of the 'full bloom' class would be more appropriate than the '4+ blossom' class. It is not unusual to observe the king blossom beginning to lose petals while the other four blossoms remain intact. The 'full bloom' class is most useful when referring to averaged values (see monitoring segment) (eg. if average observations indicate 70 - 80% of the flowers open, use the 'full bloom class'.)

Stage: Petal Fall

After bloom, if the flower is fertilized, fruit may be set and begin to grow. If fertilization does not occur (or is incomplete) the flower will abcise. As these processes are initiated, the petals will begin to drop. The 'petal fall' classes are grouped by the number of petals lost. To classify a cluster, the average number of petals lost/cluster is used: 'Early petal fall' = <25% petal fall (Figure 5D); 'Mid petal fall' = 25 - 65% petal fall (Figure

5E); 'Late petal fall' = <65 - 100% petal fall (Figure 5F). This particular stage is directly affected by wind and rain, which can physically knock petals off blossoms.

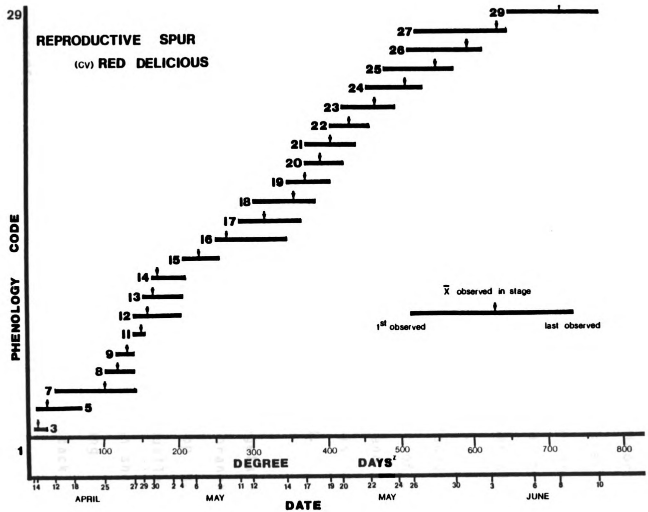
Stage: Fruit Set

Determination of fruit set is very subjective, based on visual expansion of the recepticular tissue of the apple flower. Immediately following 'late petal fall', little, if any swelling of the fruit is visible (Figure 5G). As fruit growth begins, a slight rounding is evident (Figure 5H). During 'early fruit set' 1 fruit will show swelling (usually the king blossom); 'mid fruit set', 2-3 fruitlets swollen; 'late fruit set', 4+ fruitlets swollen'. The fruit set classification is based on 4-5 fruitlets/cluster. With fewer fruitlets use an approximate percentage (eg. 2-3 fruit set = 40 -60 % set.) To be classed as set the fruit must appear to have initiated swelling (Figure 5H).

Stage: Fruit Growth

During growth fruits are classed by diameter (0.5 cm incremental increases in diameter) (Figure 5F-5M). Fruit diameter measurements are made at the largest width of the fruit, where length is the stem/calyx axis, and width is the axis perpendicular to the stem/calyx axis (Figure 5N).

Figure 2: Comparative distribution of phenophase (stages of development) as a function of degree-day accumulation (base 40) and date, for reproductive spur growth in apple: "early silver" thru early "fruit growth" stages:(cv) Red Delicious (HRC, 1983).



z Degree-day accumulation calculated at Base 40 °F using the Baskerville and Emin method (4). Start date for degree-day accumulation: April 1. Orchard site: HRC, 1983.

Other Types of Shoot Growth

Bourse Shoot Growth

Reproductive buds in apple are actually mixed buds, containing both floral and vegetative primordia. On a flowering shoot, cluster leaves subtend the cluster of flowers. Vegetative buds can develop in the axils of the subtending leaves. In some cases the bud in the axil of the first or second leaf just below the flower cluster will break and begin shoot growth (Figure 50). This growth usually begins just prior to fruit set (eg. sometime during petal fall). Growth proceeds much like that of a terminal vegetative shoot, although final extension and leaf number is less. As in regrowth shoots, bud break is followed by green tip, with the silver stages eliminated.

Watersprouts

Watersprouts are rapidly developing vegetative shoots that grow from the main trunk and scaffold branches (Figure 6M). They grow upright, and usually develop more leaves than normal extension shoots. Growth usually continues later into the season than terminal extension shoot growth, and may provide a continued source of young leaf tissue which is suceptible to disease and insect attack.

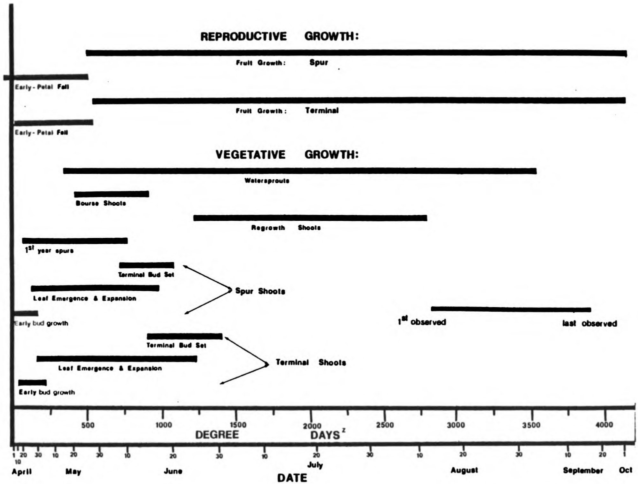
Suckers

Analagous to watersprouts, suckers are outgrowths of the root system (Figure 6N).

Conclusion

The coding/staging system presented in Section I was developed to standardize criteria for making phenometric observations in apple. Phenophases were incremented to achieve the precision necessary to design a predictive phenology model, yet it was easy to use as an orchard monitoring tool. Monitored values (Phenocodes) could be used to track spring bud development and subsequently as data inputs for a predictive phenology model. Monitoring orchard canopy development and environmental parameters, in conjunction with a predictive model, could contribute to more efficient implemetation of management stategies.

Figure 3: Comparison, by degree-day accumulation and date, of the onset and duration of growth for selected shoot types in apple (cv.) Red Delicious (HRC, 1983, 1984).



z Degree-day accumulation calculated at Base 40^{o}F using the Baskerville and Emin method (4). Start date for degree-day accumulation: April 1. Orchard site: HRC, 1983.

Figure 4. A.- O. Photographs documenting morphological stages of development for reproductive phenophases (dormant-early bloom)

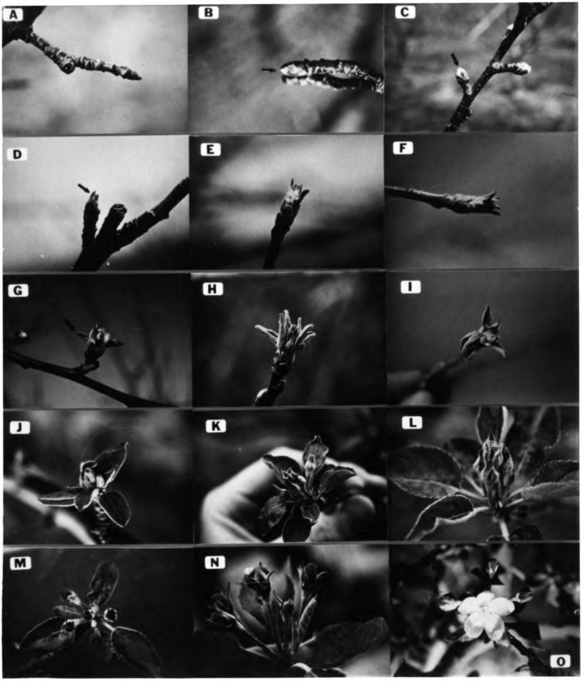

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Figure 5. A.- M. Photographs documenting morphological stages of development for reproductive phenophases (bloom - harvest) N. Measuring fruit growth O. Bourse shoot


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Figure 6. A.- L. Photographs documenting morphological stages of development for vegetative phenophases (silver tip - terminal bud set) M. Watersprouts N. Suckers O. Leaf emergence

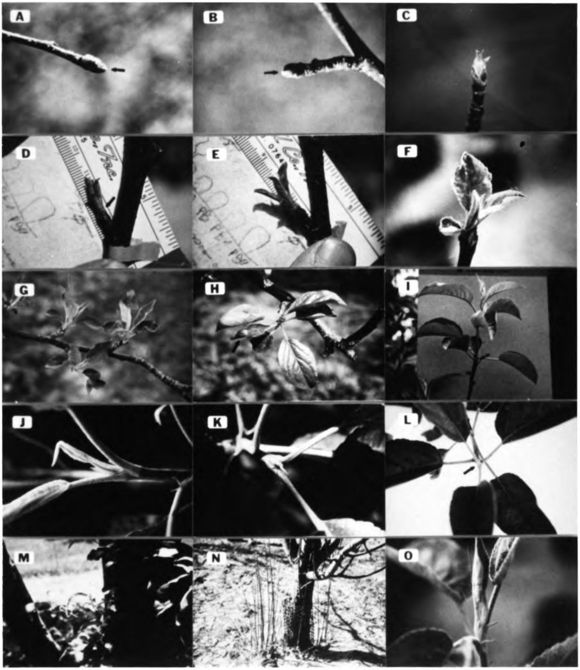
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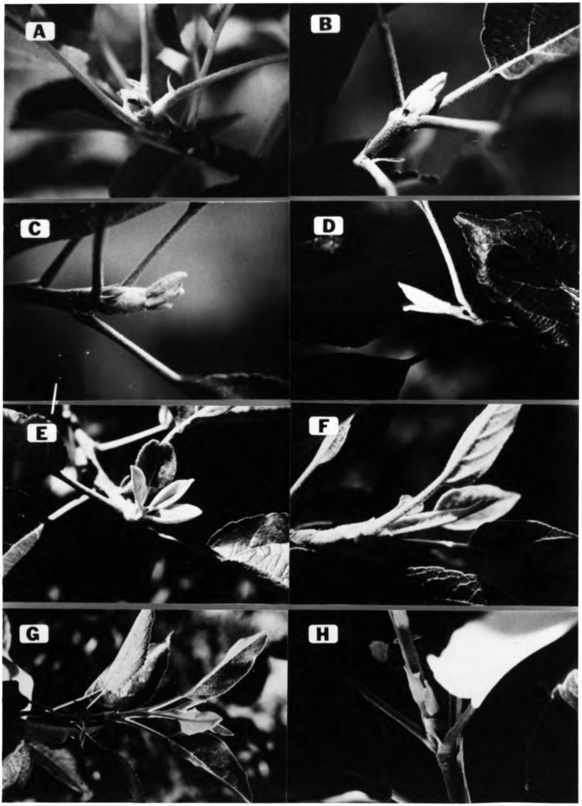
Figure 7. A.- H. Photographs documenting morphological stages of development of vegetative regrowth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Section II

Modeling Shoot Growth, Flower Development and Fruit Growth in Apple.

Abstract: An empirical predictive model of apple tree growth was developed for Red Delicious, Golden Delicious, and spur type Golden Delicious. Observations of morphological development (Phenophase) and selected environmental parameters were made at 1 to 7 day intervals. A model that would predict apple shoot growth by phenophase was desired. For monitoring and predictive purposes, shoot growth was partitioned by type as follows: vegetative spur, reproductive spur, vegetative terminal, reproductive terminal. Linear regression analysis using several environmental parameters as independent variables was performed. Non-linear equations using degree-day accumulation as the independent variable were also fitted. The best statistics of fit and predictions were generated by the asymptotic non-linear Logistic equation: $Y=B(1)/(1.+EXP(B(2)-B(3)*X+B(4)*X^2-B(5)*X^3))$ for all shoot types and varieties. Predictions of stage within 0 to 2 phenophases up to 4 months in advance are possible. The concept of Biofix, and a method of initializing the model for use in different locations and years, using Biofix values, is discussed.

Introduction

The Role of the Model

Every orchardist strives to produce quality fruit at the lowest cost. Timely cultural management and effective pest control cannot be overstated. One of the major and increasingly expensive production costs is the application of chemical sprays for pest control or growth management.

Concerns other than cost for pesticide use also exist. There is an increased awareness of the environmental hazards associated with pesticide use, and the efficacy of newly developed pesticides has been reduced as target insects and diseases develop resistance to these chemicals. A Michigan program for Integrated Pest Management (IPM) , largely designed and administered by scientists at Michigan State University, addresses some of the problems associated with pesticide use by providing information designed to improve the timing of pesticide applications with the goal of reducing the amount of pesticide required. This has been accomplished by correlating weather data with pest phenological development (in the form of field population counts) to generate predictions based on pest life cycle models (26, 69).

The ecology of the apple production system is one of complex interactions (13,14,21). Subsystems (eg. insect life cycles, disease epidemiology and physiological mechanisms of growth) have been studied, but to date a field applicable, holistic model of the apple production system has not been developed (21). Insect and disease development, cultural practices, and the environment are tied closely to the growth cycle of the apple tree (7,13,49,69). Croft et. al. (13) states "the trend in tree fruit pest control research is toward increased study of pest-plant interaction..." . A greater understanding of the growth and development of the tree and how it responds to its environment should contribute to more efficient insect and disease control by improved timing of management strategies. Use of tree phenology to develop a model to predict shoot growth would contribute to an understanding of plant development and could later be coupled with insect and disease development predictions resulting in more efficient orchard management.

The Utility of the Model

Many growers still rely on published spray schedules where timing of pesticide application is based on the occurrence of a particular stage of growth (eg. pink, bloom)(49). Timing of apple thinning is also tied to developmental stage (days after bloom or size). Many growers thin their fruit with chemical sprays that require precise timing (if the fruit are too large thinning will not occur). Timing of other growth regulators (Alar, NAA, Ethyphon) has been based on some particular stage of development. The ability to accurately predict the developmental growth stages of the apple tree would make decisions concerning pesticides and growth regulators more efficient.

Between 1982 and 1985 an apple phenology study was conducted at Michigan State University. The primary goal of this study was to provide updated and precise growth information necessary to model the vegetative and reproductive growth of the apple pest-tree-environmental system. A phenology model capable of predicting key stages of growth (eg. green tip, pink, full bloom, etc.) was developed. Based on predictive ability the main uses of this model would be: 1) improved timing and more efficient scheduling of pesticide and growth regulator applications, 2) to function as a structural base for more complex models that might later include the physiological components of growth, or interface with models of insect life cycles, disease epidemiology, orchard floor management (weed control), etc.

Types of Models

Several apple-crop system models have been designed (13, 21, 45, 58). "A systems model may be made up of a series of either theoretical or empirical equations" (64). Theoretical models describe the system in terms of the modeler's perception (theory) of how the system functions (64,66,71). Theoretical models help identify interactions, potential parameters for model expansion, and subsystems for empirical modeling (eg. organ systems, physiological mechanisms, etc.) (71) (see Russo and Seem (58), and Evans (23) for a review of the hierarchy of plant subsystems). Empirical models are based on factual data, and have the ability to 'summarize' data (as mathematical equations) (36), and to assess (rather than theorize) behavior under a variety of conditions (71). In reality, most models contain elements from both the theoretical and empirical approaches (64).

Mechanistic models view the response of the system in terms of the structure (underlying mechanisms) of the system (66). Both theoretical and empirical models can be mechanistic in nature, and while the empiricist describes the structure in terms of observable output, it is the theorist who is more likly to describe the underlying mechanisms of the system (46,64,66). Mechanistic models have been developed for system components of some fruit crops: apple physiology and growth (42,45), photosynthesis and stomatal conductance in apple (41,42,46), and carbohydrate partitioning in cherry (37).

An empirical phenology model was designed to function as a basic structural component of an apple-crop system model. The model was not designed to be a mechanistic model (does not describe the mechanisms of growth), but was designed to describe shoot growth based on observations of the morphological development. Theoretical component models (eg. physiological) could be used to help refine and expand the utility of the empirical model.

Model Variables

Environmental variables have been used to predict growth (19,30,45,62,68). Physiological events in apple have been related to various environmental parameters (41, 42,43,44,45,46), but are difficut to quantify non-destructively. Haun and others have used non-destructive methods to quantify growth based on systems of measuring changes in growth correlated to changes in the environment (31,32,35,45,47,59). Each morphological stage of development (termed 'phenophase' by Seem & Szkolnik (59)) is assigned a numerical indexing code. The relationship between growth and the environment can be determined by regressing the numerical indexing code (dependent variable) with the environmental parameters (17, 19,20,32,33,60). Cumulative or daily growth relationships can be determined by regression analysis. Several environmental parameters have been used as independent variables. Lombard, et al. (48) concluded that air temperature was the major environmental parameter related to the phenological development of fruit trees. Degree day accumulation (or degree hour accumulation) has been correlated with growth (33,55,56,61,68). Eisensmith, et al.(19,20) developed leaf emergence (leaf number) and expansion (leaf area) predictions by regressing growth with degree-days accumulated in sour cherry *Prunus cerasus* (cv. 'Montmorency').

Environmental parameters should be related to growth based on: 1) the biological significance of the independent variable being modeled; 2) increased mathematical correlation between dependent and independent variables (16, 29,36); 3) availability of environmental data ; and 4) considerations of model complexity (will the model be difficult to use?).

The Functional Approach

The functional approach is used to develop equations predicting developmental stages of growth (9, 10, 36). Mathematical functions are used to describe (or fit to) the data (frequently using regression analysis). The functional approach is especially useful to the empiricist since instantaneous values and errors are derived from equations fitted to data (eg. stage = f(time)) (36). Fitting mathematical functions tends to smooth out slight irregularities in the data, helping to show the overall trend (10, 36, 66). With the aid of the computer a number of mathematical functions ranging from simple linear models with one parameter to complex models estimating multiple parameters can be fitted to the data set. Types of functions available, and the rational behind the use of these functions are discussed in detail by Hunt (36), Causton (9), Causton and Venus (10), Gold (29), Thornley (66) and Spain (63).

Statistical estimation of errors and estimation of derivatives becomes difficult when using complex functions (36). Complex functions may closely describe the idiosyncrasies of the data fitted, but fail to show the overall trend. (36). Occasionally, complex functions will produce a curve that tends to waver about the data points, yielding high correlation statistics but never truly 'fitting' the data (18). The assignment of biological significance to model parameters is difficult, if not impossible with complex functions(36,54). Erickson (22) and Richards (54) discuss the importance of matching model parameters to biological events. Selection of the simplest model that will achieve the goals of the modeler is preferred (9,36,38). A more complex function that predicts well might be selected if accuracy of prediction was more important than relating the biology of the system to function parameters.

Concept of Biofix

The determination of the onset of growth is a major problem in modeling perennial plant growth. Apple enters a state of rest each fall and must be exposed to approximately 1200 hours of chilling temperatures (¼ 9.5^{o} C to 13^{o} C) before growth can resume (total hours varies with author and method of calculation)(42,61). Temperatures below 1.6^{o} C are thought to contribute little to chilling hour accumulation and temperatures above 13^{o} C to 19^{o} C can negate chilling hours previously accumulated, with optimum chilling occurring at 6.1^{o} C to 7.2^{o} C (42,61). Growth will resume in the spring only when rest has been completed (sufficient chilling hours have accumulated) and favorable temperatures for growth occur. Two approaches have been used. One method predicts the end of rest, based on accumulated chilling hours (3, 11,55,57,61). Models predicting spring bud development through full bloom have been developed for apple which use chilling unit accumulation to determine the onset of spring growth (Utah (42) and North Carolina (61)). The Utah model has not resulted in accurate predictions in regions outside of Utah (2,52,61), and neither model is accurate in Michigan (J. A. Flore, personal communication).

Two major problems are encountered when making predictions based on chill unit accumulation. 1) It is difficult to accurately determine the onset of dormancy (one of the chilling model requirements). 2) The growth response of apples varies based on the temperature regime at which chilling hours are accumulated (11,24,65). There is disagreement among authors as to the optimum chilling temperature (41,55,65). Additionally, in Michigan accurate hourly weather data, nor data before April 1 are available using the PMEX system (50).

A second approach eliminates the necessity of determining the occurrence of a physiological event (eg. onset of growth or dormancy). A verifiable biological event (biological reference marker or Biofix) is chosen arbitrarily to represent the onset of growth. Biofix markers have been used in models predicting insect development (7,26). Seem and Szkolnik (59) have adapted this concept, using green tip as a reference marker from which to calculate degree-day accumulation. Eisensmith et al. (19,20) have successfully used degree-days accumulated to a selected date (April 15) as the Biofix point in their predictive models of cherry leaf emergence and expansion .

Degree-Day Accumulation: Base Temperature

Different base temperatures have been used to calculate degree-day accumulation for apple (21,48,59,60,61). Richardson, et. al. (55) concluded that any temperature greater than 4.4^{o}C would result in growth. Kronenberg (40) gives a good review, reporting base temperature values of 6.1^{o} C and 6.6^{o}C if day maximum temperatures are used , concluding that using average day temperatures gives better results than maximum day temperatures, and base temperatures may vary with variety (base temperature = 0^{o}C to 8^{o}C). Different phases of growth may respond to different threshold temperatures (40,42,67,68). Early spring bud growth may respond to a lower threshold temperature (lower base temperature) than fruit growth during the summer months (42,67,68). Since this has not been well documented, a single base temperature was utilized in this study.

Materials and Methods

Plant Material

Phenological observations were made at three different orchard sites at the Michigan State Horticultural Research Center (HRC) at East Lansing, Michigan, between 1982 to 1985. Trees in each orchard were spur type Golden Delicious/MM 111, Golden Delicious/seedling, and Red Delicious/seedling 9,16, and 16 years old in 1982, respectively. Five trees/orchard were selected and four observations/tree/shoot type were recorded on each sampling date. Growth was separated into four categories: vegetative or reproductive on spurs or terminal extension shoots.

Observations were made on Golden Delicious/MM111, Red Delicious/MM111, Ida Red/MM111, and Jonathon/MM111 at the Graham Research Station in Grand Rapids, Michigan in 1983, and on Golden Delicious/Std, Golden Delicious/EM7, Golden Delicious/MM106, Empire/EM7, Red Delicious/EM7, and Red Delicious/MM106 at two commercial orchard sites in Leelanau County, Michigan in 1985. Data collected at the H.R.C. in 1983 was used to generate the predictive models, while data from other observation sites and other years (HRC) were used to test prediction equations.

Observational procedure

A numerical code (phenocode) was developed based on precisely defined morphological stages of growth (16) in which each developmental stage was assigned a numerical value (Table 1,2). Each stage is mutually exclusive, with development through consecutive stages. The mean phenocode was used to calculate a growth indice (GI) for that particular sampling date, where:

$$GI_{tj} = \frac{\Sigma X_j}{N_j}$$

t = time in days

X = phenocode at time t_j for $j = 1...k$

N = number observations of a particular type of shoot at time t_j for $j = 1...k$

This generated a series of values: GI_{t1}, GI_{t2},...GI_{tk}, which could be used as the dependent variable for correlation to selected environmental (independent) variables.

Rate observations

The differences between vegetative and reproductive development during the early stages of growth: dormant through silver tip are not readily apparent (1, 16). Errors in bud classification may occur during early growth. To decrease bud classification error, daily observations were

Table 1: Reproductive Phenocodes: Used to numerically code morphological development of reproductive shoot growth in apple.

STAGE NAME	CODE
Dormant	1
Early Silver Tip	3
Silver Tip	5
Green Tip: 0 - 0.4 cm	7
: 0.5 - 0.9 cm	8
: 1.0 - 1.4 cm	9
: 1.5+ cm	10
Pre-cluster Leaf	10
Early Tight Cluster	11
Tight Cluster	12
Early Bud Expansion	13
Bud Expansion	14
Early Pink	15
Pink	16
Full Pink	17
1 Blossom	18
2-3 Blossoms	19
4+ Blossoms	19.5
Full Bloom	20.5
Early Petal Fall	22
Mid Petal Fall	23
Late Petal Fall	24
Early Fruit Set	25
Mid (2-3) Fruit Set	26
Late (4+) Fruit Set	27
Fruit Diameter (cm):	
<0.5 cm	28
0.5 - 0.9 cm	29
1.0 - 1.4 cm	30
1.5 - 1.9 cm	31
2.0 - 2.4 cm	32
2.5 - 2.9 cm	33
3.0 - 3.4 cm	34
3.5 - 3.9 cm	35
4.0 - 4.4 cm	36
4.5 - 4.9 cm	37
5.0 - 5.4 cm	38
5.5 - 5.9 cm	39
6.0 - 6.4 cm	40
6.5 - 6.9 cm	41
7.0 - 7.4 cm	42
7.5 - 7.9 cm	43
8.0 - 8.4 cm	44

Table 2: Vegetative Phenocodes: Used to numerically code morphological development of vegetative shoot growth in apple.

STAGE NAME			CODE
Dormant			1
Early Silver Tip			3
Silver Tip			5
Green Tip:	0 - 0.4 cm		7
	: 0.5 - 0.9 cm		8
	: 1.0 - 1.4 cm		9
	: 1.5+ cm		10
Shoot Growth:			
1 Leaf			11
2 Leaves			12
3 Leaves			13
4 Leaves			14
5 Leaves			15
6 Leaves			16
7 Leaves			17
8 Leaves			18
9 Leaves			19
10 Leaves			20
11 Leaves			21
12 Leaves			22
13 Leaves			23
14 Leaves			24
15+ Leaves			CODE = leaf number + 10
Terminal Bud Set:			
Dwarfing Rootstocks			
	Spur Types:	Spur	25
		Terminal	30
Standard Rootstocks:		Spur	30
		Terminal	32

made on 40 spur and 40 terminal buds (tagged), and the stage of growth recorded for each bud. As growth progressed each bud was classified as being either vegetative or reproductive. Mean phenocodes for each sampling date and shoot type were calculated. A weighted growth indice (WGI) was calculated as follows:

where $t_j = t_1 < t_2 < t_k$ for $j = 1...k$

$$WGI_{tj} = \frac{\Sigma(P_j + X_j)}{(PN)_j + N_j}$$

t = time in days

P = phenocode (from tagged shoots) at time t_j for $j = 1...k$

PN = number of observations of tagged shoots/shoot type at time t_j for $j = 1...k$

X = phenocode (from random shoots) at time t_j for $j = 1...k$

N = number of random observations of a particular shoot type at time t_j for $j = 1...k$

WGI = weighted growth indice.

Observations were continued throughout the growing season, and the weighted growth index was used as the dependent variable from dormant through tight cluster. Beyond tight cluster there was virtually no difference between the unweighted growth indice and the weighted indice, so only the unweighted indice was used.

Weather Variables

Daily maximum and minimum temperatures, rainfall, pan evaporation, humidity, soil temperature, and wind speed were recorded beginning April 1 for each of the monitored orchard sites and compiled on the M.S.U. PMEX network. Degree-day accumulation was calculated using the Baskerville and Emin method (6). Degree hour information was not available at each site, therefore it was not used even though this method is considered more accurate for prediction (48). Weather forecasts on the PMEX network could be a good source of inputs for the predictive model (50). In most years in East Lansing, measurable growth does not begin until April 1 (eg. biofix is not reached). Weather data are not recorded on the PMEX system prior to April 1, and therefore are unavailable to growers and were excluded from the development of the model.

Adjusting the Phenocode

The vegetative phenocode for leaf number was set at: leaf code = leaf number + 10. The Terminal Bud Set (TBS) code for spurs and terminal extension shoots was set at 43 to be consistent for all shoots and to allow an interval for coding extension shoots with large (½25) leaf numbers. This caused large standard deviations for calculated growth indices on sampling dates during early bud set (eg. some shoots were still growing and some were set) (Table 3). Larger standard deviations were observed for spur shoots, since they are shorter and develop fewer leaves. Ideally, a 'floating' bud set code could be used where: TBS_t = leaf $code_{t+1}$. This would result in the lowest variance if the growth indice was calculated for each individual shoot. Since consistent coding/shoot type is necessary to maintain morphological significance, (eg. a leaf code of 30 should not = 20 leaves in one case and TBS code in another), the floating bud set code was not used.

Average leaves/shoot were calculated for three seasons. Based on 1983 data (HRC) the numeric value for TBS code was adjusted to equal average leaves/shoot + 5. The adjusted TBS code allowed an interval to code most long shoots without overlapping the TBS value, and reduced sampling variances during the early terminal bud set phase (Table 3).

<u>Determination of Degree-Day Base Temperature</u>

A series of linear regressions (using growth indice from 1983 HRC data as the dependent variable) were calculated testing base temperatures between 40 ^{o}F (4.4^{o}C) to 50 ^{o}F (10^{o}C) (temperature selection based on a review of the literature). Degree-day accumulations used for model development were calculated using the base temperature having the highest coefficient of determination. To verify

Table 3: The influence of Terminal Bud Set (TBS) phenocode on standard deviation and growth index (GI) using two phenology coding systems: 1)Terminal Bud Set code = 43, or 2) revised Terminal Bud Set code = 30, as related to percent terminal bud set (cv. Red Delicious, vegetative spurs, 1983, HRC).

Date	%Bud Set	GI using[z] TBS=43	Std. Dev.	GI using[z] TBS=30	Std. Dev.
5/27	0	18.9	1.12	18.9	1.12
6/8	50	32.1	11.26	25.6	4.62
6/10	65	35.5	10.59	27.0	4.27
6/14	80	39.3	7.71	28.9	2.41
6/17	85	39.5	7.19	29.1	1.86
6/24	95	42.5	2.46	30.1	0.45

[z] Growth Index (GI) calculated using coding system with TBS=43 or revised with TBS=30 to lower standard deviation (based on observed leaves/shoot).

base temperature selection the prediction equation selected for Red Delicious (reproductive spur) was tested using degree-day accumulations calculated at base temperatures between 40°F (4.4°C) and 50°F (10°C). The base temperature with the highest coefficient of determination and lowest sums of squares was selected (Table 5).

Model Development: Phase I

A series of linear and non-linear regressions using growth indice (GI_{tj} or WGI_{tj}) as the dependent variable, and degree-day accumulation (base 40°F (4.4°C), at time=tj) as the independent variable, were calculated to develop the most accurate prediction equation. Since the simplest model was preferred, linear models were tried first. Linear and multiple regression analysis were calculated using Genstat (28). Non-linear regression analysis was calculated using PLOTIT (18). The variables age, minimum and maximum temperature, precipitation, pan evaporation, and wind speed were considered as independent variables in the multiple linear models. Non-linear functions ranged in complexity from a two parameter exponential equation, to a five parameter logistic saddle (sigmoidal) function.

The first phase of model selection was based on the residual sums of squares, the coefficient of determination, and the visual fit of the regression line to the observed data.

Adaptation of the Biofix Concept for Prediction

Methods to adapt the predictive equations for use in other locations and years than those for which they were developed were examined. A stage of development was arbitrarily chosen as a biofix marker to represent the onset of growth.

where:

Prediction equation: $Y=B(1)/(1+EXP(B(2)-B(3)*(DD)+B(4)*(DD)^2 -B(5)*(DD)^3))$

DD= degree-days accumulated from April 1.

If silver tip was selected as the Biofix the prediction equation would be adjusted as follows:

$$Y=B(1)/(1+EXP(B(2)-B(3)*(DD-BIOFIX)+B(4)*(DD-BIOFIX)^2 -B(5)*(DD-BIOFIX)^3))$$

BIOFIX = degree-days accumulated from April 1 to silver tip

A second method utilizing a biofix marker adjusted the input values for the year (or location) to be predicted (eg. 1985) to reference the equivalent biofix marker from the original prediction curve (fit to the original data set 1983,HRC). The equations were adjusted by calculating the difference between the biofix value derived from the original prediction curve (based on 1983 data) and the biofix value observed in the year to be predicted (1985). The Biofix Difference equation follows:

$$BD = (BIOFIX\ B) - (BIOFIX\ A)$$

where:

BD = Biofix Difference

BIOFIX A = degree-days accumulated from April 1, 1983 to biofix stage (eg. silver tip), derived from the prediction curve

BIOFIX B = degree-days accumulated from (eg.) April 1, 1986 to biofix stage = silver tip

Therefore, the prediction equation would be adjusted as follows:

$$Y=B(1)/(1+EXP(B(2)-B(3)*(DD-BD)+B(4)*(DD-BD)^2 -B(5)*(DD-BD)^3))$$

Model development: Final Selection and Testing

Predicted phenocode values were calculated (using Genstat) for a range of sampling dates (representing the whole season) using the four models selected as having the best statistical and visual 'fits'. Testing and final model selection were combined by calculating predictions for each case (variety and shoot type) using data sets collected at the HRC in 1982 and 1984 or at the Graham Station in 1983. Predictions were made using both the biofix and the biofix difference values to modify the degree-day accumulation input value. The predicted values calculated using each model were compared to the observed values for each date. The final model selected predicted values closest to the observed values through the observed range of dates, over years and/or locations.

Developing a Partial Season Sub-model

Whole season growth was subdivided and these portions were modeled separately, with the objective of developing a model with fewer parameters and more accurate predictions for all portions of the growth curve. Linear and non-linear regression used the same variables as the whole season modeling. Vegetative curves were sectioned: a) dormant through green tip and b) first leaf through TBS. Reproductive curves were divided into stages: a) dormant through tight cluster b) tight cluster through fruit set and c) fruit growth.

A sub-model describing flower development from tight cluster through fruit set was developed using a refined phenocode. Phenological observations during flower development were recorded on 4 reproductive spurs/tree and 4 reproductive terminals/tree, in two orchards (Red Delicious/Std and spur type Golden Delicious/MM106), at the HRC, in 1983. A detailed phenocode dividing flowering into 20 stages of flower bud expansion was developed (Table 4,

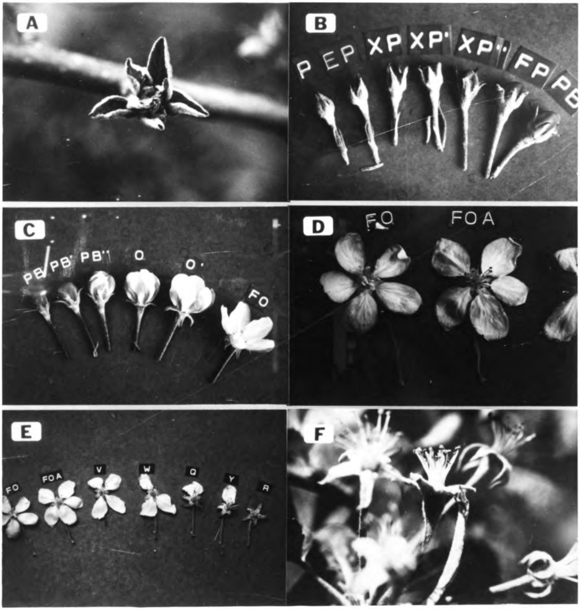
Figure 1). Individual flowers were rated, and an average phenocode/cluster was calculated. A Flower Development Index (FDI) was calculated daily by averaging the phenocode values for all clusters/shoot type/variety (100-110 observations).

Linear and non-linear regressions using FDI as the dependent variable and degree-day accumulation (base $40^{o}F$) as the independent variable were calculated. Model selection procedure and criteria were the same as that used to develop the whole season prediction equations.

Table 4: Expanded Flowering Phenocodes: Used to numerically code flower development in apple.

Phenophase	Code	Figure 1
Early Bud Expansion	0	A
Bud Expansion	1	n.a.
Early Pink	2	B
Pink	3	B
Expanded Pink 1	4	B
Expanded Pink 2	5	B
Expanded Pink 3	6	B
Full Pink	7	B
Pre-bloom 1	8	B,C
Pre-bloom 2	9	C
Pre-bloom 3	10	C
Open Petal 1	11	C
Open Petal 2	12	C
Full Open Blossom 1	13	C,D,E
Full Open Blossom 2 (aged pollen)	14	D,E
Petal Fall 1 (1 petal off)	15	E
Petal Fall 2 (2 petals off)	16	E
Petal Fall 3 (3 petals off)	17	E
Petal Fall 4 (4 petals off)	18	E
Early Fruit Set	19	E
Fruit Set	20	F

Figure 1. A-F. Photographs documenting the phenophases used to develop the flowering sub-model referenced by in Table 3.


A
B
P
EP
XP
XP'
XP''
FP
PB
C
PB
PB'
PB''
O
O'
FO
D
FO
FOA
E
FO
FOA
V
W
Q
Y
R
F

Results

Degree-Day Accumulation: Base Temperature Determination

Linear regression using growth indice (GI) (cv. Red Delicious, reproductive spurs ,1983, HRC) as the dependent variable and degree-day accumulation as the independent variable, resulted in the highest coefficient of determination when degree-days were calculated at a base temperature of 40^{o}F (4.4^{o}C) (data not shown). Non-linear regression using growth indice (GI) (cv. Red Delicious, reproductive spurs, 1983, HRC) as the dependent variable and degree-day accumulation as the independent variable calculated with the model : Y=B1/(1.+EXP(B2 +B3*X + B4*X*X + B5*X**3)) also resulted in the highest coefficient of determination and lowest residual sums of squares when degree-days were calculated at a base temperature of 40^{o}F (4.4^{o}C) (Table 5).

Model Development: Whole Season Model

Non-linear regression using degree-day accumulation base 40^{o}F (4.4^{o}C) as the independent variable yielded higher coefficients of determination, lower sums of squares, and better visual fits for all shoots and varieties than either linear or multiple regression equations (Table 6,7). Multiple regression with models containing some or all of the independent variables degree-day accumulation, age,

Table 5:The coefficient of determination and residual sums of squares for base temperatures 40-50, for the relationship between degree days and growth indice (GI) in Red Delicious (1983,HRC) for the model: Y=B(1)/1.+EXP(B(2)+B(3)*X+B(4)*X*X+B(5)*X**3))

Base Temp.[z] ^oF (^oC)	Coefficient of Determination	Residual Sum of Squares
40 (4.4)	.995	31.2
41 (5.0)	.995	33.0
42 (5.6)	.995	35.1
43 (6.1)	.995	37.6
44 (6.7)	.994	40.3
45 (7.2)	.994	43.1
47 (8.3)	.993	49.0
50 (10.0)	.991	59.2

[z] Degree days are reported in Fahrenheit on PMEX, therefore ^oF were used.

Table 6:Regression statistics for phenology data fit to a series of non-linear functions of increasing complexity (model parameters = B1 up to B5): (cv) Red Delicious reproductive spur growth where Y = growth index (GI) and X = degree day accumulation.

Model	Coefficient of Determination	Residual Sums of Squares
Linear: Y=B(0) + B(1)*X	.872	1640.98
1st Order Asymptotic Exponential: Y=B(1)*(1.0-EXP(-B(2)*X))	.987	131.97
Exponential With Position Constant: Y=B(1)*EXP(B(2)*X) + B(3)	.992	54.44
1st Order Monomolecular: Y=B(1)*(1.0-B(2)*EXP(-B(3)*X))	.992	54.44
Richard's: Y=B(1)*(1.0-EXP(-B(2)*X))**B(3)	.992	51.81
Multiplicative Exponential: Y=B(1)*(X**B(2)*EXP(B(3)*X)	.989	78.74
2nd Order Monomolecular: Y=B(1)*(1.+B(2)*EXP(-(B(3)*X+B(4)*X**2)))	.994	44.62
2nd Order Logistic: Y=B(1)/(1.+B(2)*EXP(-(B(3)*X+B(4)*X**2)))	.978	152.13
Additive Exponential: Y=B(1)*EXP(B(2)*X)+B(3)*EXP(B(4)*X)	.996	25.49
Monomolecular Saddle Function: Y=B1*(1-EXP(-(B2+B3*X+B4*X*X+B4*B4*X**3/(3*B3))))	.993	47.09
Logistic Saddle Function: Y=B1/1+EXP(B2+B3*X+B4*X*X+B4*B4*X**3/(3*B3))))	.994	38.77
Logistic Saddle Function: Y=B(1)/(1.+EXP(B(2)+B(3)*X+B(4)*X*X+B(5)*X**3))	.995	31.20

Table 7: Coefficients of determination for selected multiple linear regression models: (cv) Red Delicious - reproductive spurs, (1983,HRC)

Model	R^2
1) Degree days	.872
2) Age, Degree days	.939
3) Age, Degree days, Pan evaporation	.969
4) Age, Degree days, Precipitation	.965
5) Degree days, Max temp, Min temp	.785
6) Age, Degree days, Precipitation, Pan evaporation	.972
7) Age, Degree days, Max temp, Precipitation	.983
8) Age, Degree days, Max temp, Pan evaporation	.981
9) Age, Degree days, Max temp, Min temp	.980
10) Age, Degree days, Max temp, Pan evaporation, Precipitation	.982
11) Age, Degree days, Max temp, Min temp, Pan evaporation, Precipitation	.984

minimum and maximum temperature, precipitation, pan evaporation, and wind resulted in higher coefficients of determination when compared to the linear function with degree-day accumulation as the independent variable (Table 7), but when compared to the non-linear models there was no improvement (Table 6,7).

Several non-linear regression equations resulted in a high correlation between variables (Table 6), and a good visual fit through most of the seasonal growth curve (Figure 2). Sample predictions calculated using the four 'best fit' non-linear functions for a seasonal range of dates resulted in predicted values closer to observed values more often for the Logistic saddle function (Model 4) than for other fuctions tested (Table 8).

R^2 values did not indicate the predictive ability of a function, with visual fit a better indicator. Plots of the data showed points along the predicted curve where the predicted line deviated from the observed data (Figure 2). Predictions were less accurate for those portions of the season (compare Figure 2 to Table 8).

Assignment of biological significance to equation parameters was also considered during equation selection. Approaching harvest, fruit growth rate decreased, leading gradually to a maximum diameter. A function that accurately described asymptotic growth would be the logical choice, however an additive exponential function also fit the data well (Figure 2A). The exponential function generated an

Table 8: Observed and predicted phenophase for a seasonal range of degree days (DD) as predicted by 4 models (selection based onstatistical and visual fits to 1983 data) for spur type Golden Delicious reproductive spur growth (HRC, 1985).

DD[y]	Observed	Predicted[x] Model 1	Predicted Model 2	Predicted Model 3	Predicted Model 4
144.3	7.0	5.96	6.02	5.81	7.39z
224.6	12.0	10.18	10.12	7.78	10.57z
453.1	20.5	19.22	18.98	18.97	20.32z
536.7	24.0	21.67	20.87	22.32	23.31z
809.3	29.8	27.51	27.37	29.59	29.64z
1008.2	32.0	30.29	30.31	32.11z	31.89z
1507.1	35.0	34.29	34.75	33.97z	33.89
2553.0	38.0	37.62	38.25	36.24	37.79z
5000.0	41.0	41.88z	-	-	39.77
5500.0	41.0	42.75	-	-	39.77z

z Predicted value closest to observed value for each DD.

y Degree Days calculated at base 40 using the Baskerville and Emin method (2).

x Model 1: Y=B(1) * EXP(B(2) * X) + B(3) * EXP(B(4) * X)

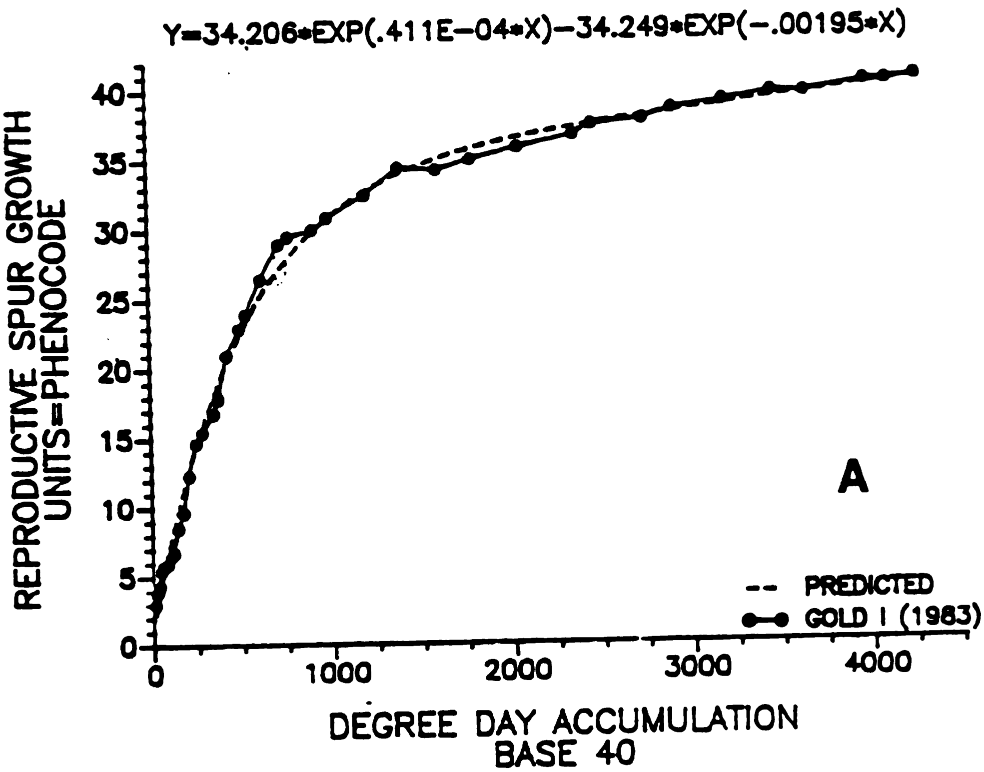
Model 2: Y=B1*(1-EXP(-(B2+B3*X+B4*X*X+B4*B4*X 3/(3*B3))))

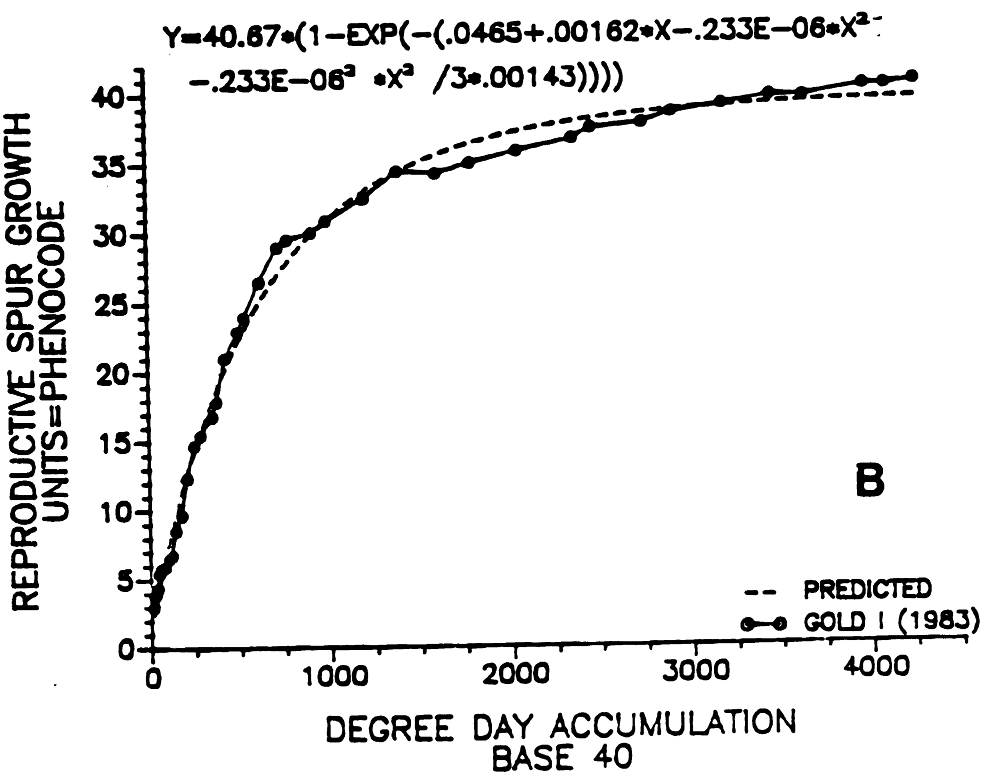
Model 3: Y=B1/(1+EXP(B2+B3*X+B4*X*X+B4*B4*X 3/(3*B3))))

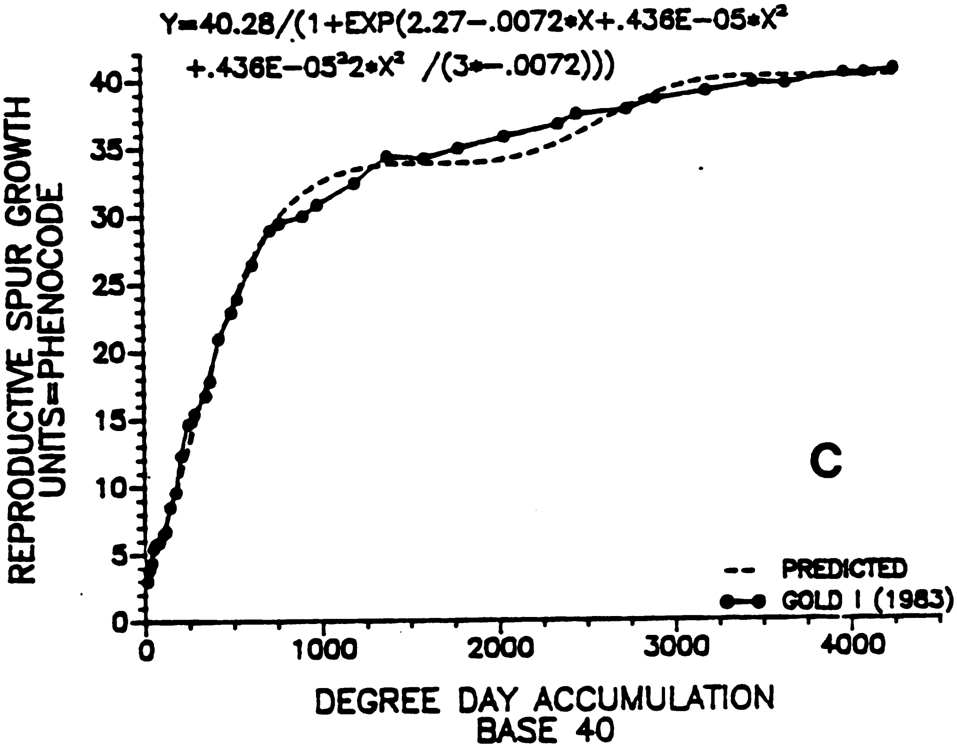
Model 4: Y=B(1)/(1+EXP(B(2)+B(3)*X+B(4)*X*X+B(5)*X 3))

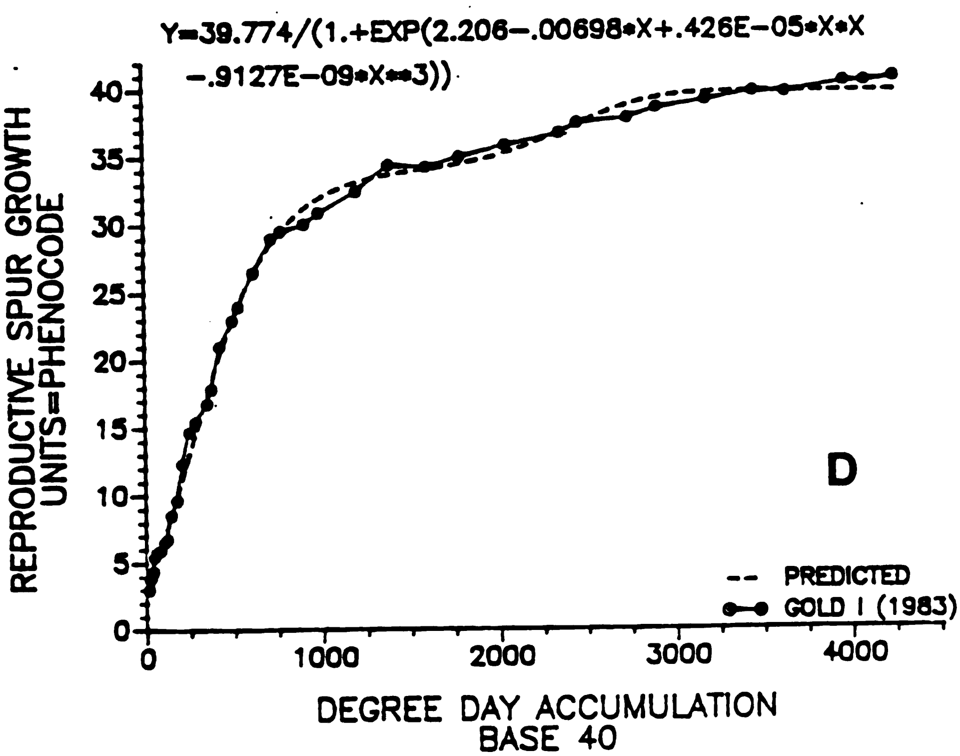
where: X = Degree days - biofix difference (see text)

Figure 2: Observed (line with symbols) and predicted (---) phenophase for 4 'best fit' models (selection based on statistical fit) for spur type Golden Delicious (Gold I) (HRC, 1983): A: Additive Exponential, B: Monomolecular Saddle Function, C: Logistic Saddle Function (4 parameter), D: Logistic Saddle Function (5 parameter).


Y=34.206*EXP(.411E-04*X)-34.249*EXP(-.00195*X)
REPRODUCTIVE SPUR GROWTH
UNITS=PHENOCODE
0
5
10
15
20
25
30
35
40
A
-- PREDICTED
GOLD I (1983)
0
1000
2000
3000
4000
DEGREE DAY ACCUMULATION
BASE 40


Y=40.87*(1-EXP(-(.0465+.00162*X-.233E-06*X²-
-.233E-06² *X³ /3*.00143))))
REPRODUCTIVE SPUR GROWTH
UNITS=PHENOCODE
0
5
10
15
20
25
30
35
40
B
-- PREDICTED
GOLD I (1983)
0
1000
2000
3000
4000
DEGREE DAY ACCUMULATION
BASE 40


Y=40.28/(1+EXP(2.27-.0072*X+.436E-05*X²
+.436E-05²2*X² /(3*-.0072)))
REPRODUCTIVE SPUR GROWTH
UNITS=PHENOCODE
C
-- PREDICTED
GOLD I (1983)
DEGREE DAY ACCUMULATION
BASE 40


Y=39.774/(1.+EXP(2.206-.00698*X+.426E-05*X*X
-.9127E-09*X**3))
REPRODUCTIVE SPUR GROWTH
UNITS=PHENOCODE
D
-- PREDICTED
GOLD I (1983)
DEGREE DAY ACCUMULATION
BASE 40

excellent statistical and visual fit of the data, but lacked the appropriate (biologically relevent) parameter to accurately describe the asymptote, overpredicting fruit diameter above 5000 degree-days (harvest = 4200-4400 degree-days) (Table 8).

Vegetative growth followed a rapid rise to the asymptote, culminating at terminal bud set (TBS). Non-asymptotic functions failed to accurately predict cessation of shoot growth, predicting continued leaf emergence beyond harvest (data not shown). The logistic equation selected did exhibit some wavering around data points in the vicinity of the asymptote (Figure 3). This wavering was a function of the equation and resulted in less accurate predictions during some stages of fruit growth (Table 8 Model D), when the predicted curve deviated from the observed values (Figure 3D).

The prediction equation selected had the general form:

(Y= B1/(1.+EXP(B2 + B3*X + B4*X*X + B5*X**3))

B1 = maximum achievable fruit diameter or TBS

B2,B3,B4,B5 = equation parameters describing the curve shape

X = degree-day accumulation from start date (April 1)

The models selcted as prediction equations for whole season growth were: (Figure 3-5)

Red Delicious (Red Del.)

Reproductive Spur (Figure 3A):

$Y=40.497/1+EXP(2.026-.00674*X+.437E-05*X^2-1.005E-08*X^3))$

Reproductive Terminal (Figure 3B):

$Y=40.395/(1+EXP(2.123-.00704*X+.471E-05*X^2-.1108E-08*X^3))$

Vegetative Spur (Figure 3 C):

$Y=29.829/(1+EXP(1.995-.01146*X+.213E-04*X^2-.1725E-07*X^3))$

Vegetative Terminal (Figure 3D):

$Y=32.198/(1+EXP(2.264-.0112*X+.159E-04*X^2-.8872E-08*X^3))$

Golden Delicious (spur type)(Gold I)

Reproductive Spur (Figure 4A):

$Y=39.774/(1+EXP(2.206-.00698*X+.426E-05*X^2-.9127E-09*X^3))$

Reproductive Terminal (Figure 4B):

$Y=38.316/(1+EXP(2.225-.00691*X+.401E-05*X^2-.8521E-09*X^3))$

Vegetative Spur (Figure 4C):

$Y=25.228/(1+EXP(1.958-.01066*X+.187E-04*X^2-.179E-07*X^3))$

Vegetative Terminal (Figure 4D):

$Y=30.0/(1+EXP(2.193-.01011*X+.159E-04*X^2-.8872E-08*X^3))$

Golden Delicious/Std (Gold II)

Reproductive Spur (Figure 5A):

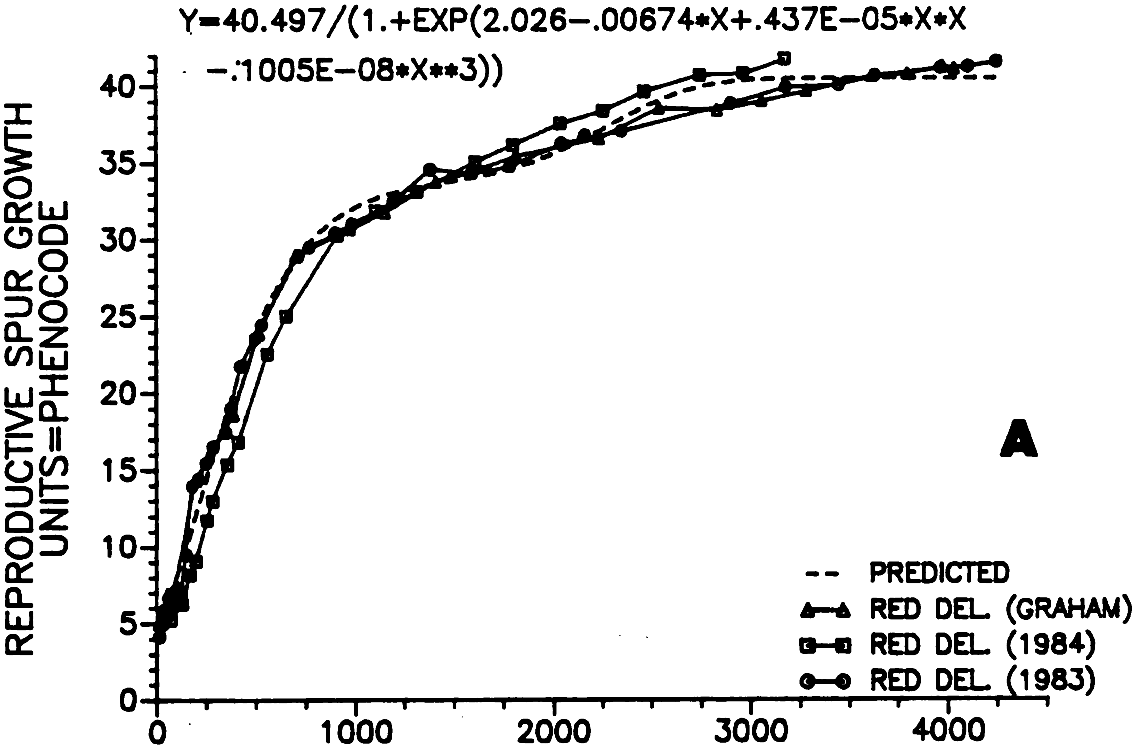
$Y=39.325/(1+EXP(2.207-.00733*X+.486E-05*X^2-.116E-08*X^3))$

Reproductive Terminal (Figure 5B):

$Y=39.26/(1+EXP(2.268-.00741*X+.483E-05*X^2-.1125E-08*X^3))$

Figure 3A. Observed (lines with symbols) and predicted (---) phenophase development for reproductive spur shoot growth as a function of degree-day accumulation, base 40°F, for Red Delicious/Std. (Red Del.).

Figure 3B. Observed (lines with symbols) and predicted (---) phenophase development for reproductive terminal shoot growth as a function of degree-day accumulation, base 40°F, for Red Delicious/Std. (Red Del.).


Y=40.497/(1.+EXP(2.026-.00674*X+.437E-05*X*X
-.1005E-08*X**3))
REPRODUCTIVE SPUR GROWTH
UNITS=PHENOCODE
A
-- PREDICTED
RED DEL. (GRAHAM)
RED DEL. (1984)
RED DEL. (1983)
0
1000
2000
3000
4000
0
5
10
15
20
25
30
35
40

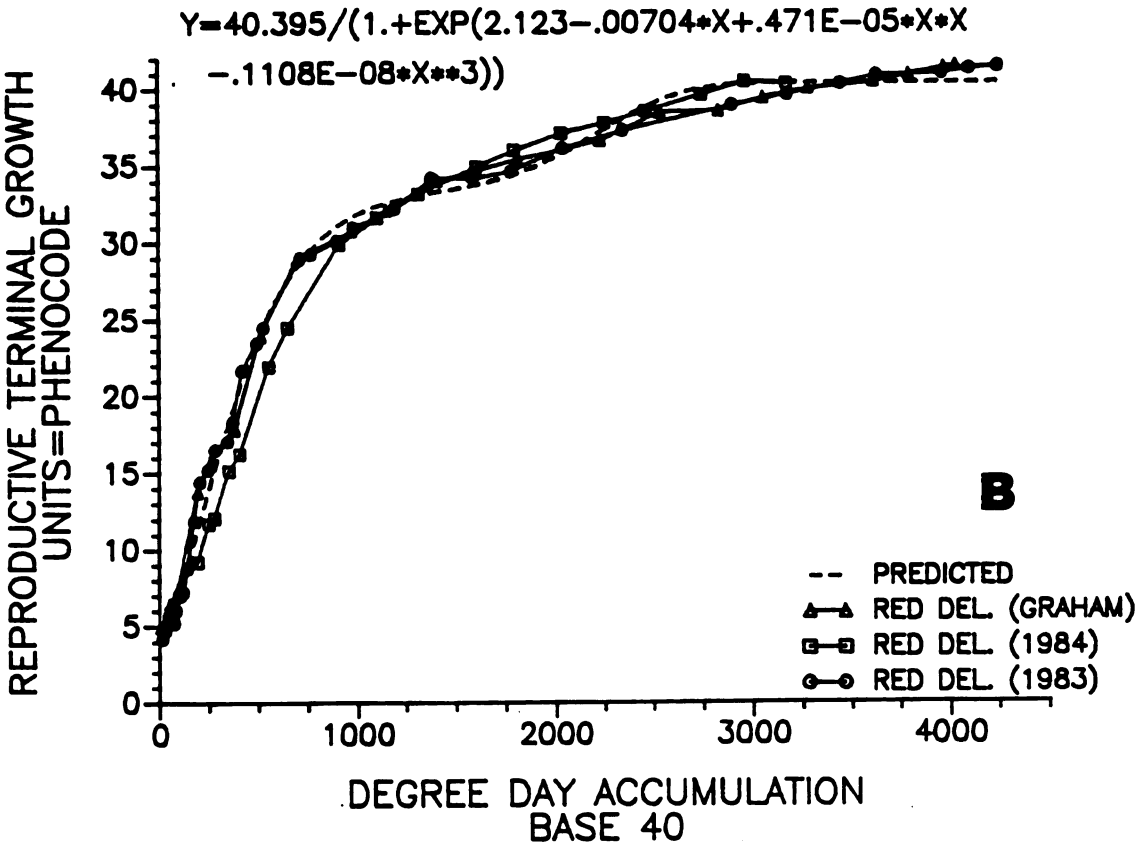

Y=40.395/(1.+EXP(2.123-.00704*X+.471E-05*X*X
-.1108E-08*X**3))
REPRODUCTIVE TERMINAL GROWTH
UNITS=PHENOCODE
B
-- PREDICTED
RED DEL. (GRAHAM)
RED DEL. (1984)
RED DEL. (1983)
0
1000
2000
3000
4000
0
5
10
15
20
25
30
35
40
DEGREE DAY ACCUMULATION
BASE 40

Figure 3C. Observed (lines with symbols) and predicted (----) phenophase development for vegetative spur shoot growth as a function of degree-day accumulation, base 40^{o}F, for Red Delicious/Std.(Red Del.).

Figure 3D. Observed (lines with symbols) and predicted (----) phenophase development for vegetative terminal shoot growth as a function of degree-day accumulation, base 40^{o}F, for Red Delicious/Std. (Red Del.).

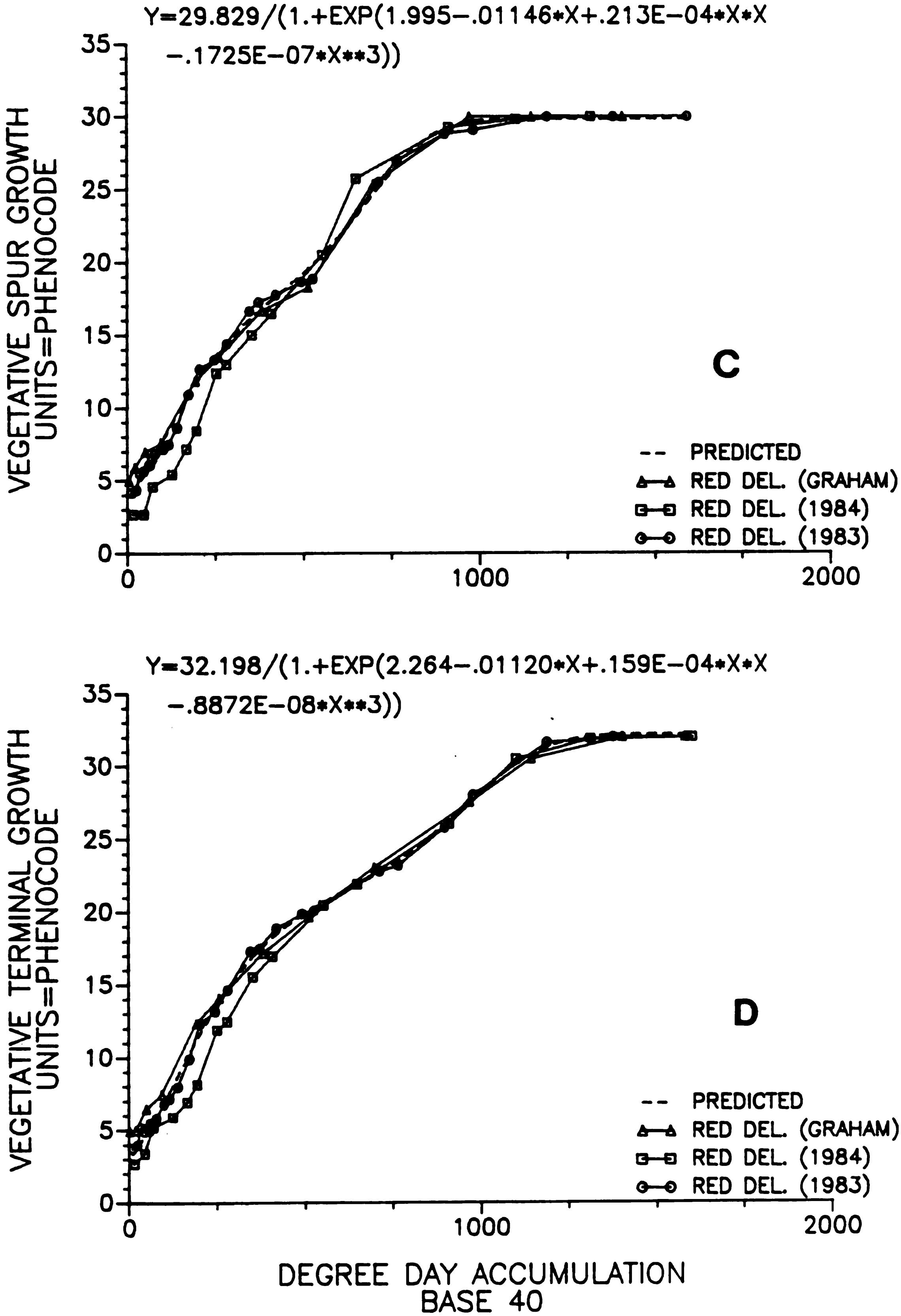
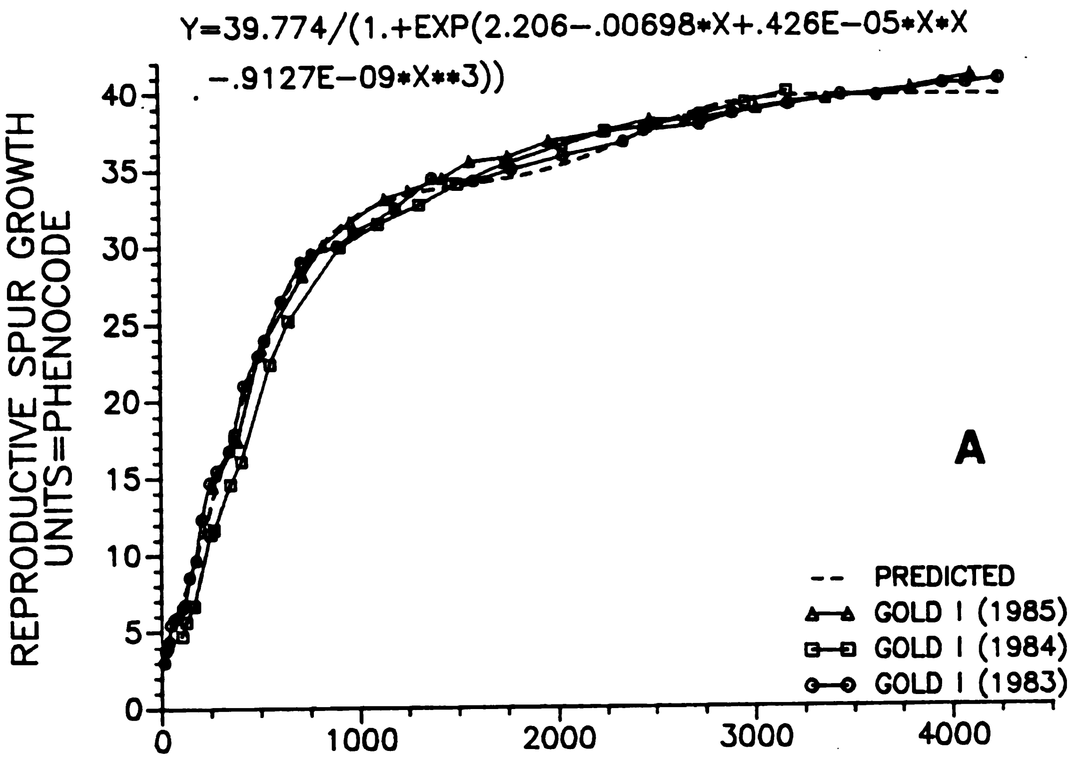

Y=29.829/(1.+EXP(1.995-.01146*X+.213E-04*X*X
-.1725E-07*X**3))
VEGETATIVE SPUR GROWTH
UNITS=PHENOCODE
35
30
25
20
15
10
5
0
0
1000
2000
C
-- PREDICTED
RED DEL. (GRAHAM)
RED DEL. (1984)
RED DEL. (1983)
Y=32.198/(1.+EXP(2.264-.01120*X+.159E-04*X*X
-.8872E-08*X**3))
VEGETATIVE TERMINAL GROWTH
UNITS=PHENOCODE
35
30
25
20
15
10
5
0
0
1000
2000
D
-- PREDICTED
RED DEL. (GRAHAM)
RED DEL. (1984)
RED DEL. (1983)
DEGREE DAY ACCUMULATION
BASE 40

Figure 4A. Observed (lines with symbols) and predicted (---) phenophase development for reproductive spur shoot growth as a function of degree-day accumulation, base 40^{o}F, for spur type Golden Delicious (Gold I).

Figure 4B. Observed (lines with symbols) and predicted (---) phenophase development for reproductive terminal shoot growth as a function of degree-day accumulation, base 40^{o}F, for spur type Golden Delicious (Gold I).


Y=39.774/(1.+EXP(2.206-.00698*X+.426E-05*X*X
-.9127E-09*X**3))
REPRODUCTIVE SPUR GROWTH
UNITS=PHENOCODE
A
-- PREDICTED
GOLD I (1985)
GOLD I (1984)
GOLD I (1983)
0
1000
2000
3000
4000

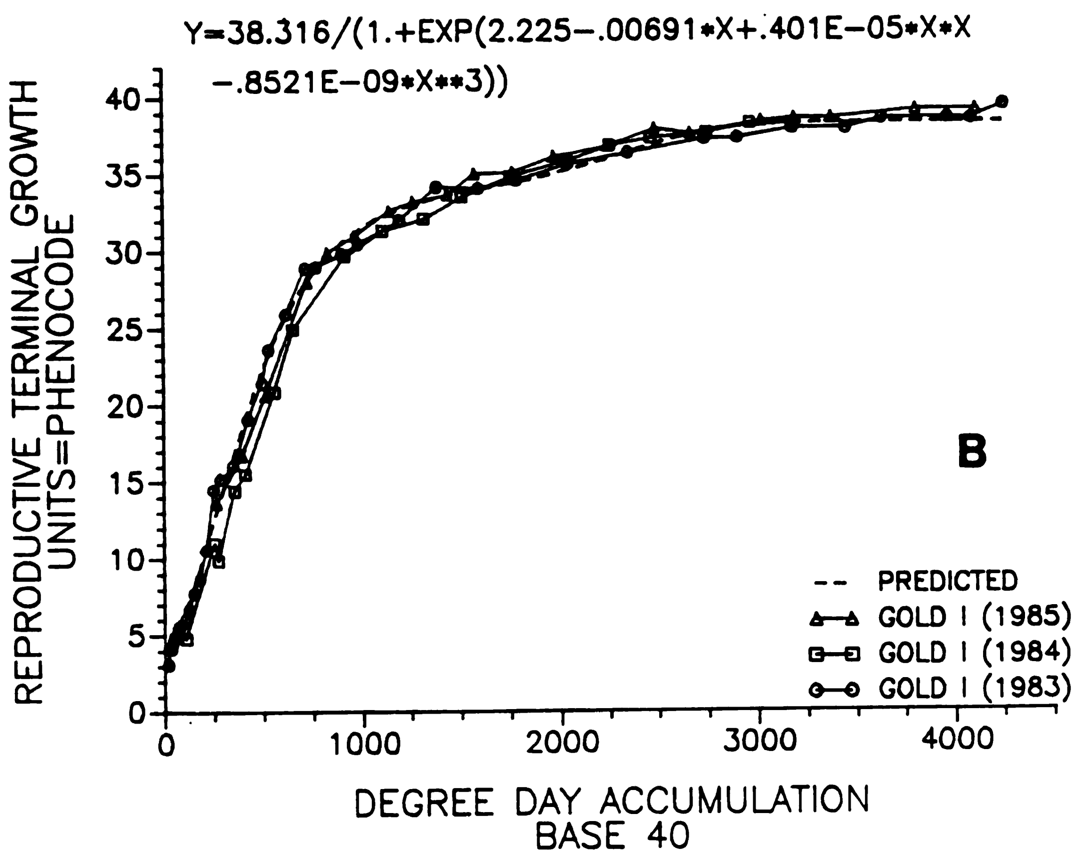

Y=38.316/(1.+EXP(2.225-.00691*X+.401E-05*X*X
-.8521E-09*X**3))
REPRODUCTIVE TERMINAL GROWTH
UNITS=PHENOCODE
B
-- PREDICTED
GOLD I (1985)
GOLD I (1984)
GOLD I (1983)
0
1000
2000
3000
4000
DEGREE DAY ACCUMULATION
BASE 40

Figure 4C. Observed (lines with symbols) and predicted (----) phenophase development for vegetative spur shoot growth as a function of degree-day accumulation, base 40^{o}F, for spur type Golden Delicious (Gold I).

Figure 4D. Observed (lines with symbols) and predicted (----) phenophase development for vegetative terminal shoot growth as a function of degree-day accumulation, base 40^{o}F, for spur type Golden Delicious (Gold I).

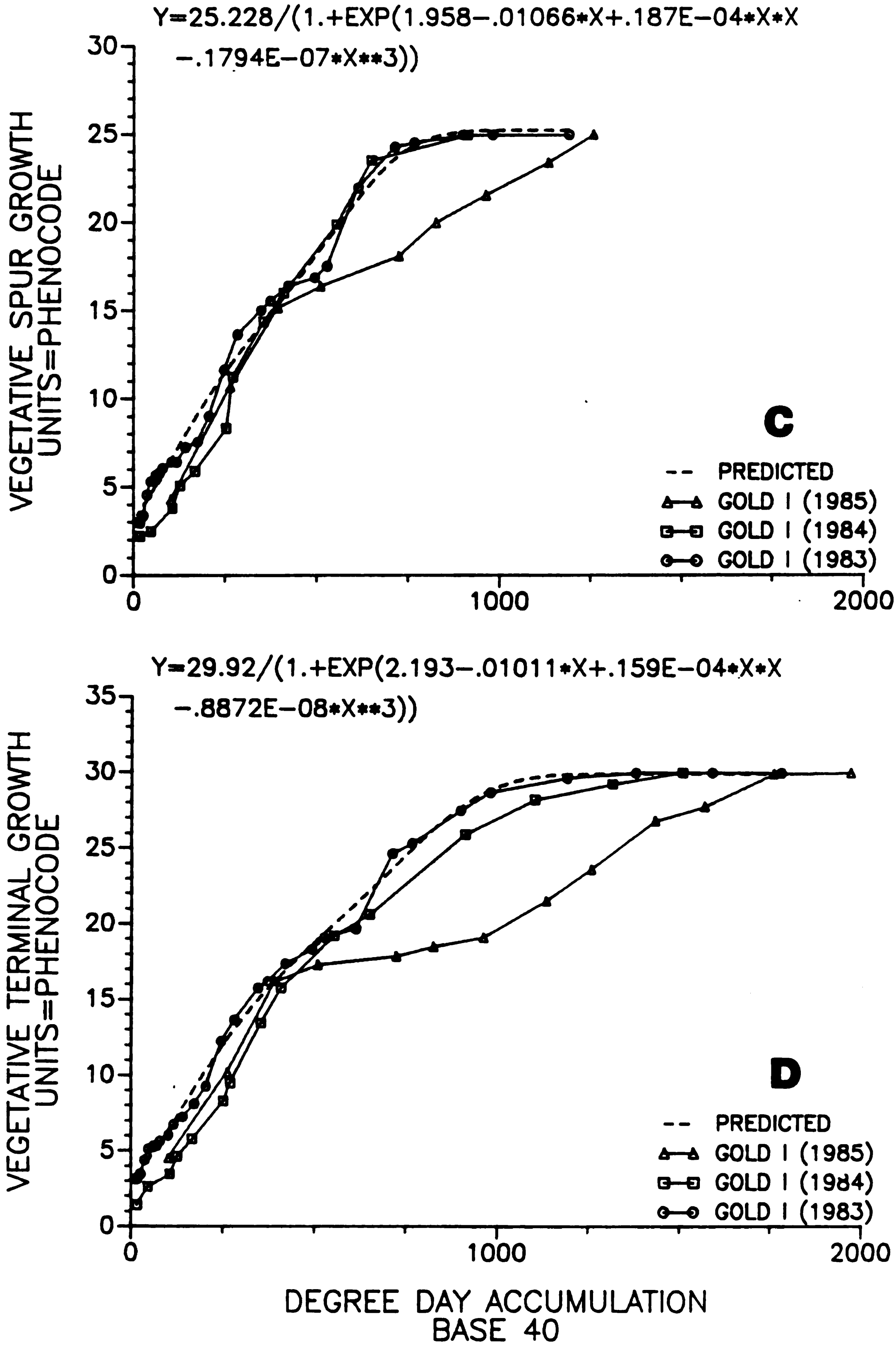

Y=25.228/(1.+EXP(1.958-.01066*X+.187E-04*X*X
-.1794E-07*X**3))
VEGETATIVE SPUR GROWTH
UNITS=PHENOCODE
30
25
20
15
10
5
0
0
1000
2000
C
-- PREDICTED
GOLD I (1985)
GOLD I (1984)
GOLD I (1983)
Y=29.92/(1.+EXP(2.193-.01011*X+.159E-04*X*X
-.8872E-08*X**3))
VEGETATIVE TERMINAL GROWTH
UNITS=PHENOCODE
35
30
25
20
15
10
5
0
0
1000
2000
D
-- PREDICTED
GOLD I (1985)
GOLD I (1984)
GOLD I (1983)
DEGREE DAY ACCUMULATION
BASE 40

Figure 5A. Observed (lines with symbols) and predicted (---) phenophase development for reproductive spur shoot growth as a function of degree-day accumulation, base 40^{o}F, for Golden Delicious/Std. (Gold II).

Figure 5B. Observed (lines with symbols) and predicted (---) phenophase development for reproductive terminal shoot growth as a function of degree-day accumulation, base 40^{o}F, for Golden Delicious/Std. (Gold II).

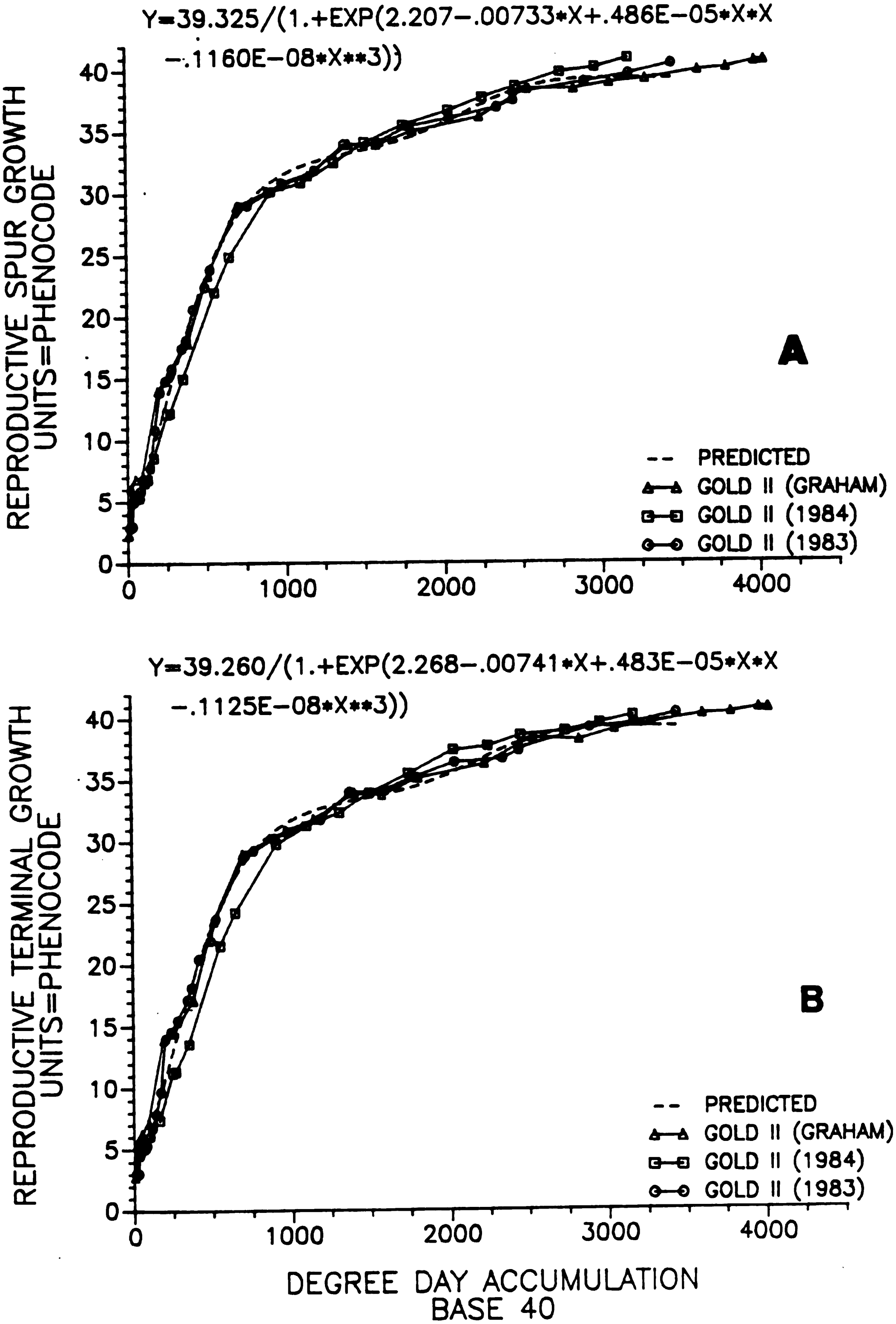
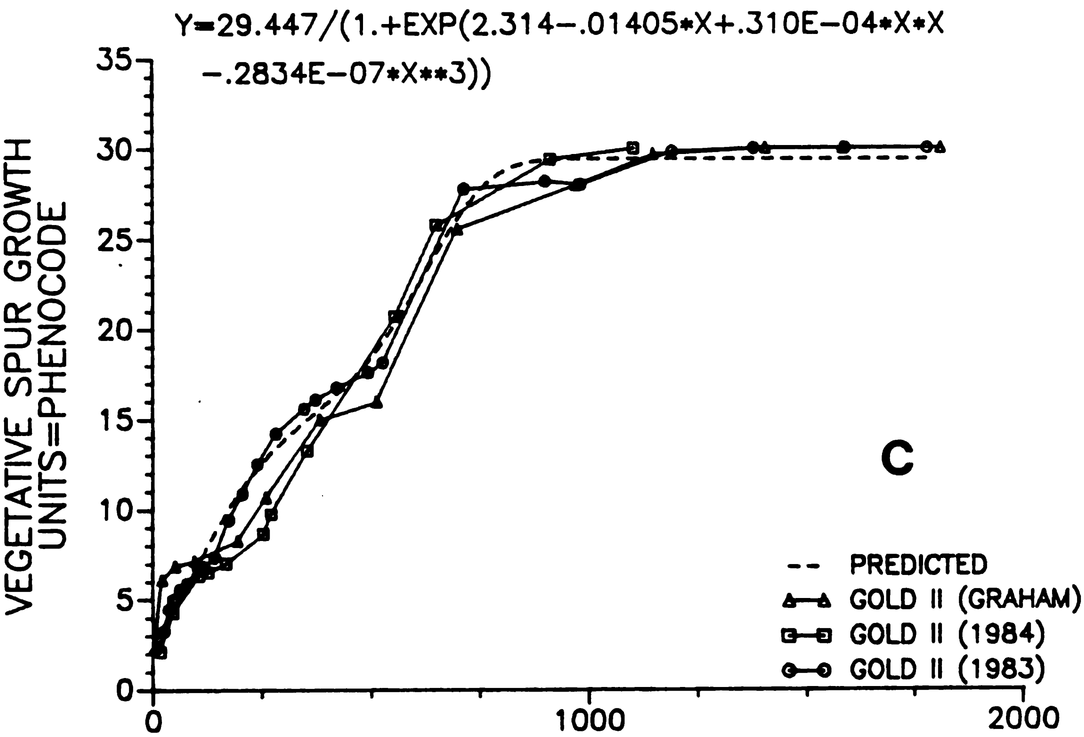
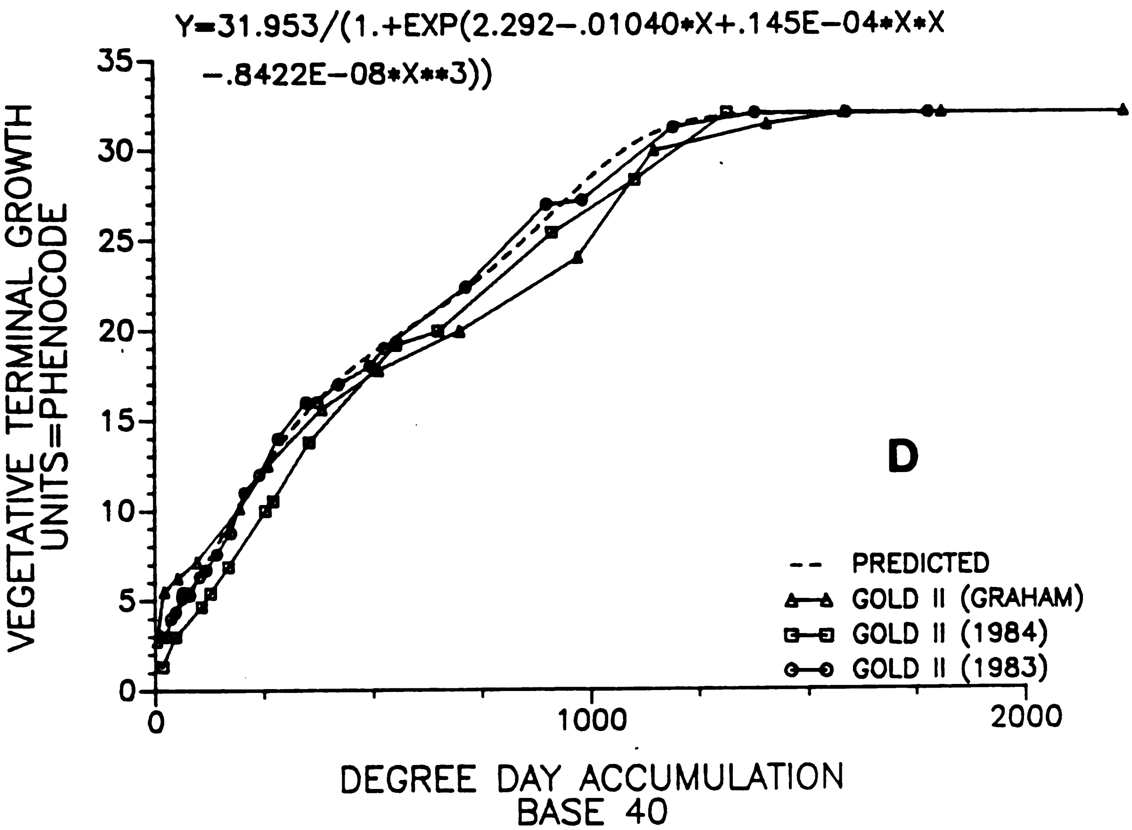

Y=39.325/(1.+EXP(2.207−.00733*X+.486E−05*X*X
−.1160E−08*X**3))
REPRODUCTIVE SPUR GROWTH
UNITS=PHENOCODE
A
-- PREDICTED
GOLD II (GRAHAM)
GOLD II (1984)
GOLD II (1983)
Y=39.260/(1.+EXP(2.268−.00741*X+.483E−05*X*X
−.1125E−08*X**3))
REPRODUCTIVE TERMINAL GROWTH
UNITS=PHENOCODE
B
-- PREDICTED
GOLD II (GRAHAM)
GOLD II (1984)
GOLD II (1983)
DEGREE DAY ACCUMULATION
BASE 40

Figure 5C. Observed (lines with symbols) and predicted (----) phenophase development for vegetative spur shoot growth as a function of degree-day accumulation, base 40°F, for Golden Delicious/Std. (Gold II).

Figure 5D. Observed (lines with symbols) and predicted (----) phenophase development for vegetative terminal shoot growth as a function of degree-day accumulation, base 40°F, for Golden Delicious/Std. (Gold II).


Y=29.447/(1.+EXP(2.314-.01405*X+.310E-04*X*X
-.2834E-07*X**3))
VEGETATIVE SPUR GROWTH
UNITS=PHENOCODE
C
-- PREDICTED
GOLD II (GRAHAM)
GOLD II (1984)
GOLD II (1983)
0
5
10
15
20
25
30
35
0
1000
2000


Y=31.953/(1.+EXP(2.292-.01040*X+.145E-04*X*X
-.8422E-08*X**3))
VEGETATIVE TERMINAL GROWTH
UNITS=PHENOCODE
D
-- PREDICTED
GOLD II (GRAHAM)
GOLD II (1984)
GOLD II (1983)
0
5
10
15
20
25
30
35
0
1000
2000
DEGREE DAY ACCUMULATION
BASE 40

Vegetative Spur (Figure 5C):

$$Y=29.447/(1+EXP(2.134-.01405*X+.310E-04*X^2-.2834E-07*X^3))$$

Vegetative Terminal (Figure 5D):

$$Y=32.0/(1+EXP(2.292-.0104*X+.145E-04*X^2-.8422E-08*X^3))$$

Developing a Partial Season Sub-model

Partial season models derived using the standard phenocodes did not improve predictive accuracy when compared to the whole season model (data not shown). Precise coding of flower development from tight cluster through fruit set yielded prediction equations with fewer parameters and allowed greater resolution between stages (Figure 7B,7D,8B,8D).

When the Flower Development Index (FDI) was plotted against degree-day accumulation the resultant curve was an asymptotic sigmoid function (Figure 6). Curve shapes between varieties were similar , with Golden Delicious flower development trailing that of Red Delicious (Figure 6). The Gompertz, Logistic, and Weibull's functions were selected as 'best fits' based on coefficients of determination and residual sums of squares (Table 9,10). The Gompertz function fit well visually up to petal fall, but did not fit data as closely as the Logistic or Weibull's function, petal fall to fruit set (data not shown). Both the Logistic and Weibull's function resulted in excellent visual fits of the data for both Golden Delicious (Figure 7)

Figure 6. Flower Development Index (FDI) (using Expanded Flowering Phenocodes, Table 3) of Golden Delicious (Gold) and Red Delicious as a function of degree-day accumulation (1983, HRC).

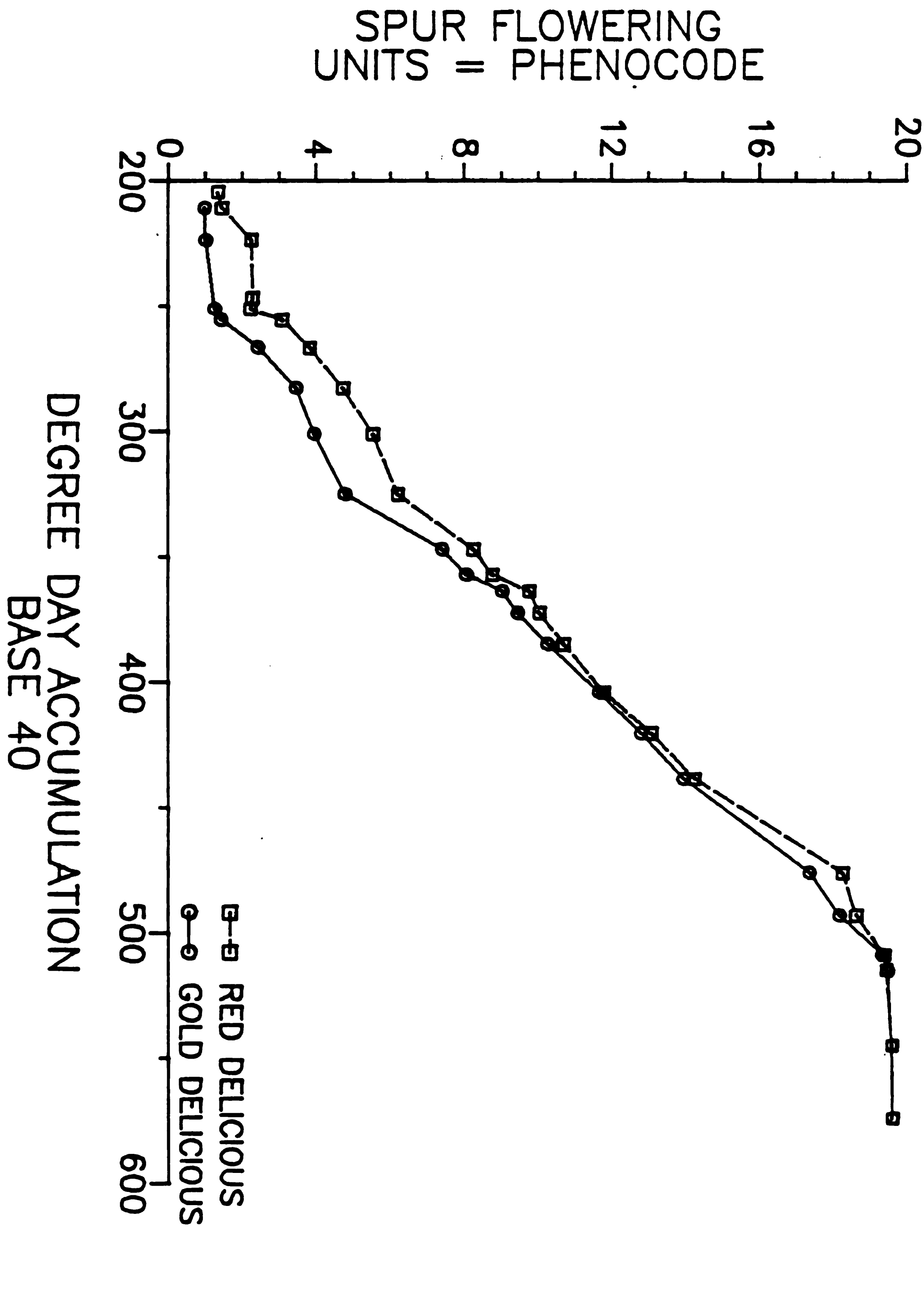
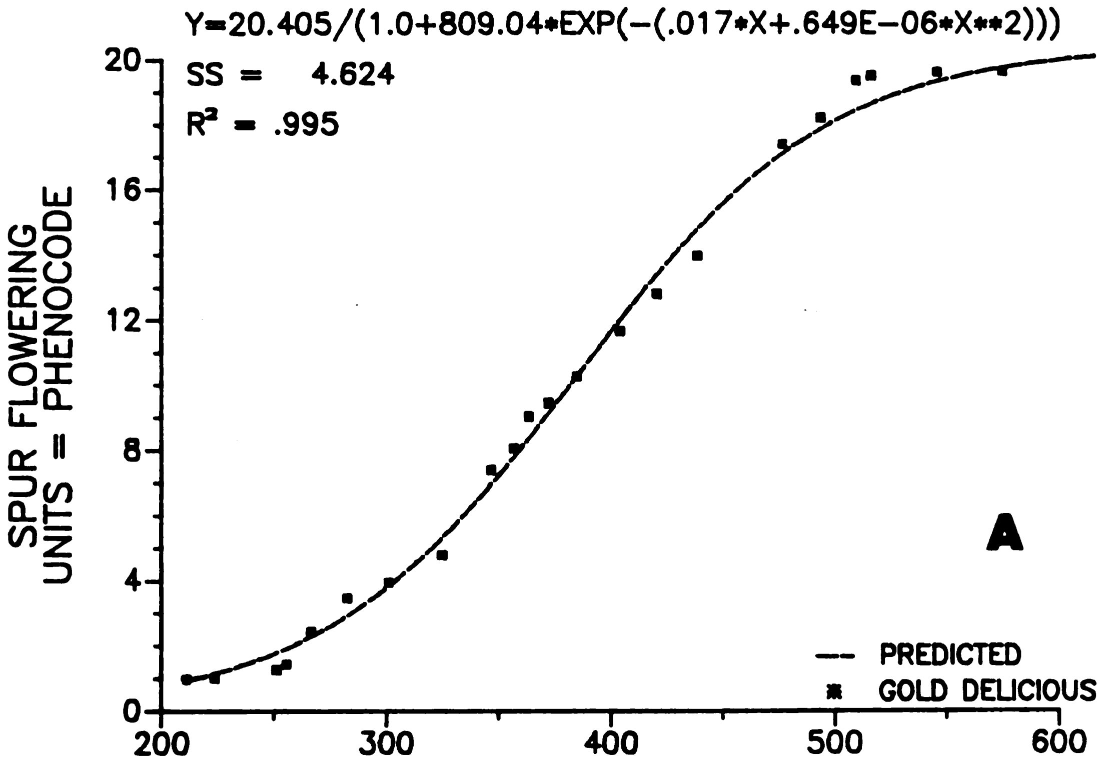
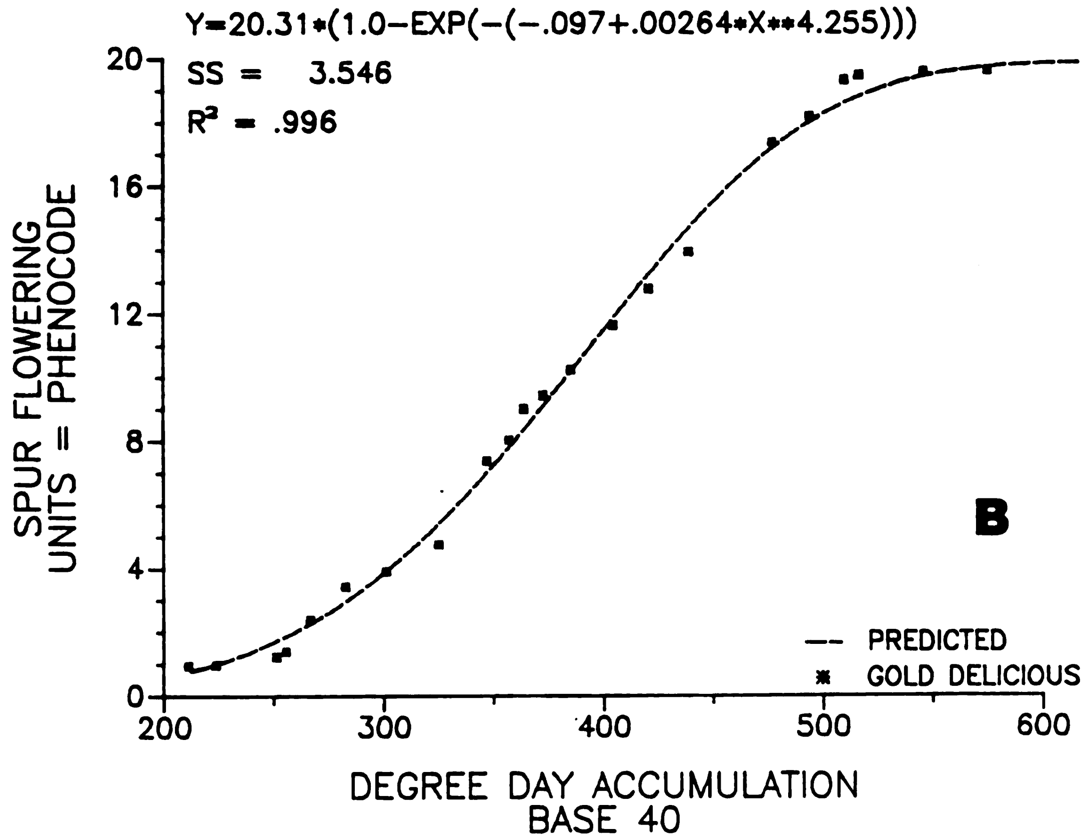

SPUR FLOWERING
UNITS = PHENOCODE
0
4
8
12
16
20
200
300
400
500
600
DEGREE DAY ACCUMULATION
BASE 40
RED DELICIOUS
GOLD DELICIOUS

Figure 7.A: Observed flower development by stage (symbols) and flowering predicted by the Logistic equation (--) for Golden (Gold) Delicious spur growth as a function of degree-day accumulation, base $40^{o}F$.

Figure 7.B: Observed flower development by stage (symbols) and flowering predicted by Weibull's function (--) for Golden (Gold) Delicious spur growth as a function of degree-day accumulation, base $40^{o}F$.



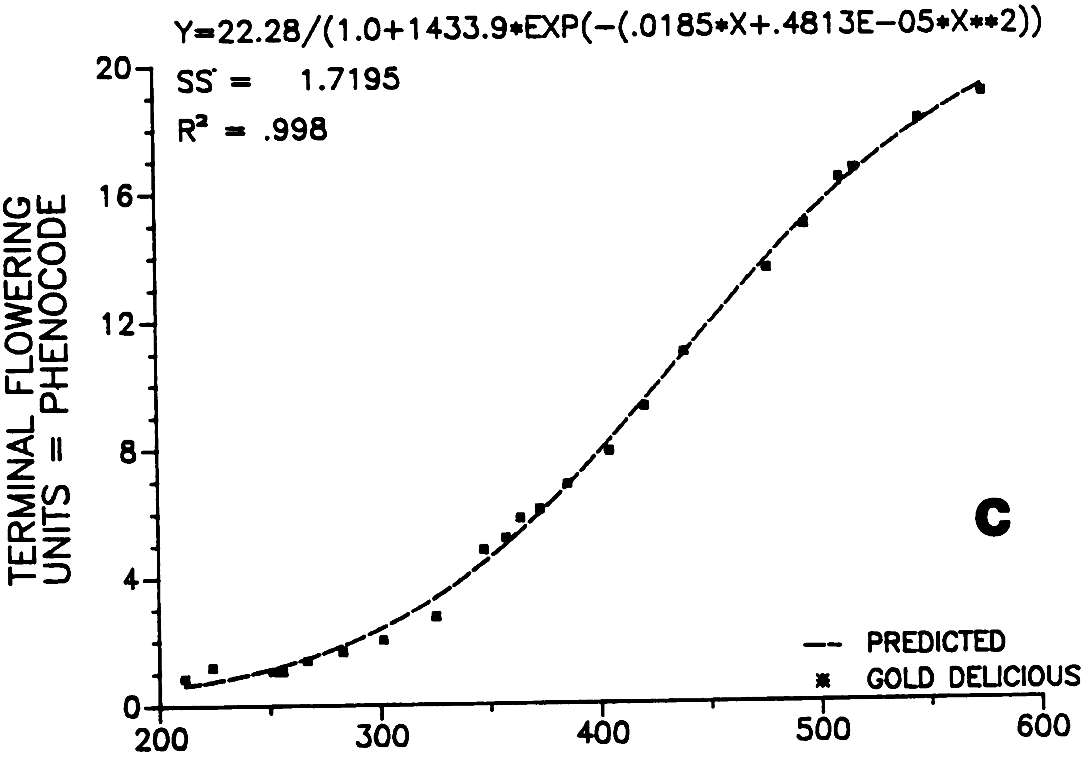
Y=20.405/(1.0+809.04*EXP(-(.017*X+.649E-06*X**2)))
SS = 4.624
R² = .995
SPUR FLOWERING
UNITS = PHENOCODE
0
4
8
12
16
20
200
300
400
500
600
A
PREDICTED
GOLD DELICIOUS



Y=20.31*(1.0-EXP(-(-.097+.00264*X**4.255)))
SS = 3.546
R² = .996
SPUR FLOWERING
UNITS = PHENOCODE
0
4
8
12
16
20
200
300
400
500
600
B
PREDICTED
GOLD DELICIOUS
DEGREE DAY ACCUMULATION
BASE 40

Figure 7.C: Observed flower development by stage (symbols) and flowering predicted by the Logistic equation (--) for Golden (Gold)Delicious terminal growth as a function of degree-day accumulation, base 40^{O}F.

Figure 7.D: Observed flower development by stage (symbols) and flowering predicted by Weibull's function (--) for Golden (Gold) Delicious spur growth as a function of degree-day accumulation, base 40^{O}F.


Y=22.28/(1.0+1433.9*EXP(-(.0185*X+.4813E-05*X**2))
SS = 1.7195
R² = .998
TERMINAL FLOWERING UNITS = PHENOCODE
C
PREDICTED
GOLD DELICIOUS
0
4
8
12
16
20
200
300
400
500
600

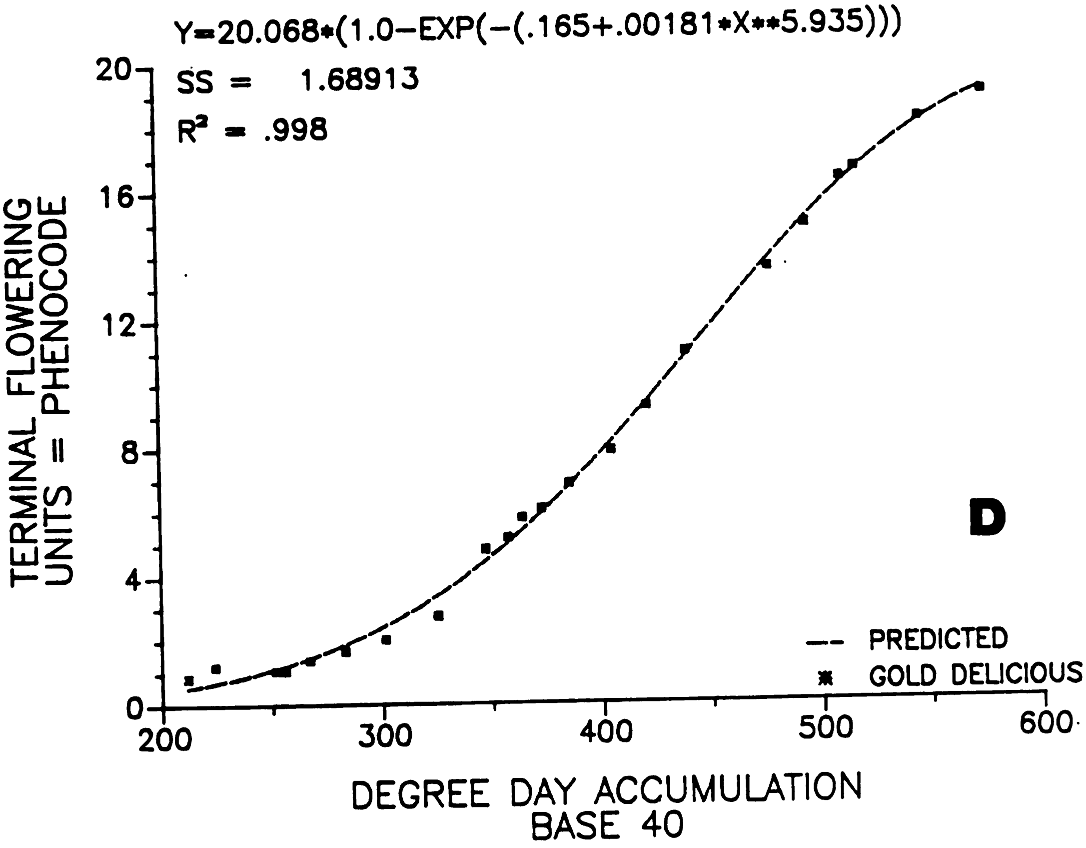
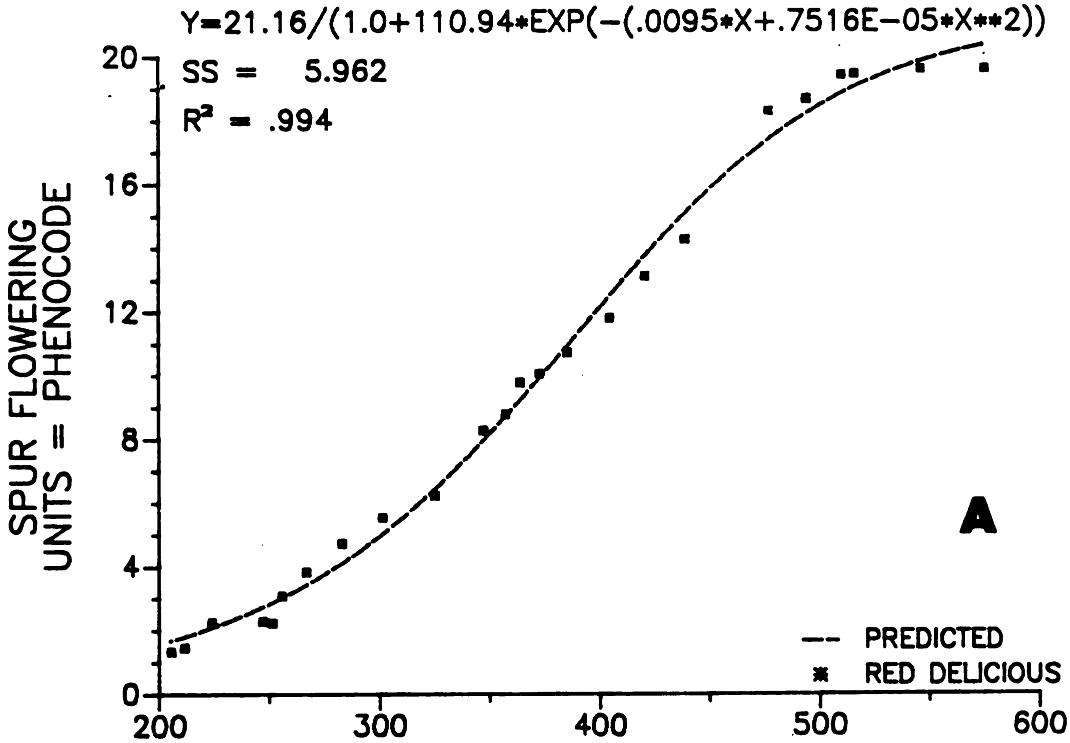

Y=20.068*(1.0-EXP(-(.165+.00181*X**5.935)))
SS = 1.68913
R² = .998
TERMINAL FLOWERING UNITS = PHENOCODE
D
PREDICTED
GOLD DELICIOUS
0
4
8
12
16
20
200
300
400
500
600
DEGREE DAY ACCUMULATION
BASE 40

Figure 8.A: Observed flower development by stage (symbols) and flowering predicted by the Logistic equation (--) for Red Delicious spur growth as a function of degree-day accumulation, base 40°F.

Figure 8.B: Observed flower development by stage (symbols) and flowering predicted by Weibull's function (--) for Red Delicious spur growth as a function of degree-day accumulation, base 40°F.


Y=21.16/(1.0+110.94*EXP(-(.0095*X+.7516E-05*X**2))
SS = 5.962
R² = .994
SPUR FLOWERING
UNITS = PHENOCODE
20
16
12
8
4
0
200
300
400
500
600
A
PREDICTED
RED DELICIOUS

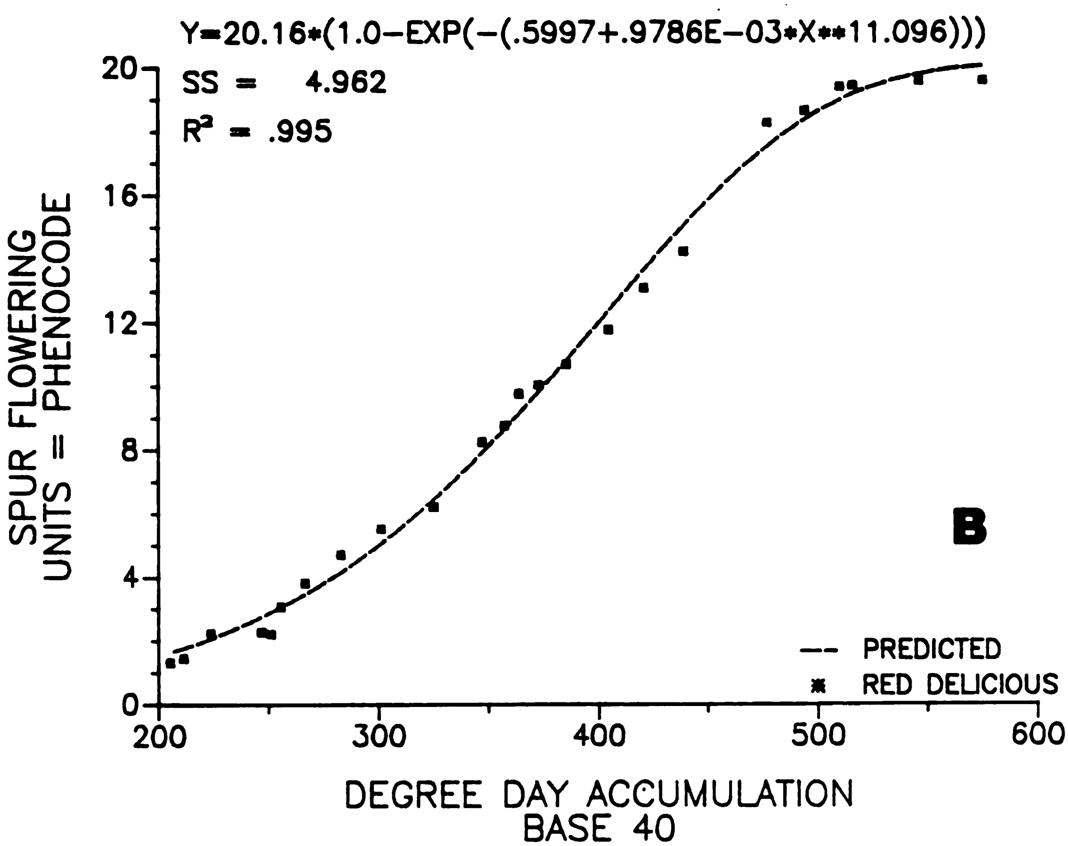
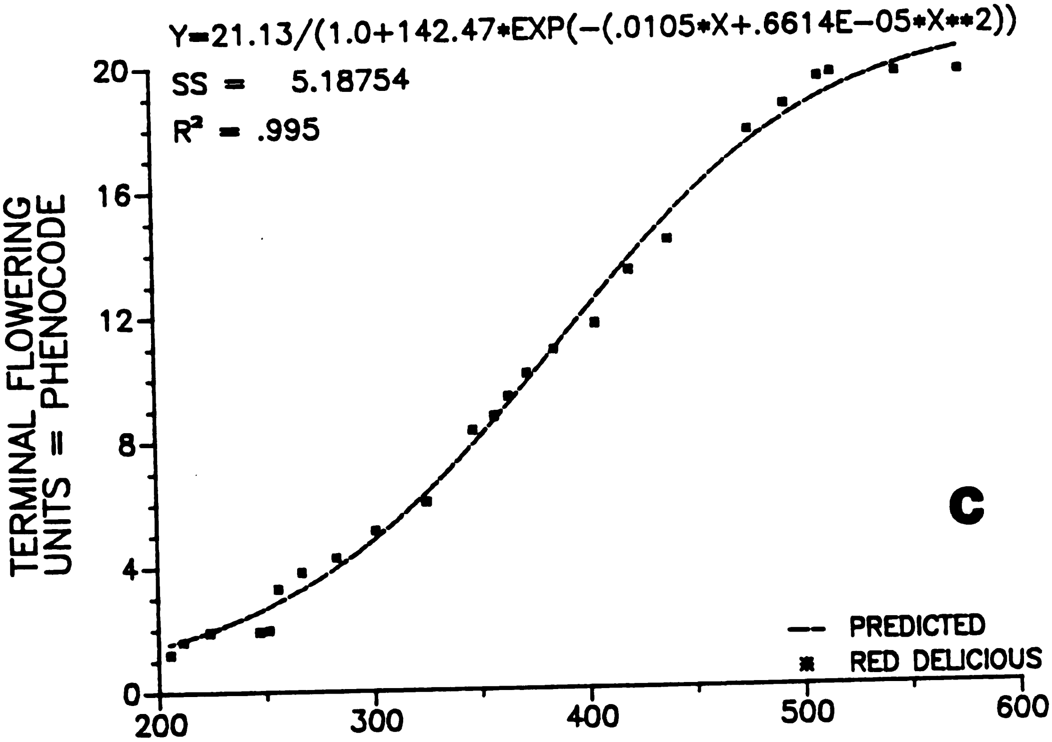

Y=20.16*(1.0-EXP(-(.5997+.9786E-03*X**11.096)))
SS = 4.962
R² = .995
SPUR FLOWERING
UNITS = PHENOCODE
20
16
12
8
4
0
200
300
400
500
600
B
PREDICTED
RED DELICIOUS
DEGREE DAY ACCUMULATION
BASE 40

Figure 8.C: Observed flower development by stage (symbols) and flowering predicted by the Logistic equation (--) for Red Delicious terminal growth as a function of degree-day accumulation, base 40°F.

Figure 8.D: Observed flower development by stage (symbols) and flowering predicted by Weibull's function (--) for Red Delicious spur growth as a function of degree-day accumulation, base 40°F.


Y=21.13/(1.0+142.47*EXP(-(.0105*X+.6614E-05*X**2))
SS = 5.18754
R² = .995
TERMINAL FLOWERING UNITS = PHENOCODE
C
PREDICTED
RED DELICIOUS
0
4
8
12
16
20
200
300
400
500
600

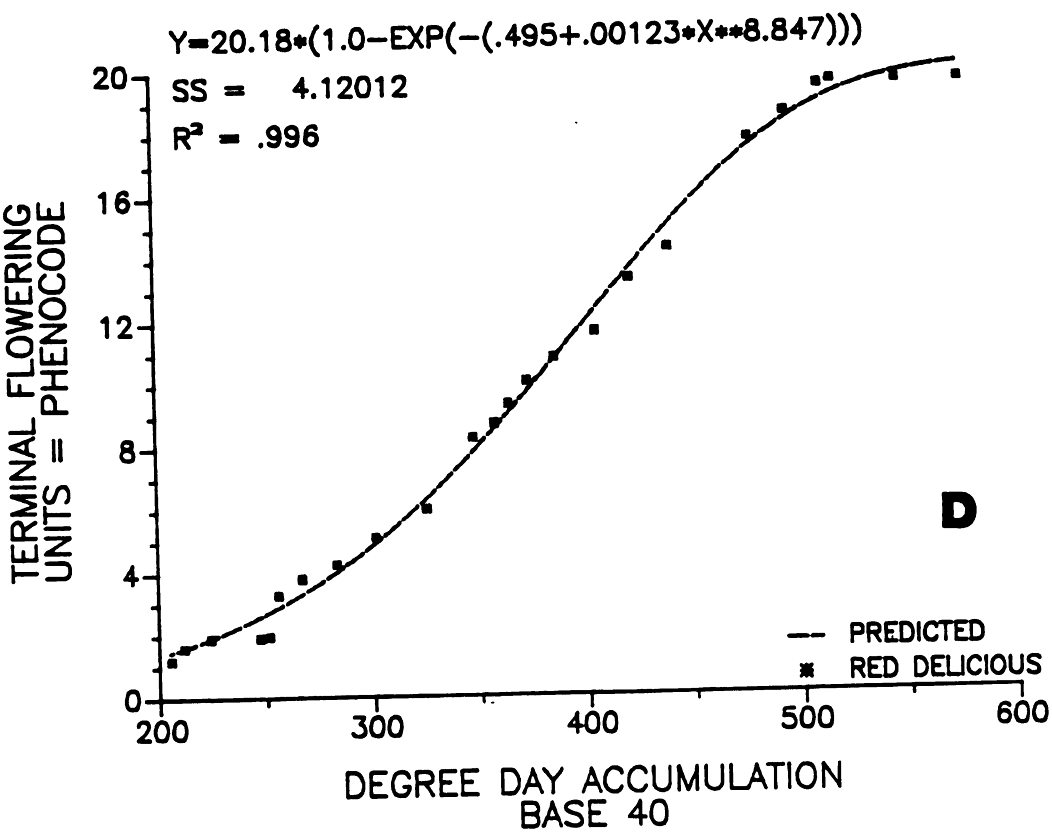

Y=20.18*(1.0-EXP(-(.495+.00123*X**8.847)))
SS = 4.12012
R² = .996
TERMINAL FLOWERING UNITS = PHENOCODE
D
PREDICTED
RED DELICIOUS
0
4
8
12
16
20
200
300
400
500
600
DEGREE DAY ACCUMULATION BASE 40

Table 9: Regression statistics for selected models correlating Flower Development Index (FDI) and temperature: reproductive spurs (1983,HRC).

Function	Coefficient of Determination	Sums of Squares	B(1) Parameter
RED DELICIOUS			
Gompertz[z]	.996	3.142	----
Logistic[y]	.994	5.962	21.16
Weibull's[x]	.995	4.694	20.16
GOLD DELICIOUS			
Gompertz	.992	7.928	----
Logistic	.995	4.698	20.41
Weibull's	.996	3.525	20.31

z Y=B(1) * EXP(-B(2) * EXP(-B(3) * X))
y Y=B(1)/(1.0 + B(2) * EXP(-(B(3) * X))
x Y=B(1) * (1.0 - EXP(-(B(2) + B(3) * X) ** B(4))))

Table 10: Regression statistics for selected models correlating Flower Development Index (FDI) and temperature: reproductive terminals.

Function	Coefficient of Determination	Sums of Squares	B(1) Parameter
RED DELICIOUS			
Gompertz[z]	.992	8.6064	-----
Logistic[y]	.995	5.1875	21.13
Weibull's[x]	.996	4.1201	20.18
GOLD DELICIOUS			
Gompertz	.997	3.0291	----
Logistic	.998	1.7195	22.28
Weibull's	.998	1.6891	20.07

[z] Y=B(1) * EXP(-B(2) * EXP(-B(3) * X))
[y] Y=B(1)/(1.0 + B(2) * EXP(-(B(3) * X))
[x] Y=B(1) * (1.0 - EXP(-(B(2) + B(3) * X) ** B(4))))

and Red Delicious (Figure 8), but Weibull's function gave a better estimate of the B1 equation parameter (should = 20) for all shoots, than the Logistic equation (Figure 7,8). Weibull's function was selected as the model to represent flowering :

Red Delicious: spurs:

Y=20.16*(1.0 - EXP(-(.5997 + .9786E-03*X**11.096)))

terminals: Y=20.18*(1.0-EXP(-(.495+.00123*X**8.847)))

Golden Delicious: spurs:

Y=20.31*(1.0-EXP(-(-.097+.00264*X**4.255)))

terminals: Y=20.07*(1.0-EXP(-(.165+.0018*X**5.935)))

<u>Adaptation of the Biofix Concept for Prediction</u>

Use of the plant biofix adjusted the prediction equation by eliminating the need for determining the onset of growth. However, predictions using degree-days accumulated to biofix as the modifying factor were not necessarily an improvement over those simply using degree-days as an input value (Table 11), where:

Prediction equation: $Y=B(1)/(1+EXP(B(2)-B(3)*(DD)+B(4)*(DD)^2 -B(5)*(DD)^3))$

DD= degree-days accumulated from April 1.

If silver tip was selected as the Biofix, the prediction equation would be modified as follows:

$$Y=B(1)/(1+EXP(B(2)-B(3)*(DD-BIOFIX)+B(4)*(DD-BIOFIX)^2 -B(5)*(DD-BIOFIX)^3))$$

BIOFIX = degree-days accumulated from April 1 to silver tip

Use of the biofix difference factor to modify the prediction equations resulted in the best predictions, especially when predictions were made at alternate locations (Table 11), where:

the Biofix Difference Equation :

$$BD = (BIOFIX\ B) - (BIOFIX\ A)$$

and :

BD = Biofix Difference

BIOFIX A = degree-days accumulated from April 1, 1983 to biofix stage (eg. silver tip), derived from the prediction curve

BIOFIX B = degree-days accumulated from April 1, 1986 to silver tip

The prediction equation would be adjusted as follows:

$$Y=B(1)/(1+EXP(B(2)-B(3)*(DD-BD)+B(4)*(DD-BD)^2 -B(5)*(DD-BD)^3))$$

Model Testing: Predictive Capabilities

The similarity between seasonal growth curves across years and locations is striking, but demonstrates graphically the reliability of the selected equations (Figure 3-5). Plots of the vegetative growth for spur type Golden Delicious show the greatest difference between years, with final leaves/shoot lower in 1985 (HRC)(Figure 5C,D).

Table 11: Comparison of predicted and observed phenophases (stage=phenocode, Table 1) for three methods of modifying the predictive model: Y=39.325/(1+EXP(2.206-.0067*X+4.26E-06*X*X-9.13E-10*X**3)), using biofix adjustments for spur type Golden Delicious reproductive spur growth (HRC, 1985).

Observed	Degree Days	Predicted[z] (No Biofix)	Difference (phenocode)	Predicted[y] (Biofix)	Difference (phenocode)	Predicted[x] (Biofix Diff)	Difference (phenocode)
GREEN TIP (7)	144.3	9.0	2.0	6.0	.5	7.5	.5
TIGHT CLUSTER (12)	224.6	12.0	0	9.0	3.0	10.5	1.0
FULL BLOOM (20.5)	453.1	22.0	1.0	19.0	2.0	20.5	0
PETAL FALL (24)	536.7	24.5	.5	22.0	2.0	23.5	.5
FRUIT THINNING 10 mm (29.8)	809.3	30.0	0	29.0	.5	29.6	0
FRUIT DIAM.=2.0-2.4 cm (32)	1008.2	32.0	0	31.5	.5	32.0	0
FRUIT DIAM.=3.5-3.9 cm (35)	1507.1	33.5	1.5	34.0	1.0	34.0	1.0
FRUIT DIAM.=5.0-5.4 cm (38)	2553.0	38.5	.5	37.5	.5	38.0	.5

[z] No modifications to the model: X = Degree Days

[y] Model modified: X =(Degree Days - Biofix) (see text)

[x] Model modified: X =(Degree Days - Biofix Difference) (see text)

The predictive model was tested using data from the HRC(1984 or 1985 data), or the Graham Station (1983 data). Predictions were calculated using the biofix difference equation to modify degree-days input. Models for reproductive growth predicted best, with an accuracy of 0 - 1.5 stage throughout the growing season (Table 12,13,14,15). Predictions for spur type Golden Delicious were most accurate, predicting full bloom and fruit thinning (10mm) accurately (0 stage difference between predicted and observed values), by 18 and 34 days in advance, respectively (Table 12). Accurate predictions for fruit size ($\pm$ 1.0 stage) using Biofix=Silver Tip (selected up to 3 months in advance) were made for all varieties tested (Table 12,14). The model underpredicted final harvest size if fruit load was low to medium (data not presented).

Vegetative curves generally predicted with less accuracy than the reproductive curves, with differences between observed and predicted values of 0 - 2.0 stage (Table 13,15). Models for terminal extension shoot growth predict best, usually predicting to within 1.0 stage (Table 15). Models predicting spur shoot growth are the least reliable, frequently generating prediction errors of 1.0 - 2.0 stages (Table 13).

Table 12: Comparison of predicted[z] and observed phenophase for selected locations and years used to validate the model: Y=B(1)/(1.+EXP(B(2)+B(3)*X+B(4)*X*X+B(5)*X**3)), for reproductive spur shoot growth on three varieties.

SPUR GROWTH

REPRODUCTIVE PHENOPHASE	SPUR TYPE GOLDEN DELICIOUS (HRC 1985)			GOLDEN DELICIOUS/STD (Graham Sta.)			RED DELICIOUS (Graham Station)		
Observed	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)
GREEN TIP (7)	144.3[y]	7.5[x]	.5	75.4	7.0	0	50.7	6.5	.5
TIGHT CLUSTER (12)	224.6	10.5	1.0	164.2	10.5	1.5	158.6	10.5	1.5
FULL BLOOM (20.5)	453.1	20.5	0	449.9	22.5	1.5	429.2	22.0	1.0
PETAL FALL (24)	536.7	23.5	.5	534.2	25.0	1.0	515.0	24.5	.5
FRUIT THINNING 10 mm (29.8)	809.3	29.6	0	826.7	30.5	.5	826.7	30.5	.5
FRUIT DIAM.=2.0-2.4 cm (32)	1008.2	32.0	0	1200.8	33.0	1.0	1176.2	33.0	1.0
FRUIT DIAM.=3.5-3.9 cm (35)	1507.1	34.0	1.0	1800.0	35.0	0	1706.2	34.5	.5
FRUIT DIAM.=5.0-5.4 cm (38)	2553.0	38.0	0	2475.6	38.5	.5	2446.1	38.5	.5

z Predicted values rounded to the nearest 0.5 stage.
y Degree days calculated by the Baskerville and Emin method (2) at base 40.
x Stages calculated using biofix difference function (see text), at silver tip stage.

Table 13: Comparison of predicted[z] and observed phenophase for selected locations and years used to validate the model: Y=B(1)/(1.+EXP(B(2)+B(3)*X+B(4)*X*X+B(5)*X**3)), for vegetative spur shoot growth on three varieties.

SPUR GROWTH

VEGETATIVE PHENOPHASE	SPUR TYPE GOLDEN DELICIOUS (HRC 1985)			GOLDEN DELICIOUS/STD (Graham Sta.)			RED DELICIOUS (Graham Station)		
Observed	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)
GREEN TIP (7)	205.2[y]	8.0[x]	1.0	75.4	5.5	1.5	50.7	7.0	0
FIRST LEAF (11)	269.5	10.0	1.0	268.7	13.0	2.0	172.5	12.0	2.0
FIFTH LEAF (15)	374.9	13.0	2.0	388.3	15.5	1.5	315.6	16.0	2.0
SEVENTH LEAF (17)	446.1	15.0	2.0	533.9	19.0	2.0	407.5	18.0	5.0
TENTH LEAF (20)	557.9	18.0	2.0	592.3	21.5	1.5	558.6	21.5	5.0
TERMINAL BUD SET (25) or (30)	913.0	25.0	0	1200.0	30.0	0	970.6	29.5	.5

z Predicted values rounded to the nearest 0.5 stage.
y Degree days calculated by the Baskerville and Emin method (2) at base 40.
x Stages calculated using biofix difference function (see text), at silver tip stage.

Table 14: Comparison of predicted[z] and observed phenophase for selected locations and years used to validate the model: Y=B(1)/(1.0+EXP(B(2)+B(3)*X+B(4)*X*X+B(5)*X**3)), for reproductive terminal growth for three varieties tested.

TERMINAL GROWTH

REPRODUCTIVE PHENOPHASE	SPUR TYPE GOLDEN DELICIOUS HRC 1984			GOLDEN DELICIOUS/STD Graham Sta.			RED DELICIOUS Graham Station		
Observed	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)
GREEN TIP (7)	161.7[y]	7.0[x]	0	88.0	7.5	.5	74.4	7.0	0
TIGHT CLUSTER (12)	291.5	11.5	.5	165.0	10.5	.5	165.9	10.5	1.5
FULL BLOOM (20.5)	547.0	22.0	1.0	452.5	22.5	1.5	440.7	22.0	1.0
PETAL FALL (24)	630.5	24.5	0.5	530.3	25.0	1.0	518.0	24.5	.5
FRUIT THIN. 10 mm (29.8)	928.1	30.2	0.5	815.2	30.5	.5	830.0	30.5	.5

[z] Predicted values rounded to the nearest 0.5 stage
[y] Degree days calculated by the Baskerville and Emin method (2) at base 40.
[x] Stages calculated using the biofix difference function (see text), at silver tip stage.

Table 15: Comparison of predicted[z] and observed phenophase for selected locations and years used to validate the model: Y=B(1)/(1.0+EXP(B(2)+B(3)*X+B(4)*X*X+B(5)*X**3)), for vegetatve terminal growth for three varieties tested.

TERMINAL GROWTH									
	SPUR TYPE GOLDEN DELICIOUS HRC 1984			GOLDEN DELICIOUS/STD HRC 1984			RED DELICIOUS Graham 1983		
VEGETATIVE PHENOPHASE Observed	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)	Degree-days	Predicted	Difference (phenocode)
GREEN TIP (7)	208.4[y]	7.5[x]	.5	88.0	4.5	1.5	74.4	7.5	.5
FIRST LEAF (11)	302.6	11.0	0	217.1	9.5	1.5	165.2	11.5	.5
FIFTH LEAF (15)	391.3	14.0	1.0	357.9	14.5	.5	266.0	15.5	.5
SEVENTH LEAF (17)	461.8	16.0	1.0	376.5	15.0	2.0	334.1	17.5	.5
TENTH LEAF (20)	609.9	19.5	.5	655.0	20.5	.5	531.6	21.0	1.0
FIFTEENTH LEAF (25)	867.4	25.5	.5	894.3	25.0	0	817.6	25.0	0
TERMINAL BUD SET(30, 32)	1450.0	30.0	0	1500.0	32.0	0	1407.6	32.0	0

z Predicted values rounded to the nearest 0.5 stage

y Degree days calculated by the Baskerville and Emin method (2) at base 40.

x Stages calculated using the biofix difference function (see text), at silver tip stage.

Discussion

Adaptation of the Biofix Concept for Prediction

The model describes reproductive and vegetative shoot development on both spur and terminal shoots. Tests of the model using Michigan data, demonstrated predictive ability to within 0-2 phenophase throughout the growing season and a capability to predict in alternate years and locations (Table 12,13,14,15). The utility of many prediction models is decreased by their inability to predict accurately in locations other than those for which they were developed (2,52,61). A good model predicts well through a range of conditions (51).

Start dates for recording degree-day accumulations will vary from one region to another. Even in the same orchard biofix occurred on different dates and at a different degree-day accumulations each year (Table 16). Any stage of development can be selected as a Biofix. Accurately determining when the biofix stage occurs is necessary to make accurate growth preditions. The biofix selection can be updated (biofix = silver tip, then green tip, pink, etc.) and used to accurately predict growth, by calculating the Biofix Difference (BD) to adjust the prediction equation. Using an updated biofix allows the flexibility to chose a later biofix date, if the earlier biofix point is missed or has been inaccurately determined.

Table 16: Degree Days Accumulated (DD)[z] from April 1 to observed Biofix Date for selected stages on spur type Golden Delicious from 1982-1985 (HRC).

	1982		1983		1984		1985	
BIOFIX STAGE	DD	DATE	DD	DATE	DD	DATE	DD	DATE
Silver Tip	124.6	4/23	41.0	4/13	112.9	4/21	112.2	4/16
Green Tip	242.3	5/2	119.4	4/26	174.1	4/26	144.3	4/18
Tight Cluster	*	*	187.8	5/2	282.0	5/5	224.6	4/21
Full Bloom	515.0	5/14	421.0	5/20	502.6	5/21	443.3	5/2

[z] Degree Days calculated at Base 40 using the Baskerville and Emin method (2)

The key to successful prediction in locations outside Michigan would be a similarity in growth response to temperature. Phenology development for different crops in different sections of the country varies by many weeks for several perennial fruit species (52). The authors presented climatological data showing a large variation between sites (eg. Minnesota vs. California), but did not indicate if variation in development was the result of real differences in the functional growth response. If a different functional growth response occurs in different climates, then further refinement of the model will be necessary to generate accurate predictions in different regions.

Predictive Capabilities

Accurate predictions for early season reproductive growth (green tip - early fruit size) are important from a management standpoint, and under Michigan conditions the model predicted this range well (Table 12,13,14,15). The model was less accurate in predicting fruit size (stages 33 - 40). The prediction curve wavered around the data points (Figure 3), suggesting that the equation may not be a 'true fit' of the data (18,36). In addition, the model tends to underpredict final harvest size if fruit load is low to medium. The predicted curve increases gradually toward a finite upper limit of Y (fruit diameter) = B(1) (equation parameter), as degree-day accumulation increases indefinitely (54). In 1983 (modeled data set), the fruit load was heavy (especially Golden Delicious), so fruit growth rate was likely less than in an average year 1 - 2 stages (.5 - 1.0 cm in diameter), and resulted in a low estimate for the B(1) parameter in the predictive equation. It may be possible to adjust equation parameters to predict for varying levels of fruit load. Heim et al. (34) discussed an interaction between total leaf area, stem diameter, and fruit load, noting increased vegetative growth under a lighter fruit load. Although fruit load varied between trees, data from the current study could not be used to confirm Heim's findings since different levels of fruiting were not sufficiently replicated to draw any conclusions. Predictions of fruit growth could be modified using leaf/shoot ratios or stem diameter as additional input factors (J. A. Flore, personal communication).

Larger differences between predicted and observed values were associated with predictions of vegetative growth and may be attributed to multiple factors. 1) Vegetative growth may be more prone to growth reduction than reproductive growth in years that growing conditions are marginal. 1985 was hot and dry at the HRC and may have contributed to lower leaf numbers/shoot for that season (Figure 4C, 4D). 2)Larger sampling errors are possible when monitoring vegetative functions (17). As each leaf expands, a decision must be made as to whether the leaf is fully expanded (margins unfurled), and therefore added to total leaf number (16). This is a highly subjective decision.

Vegetative phenology data for 1985 (HRC) were recorded by an observer using the coding system for the first time, (Figure 4C, 4D). Unfamiliarity with the coding system may have contributed to the larger differences between predicted and observed values recorded in 1985 (Figure 4C, 4D). 3)The first leaves to emerge in the spring are very small, transitional leaves (1). Many times these leaves abcise part way through the season, causing an error in the leaf count (if conducted randomly). If shoots are marked and carefully monitored, this problem can be avoided.

Precise coding of flowering from tight cluster through fruit set has yielded prediction equations with fewer parameters that allowed greater resolution between stages (Figure 7,8), and may also allow more accurate modeling of a larger number of variables (such as the wind and rain interaction at petal fall), although multiple variables were not modeled in this study. Using precise phenological coding was tedious, requiring daily, detailed observations (to avoid missing a stage), but adaptation of precise codes may be necessary to substantially improve partial season predictive models.

Physiological and environmental interactions involved in bud growth are complex, and this model is based on only one environmental factor, temperature. Correlation statistics for this model were very high, but intuitively other factors should influence growth, and vary in their effects on different stages of development. Heavy rains and/or winds can advance petal fall. Landsberg (42) indicated that bud temperature is more important than air temperature, and observed delays in reaching full bloom related to the occurrence of high winds. The effects of varying light regimes within tree canopies have been studied, showing a correlation with shoot length and leaf development (4, 8, 24). Rate of bud growth in the spring is determined in part by the length of the autumn development period (1,42), and is related to time of flower initiation (1), bud morphogenesis (5,25), and length of the chilling and chilling temperature regime (11, 28). Winter rains reduced chilling requirements for breaking winter rest of pear and apple (70). Combining chilling models and phenology models such as the type presented here may increase predictive precision.

Components of Error

Two components of error contribute to prediction variances. The random error component (experimental error) consists of within tree, between tree, and between orchard variation. The random component can not be eliminated, but can be minimized by selecting well maintained, healthy trees. Sampling error is the second component of interest. The subjective judgements required to monitor and code the phenophases comprise a large portion of the sampling error component. The phenophases are specified to be mutually exclusive, yet subjectively some overlap between stages can occur (eg. is the bloom class 4+ Blossoms or Full Bloom?). The coding system and descriptions were designed to minimize this problem (16). As a user becomes more familiar with the coding system and distinctions between phenophase, sampling error should be minimized. Most importantly, the users must be consistent in their data collection and in their subjective judgements. The weather pattern itself may contribute to error. Seem and Szkolnik observed a flattened distribution of phenophase (larger variances) during excessively warm periods (59).

Summary

The predictive capabilities of the model for Michigan conditions have been demonstrated. Adaptation of the model using the Biofix Difference Equation to adjust predictions may result in successful tests of the model in regions outside of Michigan. Modeling has been strictly empirical, with no attempt made to model physiological mechanisms. The model may be oversimplified, relying on growth response to temperature, but for the defined purpose of phenophase prediction, the model is well suited. The predictive accuracy of the model demonstrates the importance of temperature (specifically degree-day accumulations) to apple shoot development, and lends support to using $40^{o}F$ ($4.4^{o}C$) as a base temperature for accumulating degree-days.

This model can be viewed as a basic structural component for a whole tree model, and may have utility as an orchard management tool. Future models may integrate submodels of physiological processes to help refine predictive capabilities. Orchard soil characteristics and fertility, orchard floor management systems, and cultural activities may also be incorporated in an expanded model. A whole tree model, encompassing the apple ecosystem (including insect and pathogen subsystems) should be possible.

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Section III

PHENOTE: An Interactive Prediction Program for Shoot Growth, Flowering and Fruit Growth in Apple

__Abstract:__ Field application of the predictive model developed in phase II of the apple phenology study is discussed. An interactive BASIC micro-computer program 'PHENOTE' was designed. User input biofix values (determined by orchard monitoring) are used to generate predictions of phenophase as related to degree-day accumulation. Predictions of both spur and terminal shoot growth, of either vegetative or reproductive function can be made. Partial, or whole season predictions can be generated by 'PHENOTE'. Program predictions are compared to forecast degree-day accumulations (from the weather service or user calculated from weather data) to forecast the occurance of a particular phenophase. Prediction precision is limited by the accuracy of the weather forecast and the monitored biofix information. Monitoring techniques, using program output, and future modifications of 'PHENOTE' are discussed.

Introduction

One of the goals of plant modeling is prediction (3,4,8,9). Equations are used to predict system behavior (eg. plant growth) based on changing input variables (eg. environmental parameters). Plant growth is closely associated with many environmental parameters, with temperature being a component force of major importance (4,7).

PHENOTE is an apple phenology prediction program that generates growth predictions based on calculations made from a set of empirically derived equations (4). Predictions can be made for all stages of either reproductive or vegetative growth on both terminal and spur shoots. A single input variable, degree-day accumulation (calculated at base $40^{o}F$) is used to generate predictions of growth. Growth is numerically indexed by phenophase (morphologically distinct stages of development) (Table 1,2,3) (5). Predictions are based on program supplied standard degree-day curves or on user input degree-day values. Degree days for this model were calculated using the sine wave method of Baskeville and Emin (2).

PHENOTE was designed to function in concert with the Pest Management Executive System (PMEX) and the IPM program at Michigan State University (3,8). Weather information provided by the PMEX network is used to calculate model input, although degree-day accumulations calculated from

Table 1: Reproductive Phenocodes: Used to numerically code reproductive shoot development in apple.

STAGE NAME	CODE
Dormant	1
Early Silver Tip	3
Silver Tip	5
Green Tip: 0 - 0.4 cm	7
: 0.5 - 0.9 cm	8
: 1.0 - 1.4 cm	9
: 1.5+ cm	10
Pre-cluster Leaf	10
Early Tight Cluster	11
Tight Cluster	12
Early Bud Expansion	13
Bud Expansion	14
Early Pink	15
Pink	16
Full Pink	17
1 Blossom	18
2-3 Blossoms	19
4+ Blossoms	20
Full Bloom	20.5
Early Petal Fall	22
Mid Petal Fall	23
Late Petal Fall	24
Early Fruit Set	25
Mid (2-3) Fruit Set	26
Late (4+) Fruit Set	27
Fruit Diameter (cm):	
$<$0.5 cm	28
0.5 - 0.9 cm	29
1.0 - 1.4 cm	30
1.5 - 1.9 cm	31
2.0 - 2.4 cm	32
2.5 - 2.9 cm	33
3.0 - 3.4 cm	34
3.5 - 3.9 cm	35
4.0 - 4.4 cm	36
4.5 - 4.9 cm	37
5.0 - 5.4 cm	38
5.5 - 5.9 cm	39
6.0 - 6.4 cm	40
6.5 - 6.9 cm	41
7.0 - 7.4 cm	42
7.5 - 7.9 cm	43
8.0 - 8.4 cm	44

Table 2: Vegetative Phenocodes: Used to numerically code vegetative shoot development in apple.

STAGE NAME		CODE
Dormant		1
Early Silver Tip		3
Silver Tip		5
Green Tip: 0 - 0.4 cm		7
: 0.5 - 0.9 cm		8
: 1.0 - 1.4 cm		9
: 1.5+ cm		10
Shoot Growth:		
1 Leaf		11
2 Leaves		12
3 Leaves		13
4 Leaves		14
5 Leaves		15
6 Leaves		16
7 Leaves		17
8 Leaves		18
9 Leaves		19
10 Leaves		20
11 Leaves		21
12 Leaves		22
13 Leaves		23
14 Leaves		24
15+ Leaves		CODE = leaf number + 10
Terminal Bud Set:		
Spur Types and		
Dwarfing Rootstocks:	Spur	25
	Terminal	30
Standard Rootstocks:	Spur	30
	Terminal	32

Table 3: Expanded Flowering Phenocodes: Used to numerically code flower development in apple.

Phenophase	Code
Early Bud Expansion	0
Bud Expansion	1
Early Pink	2
Pink	3
Expanded Pink 1	4
Expanded Pink 2	5
Expanded Pink 3	6
Full Pink	7
Pre-bloom 1	8
Pre-bloom 2	9
Pre-bloom 3	10
Open Petal 1	11
Open Petal 2	12
Full Open Blossom 1	13
Full Open Blossom 2 (aged pollen)	14
Petal Fall 1 (1 petal off)	15
Petal Fall 2 (2 petals off)	16
Petal Fall 3 (3 petals off)	17
Petal Fall 4 (4 petals off)	18
Early Fruit Set	19
Fruit Set	20

data retrieved from any accurate weather service are acceptable. Temperature information recorded in the monitored orchard will provide the greatest predictive precision.

The Program

PHENOTE was created using prediction equations developed by Edson and Flore as part of an apple phenology study in apple (4). PHENOTE is an interactive, user friendly program written in the computer language BASIC (1).

The program was structured to allow the flexibility to predict by variety, and shoot type. The user has the choice of predicting either partial or seasonal growth, using one of five different growth curve types:

1) vegetative whole season growth curve: 'silver tip' to 'terminal bud set'

2) reproductive whole season growth curve: 'silver tip' to 'harvest'

3) early reproductive growth curve: 'silver tip' to 'early tight cluster'

4) flowering growth curve: 'tight cluster' to 'fruit set'

5) fruit growth curve: 'fruit set' to 'harvest'.

The prediction equations used by PHENOTE (for curve types 1,2,3,5) are:

Red Delicious:

1. Vegetative Spur:

$Y=29.83/(1+EXP(1.995-.01146*X+.213E-04*X^2-.1725E-07*X^3))$

2. Vegetative Terminal:

$Y=32.198/(1+EXP(2.264-.0112*X+.159E-04*X^2-.8872E-08 *X^3))$

3. Reproductive Spur:

$Y=40.497/(1+EXP(2.026-.00674*X+.437E-05*X^2-1.005E-08*X^3))$

4. Reproductive Terminal:

$Y=40.395/(1+EXP(2.123-.00704*X+.471E-05*X^2-.1108E-08*X^3))$

Golden Delicious:

1. Vegetative Spur:

$Y=29.45/(1+EXP(2.134-.01405*X+.310E-04*X^2-.2834E-07*X^3))$

2. Vegetative Terminal:

$Y=32.0/(1+EXP(2.292-.0104*X+.145E-04*X^2-.8422E-08*X^3))$

3. Reproductive Spur:

$Y=39.325/(1+EXP(2.207-.00733*X+.486E-05*X^2-.116E-08*X^3))$

4. Reproductive Terminal:

$Y=39.26/(1+EXP(2.268-.00741*X+.483E-05*X^2-.1125E-08*X^3))$

Spur type Golden Delicious (also used for dwarfing rootstocks):

1. Vegetative Spur:

$Y=25.228/(1+EXP(1.958-.01066*X+.187E-04*X^2-.179E-07*X^3))$

2. Vegetative Terminal:

$Y=29.92/(1+EXP(2.193-.01011*X+.159E-04*X^2-.8872E-08*X^3))$

3. Reproductive Spur:

$Y=39.774/(1+EXP(2.206-.00698*X+.426E-05*X^2-.9127E-09*X^3))$

4. Reproductive Terminal:

$Y=38.316/(1+EXP(2.225-.00691*X+.401E-05*X^2-.8521E-09*X^3))$

Predictive equations used to predict flower development (curve type 4) are:

Red Delicious spur:

Y=20.18*(1.0-EXP(-(.495+.00123*X 8.847)))

Red Delicious terminal:

Y=20.16*(1.0-EXP(-(.5997+.9786E-03*X 11.096)))

Golden Delicious spur:

Y=20.068*(1.0-EXP(-(.165+.00181*X 5.935)))

Golden Delicious terminal:

Y=20.31*(1.0-EXP(-(-.097+.00264*X 4.255)))

where: Y=phenophase

X=(degree-day accumulation)-(biofix difference) (see reference 4).

Monitoring

Select the apple orchard to be monitored and choose five trees. These trees should be representative of the majority of the trees in the orchard (consider pruning, vigor, etc.). Next chose four limbs about shoulder height, in different quadrants of the tree. Do this for each tree. Record phenocode values (Table 1,2,3) for a bud from each limb and shoot type from which growth is to be predicted (reproductive spur, vegetative spur, reproductive terminal, or vegetative terminal). For instance, if data on reproductive spurs is desired, record the stage of development (phenocode) for a reproductive spur bud at four different locations (branches) around the tree. Repeat this process on each of the five trees. Average the twenty values. The result is the average growth index (phenocode) for reproductive spurs for that date (4). The process must be repeated for each different shoot type. Do not select shoots on the outside edge of the orchard as they may be influenced by greater exposure to light, wind, etc. Random selection of each observation point (bud) for each date is recommended, and is most important early in the season. It is difficult to be absolutely certain if the bud selected very early in the season is a vegetative or a reproductive bud, so identifying buds for repetitive observation at that time is generally not recommended (see section I for a description of phenology and growth) (5). If a wrong bud is tagged (eg. a vegetative bud instead of a reproductive bud; a low vigor bud; or a mutant bud) the error will confound the early data. Random sampling tends to lessen this accumulation of error. As seasonal growth progresses and positive identification of shoot type (reproductive or vegetative) becomes possible, tagging shoots may make monitoring easier and more accurate for the vegetative shoots. The first leaves to expand in the spring frequently abcise during the season. If random measurements are recorded for shoots on which leaves have abcised, errors in total leave number may result. If the shoot is tagged, the abcission of the first leaves can be noted and subsequent leaf number adjusted.

Events happen quickly once warm weather arrives. When monitoring to determine a biofix or to track a particular series of stages, such as flowering, data should be taken every 1-3 days. Shorter intervals will contribute to greater accuracy. Once biofix has been determined, weekly monitoring will be sufficient to track shoot development of the trees and to assess the precision of the predictive model for a specific orchard microclimate.

Biofix Determination

Following the winter dormant period, growth is renewed each spring. Internal physiological changes continue to take place even though the bud still appears to be in the dormant stage. Growth cannot be visually quantified until outward change begins to occur. The BIOFIX or biological fixpoint, is a starting point at which a biological event can be readily identified. PHENOTE uses phenophase as the biological fixpoint. Any growth stage can be selected as a BIOFIX (eg. green tip, pink, etc.), although 'silver tip' is the first stage at which outward signs of growth are evident in apple (4). A certain number of degree-days will have accumulated by the date 'silver tip' is reached. This degree-day value is the BIOFIX VALUE. The procedure for calculating the BIOFIX VALUE follows: If 'Silver tip' is chosen as the BIOFIX , when the trees are observed to be in the 'silver tip' stage (averaged monitored phenocode value or growth index = 5), consult weather data to determine the number of degree-days that have accumulated to that date. BIOFIX VALUE = number of degree-days accumulated to date of BIOFIX. This calculated BIOFIX VALUE is used as input by PHENOTE to generate predictions.

Running the Program

To run PHENOTE first boot up the operating system (eg. MS-DOS). Insert a Basic command program disk and call up the Basic program (usually type: BASICA). Check the system manual if problems are encountered with any of these initial steps. There are two files on the PHENOTE program disk. If a printer is available then use the file: PHENOTE1.BAS. If a printer is not available or if a screen display of the output is desired, then use the file: PHENOTE2.BAS. To load PHENOTE into memory type: "LOAD ¼filename½". To run PHENOTE once it is loaded into memory type: RUN. A step can be eliminated with some versions by typing: "LOAD ¼filename½",R. Check the 'BASIC' manual .if these commands do not work. NOTE: All input into PHENOTE must be made in upper case letters. A sample program run follows, user inputs are in bold type.

Sample Program Run

```
RUN
PHENOTE: Apple Phenology Prediction Program
Model Development: C.E. Edson and Dr. J.A. Flore
Written by C.E. Edson
Version 2.5 : May 1, 1986
(C) Copyright:  Michigan State University, 1986


                          PHENOTE

Use UPPER CASE when responding to prompts.


WHICH VARIETY DO YOU WISH TO PREDICT FOR
       (1) GOLD DELICIOUS - STANDARD ROOTSTOCK
       (2) GOLD DELICIOUS - DWARFING ROOTSTOCK(or SPUR TYPE)
       (3) RED DELICIOUS - STANDARD ROOTSTOCK
       (4) OTHER VARIETY - STANDARD ROOTSTOCK
       (5) OTHER VARIETY - DWARFING ROOTSTOCK (or SPUR TYPE)

ENTER VARIETY   2

DO YOU WISH TO PREDICT (S)PUR OR (T)ERMINAL GROWTH ?   S

WHICH PREDICTION CURVE?
          (1) VEGETATIVE - WHOLE SEASON MODEL
          (2) REPRODUCTIVE - WHOLE SEASON MODEL
          (3) REPRODUCTIVE:  SILVER TIP - TIGHT CLUSTER
          (4) REPRODUCTIVE:  FLOWERING
          (5) REPRODUCTIVE:  FRUIT GROWTH
          (6) HELP

ENTER CURVE SELECTION  2

WHICH BIOFIX DO YOU WISH TO SELECT?
          (1) SILVER TIP
          (2) GREEN TIP: 0 -0.5cm
          (3) TIGHT CLUSTER
          (4) FULL BLOOM
          (5) FRUIT SET
          (6) FRUIT DIAMETER:  2.5 - 3.0 cm
          (7) BIOFIX UNDETERMINED (biofix value = degree-day
              accumulation to April 15)
          (8) HELP
```

```
ENTER BIOFIX SELECTION    1

ENTER BIOFIX VALUE      112.2


DO YOU WISH TO :
          (1) USE STANDARD DEGREE DAY PREDICTION CURVE?
          (2) SUPPLY YOUR OWN VALUES?
          (3) HELP

ENTER YOUR CHOICE    1

(OUTPUT: see Table 4)


DO YOU WISH TO DO ANOTHER PREDICTION?  (Y)ES or (N)O  Y


SAME VARIETY?  (Y)ES OR (N)O   Y

DO YOU WISH TO PREDICT (S)PUR OR (T)ERMINAL GROWTH ?   S

WHICH PREDICTION CURVE?
          (1) VEGETATIVE - WHOLE SEASON MODEL
          (2) REPRODUCTIVE - WHOLE SEASON MODEL
          (3) REPRODUCTIVE:  SILVER TIP - TIGHT CLUSTER
          (4) REPRODUCTIVE:  FLOWERING
          (5) REPRODUCTIVE:  FRUIT GROWTH
          (6) HELP

ENTER CURVE SELECTION  4


WHICH BIOFIX DO YOU WISH TO SELECT?
          (1) SILVER TIP
          (2) GREEN TIP: 0 -0.5cm
          (3) TIGHT CLUSTER
          (7) BIOFIX UNDETERMINED (biofix value = degree-day
              accumulation to April 15)
          (8) HELP


ENTER BIOFIX SELECTION  1

ENTER BIOFIX VALUE   112.2

NOTICE:
     Output from flowering curves uses a different Phenocode,
which allows the detection of smaller incremental changes  in
morphological  development;  see manual or get a printout  of
```

the FLOWERING PHENOCODES at the end of the current program run.

```
DO YOU WISH TO :
          (1) USE STANDARD DEGREE DAY PREDICTION CURVE?
          (2) SUPPLY YOUR OWN VALUES?
          (3) HELP

ENTER YOUR CHOICE    1
```

(OUTPUT: see Table 5)

```
DO YOU WANT A PRINT OF THE PHENOLOGY CODES? (Y)ES or (N)O  N
Ok
```

Using 'PHENOTE' Output

In tests of the model using Michigan data PHENOTE predicted phenophase within 0-2 stages of observed values up to 4 months in advance (4). To use PHENOTE in a predictive mode, the user must rely on interpretation of the weather forecasts to predict the occurrence of specific degree-day accumulations. The utility of PHENOTE as a field tool is limited by the accuracy of the weather predictions on which model input is based.

OUTPUT LISTING:

The output list consists of two columns, degree-day accumulation and predicted phenophase (Table 4,5). Date is not included, because degree-day accumulation (eg. physiological time) is independent of date. Once a certain number of degree-days have accumulated (left column), PHENOTE predicts growth to be in a certain stage of development (corresponding right column).

Table 4: Sample output from PHENOTE for Golden Delicious - reproductive spur: whole season model (program selection 2)

GOLD DELICIOUS - DWARF.

DEGREE DAYS (Base 40)	REPRODUCTIVE SPUR GROWTH[z]
75.00	5.17
100.00	5.94
125.00	6.78
150.00	7.68
175.00	8.64
200.00	9.64
225.00	10.69
250.00	11.76
275.00	12.86
300.00	13.96
350.00	16.16
400.00	18.29
450.00	20.30
500.00	22.15
550.00	23.81
600.00	25.29
700.00	27.72
800.00	29.54
900.00	30.88
1000.00	31.85
1100.00	32.55
1200.00	33.06
1300.00	33.42
1400.00	33.69
1500.00	33.90
1600.00	34.08
1700.00	34.26
1800.00	34.46
2000.00	35.02
2200.00	35.86
2400.00	36.94
2600.00	38.06
2800.00	38.95
3000.00	39.47
3200.00	39.69
3400.00	39.76
3600.00	39.77
3800.00	39.77

BIOFIX: Silver tip 112.2

[z] see Phenocodes, Table 1.

Table 5: Sample output from PHENOTE for Golden Delicious reproductive spur: Flowering model (program selection 4)

Degree-Days(Base 40)	Reproductive Spur[z]
160.00	0.00
180.00	0.02
200.00	0.04
220.00	0.10
240.00	0.21
260.00	0.39
280.00	0.66
300.00	1.05
320.00	1.58
340.00	2.28
360.00	3.18
380.00	4.27
400.00	5.56
420.00	7.04
440.00	8.65
460.00	10.35
480.00	12.08
500.00	13.75
520.00	15.29
540.00	16.65
560.00	17.77
580.00	18.64
600.00	19.28
620.00	19.72
640.00	20.00
660.00	20.16
680.00	20.24
700.00	20.28
720.00	20.30
740.00	20.31
BIOFIX: SILVER TIP	112.2

[z] see Flowering Phenocodes, Table 3.

DEGREE-DAYS:

The listing of degree-day accumulation output by PHENOTE is either 1) standard degree-day prediction curve (values representing seasonal accumulations at selected intervals) or 2)user supplied values. Utilizing the PHENOTE output list to predict phenophase requires the ability to forecast the occurrence of specific degree-day accumulations. Degree day accumulations can be included in the weather information retrieved from PMEX. Degree days should be calculated at base 40^{o}F using the Baskerville and Emin method (B & E) (2). This information can be compared directly to degree-days in the output list to predict growth (eg. If 100 degree-days are predicted to accumulate in a given week, add 100 to the current degree-day accumulation (left column) and read the predicted phenophase in the right column.). If weather data comes from a source other than PMEX, users may have to calculate their own degree-day accumulations using the averaging method of calculation. This will cause the model to lose some precision since B&E is the preferred method of degree-day calculation.

To calculate degree-day accumulation (for an advanced prediction) record the forecast maximum and minimum temperatures for as many days as possible.

Calculate degree-day accumulation as follows (For example: see Table 6):

$$DD = \frac{\text{MAX TEMP} + \text{MIN TEMP}}{2} - \text{THRESHOLD TEMP (Base Temp)}$$

where: DD = degree-days

Base Temp = $40^{O}F$

PREDICTING PHENOPHASE:

If a prediction of phenophase for a specific degree-day value is desired, the degree-day value can be input using: 2)user supplied values. PHENOTE will generate the appropriate phenophase prediction. Using standard PHENOTE output provides predictions based on a seasonal range of rounded degree-day values. Interpolation between output values is necessary if the user wishes to forecast the occurance of a specific stage or a specfic date.

EXAMPLE:

CASE: Assume the current stage to be full pink (stage = 17, from Table 1). Will full bloom be reached within the week? Calculations will be made using the sample averaged temperature values from Table 4. A relatively cool week is forecast. Select the appropriate Biofix and determine the Biofix Value. Run PHENOTE, inputing the Biofix Value to generate the output list.

Table 6: Sample temperature data and degree-days calculated using the averaging method.

Forecast Day:	TEMPERATURE: MAX	MIN	DEGREE DAYS[z]
Day 1	60°F	54°F	17
Day 2	73°F	41°F	17
Day 3	58°F	54°F	16
Day 4	56°F	35°F	5.5
Day 5	67°F	34°F	10.5
Day 6	69°F	47°F	18

[z] Degree days calculated at a base temperature of 40°F where $DD = \frac{max-min}{2} - 40$

INTERPOLATION of DEGREE-DAYS for STAGE 17:

Pick the values immediately above and below the stage chosen for prediction (Full bloom=20.5, from Table 1), from the output list (Table 4). In this case, the values are 20.3 and 22.15.

set: upper value = 22.15 = A

lower value = 20.3 = B

stage to predict = 20.5 = C

calculate: (eq. 1) $\frac{C - B}{A - B} = X \qquad \frac{20.5 - 20.3}{22.15 - 20.3} = .108$

X = percent C is advanced towards A

Calculate the difference between the degree-day values that correspond to the selected upper and lower stage values (A & B above) from Table 4.

upper DD - lower DD = DD difference (eq. 2)

(500 - 450) = 50

CALCULATE DEGREE DAYS ASSOCIATED WITH STAGE Y = 21:

(DD difference * X) + lower DD = Y (eq. 3)

(50 * .108) + 450 = 455.4

Y = degree-days necessary to advance to stage C (= full bloom = 20.5)

Assume the current degree-day accumulation to be 370.0 (retrieved from the weather service). The current stage is 17. If full bloom is predicted to occur at 455.4 degree-days (eq. 3), then 85.4 more degree-days are necessary to reach full bloom (predicted degree-days - current degree-days). Checking the sample degree-day forecast (Table 6), the total accumulation expected for 6 days is 84 degree-days. Based on these data, if the forecast remains reasonably accurate, full bloom can be expected to occur in 6 days. Predictions must be updated as weather information changes.

Microclimate Variance

Each orchard microclimate varies, and will affect the precision of the predictive model. Users may wish to check the accuracy of the prediction equations for a specific orchard. If degree-day information comes from a temperature recording unit in the orchard then precision should be good. If weather information comes from a local weather station, more variation can be expected. To check precision, chose the 'user supplied degree-day values' option. Record degree-day values for the specific dates selected for testing. Monitor the trees on each of the selected dates. Late afternoon or early evening is the best time to collect data. Run PHENOTE, inputing the degree-day values recorded on the dates selected. Compare the predicted values with those observed. This comparison should allow an estimate the variance associated with microclimate to be calculated (eg. perhaps the predictions lag $\pm$ 1 day behind observed values due to consistently cooler temperatures at the selected orchard site).

Some Considerations

All predictions are based on the input Biofix Value and the importance of accurately determining this value cannot be overstated. An error in determining the Biofix Value will cause PHENOTE to generate inaccurate predictions throughout the season. If inaccurate predictions occur, switching to a later, accurately determined Biofix Value may improve precision. Careful observation during all phases of monitoring is important.

Predictions are made for phenophase associated with specific degree-day accumulations, not for the day of stage occurrence. A method of interpolating the data and forecasting by day has been descibed, but variances between day forecast and day of occurrence can be large, based on the weather pattern during the projected time period (eg. ½temperature = ½degree-day accumulation). The projected date must be revised to reflect either a cooling or warming trend that may not have been accurately forecast by the weather service. Learning to interpret weather data is crucial to the successful use of PHENOTE.

When predicting cessation of shoot growth for the vegetative functions, PHENOTE does not always predict the exact coding value associated with Terminal Bud Set. Due to the asymptotic nature of the prediction equations, PHENOTE will generate a maximum phenocode value that will not increase even if the degree-day input continues to increase. This maximum predicted phenocode value may be slightly less than the expected TBS code, which will never be reached (eg. maximum value = 29.92 rather than 30.0), and will be repeated on the output list. Assign the degree-day value associated with the first occurrence of the repeatitive maximum value as the effective TBS value.

Each phenophase can occur throughout a range of degree-day values. Growth is an ongoing process and at any one time a series of different phenophases can be observed on a tree. PHENOTE was designed to predict the mean occurrence of each phenophase.

Summary

PHENOTE has demonstrated the ability to predict apple phenology accurately based on a degree-day accumulation (5). Tests of the prediction equations have demonstrated the validity of the general model (5). As a field predictive tool, limitations occur at 5 levels: (1) availability and accuracy of weather data, (2) sampling error in observation to determine the Biofix Value, (3) calculations of degree-days, (4) microclimate variance (relative proximity to the weather station), and (5) sampling error due to monitoring.

PHENOTE is user friendly and is versatile as a basic model. Future versions may incorporate more accurate prediction equations for partial season curves, should be capable of predicting fruit size based on fruit load, or leaf/fruit ratio, and may incorporate a yield component.

PHENOTE Program Lines

```
20 AA$="DEGREE DAYS (BASE 40)"
30 BB$="VEGETATIVE TERMINAL GROWTH"
40 CC$="VEGETATIVE SPUR GROWTH"
50 DD$="REPRODUCTIVE TERMINAL GROWTH"
60 EE$="REPRODUCTIVE SPUR GROWTH"
70 FF$="SPUR: SILVER TIP - TIGHT CLUSTER"
80 GG$="TERMINAL: SILVER TIP - TIGHT CLUSTER"
90 HH$="SPUR: FLOWERING"
100 II$="TERMINAL: FLOWERING"
110 JJ$="SPUR: FRUIT GROWTH"
120 KK$="TERMINAL: FRUIT GROWTH"
130 GOSUB 8740
140 PRINT "PHENOTE: Apple Phenology Prediction Program"
150 PRINT "Model Development: C.E.Edson and J.A.Flore"
160 PRINT "written by C.E.Edson"
170 PRINT "version 2.5 : May 1, 1986"
180 PRINT "(C)Copyright: Michigan State University 1986"
190 PRINT
200 PRINT
210 PRINT
220 PRINT
230 PRINT TAB(30) "PHENOTE"
240 PRINT
250 PRINT
260 PRINT "Use UPPER CASE when responding to prompts."
270 PRINT
280 PRINT
290 PRINT
300 PRINT "WHICH VARIETY DO YOU WISH TO PREDICT FOR?"
310 PRINT TAB(10) "(1) GOLDEN DELICIOUS -STANDARD ROOTSTOCK"
320 PRINT TAB(10) "(2) GOLDEN DELICIOUS  DWARFING ROOTSTOCK"
330 PRINT TAB(10) "(3) RED DELICIOUS - STANDARD ROOTSTOCK"
340 PRINT TAB(10) "(4) OTHER VARIETY - STANDARD ROOTSTOCK"
350 PRINT TAB(10) "(5) OTHER VARIETY - DWARFING ROOTSTOCK"
360 INPUT "ENTER VARIETY  ",V
370 PRINT
380 IF V=1 THEN A1$="GOLD DELICIOUS - STD."
390 IF V = 2  THEN A1$="GOLD DELICIOUS - DWARF."
400 IF V = 3  THEN A1$="RED DELICIOUS - STD."
410 IF V = 4  THEN A1$="APPLE - STD. ROOTSTOCK"
420 IF V = 5  THEN A1$="APPLE - DWARF. ROOTSTOCK"
430 INPUT "DO YOU WISH TO PREDICT (S)PUR OR (T)ERMINAL
    GROWTH   ";GR$
440 IF GR$= "S" GOTO 460
450 IF GR$= "T" GOTO 460 ELSE 430
460 GOSUB 740
470 IF CRV= 1 THEN IF GR$="T" GOTO 970 ELSE 4850
480 IF CRV= 2 THEN IF GR$="T" GOTO 1770 ELSE 5650
490 IF CRV= 3 THEN IF GR$="T" GOTO 2720 ELSE 6620
500 IF CRV= 4 THEN IF GR$="T" GOTO 3340 ELSE 7250
510 IF CRV= 5 THEN IF GR$="T" GOTO 4050 ELSE 7960
520 IF CRV= 6 GOTO 460 ELSE 460
```

```
530 PRINT
540 INPUT "DO YOU WISH TO DO ANOTHER PREDICTION?
    (Y)ES OR (N)O ", PR$
550 PRINT
560 PRINT
570 IF PR$="Y" GOTO 590
580 IF PR$="N" GOTO 620 ELSE 530
590 INPUT "SAME VARIETY";SV$
600 IF SV$="Y" GOTO 430
610 IF SV$="N" GOTO 300 ELSE 590
620 INPUT "DO YOU WANT A PRINT OF THE PHENOLOGY CODES?
    (Y)ES OR (N)O ", PC$
630 IF PC$="Y" GOTO 650
640 IF PC$="N" GOTO 730 ELSE 620
650 PRINT "DO YOU WANT:"
660 PRINT TAB(5) "(1) VEGETATTIVE CODES"
670 PRINT TAB(5) "(2) REPRODUCTIVE CODES"
675 PRINT TAB(5) "(3) FLOWERING CODES (use w/curve 4)"
680 PRINT TAB(5) "(4) ALL: 1 + 2 + 3"
690 INPUT "ENTER YOUR CHOICE ", CODE
700 IF CODE=1 GOTO 11380
710 IF CODE=2 GOTO 10810
720 IF CODE=3 GOTO 11780
725 IF CODE=4 GOTO 10810
730 END
740 PRINT "WHICH PREDICTION CURVE?"
750 PRINT TAB(10) "(1) VEGETATIVE - WHOLE SEASON MODEL"
760 PRINT TAB(10) "(2) REPRODUCTIVE - WHOLE SEASON MODEL"
770 PRINT TAB(10) "(3) REPRODUCTIVE: SILVER TIP -
    TIGHT CLUSTER"
780 PRINT TAB(10) "(4) REPRODUCTIVE: FLOWERING"
790 PRINT TAB(10) "(5) REPRODUCTIVE: FRUIT GROWTH"
800 PRINT TAB(10) "(6) HELP"
810 INPUT "ENTER CURVE SELECTION ",CRV
820 IF CRV= 6 GOTO 830 ELSE 870
830 PRINT TAB(35) "CURVE SELECTION HELP MESSAGE"
840 PRINT "For prediction purposes PHENOTE first separates
    growing points according to location (terminal or spur).
    These are subdivided according  to function  as  either
    vegetative  or  reproductive.  If you desire a general
    prediction for the coming ",
850 PRINT "season chose the appropriate whole season model.
    If  you  are  interested  in  a  particular  phase  of
    reproductive growth, chose accordingly."
860 GOTO 740
870 RETURN
880 PRINT
890 PRINT TAB(15) "HELP MESSAGE : BIOFIX SELECTION"
900 PRINT  "This  program  uses  biofix  values to generate
    predictions. The biofix is determined by monitoring bud
    and shoot development on the trees you wish",
910 PRINT "to predict. When the average observation  for  a
    given  date is equal to the code for the stage selected
    as a biofix (see manual), that biofix has",
```

```
920 PRINT "been reached.  The  degree  days accumulated to
    that date are entered as the biofix value. For example,
    if on 4/20 the average code=6.95,then",
930 PRINT "(rounding) stage 7 (green tip) has been reached.
    Green tip is the appropriate biofix.  Check the weather
    data to determine how many degree-days",
940 PRINT "have accumulated.  Enter that value.  Generally,
    better  predictions  will  result  if  the most recent
    biofix is chosen.  If you are unable to ",
950 PRINT "determine an actual biofix enter (5)."
960 RETURN
970 PRINT
980 PRINT
990 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
1000 PRINT TAB(10) "(1) SILVER TIP (5)"
1010 PRINT TAB(10) "(2)GREEN TIP  0 - 0.5cm (7)"
1020 PRINT TAB(10) "(3) FIRST LEAF (11)"
1030 PRINT TAB(10) "(4) FIFTH LEAF (15)"
1040 PRINT TAB(10) "(5) BIOFIX UNDETERMINED(biofix value =
     degree-day accumulation to April 15)"
1050 PRINT TAB(10) "(6) HELP"
1060 PRINT
1070 PRINT
1080 INPUT "ENTER BIOFIX SELECTION  ",BIO
1090 IF BIO=1 GOTO 1170
1100 IF BIO=2 GOTO 1230
1110 IF BIO=3 GOTO 1290
1120 IF BIO=4 GOTO 1350
1130 IF BIO=5 GOTO 1410
1140 IF BIO=6 GOTO 1150 ELSE 970
1150 GOSUB 880
1160 GOTO 970
1170 IF V=1 THEN BF=63.76
1180 IF V=2 THEN BF=63.44
1190 IF V=3 THEN BF=55!
1200 IF V=4 THEN BF=55!
1210 IF V=5 THEN BF=63.44
1220 GOTO 1420
1230 IF V=1 THEN BF=115.37
1240 IF V=2 THEN BF=117.57
1250 IF V=3 THEN BF=101.52
1260 IF V=4 THEN BF=101.52
1270 IF V=5 THEN BF=117.57
1280 GOTO 1420
1290 IF V=1 THEN BF=214.27
1300 IF V=2 THEN BF=222.73
1310 IF V=3 THEN BF=188.62
1320 IF V=4 THEN BF=188.62
1330 IF V=5 THEN BF=222.73
1340 GOTO 1420
1350 IF V=1 THEN BF=332.66
1360 IF V=2 THEN BF=347.34
1370 IF V=3 THEN BF=289.21
1380 IF V=4 THEN BF=289.21
```

```
1390 IF V=5 THEN BF=347.34
1400 GOTO 1420
1410 BF=60!
1420 PRINT
1430 INPUT "ENTER BIOFIX VALUE  " , FIXX
1440 LPRINT TAB(25) A1$
1450 LPRINT AA$;"          ";BB$
1460 IF BIO=1 THEN FB$="BIOFIX: SILVERTIP "
1470 IF BIO=2 THEN FB$="BIOFIX: GREEN TIP "
1480 IF BIO=3 THEN FB$="BIOFIX: FIRST LEAF "
1490 IF BIO=4 THEN FB$="BIOFIX: FIFTH LEAF "
1500 IF BIO=5 THEN FB$="BIOFIX DATE: APRIL 15"
1510 V15=FIXX-BF
1520 PRINT
1530 PRINT
1540 PRINT "DO YOU WISH TO: "
1550 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
1560 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
1570 PRINT TAB(5) "(3) HELP"
1580 INPUT "ENTER YOUR CHOICE ", CH
1590 IF CH=3 GOTO 1620
1600 IF CH=2 GOTO 1640
1610 IF CH=1 GOTO 1660 ELSE 1540
1620 GOSUB 9040
1630 GOTO 1540
1640 GOSUB 9290
1650 GOTO 540
1660 FOR I= 1 TO 30
1670 V25=DDE(I)-V15
1680 IF V=1 THEN V105=31.9528/(1+EXP(2.2917-.01042*V25+
     1.4464E-05*V25*V25-8.4229E-09*V25^3))
1690 IF V=2 THEN V105=29.9196/(1+EXP(2.1928-.01011*V25+
     1.4306E-05*V25*V25-9.8715E-09*V25^3))
1700 IF V=3 THEN V105=32.198/(1+EXP(2.264-.0112*V25+
     1.587E-05*V25*V25-8.872E-09*V25^3))
1710 IF V=4 THEN V105=32.198/(1+EXP(2.264-.0112*V25+
     1.587E-05*V25*V25-8.872E-09*V25^3))
1720 IF V=5 THEN V105=29.9196/(1+EXP(2.1928-.01011*V25+
     1.4306E-05*V25*V25-9.8715E-09*V25^3))
1730 LPRINT USING "####.##                          ";DDE(I),V105
1740 NEXT I
1750 LPRINT FB$,FIXX
1760 GOTO 540
1770 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
1780 PRINT TAB(10) "(1) SILVER TIP (5)"
1790 PRINT TAB(10) "(2) GREEN TIP 0 - 0.5 cm (7)"
1800 PRINT TAB(10) "(3) TIGHT CLUSTER (12)"
1810 PRINT TAB(10) "(4) FULL BLOOM (20.5)"
1820 PRINT TAB(10) "(5) FRUIT SET (26.5)"
1830 PRINT TAB(10) "(6) FRUIT DIAMETER = 2.0-2.5 cm (32)"
1840 PRINT TAB(10) "(7) BIOFIX UNDETERMINED (Biofix value=
           degree-day",
1850 PRINT TAB(10) "accumulation to April 15)"
```

```
1860 PRINT TAB(10) "(8) HELP "
1870 PRINT
1880 INPUT "ENTER BIOFIX SELECTION  ",BIOA
1890 IF BIOA=1 GOTO 1990
1900 IF BIOA=2 GOTO 2050
1910 IF BIOA=3 GOTO 2110
1920 IF BIOA=4 GOTO 2170
1930 IF BIOA=5 GOTO 2230
1940 IF BIOA=6 GOTO 2290
1950 IF BIOA=7 GOTO 2350
1960 IF BIOA=8 GOTO 1970 ELSE 1770
1970 GOSUB 880
1980 GOTO 1770
1990 IF V = 1  THEN BFA=47.47
2000 IF V = 2  THEN BFA=48.56
2010 IF V = 3  THEN BFA=23.28
2020 IF V = 4  THEN BFA=23.28
2030 IF V = 5  THEN BFA=48.56
2040 GOTO 2360
2050 IF V = 1  THEN BFA=106.93
2060 IF V = 2  THEN BFA=112.15
2070 IF V = 3  THEN BFA=84.51
2080 IF V = 4  THEN BFA=84.51
2090 IF V = 5  THEN BFA=112.15
2100 GOTO 2360
2110 IF V = 1  THEN BFA=227.28
2120 IF V = 2  THEN BFA=239.65
2130 IF V = 3  THEN BFA=206.82
2140 IF V = 4  THEN BFA=206.82
2150 IF V = 5  THEN BFA=239.65
2160 GOTO 2360
2170 IF V = 1  THEN BFA=423.73
2180 IF V = 2  THEN BFA=446.75
2190 IF V = 3  THEN BFA=406.27
2200 IF V = 4  THEN BFA=406.27
2210 IF V = 5  THEN BFA=446.75
2220 GOTO 2360
2230 IF V = 1  THEN BFA=618.3
2240 IF V = 2  THEN BFA=649.19
2250 IF V = 3  THEN BFA=601.91
2260 IF V = 4  THEN BFA=601.91
2270 IF V = 5  THEN BFA=649.19
2280 GOTO 2360
2290 IF V = 1  THEN BFA=1047.59
2300 IF V = 2  THEN BFA=1065.46
2310 IF V = 3  THEN BFA=1006.28
2320 IF V = 4  THEN BFA=1006.28
2330 IF V = 5  THEN BFA=1065.46
2340 GOTO 2360
2350 BFA=60!
2360 PRINT
2370 INPUT "ENTER BIOFIX VALUE: ",FIXA
2380 LPRINT TAB(30) A1$
2390 LPRINT AA$;"              ";DD$
```

```
2400 IF BIOA=1 THEN FBA$="BIOFIX: SILVER TIP"
2410 IF BIOA=2 THEN FBA$="BIOFIX: GREEN TIP"
2420 IF BIOA=3 THEN FBA$="BIOFIX: TIGHT CLUSTER"
2430 IF BIOA=4 THEN FBA$="BIOFIX: FULL BLOOM"
2435 IF BIOA=5 THEN FBA$="BIOFIX: FRUIT SET"
2440 IF BIOA=6 THEN FBA$="BIOFIX: DIAM.= 2.0-2.5 CM"
2450 IF BIOA=7 THEN FBA$="BIOFIX DATE: APRIL 15"
2460 V16=FIXA-BFA
2470 PRINT
2480 PRINT
2490 PRINT "DO YOU WISH TO:"
2500 PRINT TAB(5) "(1) USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
2510 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
2520 PRINT TAB(5) "(3) HELP"
2530 INPUT "ENTER YOUR CHOICE ", CHA
2540 IF CHA=3 GOTO 2570
2550 IF CHA=2 GOTO 2590
2560 IF CHA=1 GOTO 2610 ELSE 2490
2570 GOSUB 9040
2580 GOTO 2490
2590 GOSUB 9120
2600 GOTO 540
2610 FOR I= 1 TO 40
2620 V26=DDD(I)-V16
2630 IF V = 1  THEN V106=39.2679/(1+EXP(2.2676-.007406*V26+
     4.8296E-06*V26*V26-1.1248E-09*V26^3))
2640 IF V = 2  THEN V106=38.3164/(1+EXP(2.2248-.006917*V26+
     4.011E-06*V26*V26-8.521E-10*V26^3))
2650 IF V = 3  THEN V106=40.395/(1+EXP(2.126-.007039*V26+
     4.7093E-06*V26*V26-1.108E-09*V26^3))
2660 IF V = 4  THEN V106=40.395/(1+EXP(2.126-.007039*V26+
     4.7093E-06*V26*V26-1.108E-09*V26^3))
2670 IF V = 5  THEN V106=38.3164/(1+EXP(2.2248-.006917*V26+
     4.011E-06*V26*V26-8.521E-10*V26^3))
2680 LPRINT USING "####.##                          ";DDD(I),V106
2690 NEXT I
2700 LPRINT  FBA$,FIXA
2710 GOTO 540
2720 PRINT
2730 PRINT
2740 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
2750 PRINT TAB(10) "(1) SILVER TIP (5)"
2760 PRINT TAB(10) "(2)GREEN TIP  0 - 0.5cm (7) "
2770 PRINT TAB(10) "(3) BIOFIX UNDETERMINED(biofix value =
     degree-day accumulation toApril 15)"
2780 PRINT TAB(10) "(4) HELP"
2790 PRINT
2800 PRINT
2810 INPUT "ENTER BIOFIX SELECTION  ",BIOB
2820 IF BIOB=1 GOTO 2880
2830 IF BIOB=2 GOTO 2940
2840 IF BIOB=3 GOTO 3000
2850 IF BIOB=4 GOTO 2860 ELSE 2720
```

```
2860 GOSUB 880
2870 GOTO 2720
2880 IF V=1 THEN BFB=47.5
2890 IF V=2 THEN BFB=48.56
2900 IF V=3 THEN BFB=23.84
2910 IF V=4 THEN BFB=23.84
2920 IF V=5 THEN BFB=48.56
2930 GOTO 3010
2940 IF V=1 THEN BFB=106.93
2950 IF V=2 THEN BFB=112.15
2960 IF V=3 THEN BFB=84.51
2970 IF V=4 THEN BFB=84.51
2980 IF V=5 THEN BFB=112.15
2990 GOTO 3010
3000 BFB=60!
3010 PRINT
3020 INPUT "ENTER BIOFIX VALUE  " , FIXB
3030 LPRINT TAB(25) A1$
3040 LPRINT AA$;"         ";GG$
3050 IF BIOB=1 THEN FBB$="BIOFIX: SILVERTIP"
3060 IF BIOB=2 THEN FBB$="BIOFIX: GREEN TIP"
3070 IF BIOB=3 THEN FBB$="BIOFIX DATE: APRIL 15"
3080 V17=FIXB-BFB
3090 PRINT
3100 PRINT
3110 PRINT "DO YOU WISH TO: "
3120 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
3130 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
3140 PRINT TAB(5) "(3) HELP"
3150 INPUT "ENTER YOUR CHOICE ",CHB
3160 IF CHB=3 GOTO 3190
3170 IF CHB=2 GOTO 3210
3180 IF CHB=1 GOTO 3230 ELSE 3110
3190 GOSUB 9040
3200 GOTO 3110
3210 GOSUB 9460
3220 GOTO 540
3230 FOR I= 1 TO 24
3235 V27= DDA(I)-V17
3250 IF V=1 THEN V107=39.2679/(1+EXP(2.2676-.007406*V27+
     4.8296E-06*V27*V27-1.1248E-09*V27^3))
3260 IF V=2 THEN V107=38.3164/(1+EXP(2.2248-.006917*V27+
     4.011E-06*V27*V27-8.521E-10*V27^3))
3270 IF V=3 THEN V107=40.395/(1+EXP(2.126-.007039*V27+
     4.709E-06*V27*V27-1.108E-09*V27^3))
3280 IF V=4 THEN V107=40.395/(1+EXP(2.126-.007039*V27+
     4.709E-06*V27*V27-1.108E-09*V27^3))
3290 IF V=5 THEN V107=38.3164/(1+EXP(2.2248-.006917*V27+
     4.011E-06*V27*V27-8.521E-10*V27^3))
3300 LPRINT USING "####.##                    ";DDA(I),V107
3310 NEXT I
3320 LPRINT FBB$,FIXB
3330 GOTO 540
```

```
3340 PRINT
3350 PRINT
3360 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
3370 PRINT TAB(10) "(1) SILVER TIP (5)"
3380 PRINT TAB(10) "(2)GREEN TIP  0 - 0.5cm  (7)"
3390 PRINT TAB(10) "(3) TIGHT CLUSTER (12)"
3400 PRINT TAB(10) "(4) BIOFIX UNDETERMINED(biofix value =
     degree-day accumulation toApril 15)"
3410 PRINT TAB(10) "(5) HELP"
3420 PRINT
3430 PRINT
3440 INPUT "ENTER BIOFIX SELECTION  ",BIOC
3450 IF BIOC=1 GOTO 3520
3460 IF BIOC=2 GOTO 3580
3470 IF BIOC=3 GOTO 3640
3480 IF BIOC=4 GOTO 3700
3490 IF BIOC=5 GOTO 3500 ELSE 3340
3500 GOSUB 880
3510 GOTO 3340
3520 IF V=1 THEN BFC=47.47
3530 IF V=2 THEN BFC=48.56
3540 IF V=3 THEN BFC=23.84
3550 IF V=4 THEN BFC=23.84
3560 IF V=5 THEN BFC=48.56
3570 GOTO 3710
3580 IF V=1 THEN BFC=106.93
3590 IF V=2 THEN BFC=112.15
3600 IF V=3 THEN BFC=84.51
3610 IF V=4 THEN BFC=84.51
3620 IF V=5 THEN BFC=112.15
3630 GOTO 3710
3640 IF V=1 THEN BFC=227.28
3650 IF V=2 THEN BFC=239.65
3660 IF V=3 THEN BFC=206.82
3670 IF V=4 THEN BFC=206.82
3680 IF V=5 THEN BFC=239.65
3690 GOTO 3710
3700 BFC=60!
3710 PRINT
3720 INPUT "ENTER BIOFIX VALUE  " , FIXC
3730 LPRINT TAB(25) A1$
3740 LPRINT AA$;"         ";II$
3750 IF BIOC=1 THEN FBC$="BIOFIX: SILVERTIP"
3760 IF BIOC=2 THEN FBC$="BIOFIX: GREEN TIP"
3770 IF BIOC=3 THEN FBC$="BIOFIX: TIGHT CLUSTER"
3780 IF BIOC=4 THEN FBC$="BIOFIX DATE: APRIL 15"
3790 V15=FIXC-BFC
3800 PRINT
3810 PRINT
3811 PRINT "NOTICE:"
3812 PRINT TAB(5) "Output from flowering curves uses a
     different"
3813 PRINT TAB(5) "phenocode, which allows the detection
     of"
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3814 PRINT TAB(5) "smaller incremental changes in
     morphological"
3815 PRINT TAB(5) "development; see manual or get a
     printout"
3816 PRINT TAB(5) "of the FLOWERING PHENOCODES at the end
     of the"
3817 PRINT TAB(5) "current program run"
3818 PRINT
3819 PRINT
3820 PRINT "DO YOU WISH TO: "
3830 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
3840 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
3850 PRINT TAB(5) "(3) HELP"
3860 INPUT "ENTER YOUR CHOICE ", CHC
3870 IF CHC=3 GOTO 3900
3880 IF CHC=2 GOTO 3920
3890 IF CHC=1 GOTO 3940 ELSE 3820
3900 GOSUB 9040
3910 GOTO 3820
3920 GOSUB 9620
3930 GOTO 540
3940 FOR I= 1 TO 30
3950 V28=DDB(I)-V15
3960 IF V=1 THEN V108=20.18*(1-EXP(-(.495+.0013*V28)^8.847))
3970 IF V=2 THEN V108=20.068*(1-EXP(-(.165+.0011*V28)^5.94))
3980 IF V=3 THEN V108=20.18*(1-EXP(-(.495+.00123*V28)^8.85))
3990 IF V=4 THEN V108=20.18*(1-EXP(-(.495+.00123*V28)^8.85))
4000 IF V=5 THEN V108=20.068*(1-EXP(-(.165+.0018*V28)^5.94))
4010 LPRINT USING "####.##                         ";DDB(I),V108
4020 NEXT I
4030 LPRINT FBC$,FIXC
4040 GOTO 540
4050 PRINT
4060 PRINT
4070 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
4080 PRINT TAB(10) "(1) SILVER TIP (5)"
4090 PRINT TAB(10) "(2) FRUIT SET (26.5)"
4100 PRINT TAB(10) "(3) FRUIT DIAMETER = 1.5-2.0 cm (31)"
4110 PRINT TAB(10) "(4) FRUIT DIAMETER = 3.5-4.0 cm (35)"
4120 PRINT TAB(10) "(5) BIOFIX UNDETERMINED(biofix value =
     degree-day accumulation toApril 15)"
4130 PRINT TAB(10) "(6) HELP"
4140 PRINT
4150 PRINT
4160 INPUT "ENTER BIOFIX SELECTION  ",BIOD
4170 IF BIOD=1 GOTO 4250
4180 IF BIOD=2 GOTO 4310
4190 IF BIOD=3 GOTO 4370
4200 IF BIOD=4 GOTO 4430
4210 IF BIOD=5 GOTO 4490
4220 IF BIOD=6 GOTO 4230 ELSE 4050
4230 GOSUB 880
4240 GOTO 4050
```

```
4250 IF V=1 THEN BFD=47.47
4260 IF V=2 THEN BFD=48.56
4270 IF V=3 THEN BFD=23.84
4280 IF V=4 THEN BFD=23.84
4290 IF V=5 THEN BFD=48.56
4300 GOTO 4500
4310 IF V=1 THEN BFD=618.3
4320 IF V=2 THEN BFD=649.19
4330 IF V=3 THEN BFD=601.91
4340 IF V=4 THEN BFD=601.91
4350 IF V=5 THEN BFD=649.19
4360 GOTO 4500
4370 IF V=1 THEN BFD=1035.15
4380 IF V=2 THEN BFD=1053!
4390 IF V=3 THEN BFD=990.8
4400 IF V=4 THEN BFD=990.8
4410 IF V=5 THEN BFD=1053!
4420 GOTO 4500
4430 IF V=1 THEN BFD=1745.4
4440 IF V=2 THEN BFD=1884.9
4450 IF V=3 THEN BFD=1850.2
4460 IF V=4 THEN BFD=1850.2
4470 IF V=5 THEN BFD=1884.9
4480 GOTO 4500
4490 BFD=60!
4500 PRINT
4510 INPUT "ENTER BIOFIX VALUE  " , FIXD
4520 LPRINT TAB(25) A1$
4530 LPRINT AA$;"          ";KK$
4540 IF BIOD=1 THEN FBD$="BIOFIX: SILVERTIP"
4550 IF BIOD=2 THEN FBD$="BIOFIX: FRUIT SET"
4560 IF BIOD=3 THEN FBD$="BIOFIX: FRUIT DIAM.=1.5-2.0cm"
4570 IF BIOD=4 THEN FBD$="BIOFIX: FRUIT DIAM.=3.5-4.0cm"
4580 IF BIOD=5 THEN FBD$="BIOFIX DATE: APRIL 15"
4590 V19=FIXD-BFD
4600 PRINT
4610 PRINT
4620 PRINT "DO YOU WISH TO: "
4630 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
4640 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
4650 PRINT TAB(5) "(3) HELP"
4660 INPUT "ENTER YOUR CHOICE ", CHD
4670 IF CHD=3 GOTO 4700
4680 IF CHD=2 GOTO 4720
4690 IF CHD=1 GOTO 4740 ELSE 4620
4700 GOSUB 9040
4710 GOTO 4620
4720 GOSUB 9790
4730 GOTO 540
4740 FOR I= 1 TO 30
4750 V29=DDC(I)-V19
```

```
4760 IF V=1 THEN V109=39.2679/(1+EXP(2.2676-.007406*V29+
      4.8296E-06*V29*V29-1.1248E-09*V29^3))
4770 IF V=2 THEN V109=38.3164/(1+EXP(2.2248-.006917*V29+
     4.011E-06*V29*V29-8.521E-10*V29^3))
4780 IF V=3 THEN V109=40.395/(1+EXP(2.126-.007039*V29+
     4.709E-06*V29*V29-1.108E-09*V29^3))
4790 IF V=4 THEN V109=40.395/(1+EXP(2.126-.007039*V29+
     4.709E-06*V29*V29-1.108E-09*V29^3))
4800 IF V=5 THEN V109=38.3164/(1+EXP(2.2248-.006917*V29+
     4.011E-06*V29*V29-8.521E-10*V29^3))
4810 LPRINT USING "####.##                           ";DDC(I),V109
4820 NEXT I
4830 LPRINT FBD$,FIXD
4840 GOTO 540
4850 PRINT
4860 PRINT
4870 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
4880 PRINT TAB(10) "(1) SILVER TIP (5)"
4890 PRINT TAB(10) "(2)GREEN TIP  0 - 0.5cm  (7)"
4900 PRINT TAB(10) "(3) FIRST LEAF (11)"
4910 PRINT TAB(10) "(4) FIFTH LEAF (15)"
4920 PRINT TAB(10) "(5) BIOFIX UNDETERMINED(biofix value =
     degree-day accumulation toApril 15)"
4930 PRINT TAB(10) "(6) HELP"
4940 PRINT
4950 PRINT
4960 INPUT "ENTER BIOFIX SELECTION  ",BIOE
4970 IF BIOE=1 GOTO 5050
4980 IF BIOE=2 GOTO 5110
4990 IF BIOE=3 GOTO 5170
5000 IF BIOE=4 GOTO 5230
5010 IF BIOE=5 GOTO 5290
5020 IF BIOE=6 GOTO 5030 ELSE 4850
5030 GOSUB 880
5040 GOTO 4850
5050 IF V=1 THEN BFE=58.89
5060 IF V=2 THEN BFE=58.14
5070 IF V=3 THEN BFE=36.63
5080 IF V=4 THEN BFE=36.63
5090 IF V=5 THEN BFE=58.14
5100 GOTO 5300
5110 IF V=1 THEN BFE=102.86
5120 IF V=2 THEN BFE=114.24
5130 IF V=3 THEN BFE=82.76
5140 IF V=4 THEN BFE=82.76
5150 IF V=5 THEN BFE=114.24
5160 GOTO 5300
5170 IF V=1 THEN BFE=199.81
5180 IF V=2 THEN BFE=267.8
5190 IF V=3 THEN BFE=176.34
5200 IF V=4 THEN BFE=176.34
5210 IF V=5 THEN BFE=267.8
5220 GOTO 5300
5230 IF V=1 THEN BFE=354.5
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```
5240 IF V=2 THEN BFE=380.4
5250 IF V=3 THEN BFE=302.22
5260 IF V=4 THEN BFE=302.22
5270 IF V=5 THEN BFE=380.4
5280 GOTO 5300
5290 BFE=60!
5300 PRINT
5310 INPUT "ENTER BIOFIX VALUE  " , FIXE
5320 LPRINT TAB(25) A1$
5330 LPRINT AA$;"          ";CC$
5340 IF BIOE=1 THEN FBE$="BIOFIX: SILVERTIP"
5350 IF BIOE=2 THEN FBE$="BIOFIX: GREEN TIP"
5360 IF BIOE=3 THEN FBE$="BIOFIX: FIRST LEAF"
5370 IF BIOE=4 THEN FBE$="BIOFIX: FIFTH LEAF
5380 IF BIOE=5 THEN FBE$="BIOFIX DATE: APRIL 15"
5390 V20=FIXE-BFE
5400 PRINT
5410 PRINT
5420 PRINT "DO YOU WISH TO: "
5430 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
5440 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
5450 PRINT TAB(5) "(3) HELP"
5460 INPUT "ENTER YOUR CHOICE ", CHE
5470 IF CHE=3 GOTO 5500
5480 IF CHE=2 GOTO 5520
5490 IF CHE=1 GOTO 5540
5500 GOSUB 9040
5510 GOTO 5420
5520 GOSUB 9960
5530 GOTO 540
5540 FOR I= 1 TO 30
5550 V30=DDE(I)-V20
5560 IF V=1 THEN V110=29.53/(1+EXP(2.315-.014*V30+
     .0000308*V30*V30-2.834E-08*V30^3))
5570 IF V=2 THEN V110=25.229/(1+EXP(1.958-.0107*V30+
     1.8671E-05*V30*V30-1.794E-08*V30^3))
5580 IF V=3 THEN V110=29.829/(1+EXP(1.995-.0115*V30+
     2.118E-05*V30*V30-1.725E-08*V30^3))
5590 IF V=4 THEN V110=29.829/(1+EXP(1.995-.0115*V30+
     2.118E-05*V30*V30-1.725E-08*V30^3))
5600 IF V=5 THEN V110=25.229/(1+EXP(1.958-.0107*V30+
     1.8671E-05*V30*V30-1.794E-08*V30^3))
5610 LPRINT USING "####.##                        ";DDE(I),V110
5620 NEXT I
5630 LPRINT FBE$,FIXE
5640 GOTO 540
5650 PRINT
5660 PRINT
5670 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
5680 PRINT TAB(10) "(1) SILVER TIP (5)"
5690 PRINT TAB(10) "(2)GREEN TIP  0 - 0.5cm (7) "
5700 PRINT TAB(10) "(3) TIGHT CLUSTER (12)"
5710 PRINT TAB(10) "(4) FULL BLOOM (20.5)"
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```
5720 PRINT TAB(10) "(5) FRUIT SET (26.5)"
5730 PRINT TAB(10) "(6) FRUIT DIAMETER = 2.0-2.5 cm (32)"
5740 PRINT TAB(10) "(7) BIOFIX UNDETERMINED(biofix value =
     degree-day accum. START DATE+15 DAYS)"
5750 PRINT TAB(10) "(8) HELP"
5760 PRINT
5770 PRINT
5780 INPUT "ENTER BIOFIX SELECTION  ",BIOF
5790 IF BIOF=1 GOTO 5890
5800 IF BIOF=2 GOTO 5950
5810 IF BIOF=3 GOTO 6010
5820 IF BIOF=4 GOTO 6070
5830 IF BIOF=5 GOTO 6130
5840 IF BIOF=6 GOTO 6190
5850 IF BIOF=7 GOTO 6250
5860 IF BIOF=8 GOTO 5870 ELSE 5650
5870 GOSUB 880
5880 GOTO 5650
5890 IF V=1 THEN BFF=39.27
5900 IF V=2 THEN BFF=38.77
5910 IF V=3 THEN BFF=9.8
5920 IF V=4 THEN BFF=9.8
5930 IF V=5 THEN BFF=38.77
5940 GOTO 6260
5950 IF V=1 THEN BFF=98.58
5960 IF V=2 THEN BFF=100.53
5970 IF V=3 THEN BFF=71.3
5980 IF V=4 THEN BFF=71.3
5990 IF V=5 THEN BFF=100.53
6000 GOTO 6260
6010 IF V=1 THEN BFF=219.05
6020 IF V=2 THEN BFF=225.11
6030 IF V=3 THEN BFF=196.07
6040 IF V=4 THEN BFF=196.07
6050 IF V=5 THEN BFF=225.11
6060 GOTO 6260
6070 IF V=1 THEN BFF=416.66
6080 IF V=2 THEN BFF=425.07
6090 IF V=3 THEN BFF=398.02
6100 IF V=4 THEN BFF=398.02
6110 IF V=5 THEN BFF=425.07
6120 GOTO 6260
6130 IF V=1 THEN BFF=613.5
6140 IF V=2 THEN BFF=596.18
6150 IF V=3 THEN BFF=592.63
6160 IF V=4 THEN BFF=592.63
6170 IF V=5 THEN BFF=596.18
6180 GOTO 6260
6190 IF V=1 THEN BFF=1056.08
6200 IF V=2 THEN BFF=988.57
6210 IF V=3 THEN BFF=988.51
6220 IF V=4 THEN BFF=988.51
6230 IF V=5 THEN BFF=988.57
6240 GOTO 6260
```

```
6250 BFF=60!
6260 PRINT
6270 INPUT "ENTER BIOFIX VALUE  " , FIXF
6280 LPRINT TAB(25) A1$
6290 LPRINT AA$;"          ";EE$
6300 IF BIOF=1 THEN FBF$="BIOFIX: SILVERTIP (5)"
6310 IF BIOF=2 THEN FBF$="BIOFIX: GREEN TIP (7)"
6320 IF BIOF=3 THEN FBF$="BIOFIX: TIGHT CLUSTER (12)"
6330 IF BIOF=4 THEN FBF$="BIOFIX: FULL BLOOM (20.5)"
6340 IF BIOF=5 THEN FBF$="BIOFIX: FRUIT SET (26.5)"
6350 IF BIOF=6 THEN FBF$="BIOFIX: FRUIT DIAM.=2.0-2.5cm(32)"
6360 IF BIOF=7 THEN FBF$="BIOFIX DATE: START DATE + 15 DAYS"
6370 V21=FIXF-BFF
6380 PRINT
6390 PRINT
6400 PRINT "DO YOU WISH TO :"
6410 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
6420 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
6430 PRINT TAB(5) "(3) HELP"
6440 INPUT "ENTER YOUR CHOICE ", CHF
6450 IF CHF=3 GOTO 6480
6460 IF CHF=2 GOTO 6500
6465 IF CHF=1 GOTO 6515
6480 GOSUB 9040
6490 GOTO 6400
6500 GOSUB 10130
6510 GOTO 540
6515 FOR I=1 TO 40
6520 V31=DDD(I)-V21
6530 IF V=1 THEN V111=39.325/(1+EXP (2.207-.007329*V31+
     4.864E-06*V31*V31-1.16E-09*V31^3))
6540 IF V=2 THEN V111=39.774/(1+EXP(1.927-.006634*V31+
     4.146E-06*V31*V31-9.127E-10*V31^3))
6550 IF V=3 THEN V111=40.497/(1+EXP(2.026-.006737*V31+
     4.378E-06*V31*V31-1.005E-09*V31^3))
6560 IF V=4 THEN V111=40.497/(1+EXP(2.026-.006737*V31+
     4.378E-06*V31*V31-1.005E-09*V31^3))
6570 IF V=5 THEN V111=39.774/(1+EXP(1.927-.006634*V31+
     4.146E-06*V31*V31-9.127E-10*V31^3))
6580 LPRINT USING "####.##                         ";DDD(I),V111
6590 NEXT I
6600 LPRINT FBF$,FIXF
6610 GOTO 540
6620 PRINT
6630 PRINT
6640 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
6650 PRINT TAB(10) "(1) SILVER TIP (5)"
6660 PRINT TAB(10) "(2)GREEN TIP  0 - 0.5cm (7) "
6670 PRINT TAB(10) "(3) BIOFIX UNDETERMINED(biofix value =
     degree-day",
6680 PRINT "accumulation to April 15)"
6690 PRINT TAB(10) "(4) HELP"
6700 PRINT
```

```
6710 PRINT
6720 INPUT "ENTER BIOFIX SELECTION  ",BIOG
6730 IF BIOG=1 GOTO 6790
6740 IF BIOG=2 GOTO 6850
6750 IF BIOG=3 GOTO 6910
6760 IF BIOG=4 GOTO 6770 ELSE 6620
6770 GOSUB 880
6780 GOTO 6620
6790 IF V=1 THEN BF=39.27
6800 IF V=2 THEN BF=38.77
6810 IF V=3 THEN BF=9.8
6820 IF V=4 THEN BF=9.8
6830 IF V=5 THEN BF=38.77
6840 GOTO 6920
6850 IF V=1 THEN BF=98.58
6860 IF V=2 THEN BF=100.53
6870 IF V=3 THEN BF=71.3
6880 IF V=4 THEN BF=71.3
6890 IF V=5 THEN BF=100.53
6900 GOTO 6920
6910 BFG=60!
6920 PRINT
6930 INPUT "ENTER BIOFIX VALUE  " , FIXG
6940 LPRINT TAB(25) A1$
6950 LPRINT AA$;"          ";FF$
6960 IF BIOG=1 THEN FBG$="BIOFIX: SILVER TIP"
6970 IF BIOG=2 THEN FBG$="BIOFIX: GREEN TIP"
6980 IF BIOG=3 THEN FBG$="BIOFIX DATE: APRIL 15"
6990 V22=FIXG-BFG
7000 PRINT
7010 PRINT
7020 PRINT "DO YOU WISH TO:"
7030 PRINT TAB(5) "(1) USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
7040 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
7050 PRINT TAB(5) "(3) HELP"
7060 INPUT "ENTER YOUR CHOICE ", CHG
7070 IF CHG=3 GOTO 7100
7080 IF CHG=2 GOTO 7120
7090 IF CHG=1 GOTO 7140 ELSE 7020
7100 GOSUB 9040
7110 GOTO 7020
7120 GOSUB 10300
7130 GOTO 540
7140 FOR I = 1 TO 24
7150 V32=DDA(I)-V22
7160 IF V=1 THEN V112=39.325/(1+EXP(2.207-.007329*V32+
     4.864E-06*V32*V32-1.16E-09*V32^3))
7170 IF V=2 THEN V112=39.774/(1+EXP(1.927-.00664*V32+
     4.146E-06*V32*V32-9.127E-10*V32^3))
7180 IF V=3 THEN V112=40.497/(1+EXP(2.026-.006737*V32+
     4.378E-06*V32*V32-1.005E-09*V32^3))
```

```
7190 IF V=4 THEN V112=40.497/(1+EXP(2.026-.006737*V32+
     4.378E-06*V32*V32-1.005E-09*V32^3))
7200 IF V=5 THEN V112=39.774/(1+EXP(1.927-.00664*V32+
     4.146E-06*V32*V32-9.127E-10*V32^3))
7210 LPRINT USING "####.##                         ";DDA(I),V112
7220 NEXT I
7230 LPRINT FBG$,FIXG
7240 GOTO 540
7250 PRINT
7260 PRINT
7270 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
7280 PRINT TAB(10) "(1) SILVER TIP (5)"
7290 PRINT TAB(10) "(2)GREEN TIP  0 - 0.5cm (7) "
7300 PRINT TAB(10) "(3) TIGHT CLUSTER (12)"
7310 PRINT TAB(10) "(4) BIOFIX UNDETERMINED(biofix value =
     degree-day accumulation toApril 15)"
7320 PRINT TAB(10) "(5) HELP"
7330 PRINT
7340 PRINT
7350 INPUT "ENTER BIOFIX SELECTION  ",BIOH
7360 IF BIOH=1 GOTO 7430
7370 IF BIOH=2 GOTO 7490
7380 IF BIOH=3 GOTO 7550
7390 IF BIOH=4 GOTO 7610
7400 IF BIOH=5 GOTO 7410 ELSE 7250
7410 GOSUB 880
7420 GOTO 7250
7430 IF V=1 THEN BFH=39.27
7440 IF V=2 THEN BFH=38.77
7450 IF V=3 THEN BFH=9.8
7460 IF V=4 THEN BFH=9.8
7470 IF V=5 THEN BFH=38.77
7480 GOTO 7620
7490 IF V=1 THEN BFH=98.58
7500 IF V=2 THEN BFH=100.53
7510 IF V=3 THEN BFH=71.3
7520 IF V=4 THEN BFH=71.3
7530 IF V=5 THEN BFH=100.53
7540 GOTO 7620
7550 IF V=1 THEN BFH=219.05
7560 IF V=2 THEN BFH=225.11
7570 IF V=3 THEN BFH=196.07
7580 IF V=4 THEN BFH=196.07
7590 IF V=5 THEN BFH=225.11
7600 GOTO 7620
7610 BFH=60!
7620 PRINT
7630 INPUT "ENTER BIOFIX VALUE  " , FIXH
7640 LPRINT TAB(25) A1$
7650 LPRINT AA$;"          ";HH$
7660 IF BIOH=1 THEN FBH$="BIOFIX: SILVERTIP"
7670 IF BIOH=2 THEN FBH$="BIOFIX: GREEN TIP"
7680 IF BIOH=3 THEN FBH$="BIOFIX: TIGHT CLUSTER"
7690 IF BIOH=4 THEN FBH$="BIOFIX DATE: APRIL 15"
```

```
7700 V23=FIXH-BFH
7710 PRINT
7720 PRINT
7721 PRINT "NOTICE:"
7722 PRINT TAB(5) "Output from flowering curves uses a
     different"
7723 PRINT TAB(5) "phenocode, which allows the detection
     of"
7724 PRINT TAB(5) "smaller incremental changes in
     morphological"
7725 PRINT TAB(5) "development; see manual or get a
     printout"
7726 PRINT TAB(5) "of the FLOWERING PHENOCODES at the end
     of the"
7727 PRINT TAB(5) "current program run"
7728 PRINT
7729 PRINT
7730 PRINT "DO YOU WISH TO: "
7740 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
7750 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
7760 PRINT TAB(5) "(3) HELP"
7770 INPUT "ENTER YOUR CHOICE ", CHH
7780 IF CHH=3 GOTO 7810
7790 IF CHH=2 GOTO 7830
7800 IF CHH=1 GOTO 7850 ELSE 7730
7810 GOSUB 9040
7820 GOTO 7730
7830 GOSUB 10470
7840 GOTO 540
7850 FOR I= 1 TO 30
7860 V33=DDB(I)-V23
7870 IF V=1 THEN V113=20.16*(1!-EXP(-(.5997+
     .0009786*V33) 11.096))
7880 IF V=2 THEN V113=20.31*(1!-EXP(-(-.097+
     .00264*V33) 4.255))
7890 IF V=3 THEN V113=20.16*(1!-EXP(-(.5997+
     .0009786*V33) 11.096))
7900 IF V=4 THEN V113=20.16*(1!-EXP(-(.5997+
     .0000786*V33) 11.096))
7910 IF V=5 THEN V113=20.31*(1!-EXP(-(-.097+
     .00264*V33) 4.255))
7920 LPRINT USING "####.##                      ";DDB(I),V113
7930 NEXT I
7940 LPRINT FBH$,FIXH
7950 GOTO 540
7960 PRINT
7970 PRINT
7980 PRINT "WHICH BIOFIX DO YOU WISH TO SELECT?"
7990 PRINT TAB(10) "(1) SILVER TIP (5)"
8000 PRINT TAB(10) "(2) FRUIT SET  (26.5)"
8010 PRINT TAB(10) "(3) FRUIT DIAMETER = 1.5-2.0 cm (31)"
8020 PRINT TAB(10) "(4) FRUIT DIAMETER = 3.5-4.0 cm (35)"
8030 PRINT TAB(10) "(5) BIOFIX UNDETERMINED(biofix value =
```

```
     degree-day accumulation toApril 15)"
8040 PRINT TAB(10) "(6) HELP"
8050 PRINT
8060 PRINT
8070 INPUT "ENTER BIOFIX SELECTION  ",BIOI
8080 IF BIOI=1 GOTO 8160
8090 IF BIOI=2 GOTO 8220
8100 IF BIOI=3 GOTO 8280
8110 IF BIOI=4 GOTO 8340
8120 IF BIOI=5 GOTO 8400
8130 IF BIOI=6 GOTO 8140 ELSE 7960
8140 GOSUB 880
8150 GOTO 7960
8160 IF V=1 THEN BFI=39.27
8170 IF V=2 THEN BFI=38.77
8180 IF V=3 THEN BFI=9.8
8190 IF V=4 THEN BFI=9.8
8200 IF V=5 THEN BFI=38.77
8210 GOTO 8410
8220 IF V=1 THEN BFI=613.5
8230 IF V=2 THEN BFI=596.19
8240 IF V=3 THEN BFI=592.63
8250 IF V=4 THEN BFI=592.63
8260 IF V=5 THEN BFI=596.19
8270 GOTO 8410
8280 IF V=1 THEN BFI=1028.8
8290 IF V=2 THEN BFI=1012!
8300 IF V=3 THEN BFI=975.2
8310 IF V=4 THEN BFI=975.2
8320 IF V=5 THEN BFI=1012!
8330 GOTO 8410
8340 IF V=1 THEN BFI=1715.2
8350 IF V=2 THEN BFI=1780.9
8360 IF V=3 THEN BFI=1815.6
8370 IF V=4 THEN BFI=1815.6
8380 IF V=5 THEN BFI=1780.9
8390 GOTO 8410
8400 IF V=1 THEN BFI=60!
8410 PRINT
8420 INPUT "ENTER BIOFIX VALUE  " , FIXI
8430 LPRINT TAB(25) A1$
8440 LPRINT AA$;"          ";JJ$
8450 IF BIOI=1 THEN FBI$="BIOFIX: SILVERTIP"
8460 IF BIOI=2 THEN FBI$="BIOFIX: FRUIT SET"
8470 IF BIOI=3 THEN FBI$="BIOFIX: FRUIT DIAM.=1.5-2.0 cm"
8480 IF BIOI=4 THEN FBI$="BIOFIX: FRUIT DIAM.=3.5-4.0 cm"
8490 IF BIOI=5 THEN FBI$="BIOFIX DATE: APRIL 15"
8500 V24=FIXI-BFI
8510 PRINT
8520 PRINT "DO YOU WISH TO: "
8530 PRINT TAB(5) "(1)USE STANDARD DEGREE DAY PREDICTION
     CURVE?"
8540 PRINT TAB(5) "(2) SUPPLY YOUR OWN DEGREE DAY VALUES?"
8550 PRINT TAB(5) "(3) HELP"
```

```
8560 INPUT "ENTER YOUR CHOICE ", CHI
8570 IF CHI=3 GOTO 8600
8580 IF CHI=2 GOTO 8620
8590 IF CHI=1 GOTO 8630 ELSE 8520
8600 GOSUB 9040
8610 GOTO 8520
8620 GOSUB 10640
8625 GOTO 540
8630 FOR I= 1 TO 30
8640 V34=DDC(I)-V24
8650 IF V=1 THEN V114=39.3246/(1+EXP(2.207-.007329*V34+
     4.864E-06*V34*V34-1.16E-09*V34^3))
8660 IF V=2 THEN V114=39.774/(1+EXP(1.927-.006634*V34+
     4.146E-06*V34*V34-9.127E-10*V34^3))
8670 IF V=3 THEN V114=40.497/(1+EXP(2.026-.0067*V34+
     4.378E-06*V34*V34-1.005E-09*V34^3))
8680 IF V=4 THEN V114=40.497/(1+EXP(2.026-.0067*V34+
     4.378E-06*V34*V34-1.005E-09*V34^3))
8690 IF V=5 THEN V114=39.774/(1+EXP(1.927-.006634*V34+
     4.146E-06*V34*V34-9.127E-10*V34^3))
8700 LPRINT USING "####.##                          ";DDC(I),V114
8710 NEXT I
8720 LPRINT FBI$,FIXI
8730 GOTO 540
8740 OPTION BASE 1
8750 DIM DDE(30),DDD(40),DDA(24),DDB(30),DDC(30)
8760 FOR I=1 TO 30
8770 READ DDE(I)
8780 NEXT I
8790 FOR I=1 TO 40
8800 READ DDD(I)
8810 NEXT I
8820 FOR I=1 TO 24
8830 READ DDA(I)
8840 NEXT I
8850 FOR I=1 TO 30
8860 READ DDB(I)
8870 NEXT I
8880 FOR I=1 TO 30
8890 READ DDC(I)
8900 NEXT I
8910 DATA 75,100,125,150,175,200,225,250,275,300,325,350,
     400,450,500,550,600
8920 DATA 700,800,900,1000,1100,1200,1300,1400,1500,1600,
     1800,2000,2200
8930 DATA 75,100,125,150,175,200,225,250,275,300,350,400,
     450,500,550,600
8940 DATA 700,800,900,1000,1100,1200,1300,1400,1500,1600,
     1700,1800,2000
8950 DATA 2200,2400,2600,2800,3000,3200,3400,3600,3800,
     4000,4200
8960 DATA 75,85,90,100,110,120,130,140,150,160,170,180,
     190,200
8970 DATA 210,220,230,240,250,260,270,280,290,300
```

```
8980 DATA 160,180,200,220,240,260,280,300,320,340,360,380,
     400,420,440
8990 DATA 460,480,500,520,540,560,580,600,620,640,660,680,
     700,720,740
9000 DATA 700,725,750,775,800,825,850,875,900,925,950,975,
     1000,1200
9010 DATA 1400,1600,1800,2000,2200,2400,2600,2800,3000,3200,
     3400
9020 DATA 3600,3800,4000,4200,4400
9030 RETURN
9040 PRINT "The standard degree-day prediction curve will
     generate growth stage predictions for a standardized
     set of degree-day values at selected intervals.",
9050 PRINT "For most applications  this  is  the  fastest,
     easiest, and most appropriate choice.  If you wish to
     generate a more exacting prediction (eg. to ",
9060 PRINT " test the model for  your area or variety)
     you should select (2).  This  choice  allows  you to
     input specific degree-day values, but will not",
9070 PRINT "generate a series for  you.  You  must  supply
     each value."
9080 PRINT
9090 PRINT
9100 PRINT
9110 RETURN
9120 PRINT
9130 PRINT
9140 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
     TO QUIT"
9150 PRINT
9160 PRINT
9170 INPUT "DEG. DAY VALUE = ",VLA
9180 IF VLA = 10000  GOTO 9270
9190 V266=VLA -V16
9200 IF V = 1 THEN V1066=39.2679/(1+EXP(2.2676-.007406*V266+
     4.8296E-06*V266*V266-1.1248E-09*V266^3))
9210 IF V = 2 THEN V1066=38.3164/(1+EXP(2.2248-.006917*V266+
     4.011E-06*V266*V266-8.521E-10*V266^3))
9220 IF V = 3 THEN V1066=40.395/(1+EXP(2.126-.007039*V266+
     4.7093E-06*V266*V266-1.108E-09*V266^3))
9230 IF V = 4 THEN V1066=40.395/(1+EXP(2.126-.007039*V266+
     4.7093E-06*V266*V266-1.108E-09*V266^3))
9240 IF V = 5 THEN V1066=38.3164/(1+EXP(2.2248-.006917*V266+
     4.011E-06*V266*V266-8.521E-10*V266^3))
9250 LPRINT USING "####.##                          "; VLA ,V1066
9260 GOTO 9170
9270 LPRINT FBA$ ,FIXA
9280 RETURN
9290 PRINT
9300 PRINT
9310 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
     TO QUIT"
9320 PRINT
9330 PRINT
```

```
9340 INPUT "DEG. DAY VALUE = ", VL
9350 IF VL  = 10000 GOTO 9440
9360 V255=VL-V15
9370 IF V=1 THEN V1050=31.9528/(1+EXP(2.2917-.01042*V255+
     1.4464E-05*V255*V255-8.4229E-09*V255^3))
9380 IF V=2 THEN V1050=29.9196/(1+EXP(2.1928-.01011*V255+
     1.4306E-05*V255*V255-9.8715E-09*V255^3))
9390 IF V=3 THEN V1050=32.198/(1+EXP(2.264-.0112*V255+
     1.587E-05*V255*V255-8.872E-09*V255^3))
9400 IF V=4 THEN V1050=32.198/(1+EXP(2.264-.0112*V255+
     1.587E-05*V255*V255-8.872E-09*V255^3))
9410 IF V=5 THEN V1050=29.9196/(1+EXP(2.1928-.01011*V255+
     1.4306E-05*V255*V255-9.8715E-09*V255^3))
9420 LPRINT USING "####.##                           "; VL  ,V1050
9430 GOTO 9340
9440 LPRINT FB$, FIXX
9450 RETURN
9460 PRINT
9470 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
     TO QUIT"
9480 PRINT
9490 PRINT
9500 INPUT "DEG. DAY VALUE = ", VLB
9510 IF VLB=10000 GOTO 9600
9524 V277=VLB-V17
9530 IF V=1 THEN V1077=39.2679/(1+EXP(2.2676-.007406*V277+
     4.8296E-06*V277*V277-1.1248E-09*V277^3))
9540 IF V=2 THEN V1077=38.3164/(1+EXP(2.2248-.006917*V277+
     4.011E-06*V277*V277-8.521E-10*V277^3))
9550 IF V=3 THEN V1077=40.395/(1+EXP(2.126-.007039*V277+
     4.7093E-06*V277*V277-1.116E-09*V277^3))
9560 IF V=4 THEN V1077=40.395/(1+EXP(2.126-.007039*V277+
     4.7093E-06*V277*V277-1.116E-09*V277^3))
9570 IF V=5 THEN V1077=38.3164/(1+EXP(2.2248-.006917*V277+
     4.011E-06*V277*V277-8.521E-10*V277^3))
9580 LPRINT USING "####.##                        ";VLB,V1077
9590 GOTO 9500
9600 LPRINT FBB$, FIXB
9610 RETURN
9620 PRINT
9630 PRINT
9640 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
     TO QUIT"
9650 PRINT
9660 PRINT
9670 INPUT "DEG. DAY VALUE = ",VLC
9680 IF VLC=10000 GOTO 9770
9690 V288=VLC-V15
9700 IF V=1 THEN V1088=20.18*(1!-EXP(-(.495+
     .00123*V288) 8.847))
9710 IF V=2 THEN V1088=20.068*(1!-EXP(-(.165+
     .00181*V288) 5.935))
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```
9720 IF V=3 THEN V1088=20.18*(1!-EXP(-(.495+
     .00123*V288) 8.847))
9730 IF V=4 THEN V1088=20.18*(1!-EXP(-(.495+
     .00123*V288) 8.847))
9740 IF V=5 THEN V1088=20.068*(1!-EXP(-(.165+
     .00181*V288) 5.935))
9750 LPRINT USING "####.##                    ";VLC,V1088
9760 GOTO 9670
9770 LPRINT FBC$, FIXC
9780 RETURN
9790 PRINT
9800 PRINT
9810 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
     TO QUIT"
9820 PRINT
9830 PRINT
9840 INPUT "DEG. DAY VALUE = ",VLD
9850 IF VLD=10000 GOTO 9940
9860 V299=VLD-V19
9870 IF V=1 THEN V1099=39.2679/(1+EXP(2.2676-.007406*V299+
     4.8296E-06*V299*V299-1.1248E-09*V299^3))
9880 IF V=2 THEN V1099=38.3164/(1+EXP(2.2248-.006917*V299+
     4.011E-06*V299*V299-8.521E-10*V299^3))
9890 IF V=3 THEN V1099=40.395/(1+EXP(2.126-.007039*V299+
     4.7093E-06*V299*V299-1.108E-09*V299^3))
9900 IF V=4 THEN V1099=40.395/(1+EXP(2.126-.007039*V299+
     4.7093E-06*V299*V299-1.108E-09*V299^3))
9910 IF V=5 THEN V1099=38.3164/(1+EXP(2.2248-.006917*V299+
     4.011E-06*V299*V299-8.521E-10*V299^3))
9920 LPRINT USING "####.##                    ";VLD,V1099
9930 GOTO 9840
9940 LPRINT FBD$, FIXD
9950 RETURN
9960 PRINT
9970 PRINT
9980 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
     TO QUIT"
9990 PRINT
10000 PRINT
10010 INPUT "DEG. DAY VALUE = ",VLE
10020 IF VLE=10000 GOTO 10110
10030 V300=VLE-V20
10040 IF V=1 THEN V1100=29.53/(1+EXP(2.315-.014*V300+
      .0000308*V300*V300-2.834E-08*V300^3))
10050 IF V=2 THEN V1100=25.229/(1+EXP(1.958-.0107*V300+
      1.8671E-05*V300*V300-1.794E-08*V300^3))
10060 IF V=3 THEN V1100=29.829/(1+EXP(1.995-.0115*V300+
      2.118E-05*V300*V300-1.725E-08*V300^3))
10070 IF V=4 THEN V1100=29.829/(1+EXP(1.995-.0115*V300+
      2.118E-05*V300*V300-1.725E-08*V300^3))
10080 IF V=5 THEN V1100=25.229/(1+EXP(1.958-.0107*V300+
      1.8671E-05*V300*V300-1.794E-08*V300^3))
10090 LPRINT USING "####.##                    ";VLE, V1100
10100 GOTO 10010
```

```
10110 LPRINT FBE$,FIXE
10120 RETURN
10130 PRINT
10140 PRINT
10150 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OF '10000'
      TO QUIT"
10160 PRINT
10170 PRINT
10180 INPUT "DEG. DAY VALUE = ", VLF
10190 IF VLF=10000 GOTO 10280
10200 V310=VLF-V21
10210 IF V=1 THEN V1110=39.325/(1+EXP (2.207-.007329*V310+
      4.864E-06*V310*V310-1.16E-09*V310^3))
10220 IF V=2 THEN V1110=39.774/(1+EXP(1.927-.006634*V310+
      4.146E-06*V310*V310-9.127E-10*V310^3))
10230 IF V=3 THEN V1110=40.497/(1+EXP(2.026-.006737*V310+
      4.378E-06*V310*V310-1.005E-09*V310^3))
10240 IF V=4 THEN V1110=40.497/(1+EXP(2.026-.006737*V310+
      4.378E-06*V310*V310-1.005E-09*V310^3))
10250 IF V=5 THEN V1110=39.774/(1+EXP(1.927-.006634*V310+
      4.146E-06*V310*V310-9.127E-10*V310^3))
10260 LPRINT USING "####.##                    ";VLF,V1110
10270 GOTO 10150
10280 LPRINT FBF$, FIXF
10290 RETURN
10300 PRINT
10310 PRINT
10320 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
      TO QUIT"
10330 PRINT
10340 PRINT
10350 INPUT "DEG. DAY VALUE = ", VLG
10360 IF VLG=10000 GOTO 10450
10370 V320=VLG-V22
10380 IF V=1 THEN V1120=39.325/(1+EXP (2.207-.007329*V320+
      4.864E-06*V320*V320-1.16E-09*V320^3))
10390 IF V=2 THEN V1120=39.774/(1+EXP(1.927-.006634*V320+
      4.146E-06*V320*V320-9.127E-10*V320^3))
10400 IF V=3 THEN V1120=40.497/(1+EXP(2.026-.006737*V320+
      4.378E-06*V320*V320-1.005E-09*V320^3))
10410 IF V=4 THEN V1120=40.497/(1+EXP(2.026-.006737*V320+
      4.378E-06*V320*V320-1.005E-09*V320^3))
10420 IF V=5 THEN V1120=39.774/(1+EXP(1.927-.006634*V320+
      4.146E-06*V320*V320-9.127E-10*V320^3))
10430 LPRINT USING "####.##                    ";VLG,V1120
10440 GOTO 10350
10450 LPRINT FBG$,FIXG
10460 RETURN
10470 PRINT
10480 PRINT
10490 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
      TO QUIT"
10500 PRINT
10510 PRINT
```

```
10520 INPUT " DEG. DAY VALUE = ", VLH
10530 IF VLH=10000 GOTO 10620
10540 V330=VLH-V23
10550 IF V=1 THEN V1130=20.16*(1!-EXP(-(.5997+
      .0009786*V330)^11.096))
10560  IF V=2 THEN V1130=20.31*(1!-EXP(-(-.097+
     .00264*V330)^4.255))
10570 IF V=3 THEN V1130=20.16*(1!-EXP(-(.5997+
      .0009786*V330)^11.096))
10580 IF V=4 THEN V1130=20.16*(1!-EXP(-(.5997+
      .0009786*V330)^11.096))
10590 IF V=5 THEN V1130=20.31*(1!-EXP(-(-.097+
      .00264*V330)^4.255))
10600 LPRINT USING "####.##                        ";VLH,V1130
10610 GOTO 10520
10620 LPRINT FBH$, FIXH
10630 RETURN
10640 PRINT
10650 PRINT
10660 PRINT "ENTER DEGREE DAY VALUE (BASE 40) OR '10000'
    ' TO QUIT"
10670 PRINT
10680 PRINT
10690 INPUT "DEG. DAY VALUE = ", VLI
10700 IF VLI=10000 GOTO 10790
10710 V340=VLI-V24
10720 IF V=1 THEN V1140=39.325/(1+EXP (2.207-.007329*V340+
      4.864E-06*V340*V340-1.16E-09*V340^3))
10730 IF V=2 THEN V1140=39.774/(1+EXP(1.927-.006634*V340+
      4.146E-06*V340*V340-9.127E-10*V340^3))
10740 IF V=3 THEN V1140=40.497/(1+EXP(2.026-.006737*V340+
      4.378E-06*V340*V340-1.005E-09*V340^3))
10750 IF V=4 THEN V1140=40.497/(1+EXP(2.026-.006737*V340+
      4.378E-06*V340*V340-1.005E-09*V340^3))
10760 IF V=5 THEN V1140=39.774/(1+EXP(1.927-.006634*V340+
      4.146E-06*V340*V340-9.127E-10*V340^3))
10770 LPRINT USING "####.##                        ";VLI,V1140
10780 GOTO 10690
10790 LPRINT FBI$,FIXI
10800 RETURN
10810 LPRINT
10820 LPRINT "---------------------------------------------"
10830 LPRINT
10840 LPRINT TAB(15) "REPRODUCTIVE STAGING CODES"
10850 LPRINT
10860 LPRINT
10870 LPRINT "STAGE NAME:";"                    ";"CODE:"
10880 LPRINT
10890 LPRINT "DORMANT";"                    ";"  1"
10900 LPRINT "EARLY SILVER TIP";"           ";"  3"
10910 LPRINT "SILVER TIP";"                 ";"  5"
10920 LPRINT "GREEN TIP:0 - 0.4 cm";"       ";"  7"
10930 LPRINT "GREEN TIP:0.5 - 0.9 cm";"     ";"  8"
10940 LPRINT "GREEN TIP:1.0 - 1.4 cm";"     ";"  9"
```

```
10950 LPRINT "GREEN TIP:½ 1.5 cm ";"        ";" 10"
10960 LPRINT "PRE-CLUSTER LEAF";"           ";" 10"
10970 LPRINT "EARLY TIGHT CLUSTER";"        ";" 11"
10980 LPRINT "TIGHT CLUSTER";"              ";" 12"
10990 LPRINT "EARLY BUD EXPANSION";"        ";" 13"
11000 LPRINT "BUD EXPANSION";"              ";" 14"
11010 LPRINT "EARLY PINK";"                 ";" 15"
11020 LPRINT "PINK";"                       ";" 16"
11030 LPRINT "FULL PINK";"                  ";" 17"
11040 LPRINT "1 BLOSSOM";"                  ";" 18"
11050 LPRINT "2-3 BLOSSOMS";"               ";" 19"
11060 LPRINT "4+ BLOSSOMS";"                ";" 20"
11070 LPRINT "FULL BLOOM";"                 ";" 20.5"
11080 LPRINT "EARLY PETAL FALL";"           ";" 22"
11090 LPRINT "MID PETAL FALL";"             ";" 23"
11100 LPRINT "LATE PETAL FALL";"            ";" 24"
11110 LPRINT "EARLY FRUIT SET";"            ";" 25"
11120 LPRINT "MID (2-3) FRUIT SET";"        ";" 26"
11130 LPRINT "LATE (4+) FRUIT SET";"        ";" 27"
11140 LPRINT
11150 LPRINT "FRUIT SIZE:"
11160 LPRINT TAB(2) "¼ 0.5 cm";"            ";" 28"
11170 LPRINT TAB(2) "0.5 - 0.9 cm";"        ";" 29"
11180 LPRINT TAB(2) "1.0 - 1.4 cm";"        ";" 30"
11190 LPRINT TAB(2) "1.5 - 1.9 cm";"        ";" 31"
11200 LPRINT TAB(2) "2.0 - 2.4 cm";"        ";" 32"
11210 LPRINT TAB(2) "2.5 - 2.9 cm";"        ";" 33"
11220 LPRINT TAB(2) "3.0 - 3.4 cm";"        ";" 34"
11230 LPRINT TAB(2) "3.5 - 3.9 cm";"        ";" 35"
11240 LPRINT TAB(2) "4.0 - 4.4 cm";"        ";" 36"
11250 LPRINT TAB(2) "4.5 - 4.9 cm";"        ";" 37"
11260 LPRINT TAB(2) "5.0 - 5.4 cm";"        ";" 38"
11270 LPRINT TAB(2) "5.5 - 5.9 cm";"        ";" 39"
11280 LPRINT TAB(2) "6.0 - 6.4 cm";"        ";" 40"
11290 LPRINT TAB(2) "6.5 - 6.9 cm";"        ";" 41"
11300 LPRINT TAB(2) "7.0 - 7.4 cm";"        ";" 42"
11310 LPRINT TAB(2) "7.5 - 7.9 cm";"        ";" 43"
11320 LPRINT TAB(2) "8.0 - 8.4 cm";"        ";" 44"
11330 LPRINT TAB(2) "8.5 - 8.9 cm";"        ";" 45"
11340 LPRINT
11350 LPRINT  "---------------------------------------------"
11360 IF CODE=3 GOTO 11380
11365 IF CODE=4 GOTO 11380
11370 GOTO 730
11380 LPRINT
11390 LPRINT "---------------------------------------------"
11400 LPRINT TAB(15) "VEGETATIVE STAGING CODES"
11410 LPRINT
11420 LPRINT
11430 LPRINT "STAGE NAME:";"                        ";"CODE:"
11440 LPRINT
11450 LPRINT
11460 LPRINT "DORMANT";"                                      ";"  1"
11470 LPRINT "EARLY SILVER TIP";"                             ";"  3"
```

```
11480 LPRINT "SILVER TIP";"                                    ";"  5"
11490 LPRINT "GREEN TIP:0 - 0.4 cm";"                          ";"  7"
11500 LPRINT "GREEN TIP:0.5 - 0.9 cm";"                        ";"  8"
11510 LPRINT "GREEN TIP:1.0 - 1.4 cm";"                        ";"  9"
11520 LPRINT "GREEN TIP: ½ 1.5 cm";"                           ";" 10"
11530 LPRINT "SHOOT GROWTH:"
11540 LPRINT TAB(3) " 1 LEAF";"                                ";" 11"
11550 LPRINT TAB(3) " 2 LEAVES";"                              ";" 12"
11560 LPRINT TAB(3) " 3 LEAVES";"                              ";" 13"
11570 LPRINT TAB(3) " 4 LEAVES";"                              ";" 14"
11580 LPRINT TAB(3) " 5 LEAVES";"                              ";" 15"
11590 LPRINT TAB(3) " 6 LEAVES";"                              ";" 16"
11600 LPRINT TAB(3) " 7 LEAVES";"                              ";" 17"
11610 LPRINT TAB(3) " 8 LEAVES";"                              ";" 18"
11620 LPRINT TAB(3) " 9 LEAVES";"                              ";" 19"
11630 LPRINT TAB(3) "10 LEAVES";"                              ";" 20"
11640 LPRINT TAB(3) "11 LEAVES";"                              ";" 21"
11650 LPRINT TAB(3) "12 LEAVES";"                              ";" 22"
11660 LPRINT TAB(3) "13 LEAVES";"                              ";" 23"
11670 LPRINT TAB(3) "14 LEAVES";"                              ";" 24"
11680 LPRINT TAB(3) "15+ LEAVES";"  ";"code = leaf number +10"
11690 LPRINT
11700 LPRINT "TERMINAL BUD SET:"
11710 LPRINT TAB(3) "DWARFING ROOTSTOCK: SPUR";"       ";" 25"
11720 LPRINT TAB(3) "DWARFING ROOTSTOCK: TERMINAL";"   ";" 30"
11730 LPRINT TAB(3) "STANDARD ROOTSTOCK: SPUR";"       ";" 30"
11740 LPRINT TAB(3) "STANDARD ROOTSTOCK: TERMINAL";"   ";" 32"
11750 LPRINT
11760 LPRINT "----------------------------------------------
11765 IF CODE=4 GOTO 11780
11770 GOTO 730
11780 LPRINT
11790 LPRINT
11800 LPRINT "----------------------------------------------"
11810 LPRINT TAB(15) "PHENOLOGY CODES for FLOWERING"
11820 LPRINT TAB(5) "Use with CURVE 4 (Tight Cluster-Fruit Set)"
11825 LPRINT
11830 LPRINT "STAGE NAME:";"                               ";" CODE:"
11840 LPRINT "Early Bud Expansion";"                        ";"  0"
11850 LPRINT "Bud Expansion";"                              ";"  1"
11860 LPRINT "Early Pink";"                                 ";"  2"
11870 LPRINT "Pink";"                                       ";"  3"
11880 LPRINT "Expanded Pink 1";"                            ";"  4"
11890 LPRINT "Expanded Pink 2";"                            ";"  5"
11900 LPRINT "Expanded Pink 3";"                            ";"  6"
11910 LPRINT "Full Pink";"                                  ";"  7"
11920 LPRINT "Pre-bloom 1";"                                ";"  8"
11930 LPRINT "Pre-bloom 2";"                                ";"  9"
11940 LPRINT "Pre-bloom 3";"                                ";" 10"
11950 LPRINT "Open Petal 1";"                               ";" 11"
11960 LPRINT "Open Petal 2";"                               ";" 12"
11970 LPRINT "Full Open Blossom 1";"                        ";" 13"
11980 LPRINT "Full Open Blossom 2 (aged pollen)";"          ";" 14"
11990 LPRINT "Petal Fall 1 (1 petal off)";"                 ";" 15"
```

```
12000 LPRINT "Petal Fall 2 (2 petals off)";"            ";" 16"
12010 LPRINT "Petal Fall 3 (3 petals off)";"            ";" 17"
12020 LPRINT "Petal Fall 4 (4 petals off)";"            ";" 18"
12030 LPRINT "Early Fruit Set";"                        ";" 19"
12040 LPRINT "Fruit Set";"                              ";" 20"
12050 LPRINT
12055 LPRINT "-----------------------------------------------
12060 GOTO 730
```

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APPENDIX A: Base biofix values used in PHENOTE

Table 1: Biofix values calculated from prediction equations fit to 1983 phenology data sets, used by PHENOTE to calculate the Biofix Difference values.

	TERMINAL SHOOTS			SPUR SHOOTS		
BIOFIX	GD1	GD2	RD	GD1	GD2	RD
Veg. Exp. Silver	63.44	63.76	55.00	58.14	58.89	36.63
Veg. Green Tip	117.57	115.37	101.52	114.24	102.86	82.70
First Leaf	222.73	214.27	188.62	267.80	199.81	176.34
Fifth Leaf	347.34	332.66	289.21	380.40	354.50	302.22
Rep. Exp. Silver	48.56	47.47	23.84	38.77	39.27	9.80
Rep. Green Tip	112.15	106.93	84.51	100.53	98.58	71.30
Tight Cluster	239.65	227.28	206.82	225.11	219.05	196.07
Full Bloom	446.75	423.73	406.27	425.07	416.66	398.02
Fruit Set	649.19	618.30	601.91	596.18	613.50	592.63
Fruit Diam.=1.5-2.0 cm	1053.00	1035.20	990.80	1012.00	1028.80	975.20
Fruit Diam.=2.0-2.5 cm	1193.40	1214.20	1159.60	1132.00	1212.90	1120.60
Fruit Diam.=3.5-4.0 cm	1884.90	1745.40	1850.20	1780.90	1715.20	1815.60
April 15,1983	60.0	60.0	60.0	60.0	60.0	60.0

GD1=Spur Gold Delicious/MM106
GD2=Gold Delicious/Std
RD =Red Delicious/Std