ANNUAL SUMMARY

Project Leader: Dale Kester

Project No. 85-K12. Tree and Crop Research
Bud Failure and Nonproductive Disorders in Almonds

TABLE OF CONTENTS

ANNUAL SUMMARY

Project No. 85-K12. Tree and Crop Research
Bud Failure and Nonproductive Disorders in Almonds

Project Leader: Dr. Dale E. Kester (916) 752-0914
Dept. of Pomology (916) 752-0122
University of California
Davis, CA 95616

Personnel: Linda Liu, Warren C. Micke, Mario Viveros, Mark Freeman, Joe Connell, Dr. C.A.L. Fenton, Dr. Don Durzan

Objectives:

1. Continue testing for BF-free and BF-resistant varieties and make selections of potential germplasm via progeny screening of almond x peach hybridization.
2. Summarize extensive field observations and data on BF distribution in relation to source and continue field observations as required.
3. In cell and tissue culture media, determine the relationship between source, culture media, and imposed stresses on cellular expression of BF and use this procedure to measure differences among sources and the effects of specific cultural conditions.
4. Search for linked genetic markers to the BF factor in almond x peach progeny by extending the isozyme procedure to additional systems.
5. Continue field observations on nonproductivity syndrome as needed.
6. Continue to monitor *Prunus* ring spot and calico virus in Regional Variety Trial (RVT) plots.

OVERALL INTERPRETIVE SUMMARY

Noninfectious bud-failure is a complex problem that has required a many faceted approach involving field work that extends over a number of growing seasons as well as shorter term laboratory procedures. This years annual report is comprehensive and brings together the various threads of investigation, some going back to 1978. There are six parts of the report, each covering different lines of investigation.

PART I describes results of orchard studies designed to understand better the epidemiological patterns of BF within specific commercial varieties and the relationship between SOURCE and PROGENY ORCHARDS. These studies involve VEGETATIVE PROGENCY TESTS of specific kinds of sources, including (a) ORCHARD SOURCES, (b) PROGENY ORCHARD SOURCES, and (c) SINGLE TREE SOURCES (which can give rise to SOURCE-CLONES). Since 1970 we have been studying the BF incidence in 'Nonpareil' in specific progeny orchards in specific test locations originating from selected sources. These include (a). 15 separate source orchards (b). six source-clones, and (c) 5 nursery sources. In these progeny orchards, we found that although none of the sources had obvious symptoms, some BF trees eventually appeared in all their progeny. There were differences not only in inherent level of BF-potential among the sources but in the variability patterns in the progeny. These differences depended both on the SPECIFIC SOURCE and on the KIND OF SOURCE.

Thirteen 'Nonpareil' source-clones have been selected and identified as having relatively low BF-potential as shown by their vegetative progeny remaining free from BF symptoms for 13 years under high stress conditions in WSFS, (western Fresno Co.) and in the RVT plots. These source-clones are maintained in a Foundation Orchard at UC, Davis, which is a relatively low heat stress area. Some of these sources are now available as alternates or supplements to other sources.

Data from these studies have been used to construct BF development models (Part II) which can predict future development of BF from specific kinds of sources. With 'Nonpareil', there appears to be a reservoir of low potential bud-failure sources within the variety providing methods can be applied to identify them, measure their BF-potentiality, maintain and multiply them under conditions to minimize increase in BF-potential.

'Carmel' shows a similar pattern to 'Nonpareil' but differs in that the range of variability among different sources may be less than with 'Nonpareil'. There is indication that the BF-potential throughout the variety is increasing leading to increasing percentages of BF trees at younger and younger ages. This pattern is now being observed in 'Price' as it has previously in 'Harvey' and others. This pattern represents a general phenomenon that may be expected to occur with other newly introduced varieties. Selection of budwood sources representing young clonal age of the original parent tree is being attempted by commercial nurseries.

PART II summarizes concepts of mathematical models to describe the development of BF symptoms among trees of a specific orchard and to predict its future course once symptoms have started to appear (Model I). Data obtained in Part I was used in this study. An extension of this model (Model II) provides a BF model which can be applied to predict the future course of the disorder in source-progeny relationships. These models are based on the premise that BF-potential is present within all trees of the variety and was acquired at the time of its origin as a seedling (as described in Part III).

MODEL II defines the PROBABILITY of bud-failure to develop at a particular AGE within an orchard (or a variety) as an interaction of (a) the NUMBER OF SOURCE TREES used in propagation, (b) the inherent BF-POTENTIAL of the source trees, (c) the RATE OF CHANGE with time and (d) AGE. Rate of change was found to be directly proportional to the annual accumulated temperatures above 80°F. Also, active shoot growth appears to be required for the change either preceding or accompanying the high temperature. The most sensitive period when growth and exposure to high temperatures interact is in the nursery row and the first 4 to 6 years in the orchard. After that the amount of new growth is less but may be increased by severe pruning or a seasonal crop failure which results in increased vegetative growth.

The probability for bud-failure to occur in the progeny of any source depends upon (a) the previous history of the source, (b) growth conditions in the nursery and (c) the environmental and management conditions in the progeny orchards. Given time, a sufficient number of consecutive "scion generations" exposure to current environmental and management conditions and as practiced in both the nursery and orchard industries, it is almost inevitable that varying percentages of BF trees will eventually appear with any variety and any propagation source. The reason is that BF development within a variety follows a pattern associated with "clonal aging" in which the lowest BF-potential exists in trees of the youngest clonal age, i.e., near the original parent plant. The rate of subsequent "aging" depends upon the level of BF-potential in the original plant and subsequent propagation and production patterns which vary greatly under different conditions.

The direct effect of factors, such as low moisture and high temperature stress on the actual development of symptoms in the progeny orchard is not defined by the current model. This subject is considered in other parts of the report and involves the seasonal pattern of accumulated degree days in different years and locations in California.

PART III describes research on the inheritance of BF and the relationship between level of BF-potential in a source and its ability to transmit the BF factor to its SEEDLING OFFSPRING (as contrasted to its vegetative progeny). The model described in Part II was found to apply to populations of seedling progeny from almond x almond crosses. Populations of seedling offspring are produced which individually differ in their inherent BF-potential. These differences may not be expressed immediately in the seedling progeny as visible symptoms but develop gradually with time involving scion generations and repropagation sequences. Since the average BF-potential in the population of seedling offspring is directly proportional to the BF potential in the two parents, BF-potential may be determined by a <u>seedling</u> <u>progeny</u> test. Specific sources of a variety would be testcrossed to a severely affected BF test parent.

Hybridization of almond x peach shows a different pattern and have indicated to us that BF phenomenon is unique to almond and NOT PEACH. Specific almond varieties crossed to a specific peach tester parent produce up to 50% severely BF affect progeny within one or two years. Almond varieties fall into three categories:

(a) Current varieties with significant BF problems (Nonpareil, Carmel, Jordanolo, Harpareil, Jubilee) which produce high percentage of BF offspring whether or not symptoms are present in the specific parent source.
(b) Varieties without known BF problems but which produce BF offspring (I.X.L., Ne Plus Ultra).
(c) Varieties which have not produced BF offspring (Mission, Price, Butte, Padre, some selections). BF is now found in Mission and Price.

Presence of BF progeny in these seedling populations has been directly associated with the average chilling requirements of the progeny. THe use of a very early blooming (short chilling) peach as a tester parent appears to be essential in the carrying out these tests.

The BF factor has been shown to skip the F1 generation but segregate in the next (F2) generation. Preliminary studies have indicated that an isozyme marker may be associated with BF factors. If confirmed, a procedure may be available to monitor the segregation of a BF factor in crosses even in the absence of BF symptoms. Breeding experiments are in progress to test the concept of eliminating BF by segregation from populations of F2 hybrids followed by the selection of BF-free breeding lines.

An immediate application of these breeding studies is to show that varieties with higher than expected levels of BF potential can be expected among the large number of new almond varieties being introduced, particularly those which are chance seedlings. Isozyme and other studies have indicated that Nonpareil is a parent of essentially all of these varieties along with Mission. Increased levels of BF-potentiality in Nonpareil in commercial orchards may be increasing the risk of introducing high BF potential varieties.

PART IV describes research that has been conducted to establish a system of growing almond cells in culture. Methodology to grow shoot tips, cell suspensions and callus tissue in culture have been developed. Some differences occur between the cells and tissues in culture originating from BF sources and non-BF sources. Those from BF sources have shown greater growth rates than these from non-BF sources but these differences vary with the medium and the age of the culture.

Extended exposure (2-4 weeks) moderately high temperature (95°F) has inhibited growth in callus from BF sources but this response has not been consistently confirmed. Short term exposure (2-6 hours) to high temperature (105°F or higher) heat shocks or to PEG induced drought stress has shown that the cells from BF sources were actually more resistant than the cells from nonBF sources. There is an indication that this latter resistance is associated with higher proline levels in the tissues at the time of exposure and is a different reaction to that produced with the longer term, lower temperature exposure associated with BF symptoms production.

PART V describes recent analyses on a multiple group of amino acids and related nitrogenous compounds carried out in collaboration with Dr. Don Durzan. Seasonal changes (August, September and October) occurred in the levels of nitrogenous compounds in leaves and vegetative buds of BF and nonBF trees. Although some differences occurred in several specific amino acids and amides (e.g., glutamic acid and asparagine) the most striking differences were in the levels and changes of proline, an amino acid whose changes have been associated with exposure to stress. Proline content of leaves of BF trees were somewhat higher than in the nonBF trees in August and Sept. In October, (which conincides with the onset of bud necrosis) the leaves on the BF tree were senescing and levels of all amino acids dropped except proline. Vegetative buds from BF trees were 2 to 4 times higher in proline and the amount increased 5 to 10 times from the September to October sampling.

Cell suspensions from a BF source showed a higher level of all amino acids and amides, which may reflect their greater cellular activity. However, proline and proline precursors were greater in amount suggesting that proline, as well as other similar compounds, may be effective markers for analyzing differences between BF and nonBF sources.

okay

Project No. 85-K12. Tree and Crop Research
Bud-failure and Nonproductivity Disorders in Almond

# NONINFECTIOUS BUD-FAILURE IN ALMONDS
## I. Source variation and selection

by

Dale E. Kester, W.C. Micke, M. Viveros, M. Freeman, and J. Connell

The purposes of the investigation were:

(a) to establish the developmental pattern of noninfectious bud-failure (BF) symptoms within varieties of almond,

(b). to test the concept of vegetative progeny tests for comparing BF-potential among different propagation sources,

(c) to compare BF-potentiality among specific Nonpareil source-clones

The basic concept of noninfectious bud-failure (BF) is that the disorder is noninfectious and that the potentiality to produce BF symptoms is an inherent property of susceptible varieties. BF-potentiality is expressed by the production of symptoms either within the plant itself or in progeny trees propagated from it. There is a time requirement for BF-expression that must be understood before one can make judgments about source selection and maintenance.

### A. Studies with Nonpareil

An earlier series of studies carried out from 1969 through mid 1970"s demonstrated that in Nonpareil the production of BF-affected trees in an orchard is related to both the LOCATION of the progeny orchard (Kester and Asay, 1978a) and the SOURCE of the propagation material (Kester and Asay, 1978b). High summer temperatures were shown to be the principal factor in location effects. Following these early location-source experiments, further studies were initiated to study the variation in BF development in different kinds of sources or from different origins. Test sites for progeny orchards were those which the earlier studies showed to have the highest probability for early and severe BF, i.e., under conditions of high summer temperatures.

Other early experiments involved rapid consecutive repropagation followed by growing in high and low temperatures in the greenhouse (Kester, et.al., 1976). Followup long-term observations have continued from progeny trees of this experiment. The purpose was to simulate environmental conditions and procedures which were thought to be responsible for the patterns of BF development in commercial nursery and orchard operations.

Various source-clones have been selected for low BF-potential have been made as part of these studies. These have ben grown in Regional Variety Trial plots to test for BF production and for yield comparisons.

Data from these studies have been used to formulate developmental (epidemiological) models. These are described in part II of this report. The ultimate goals of all of these studies are to establish basic principles and procedures for selection of low BF-POTENTIAL sources, subsequent maintenance and multiplication for propagation and distribution.

## MATERIALS AND METHODS

Different types of Nonpareil sources were used to produce progeny trees that would provide a range of BF-potential represented in the Nonpareil variety. Definitions are provided in Appendix I and specific origins of source-clones are described in

Appendix II.

a. Bearing Nonpareil orchards. These were chosen because of location (7 in Wasco, Kern Co., and 8 in Manteca, San Joaquin Co.), age (5 to 10 years old), and low numbers of BF-affected trees (none or less than 1%). Planting records indicated that three separate commercial nurseries provided the trees, all being represented in both locations. A single budstick was collected from each of 60 trees.

b. Donations from commercial nurseries who provided trees from sources where past history of freedom from BF was claimed. Fifty to 100 trees were obtained from each nursery.

c. Source-clones and/or candidates of the Foundation Seed and Plant Materials Service (FSPMS), UCD. These had originated from single trees previously selected for their virus freedom. Enough budsticks were obtained from each source where available to produce 3 replications of 20 trees each in the orchard.

d. Progeny originating from previously irradiated scions of a BF-affected tree at the USDA Research Station, Fresno. Treatment had been carried out by Dr. Robt. Jones. All available propagation material was used from each subsource (separate branches) but the numbers of trees were limited.

Propagation was carried out by June budding to Nemaguard peach by two commercial nurseries, one at Modesto and one at Wasco. To test the effect of nursery location on rates of BF development, budsticks were cut in half and alternate upper and lower sections were supplied to each nursery who were instructed to bud one tree per stick.

Progeny trees of Nonpareil source orchards (group a, above) were planted in a commercial orchard at Lost Hills (western Kern Co.) as replants in an orchard where 80 per cent of the trees had been previously removed because of severe BF.

Progeny trees of nursery sources (group b, above), source-clones (group c, above), and irradiated scions (group d, above) were planted at the West Side Field Station (western Fresno Co.) in hedge rows spaced 3 x 18 feet apart. Five trees of each of the nursery sources as well as from irradiated scions were also planted at close planting at UCD. A single tree of each of the nursery sources as well as the source clones was indexed for viruses and, if "clean", was established in the FSPMS Foundation Orchard at UCD for possible future inclusion in the Certificatin and Registration program (Appendix II).

Trees were rated for bud-failure symptoms annually in late March or early April when symptoms were well expressed (see Box). Planting was done in the spring 1972. BF affected sources were removed in 1976 except for a few plants and, at the same time, alternate trees were removed to alleviate crowding. In 1980 trees were pruned severely but allowed to redevelop. Irrigation was by a drip system but, because of tree numbers and crowding even after orchard thinning, the trees were stressed most years and did not make much growth in recent years. The experiment was discontinued in 1986 but some sources have been repropagated.

## RESULTS

Progeny tests from individual source orchards. (Lost Hills Expt)

Fig. 1A shows the total BF percentages that developed with time for each of the 15 orchard sources of Nonpareil. Some BF symptoms eventually developed on some trees of every source progeny but there was a wide range of responses among the various progeny.

The following points can be made about the results of the study.

a. Similarities were shown among sources in that there was an increasing percentage of BF affected progeny trees with time. Differences were shown in the age at which BF symptoms first began to appear. Once a tree was affected it usually continued to produce symptoms annually particularly when the symptoms began at an early age and the symptoms were rated as moderate to severe, (e.g., BF+ or BF++).

b. Table 1 shows that the earlier the symptoms develop in the tree the greater the severity of the symptoms later on. Those that started from the 3rd through the 7th year were mostly rated as BF+ or BF++ by the 13th year; those that started in the 8 and 9th years showed the entire range whereas those starting at later ages were primarily BF or BF-. This arrangement also identifies years when more trees developed symptoms than usual. These included 1976,1977, 1982 and 1985.

c. Differences were shown among years in the percentage affected and the severity of the symptoms, such that some trees did not show symptoms every year. This seasonal variation was most apparent after the trees were 5-7 years old at which time they had slowed down in growth, new symptoms were mild (BF-) and confined to the tops of the trees (see Table 1 )

Consequently the curves were recalculated to show the accumulated percentage of BF-affected trees with time (Fig. 1B). This procedure provides a more accurate way to show changein BF-potential and is the form by which developmental models have been determined (see Part II, this report).

d. When comparisons are made by either method (accumulative or actual percentage), certain years are shown to be particularly significant in increasing the percentage of BF affected trees. Since symptoms are determined in the summer preceding the actual appearance of symptoms, one can identify 1981 and 1984 as being "BF-inducing years" whereas 1980, 1982, and possibly 1983 are not. 1981 and 1984 have been identified as having maximum hours above 80oF whereas 1980, 1982 and 1983 have minimum hours above 80oF. (see Table ooo, Part II, and Fig. ooo). Differences between accumulative and actual percentages is shown for the combined data of all sources (Figure 2).

e. Source orchards located in Wasco tended to produce more BF trees than those produced from the Manteca area (Fig 3) but the difference was not as great as differences among individual source progeny. Furthermore, there appeared to be differences stemming from the previous history of the source orchard since some differences were shown among the three originating nurseries.

f. Differences in BF development associated with production in the nursery were shown in previous experiments (Kester and Asay, 1978a) and in other experiments (Table 4). However, in the this test, the comparisons were inconsistent. Tree growth and survival was better with the Modesto grown trees. The Wasco grown trees did not grow as well in the nursery and their growth was inhibited from early warm temperatures after budding. Progeny from the Manteca source orchards produced somewhat more BF affected trees later in the orchard across all sources whereas the progeny trees from the Wasco source orchards produced somewhat more BF from the Wasco grown nursery trees.

Progeny tests from nursery sources (Table 3).

Results of progeny tests involving nursery sources (as supplied from 5 commercial nurseries) growing from 1973 to 1986 in the West Side Field Station were essentially similar to that produced from the orchard sources albeit with some differences. No Bf trees were produced from the B-Jones (although 1 suspicious tree was noted), B-Wells, or F-B trees prior to the 1980 pruning. One severely affected tree was produced from the Nonpareil-St source. Several were produced from the Nonparei-WN source during the first few years but none thereafter indicating that a mixture of two sources occurred.

After the 1980 pruning some symptoms were observed to occur on the B-Wells, F-B and ST trees will be number being in the 10 to 15 percent range.

Progeny tests of source-clones (Table 4)

Effect of source. Nonpareil 3-8-1-63 produced 100 percent BF trees within 2 to 4 years after planting. A second source-clone (Nonpareil C-N) produced no symptoms during the first phase of the test but after the severe pruning in 1980, BF began to develop rapidly from 1982 to 1985. Four remaining Nonpareil source-clones (McEnespy -2, McEnespy-7, F-N and IR 15-1 respectively) did not produce any symptoms during the 13 years of the test. Although one cannot claim them to be BF-free, one can conclude that their BF-potentiality is significantly lower than that of the other two source-clones that developed BF progeny.

Effect of nursery site. Differences were shown in the BF-potential level in the trees produced at the two nursery sites as shown by the rate at which BF developed in progeny trees of both 3-8-1-63 (1974 to 76) and the C-N source (1982 to 1985). However, the duration and vigor of growth was more important than location. Trees produced at the Modesto nursery had grown vigorously and continuously during the nursery year and at the time of planting were larger in size as compared to those from the Wasco nursery. The Wasco trees were smaller evidently because of later budding. Also some inhibition in development occurred related to exposure to hot temperatures in late June. Consequently the location of the nursery had a lesser effect on BF-potential than did the growing conditions of the trees in the nursery and the time of budding. Earlier budding and continuous, vigorous growth of the nursery tree was associated with an increase in the size of the tree at digging and an increase in the BF-potential of the tree at the time of planting.

Irradiated sources. (Data not shown). Between 1974 to 1976, all progenies of the irradiated subsources from the original source tree showed varying amounts of BF. Since the original source tree was showing BF symptoms in at least half of the branches during the same period (Dr. R. Jones, personal correspondence), we can conclude that the BF-potential was not affected by the irradiation treatment.

B. Studies with Carmel

Following the pattern of annual monitoring of BF symptoms in specific Nonpareil orchards (see part A), a program began in 1980 to monitor commercial Carmel orchards where BF had begun to appear. Five commercial orchards in Fresno and Kern Co. were studied through 1986 although some years of monitoring were not made. Orchards were planted in 1983 and all came from the same orchard source. According to the records of the nursery, these would have been a third scion generation from the original tree of the variety. Ratings have been made by the scale described in the box. This data has provided the original basic information for the development of the BF model described in Part II.

RESULTS

Figs 5A to E compares the five orchards in the trends of increasing BF incidence with age. As with the Nonpareil tests (Fig. IA,B) symptoms were not always expressed by the same tree each year primarily due to seasonal variation associated with the amount of growth and the temperature pattern occurring in the previous summer. All plots showed a gradually increasing trend of more and more trees producing some BF symptoms with age. However, as the trees came into maturity, there is a greater tendency for annual fluctuations of actual expressed symptoms.

The pattern, trends and severity of symptoms have depended on the age of the tree and the proportion of the tree affected, similar to that observed with Nonpareil. Table 5 shows that by 1986 approximately one half of the trees have only BF- symptoms and that 29 percent are affected severely BF+ and BF++. Table 6 shows that the severity grade is related primarily to the relative height in the tree at which symptoms first began to appear since once symptoms started in a branch, subsequent growth then showed symptoms.

Table 7 shows the correlation of BF severity to the age at which symptoms actually began to appear. Those that develop early in the life of the tree, as in the first five years, tend to involve all of the parts of the tree that grow subsequent to that; those that develop later begin higher in the tree or only in certain branches and do not spread to other parts of the tree. After a tree reached full maturity and little increase in height or growth occurred (except with heavy pruning) BF symptoms tend to be produced only in small branches in the very top of the tree. It is these BF- or BF rated symptoms may not be expressed every year due to lack or shoot growth or lower temperatures of the previous summer. Thus, 1981 and 1984 seasons were shown to have had a major effect in the BF symptoms the following spring although in some of the orchards lack of vigor and crowding of the trees evidently offset this effect to some extent. (Figures 5). In spring, there was a lessening of BF symptom expression in each of the five plots as well as in commercial orchards in general. The 1985 season was characterized by high temperatures in the early part of the season but from early July the temperatures were very mild. This suggests that the heat in the latter part of the summer is more critical in the expression of BF symptoms than that occurring earlier.

Table 000 is a summary of BF development as of 1985 in a young Carmel orchard planted in 1981 where significantly larger percentages of BF tree with considerable severity of symptoms were observed. In 1986, no increase was noted in level of BF symptoms.

C. Other varieties

BF-affected Price have appeared in 4 or 5 orchards in 1985 in young orchards 4 or 5 years old. These appear to follow a similar pattern to that of other varieties in following a repropagation line of a particular source.

In the RVT plots, BF affected trees have occurred in Carmel, Merced, Harvey, Carrion and Sorrenti.

On 1980, two trees of Mission were discovered in an orchard in Kern Co. to have typical BF symptoms. This diagnosis has been confirmed in a 3 year ~~old~~ repropagation test at Wolfskill Experimental Orchard, Winters.

DISCUSSION AND CONCLUSION

Nonpareil has been grown as a major variety in the California almond industry for about 100 years. The purpose of the current investigations was to get some picture of the variability in BF-potential that occurs when one selects budwood from symptomless trees from different origins within the variety when progeny trees are grown under conditions selected to have the greatest probability to bring out symptoms. Comparison among sources is shown in:

a. the TIME (AGE) at which BF symptoms begin to appear

b. the VARIABILITY among progeny trees which is manifested in

(1) the number of trees affected at any one age, (2) the proportion of the tree affected and (3) the severity of symptoms on individual branches.

These two factors are incorporated into a BF development model which is described in Part II (this report).

The studies also show that BF-potentiality and BF-expression are not necessarily the same but that the individual season (based on total high temperature exposure) and amount and pattern of shoot growth can affect the extent of symptom expression as well as affect the rate of change of BF-potentiality.

The results show that one should expect that some progeny trees will eventually produce BF symptoms from any symptomless tree or orchard source. However, the studies also reveal that there is a wide range of variability of BF-potentiality with considerable reservoir for relatively low (although not freedom from) BF-potentiality. Source selection is possible but depends upon the kind of source one selects as well as the specific source one uses. Furthermore the percentage of BF affected-trees (i.e., the inherent level of BFpotentiality) can be expected to increase with repropagation of further scion generations depending upon the temperature regime within which they are growing.

Different kinds of sources have been defined (see Appendix) as ORCHARD SOURCE, PROGENY-ORCHARD SOURCE, SINGLE-TREE SOURCE and SOURCE-CLONE and each can produce different patterns of variability. Orchard and progeny-orchard source can be expected to produce a wider range of BF potentiality which would result in a lower percentage of BF appearing at younger ages with a gradual increase occurring over a longer period and at older ages such that most BF affected trees have relatively mild symptoms.

Age at which BF can occur in progeny determines selection of the individual source irrespective of the type of source uses. Selection of a source orchard should be based on visual inspections of the entire orchard, not just the trees from which budwood is taken since the fraction of trees that are affected will tend to correlate to the total BF-potential in the orchard. Selection of an individual tree source or the development of a source-clone must be made by use of vegetative progeny tests (or other tests yet to be devised) since the BF-potential of symptomless trees may range from those which require only a few years for BF to develop to those that may take 10 to 15 years or more.

In either case, consecutive repropagation at high growing temperatures can be expected to result in increasing levels of BF-potential.

One of the outcomes of the research is to identify a number of source-clones of Nonpareil which appear to have a low level of BF-potential. These are described in Appendix II and are now being made available for propagation use through the Foundation Seed and Plant Materials Service , Davis.

However, best procedures to maintain and distribute this material without change in their BF-potential need further examination.

Other varieties

Carmel, Price, and other new varieties cited with bud-failure have recently been introduced to the industry and represent varieties where the entire sequence from the original tree to current source and progeny orchards can be established. The five orchards studied show similar patterns although varying somewhat due to individual orchard and location. These represent the third scion generation from the original tree which was discovered in an orchard near LeGrand. Since there is experimental evidence that this tree was not a seedling or a sport (Hauagge, et.al.) but was an earlier selected seedling evidently carried along in propagation material one cannot be certain as to the age of the variety.

Figure 6 compares the pattern of Carmel orchards studied with that of Nonpareil from various sources. Carmel corresponds to the approximate BF level of Nonpareil sources studied with the most BF-potential and with more BF-potential than those of the least BF-potential.

Carmel and Price appear to be following a pattern similar to that earlier observed in Jordanolo, Harpareil, Merced, and Harvey in that there had been an increasing hazard with time. At this point it is uncertain whether the more recent outbreaks of Carmel are due to the progressive buildup with repropagation that is possible, to the selection of specific source trees or orchards or to the direct effect of high temperature inducing years such as 1981 and 1984.

## RATINGS FOR SYMPTOMS OF BUD-FAILURE

The primary symptom is the failure of vegetative buds to emerge in the spring. This usually is confined to shoots which are relatively vigorous. A gr

Trees have been rated visually in the spring after leafing-out is complete, blossoming is over and preferably before nut drop is complete. This has usually been in late March and early April. (The reason for concerns for nut drop is that sometimes failure to set on vigorous lateral or terminal shoots leaving missing nodes could be confused with bud failure).

There are two criteria that may affect severity of bud failure. One is the proportion of the tree affected in terms of location and numbers of branches. The other is the proportion of the buds on any one branch that fail. In general the two aspects are correlated and a general impression visual rating can be given without analyzing the individual branches.

BF- = onlya few branches affected and not all buds on these affected. Usually found in the top of the tree.

BF = sufficient bud-failure to indicate a definite diagnosis. Involves several branches, up to 25 per cent of the tree

BF+ = severe bud-failure affecting around half of tree. Most of buds on these branches failing

BF++ = very severe bud-failure, essentially 90 per cent of the tree affected. Most buds failing.

BF+++ = essentially all buds of the tree failing.

Roughbark symptoms may be associated with BF+ grades or more

Table 1. Relationship between severity of symptoms in 1985 with age at which tree first developed symptoms. Rating based on scale of 1 (none) to 2 (BF-) to 5 (BF++). Nonpareil.

| Year | Age | BF grade 2 | 3 | 4 | 5 | Ave. grade | No. starting that year | |
|---|---|---|---|---|---|---|---|---|
| 1975 | 1) 3 | | | 1 | 2 | 4.7 | 3 | |
| | 2) 8 | | | | 3 | 5.0 | 3 | |
| 1976 | 1) 4 | | | 2 | 8 | 4.2 | 10 | BF |
| | 2) 9 | | | 4 | 2 | 4.7 | 6 | induction |
| 1977 | 1) 5 | | | 1 | 5 | 4.2 | 6 | phase |
| | 2) 10 | | | 4 | 3 | 4.6 | 7 | |
| 1978 | 1) 6 | | 1 | 1 | 3 | 4.8 | 5 | |
| | 2) 11 | | | 1 | 1 | 4.5 | 1 | |
| 1979 | 1) 7 | | | | 1 | 5.0 | 1 | |
| | 2) 12 | | | | - | - | | |
| 1980 | 1) 8 | 2 | 2 | 3 | 2 | 3.5 | 9 | Transition |
| | 2) 13 | | | | - | - | | |
| 1981 | 1) 9 | 1 | 1 | 3 | 3 | 3.8 | 8 | |
| | 2) 14 | 2 | | | | 2.0 | 2 | |
| 1982 | 1) 10 | 4 | 13 | 10 | 1 | 3.3 | 28 | |
| | 2) 15 | | 3 | 1 | | 3.2 | 4 | |
| 1983 | 1) 11 | 1 | 4 | | | 2.8 | 5 | |
| | 2) 16 | | 1 | | | 3.0 | 1 | equilibrium |
| 1984 | 1) 12 | | 8 | 2 | | 3.8 | 10 | |
| | 2) 17 | | 3 | 1 | | 3.2 | 4 | |
| 1985 | 1) 13 | 27 | 17 | | | 3.2 | 44 | |
| | 2) 18 | 4 | 1 | | | 2.2 | 5 | |
| Total | 1) | 35 | 46 | 29 | 19 | | | |
| | 2) | 6 | 8 | 8 | 12 | | | |

1)total population of trees = 1039. Planted 1973 as replants
2)original trees in orchard planted 1969 had 83 percent BF which were removed in 1971. Remaining population of trees = 217.

## REFERENCES CITED

Hauagge, R. D.E. Kester, A. Arulsekar, D. Parfitt and L. Liu, J. Amer. Soc. Hort. Sci., submitted

Kester. D.E. and R.N. Asay. 1978a.

Kester, D.E. and R.N. Asay, 1978b.

Kester, D.E. Hellali, and R.N.Asay. 1976.

Table 2. Numbers of accumulated degree days greater than 80oF for the years shown

| Year | Davis | Fresno | WSFS (Fresno Co.) | Bakersfield |
|---|---|---|---|---|
| 1981 | 475 | 780 | 580 * | 920 |
| 1982 | 300 | 410 | 430 | 620 |
| 1984 | 510 | 715 | 710 | 850 |
| 1985 | 415 | 580 | 640 | 690 |

* needs rechecking. Seems low

Table 3. Percentage of BF affected trees at different ages in progeny trees of different nursery sources of Nonpareil growing at the West Side Field Station (western Fresno CO.) Trees were planted in 1972. Trees were thinned out and remaining trees pruned back severely in 1980

| Nursery Source | No. of trees | Percentage of BF trees in following years: 1974 | 1975 | 1976 | Ave..... grade* | 1983 | 1984 | 1985 | Ave. grade * |
|---|---|---|---|---|---|---|---|---|---|
| B-Jones | | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 0 |
| B-Wells | | 0 | 0 | 0 | 1.0 | 0 | 5 | 10 | 2.0 |
| F-B | | 0 | 0 | 0 | 1.0 | 0 | 6 | 15 | 2.3 |
| ST | | 2 | 2 | 2 | 2.0 | 0 | 5 | 10 | 4.0 |
| WN | | 6 | 11 | 7 | 4.20 | 5 | 5 | 8 | 4.1 |

* of affected trees

Table 4. Percentage of BF affected trees at different ages in progeny of different Nonpareil source-clones growing at the West Side Field Station (Fresno Co.) Trees were planted in 1972. Trees were thinned out and remaining trees pruned severely in 1980

| Source | No. of trees | Nurs Loc. | 1974 | 1975 | 1976 | Ave. grade* | ...1983 | 1984 | 1985 | Ave. grade* |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-8-1-63 | | A | 8 | 50 | 100 | 2.5 | removed | | | |
| | | B | 85 | 95 | 100 | 4.3 | removed | | | |
| C-N | | A | 0 | 0 | 0 | 1.0 | 18 | 14 | 36 | 2.8 |
| | | B | 0 | 0 | 0 | 1.0 | 76 | 57 | 85 | 3.2 |
| McEnespy-2 | | A | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |
| | | B | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |
| McEnespy-7 | | A | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |
| | | B | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |
| IR 15-1 | | A | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |
| | | B | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |
| N-F | | A | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |

Header note: "Percentage of BF trees in following years" spans the year columns.

(1). Grade based on scale of 1 (none) to 5 (very severe)
(2) A = Wasco nursery; B = Modesto nursery
* of affected trees

Table 5. Distribution of severity grades of BF in five Carmel orchards in 1986. Data is given in percentages of trees affected

| | Payne | Billington | Lyda | LaBorde | Gunland | Ave. |
|---|---|---|---|---|---|---|
| BF- | 44 | 48 | 48 | 48 | 38 | 47.4 |
| BF | 32 | 18 | 34 | 21 | 27 | 26.4 |
| BF+ | 21 | 21 | 12 | 24 | 23 | 20.2 |
| BF++ | 3 | 17 | 6 | 7 | 11 | 8.8 |

Fig. 6. Correlation between the percentage of the tree area xaffected by BF symptoms and severity rating. Percentage is estimates of vertical distance down from the top of the tree

| | Payne | Billington | Lyda | LaBorde | Gunland | Ave. |
|---|---|---|---|---|---|---|
| BF- | 5 | 5 | 5 | 6 | 5 | 5.2 |
| BF | 23 | 23 | 28 | 20 | 14 | 21.6 |
| BF+ | 80 | 47 | 52 | 34 | 52 | 53 |
| BF++ | 95 | 91 | 90 | 95 | 95 | 94 |

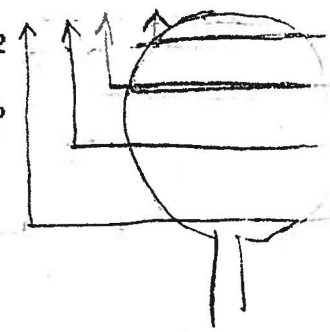


Table 7. Relationship between BF severity rating and age when first showed symptoms.

| Year | Age | BF Grade 2 | 3 | 4 | 5 | 6 | Total No. |
|---|---|---|---|---|---|---|---|
| 1980 | 8 | 0 | 4 | 25 | 7 | 4 | 40 |
| 1981 | 9 | 2 | 25 | 12 | 3 | | 42 |
| 1982 | 10 | 13 | 17 | 4 | | | 34 |
| 1983 | 11 | 39 | 22 | 2 | | | 63 |
| 1984 | 12 | 49 | 19 | 1 | | | 69 |
| 1985 | 13 | 23 | 2 | 2 | | | 25 |
| 1986 | 14 | 5 | 2 | | | | 7 |
| Ave. age | | 11.7 | 10.5 | 9.5 | <8.3 | <8 | |

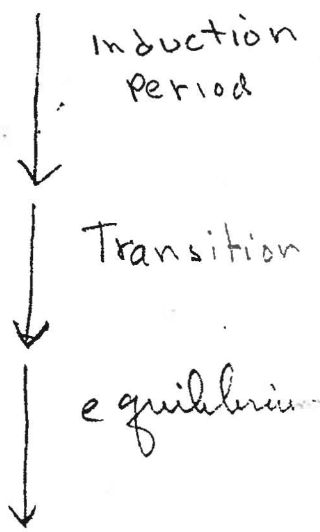


Fig 1A Nonpareil. Lost Hills, Actual …

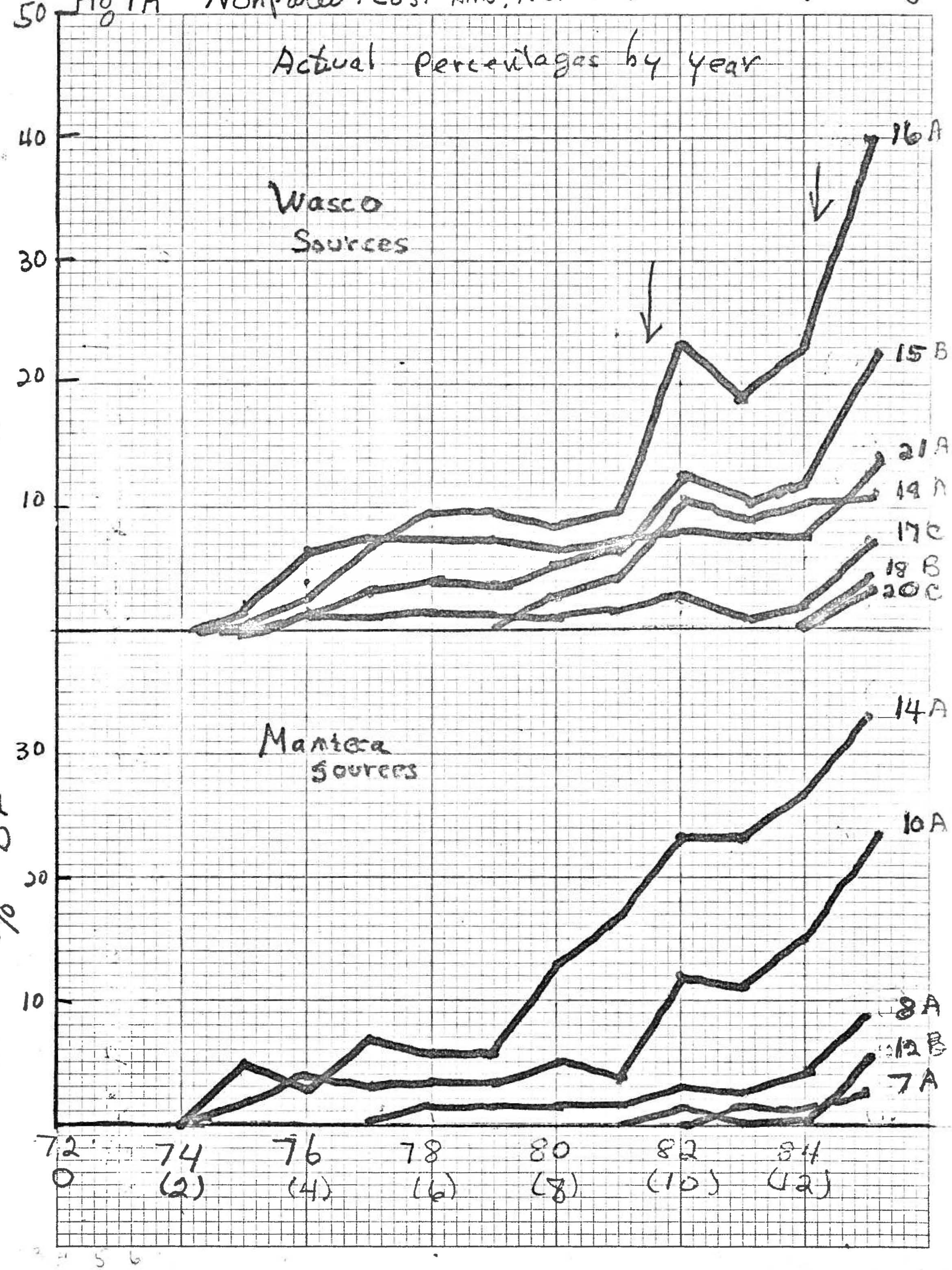
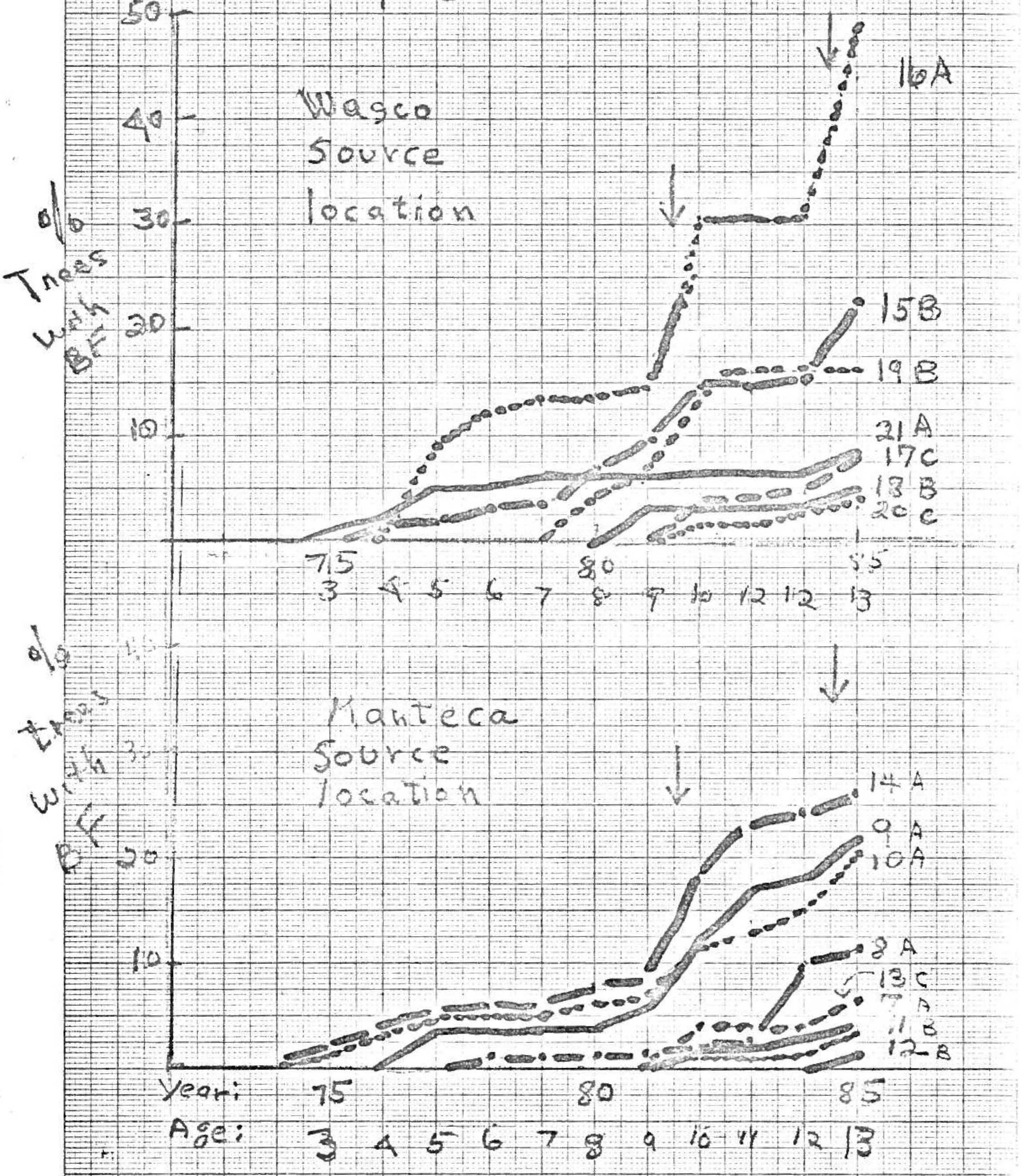
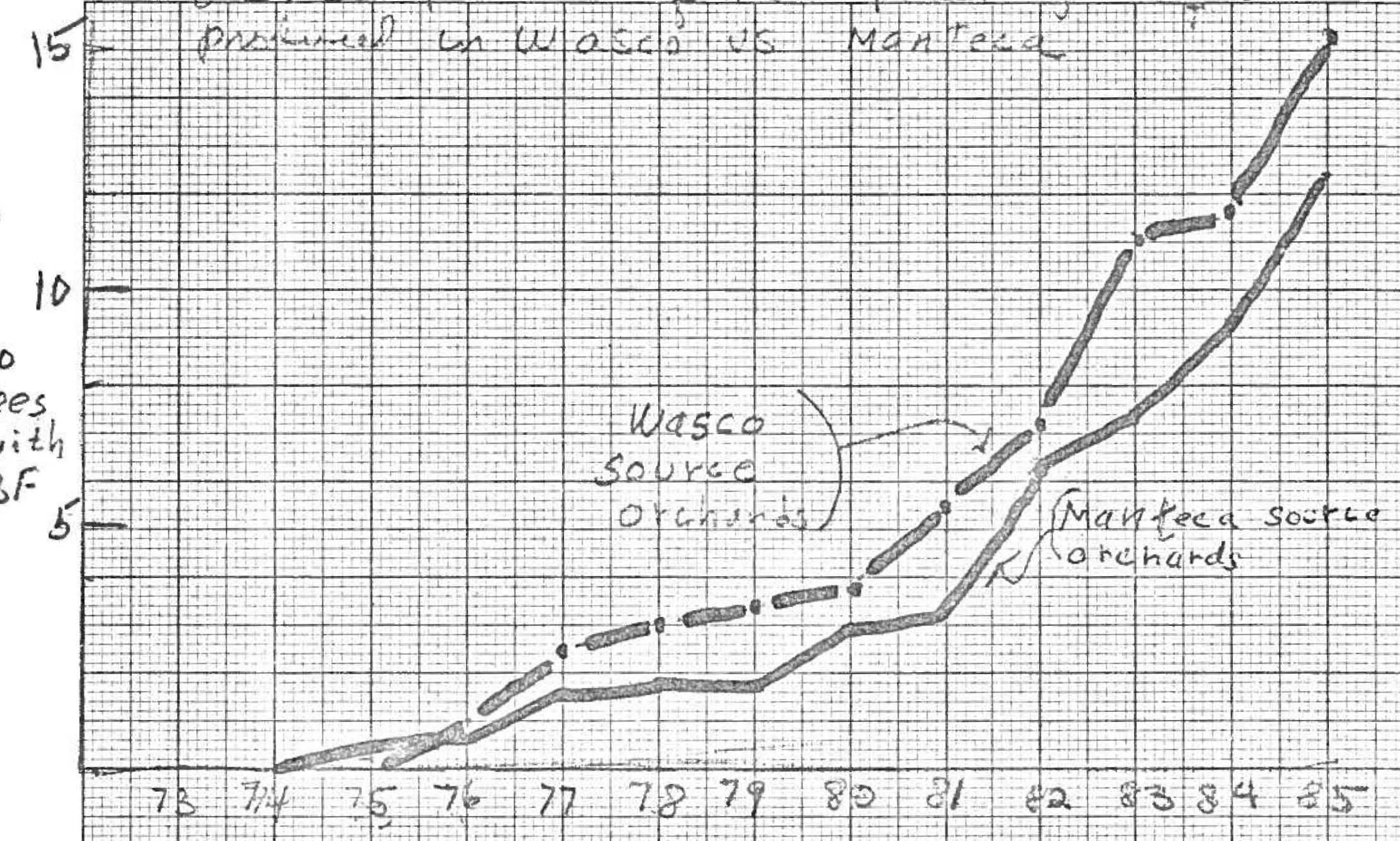


Fig 1B. Nonpareil, Lost Hills, Accumulated BF percentage by year




Accumulative Susceptibility

Fig 3. Comparison of mean percentages of trees produced in Wasco vs Manteca



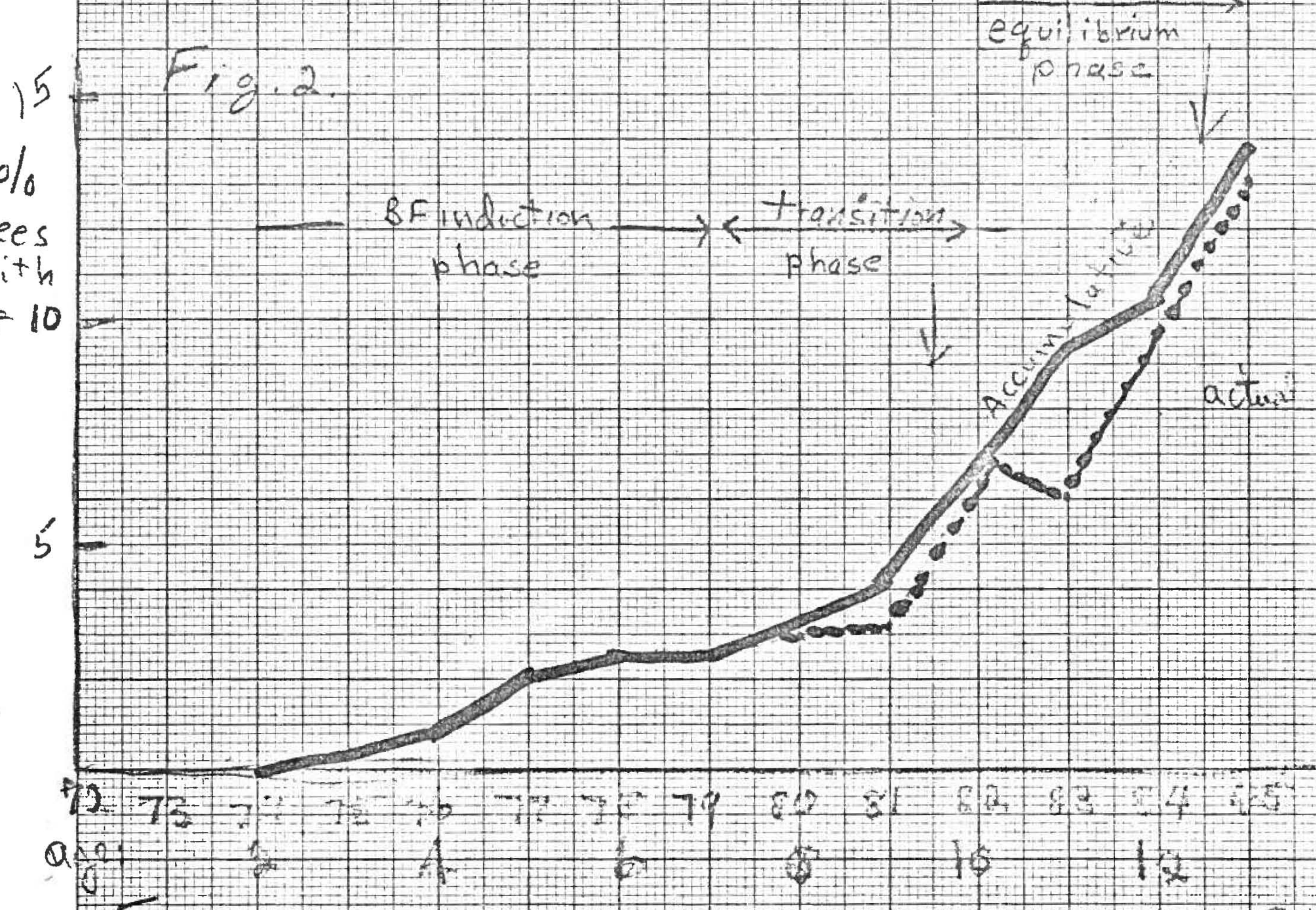




Fig 2. Comparison of mean percentages of BF trees in terms of accumulative vs. actual percentages

Fig 5A. BF production in Carmel - Payne orchard

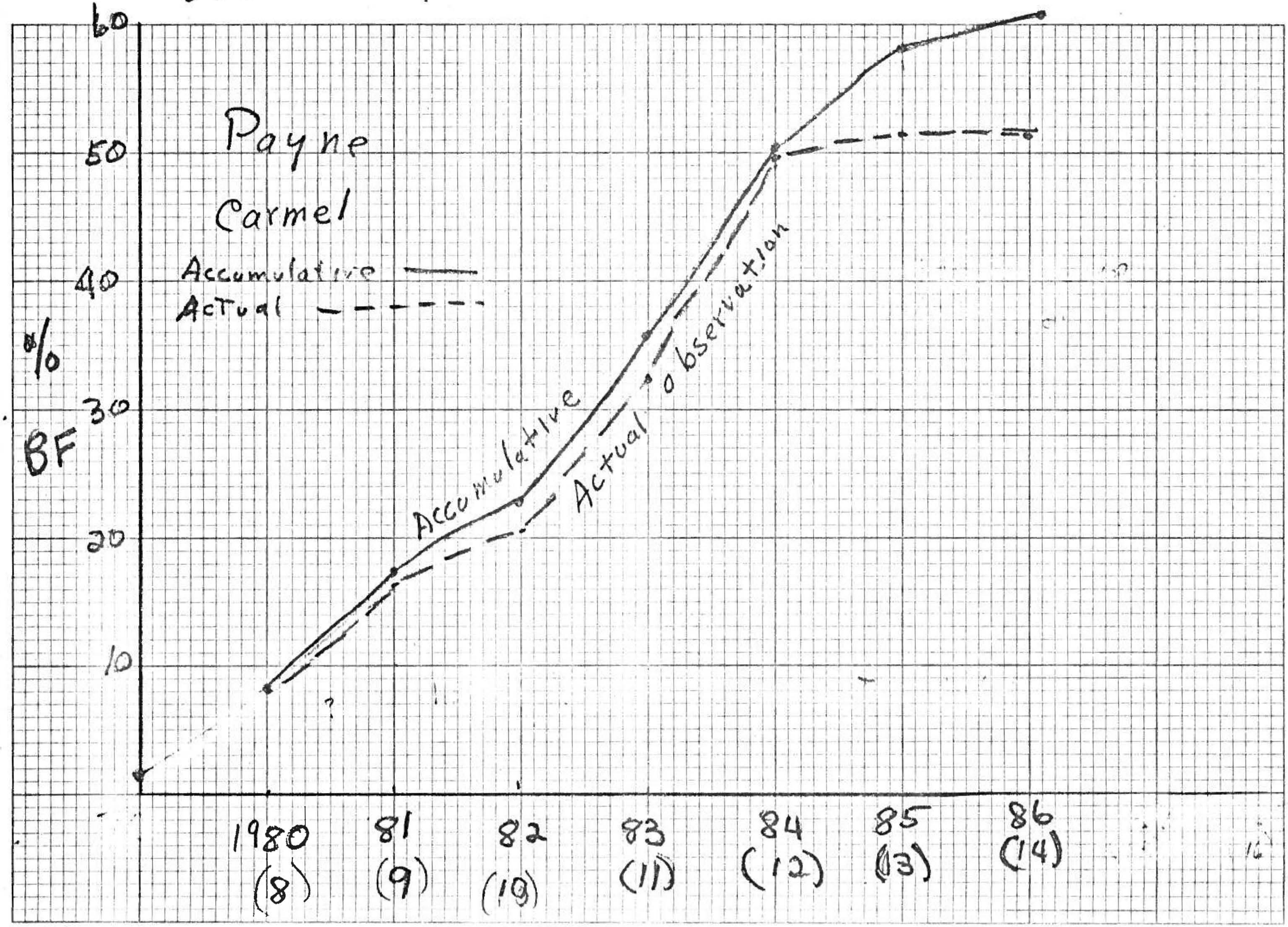


Fig 5B. BF production in Carmel - Lyda

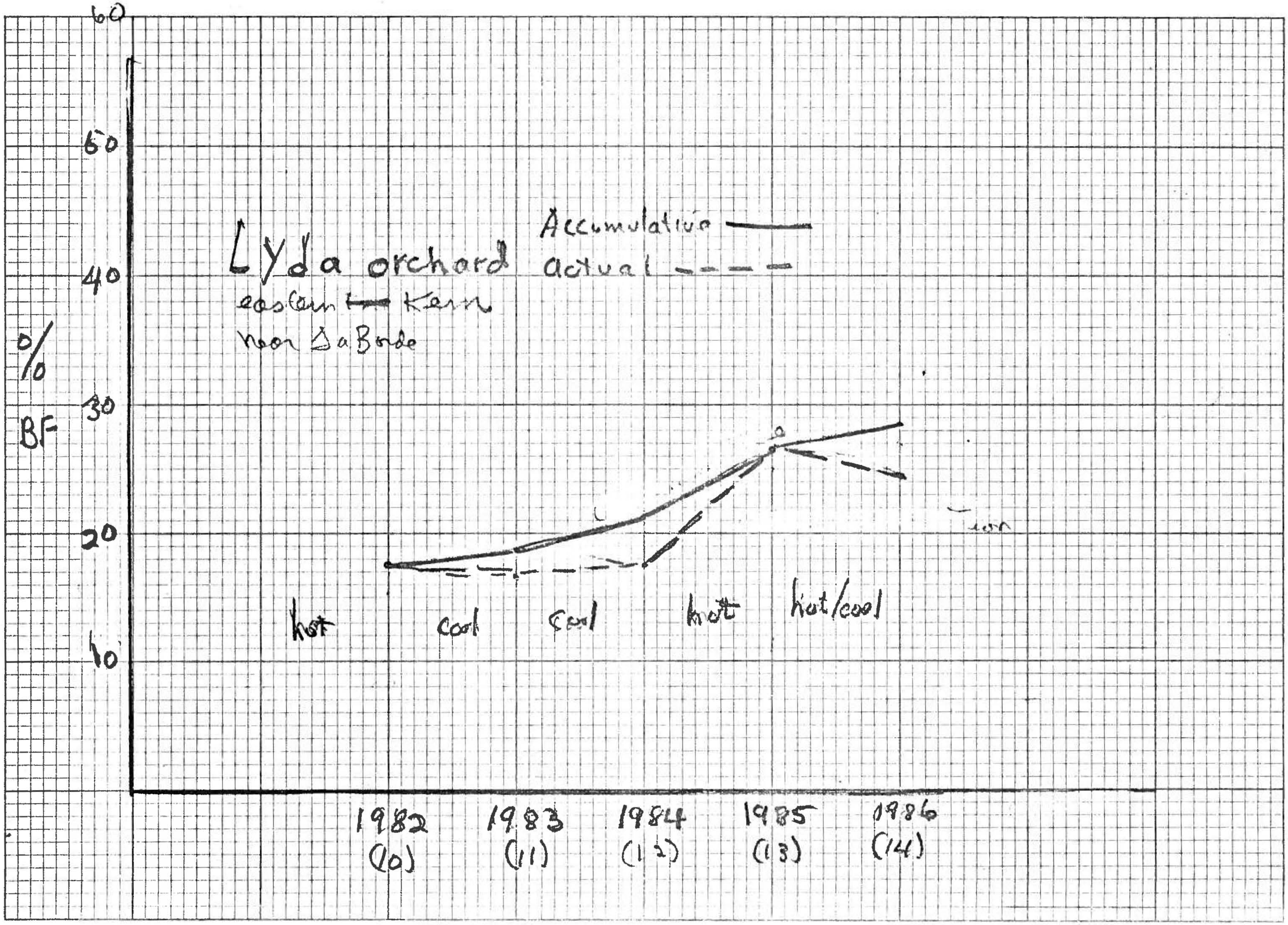
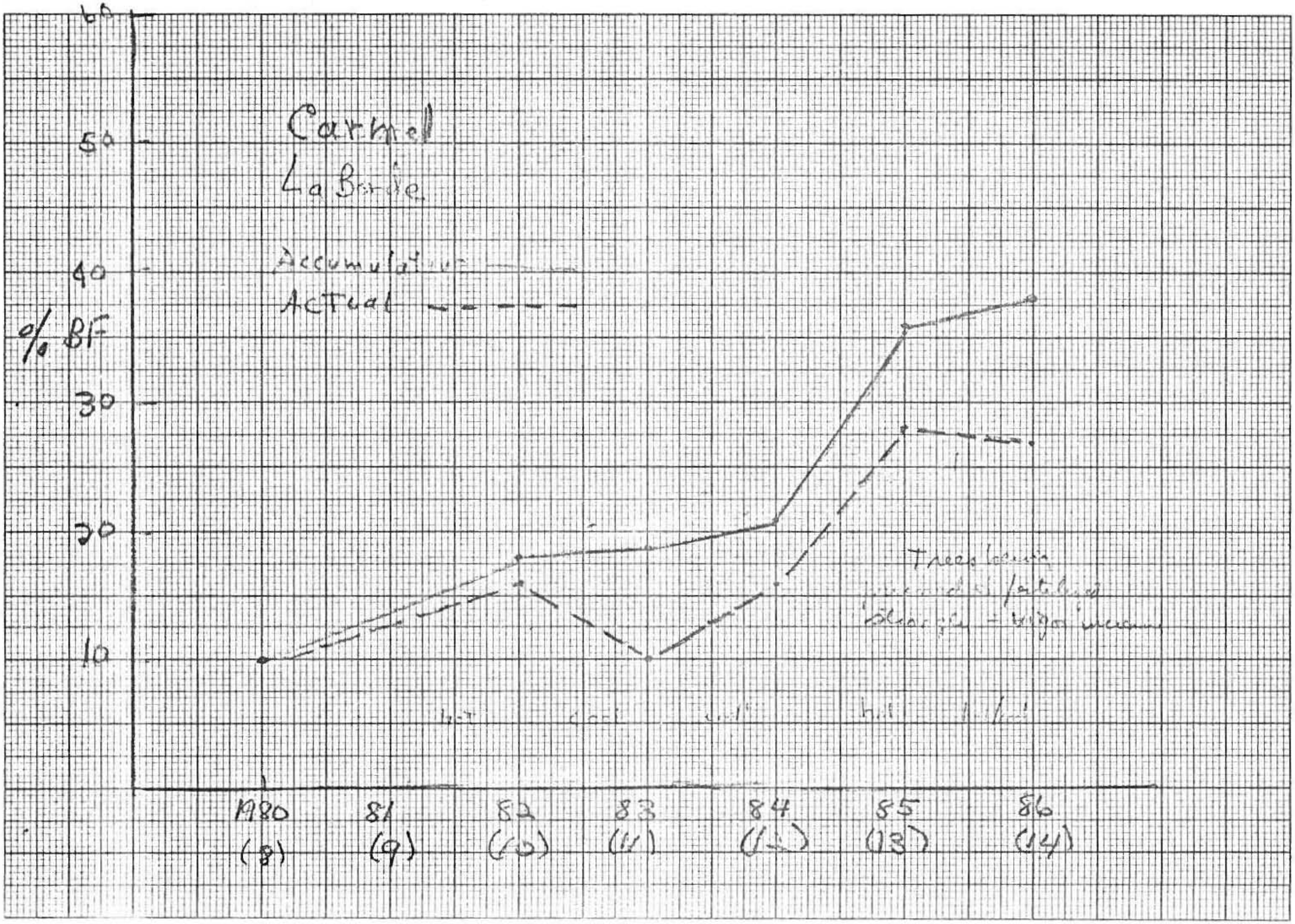


Fig 5c BF production in Carmel, La Bordo orchard



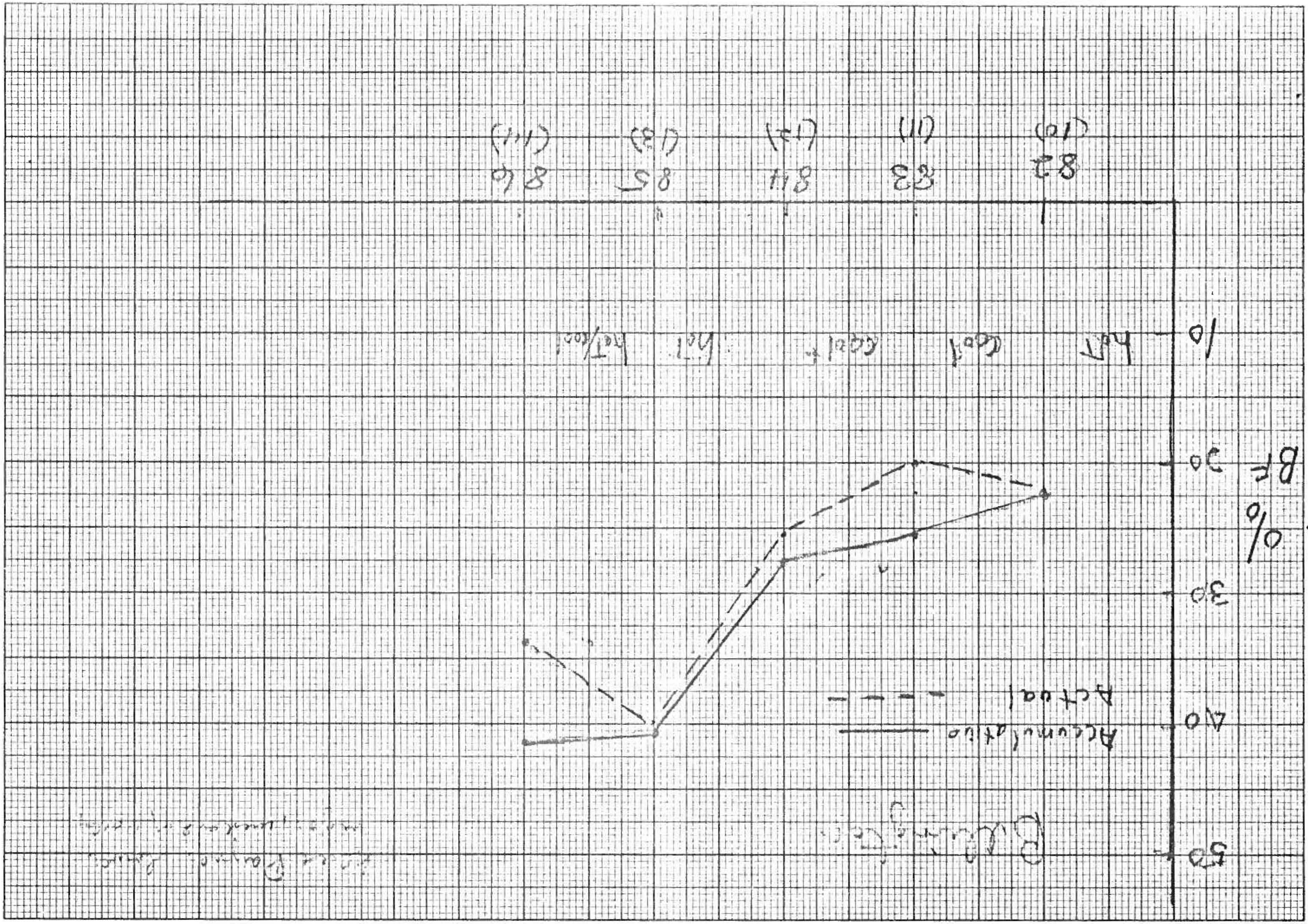



Fig. 5D, BF production in Cornus Billington

Fig. 5E. BF production in Carmel, Gunland orchard

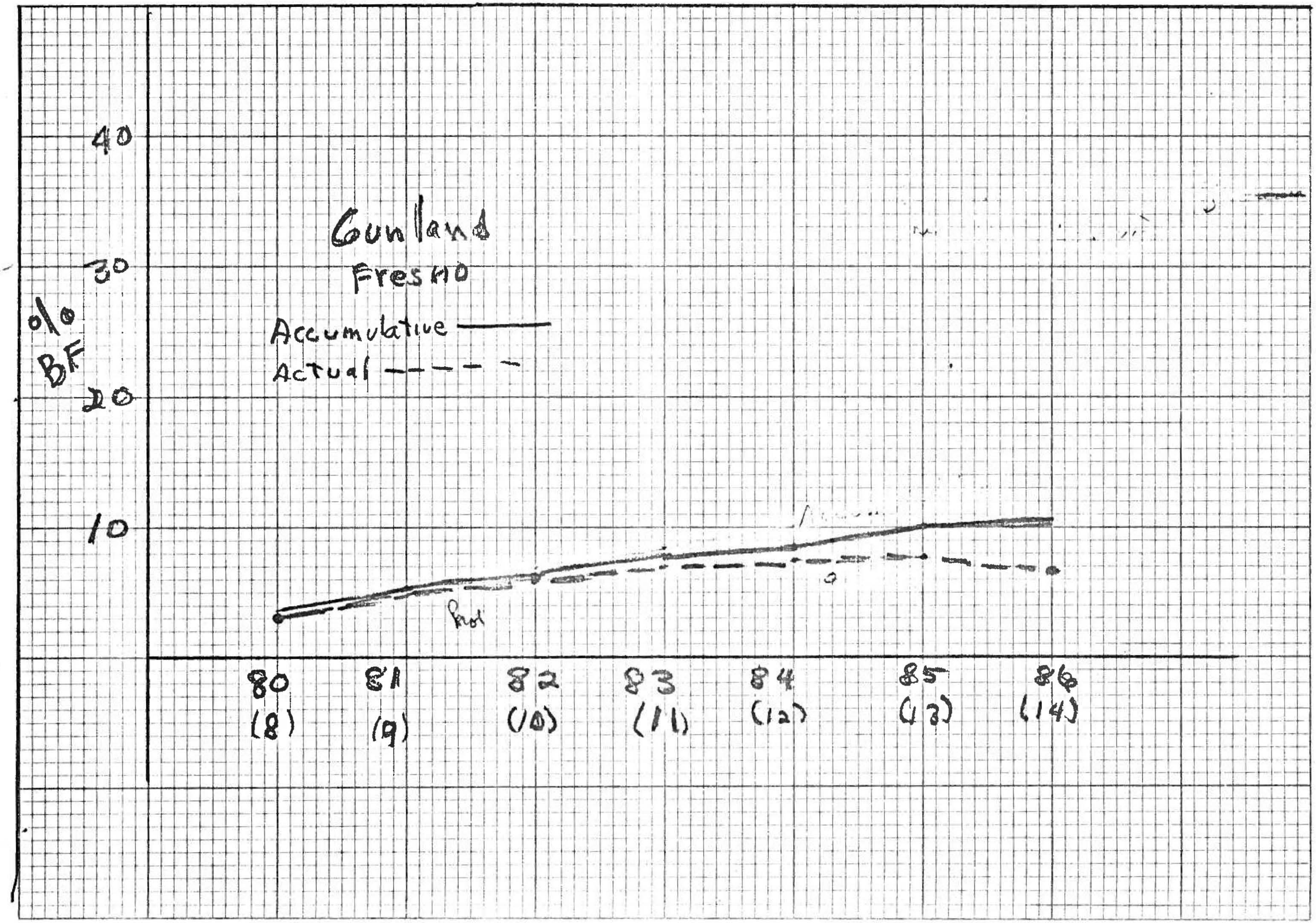
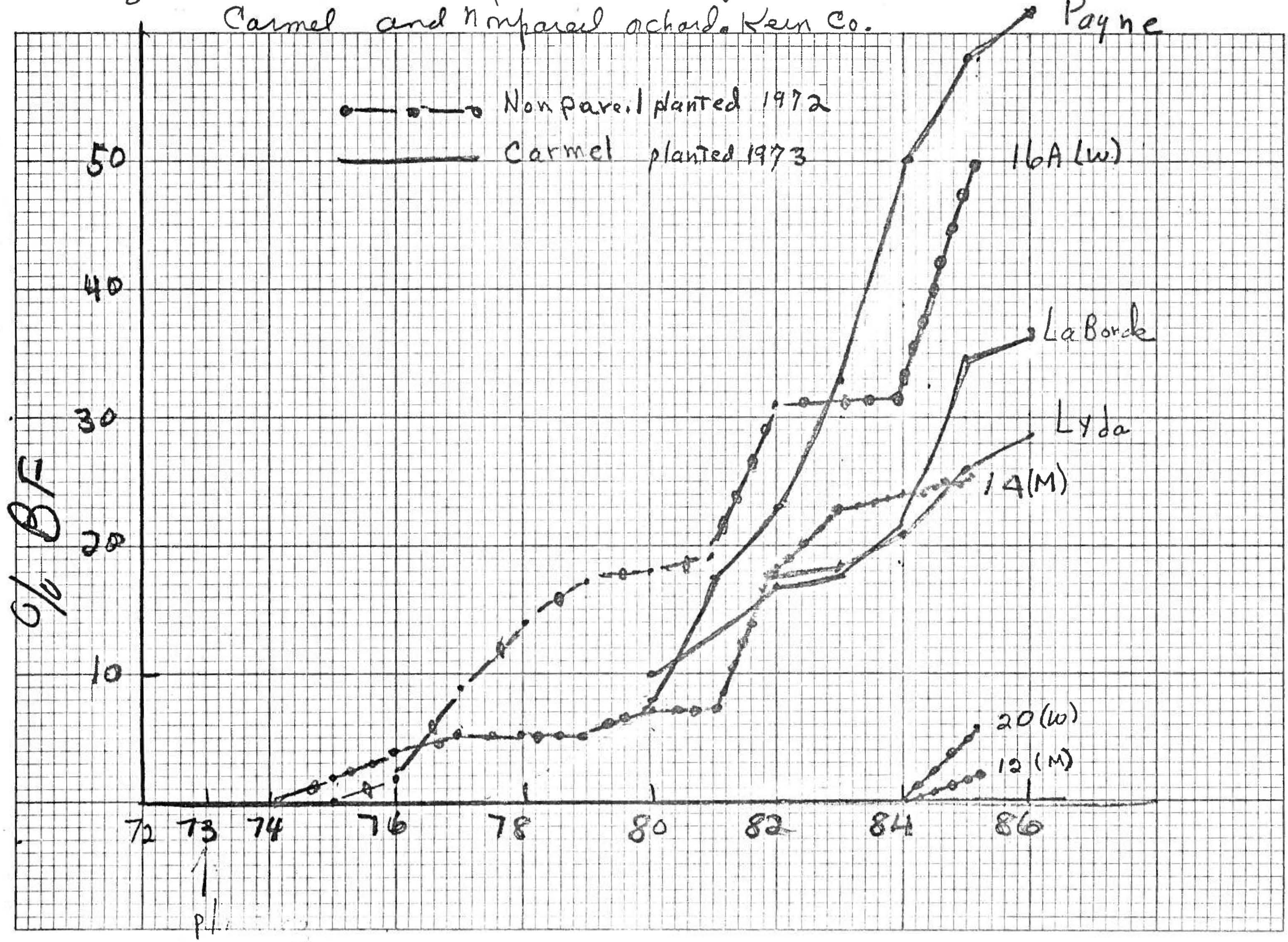


Fig. 6. Comparison of BF development in Carmel and Nonpareil orchards Kern Co.



## APPENDIX I. DEFINITIONS:

1. SOURCE - any plant or group of plants from which propagation material (seeds, buds or scions) is obtained to propagate nursery trees of a particular cultivar.

2. KINDS OF SOURCES:

   ORCHARD SOURCE - individual orchard from which propagation material is obtained. Selection of orchard based upon visual inspections and performance. Could be from the GROWER'S orchard who supplies buds. Or could be selected by the NURSERYMAN from a commercial orchard.

   ORCHARD PROGENY SOURCE - sequence of orchards originating from a particular orchard source. May include a number of vegetative progeny generations of commercial orchards in which nurseryman shifts to younger progeny orchards as the older ones decline in budwood production.

   TREE SOURCE - a single tree whose identify is maintained is used to provide propagation material. May be multiplied into a SCION ORCHARD or NURSERY INCREASE BLOCK. The vegetative progeny from an individual tree source whose identify is maintained separately from other sources of that cultivar becomes a SOURCE-CLONE.

3. SOURCE IDENTITY - maintenance of the identity of a source that is used in propagation and its maintenance into the orchard that is being propagated.

4. VARIANT - any kind of biological variant that modifies the cultivar from its original characteristics, persists within the vegetative progeny and affects its commercial use.

   These can include a wide range of biological phenomena often unique to the particular species or cultivar. In general they can be classified into 3 basic groups:

   1. transmissable or infectious types: includes viruses and virus-like pathogens.

   2. Genetic disorders or changes:

      a. MUTATIONS of various kinds that result in sudden changes of genotype. Can result from chance mutation or from mutagenic agents in the environment.

      b. SPECIES OR CULTIVAR-SPECIFIC GENETIC DISORDERS (noninfectious bud-failure in almond, crinkle in cherry, June yellows in strawberry). Involves progressive shifts in "genotype"

c. Unknown or unclassified

5. REGISTRATION AND CERTIFICATION - a program of nursery management described in the Agricultural Code of California which involves the REGISTRATION of specific source-clones and their CERTIFICATION as having gone through a program to maintain source identity and to minimize virus infection.

6. SCION ORCHARD - a special orchard grown for the purpose of providing budwood for propagation. As prescribed by Registration and Certification regulations, requires isolation and specified conditions of management and inspection.

7. INCREASE NURSERY OR ORCHARD - nursery row or young orchard of budded trees that is maintained an extra year (or more) to provide a source of propagation material. Might apply to a young non-bearing orchard. The purpose of these blocks is to increase the supply of budwood of a particular source in short supply. To minimize potential problems resulting from distributing undetected variants identity of source should be maintained, numbers of buds taken from and single tree should be kept to a minimum and the block should not be used for repropagation of another generation.

okay

Project No. 85-K12. Tree and Crop Research
Bud-failure and Nonproductivity Disorders in Almond

# NONINFECTIOUS BUD-FAILURE IN ALMONDS

## Part II. Development of epidemiology models

by

Dale E. Kester and C.A.L. Fenton

The purposes of this section are:

a. to present mathematical models that describe the epidemiology of BF within almond varieties in different orchards, identify factors that affect BF development and predict the development of BF in progeny orchards of particular kinds of sources.

b. to apply these models to the development of procedures for selection of specific kinds of sources and the distribution of progeny trees from these sources.

The epidemiological pattern of BF development in particular almond varieties has been perceived as involving changes in BF-potential* with age nd exposure to environmental and management conditions. Part I (this report) describes the actual patterns of BF development in specific progeny orchards arising from different kinds of sources and provides the basic data by which the MODELS were devised. In turn, the models in this part of the report are utilized to interpret the patterns found and to suggest basic principles by which both selection of sources, their maintenance, and subsequent propagation can be controlled to reduce the probability of BF development in progeny orchards.

VARIETY INTRODUCTION MODEL (Fig. II-1)

a. Selection of a variety as a seedling (or possibly mutation) and its subsequent introduction into the industry.

In California, the original group of varieties included Nonpareil, Mission, Peerless, Ne Plus Ultra, IXL and Drake which had originated as chance seedling before 1900. Varieties introduced since 1930 have either appeared as chance seedlings, predominantly from Nonpareil and Mission parentage or from breeding programs also with Nonpareil as a main source of genes.

b. Historical sequence of subsequent propagation.

Older varieteis are 100 or more years old and have gone through repeated repropagations. Newer varieties have a shorter connection between the original seedling plant and their current commercial sources. In many cases the entire sequence of source progeny may be in existence.

c. Selection of a propagation (budwood) source

Typically a bearing commercial almond orchard is used as a propagation source by commercial propagators. The number of individual trees used for propagation varies, depending upon the size of the operation. The same source trees or orchard may be used for a several years particularly when relatively young and the tree growth is sufficiently vigorous to produce good budwood. This period may involve ages of 4 to 10 years.

d. Nursery tree production. Most nursery trees are June budded but a small percentage are fall budded. Sometimes rooted cuttings or Marianna 2624 are budded in late spring with stored budwood collected during the winter. For June budding, current buds are collected from a SOURCE ORCHRD or SOURCE TREE using shoots that grew during the spring months. After budding in May and early June, the buds are forced into growth immediately and the resulting shoots grow more or less continuously during the remainder of the season. If fall budding is done, shoots which grew on the source tree during the current season are collected in August September for budding. After cutting back in the spring, new shoots start to grow in the spring continuing to grow during the entire season. Nursery trees are dug at the end of the year and transplanted to produce PROGENY ORCHARDS.

e. Growth and development in the progeny orchard.

Trees in the progeny orchard represent a single production cycle, or a SCION or VEGETATIVE GENERATION, beginning with buds on the source tree. After planting, approximately one half or more of the nursery plant is pruned away and new shoots grow moreor less continuously during the first year, often in consecutive flushes of growth. The objective of training is to build is to build a strong and relatively large frameworkand to get the tree into bearing as early as possible. At the end of the first year, trees are usually pruned with little or no heading. During subsequent years, the process is repeated but the total extension of growth generally decreases year by year. As the trees come into bearing and develop a spur system, they increase in yield during the 4th to about the 7th year, shoot growth slows down but must be sufficient to maintain yield. If the tree is subjected to severe crop reduction or to heavy pruning, considerable new growth may again occur.

f. <u>Selection of progeny orchards.</u>

Eventually the SOURCE ORCHARD becomes older and comes into heavy bearing, new growth slows down and the orchard becomes less suitable for budwood collection. A new orchard source is selected, usually from oe of the younger PROGENY ORCHARDS of the original propagation source. This sequence may be repeated and with time a series of scion generations occurs to create a PROGENY ORCHARD SOURCE ( Fig. II-1).

## MATERIALS AND METHODS

A reanalysis of earlier published information of Nonpareil growing in different locations in California (Kester and Asay 1978) was used in the initial analysis. The procedure was extended to the Carmel orchards described in Part I (this report) and will be extended to the other Nonpareil data given in part I.

Statistical analysis was based uspon SURVIVORSHIP ANALYSIS (Lee, 1980, Loveless, ). The procedure is similar to that used to plot various failure analyses, including death rates, cancer epidemiology, etc. The procedure assumes that all objects of the sample are eventually subject to the condition resulting in failure. Analyses were carried out with the computer program SAS at the UC Computer Center.

Temperature relationships were analyzed by regression of the <u>hazard rates</u> (to be described later in the report) against temperature accumulations above 80 F. calculated by a method of Kimball and Brooks (California Agriculture, 1957). Data in 6 different locations in California were used. A single Nonpareil source-clone was used and six years of data compared. Further temperature analysesto examine minimu and maximum temperature patterns were made from data of degree day summations of the UC-IPM Computer Center.

## RESULTS

A. BF development model

The model describes the pattern of development of BF symptoms among trees of a single orchard once they have begun to appear but several years of subsequent observations are required to establish a pattern. It has the following form:

MODEL I. $p(t) = 1 - e^{(-\lambda t)^{\beta}}$

and has the following important factors:

p(t) - the PROBABILITY (p) for symptoms to appear at a particular AGE (t)

$\lambda$ - a RATE factor that indicates how rapidly BF symptoms appear in different trees of the orchard

$\beta$ - a SHAPE factor that indicates the VARIABILITY in the rate of BF development among trees of the orchard

The Bud-failure model produces a curve (Fig. II-2) that describes the development of bud-failure affected trees in the orchard with time. It is therefore called a CUMULATIVE PROBABILITY CURVE. Once a pattern is established, the rate at which BF may appear in that orchard in the future can be predicted assuming that the conditions of the orchard remain the same. Data from Nonpareil and Carmel orchards or test plantings described in Part I of this report can be used in the model. These show that once BF begins to appear in an orchard there is an increasing probability that BF will continue to develop in that orchard although the RATE and the PATTERN (variation) at which it develops varies with the source and the location where the orchard is planted.

A second important relationship is to show the frequency distribution of trees of differing potential for BF as shown by the length of time required for BF to develop in that tree. This relationship provides a curve (derived by mathematically rearranging the formula to produce a PROBABILITY DISTRIBUTION FUNCTION, or p.d.f. )(Fig. II-3). This curve plots the relative probability of a tree to show symptoms at any one age (assuming none has appeared up to then). It is a distribution curve for BF-potential present in trees at the time of planting.

A third important curve derived from these formulas is known as a HAZARD FUNCTION, which predicts the probability of nonaffected trees to show BF symptoms at any given age. For most of the orchards studied, the hazard rate increases with time but in some sources (as in the Nonpareil 3-8-1-63) it shows a constant hazard. This means that as the number of affected trees in an orchard increase,the probability for the remaining trees also increases. Eventually as all trees become affected, then the hazard assumes a straight line. This curve has significance in that it shows that the hazard of using unaffected trees for budwood purposes increases as the percentage of affected trees in the orchard increases.

B. Development of Model II

This model is an expanded version of Model I which introduces two additional factors:

MODEL II $$p(t) = \frac{1}{N} \sum_{i=1}^{n} \left[ 1 - e^{[-kt]} \right]^{\frac{1}{b_1}}$$

It includes the following factors:

p(t) = probability to develop BF at age (t)

$b_i$ = the inherent BF-potential of a source tree

N = the number of trees used as a source

k = a constant for rate of change in BF-potential with time

t = the age of the tree

Four factors contribute to the development of BF within orchards:

1. BF-Potential ($b_i$)

This is an inherent condition within the tree or bud that is measured as the time required for BF symptoms to develop in progeny trees. Evidence has been produced (Part III this report) that a characteristic initial BF-potential is present at the time the plant originates as a seedling tree. Subsequently BF-potential may increase with time and develops variability

in BF-potential devwas shown in Part I, this report, to vary from tree to tree but to increase with time.

## 2. NUMBER OF SOURCE TREES

The number of separate propagation source trees with different BF-potential and their subsequent handling establishes the kind of sources (see Appendix I) and affects the variability pattern of BF development within the progeny orchard. If one would separate the progeny of each tree from the others one could identify differences in BF-potential among them since the range of BF-potential within each progeny would be narrow. The smaller the number of source trees, the narrower the range. Such a procedure is the basis of the selection of SOURCE-CLONES with relatively different BF-potential as described in Part I of this report.

As the number of source trees (with different individual BF-potentials) increases and, if their progeny is combined and planted together, the range of variability expands (See Fig. II-6).

Consequently, the larger the number of individual source trees used, the greater the chance that some progeny trees will show bud failure but the subsequent slow initial percentage will be low. On the other hand, as the number of source trees decreases, the greater the percentage of trees of the progeny that could develop BF symptoms at any one time. If a source of relatively high BF-potential was used, early and severe BF would develop. If the source tree has low BF-potential, than the onset will be delayed and BF trees may never appear in the orchard. The selection of individual source-trees with low BF-potential and the subsequent development of a SOURCE-CLONE is a basic method of selection against BF.

3. RATE FACTOR

BF-potential does not remain constant but can change with time and age. The effect of specific factors on the rate of change with time can be determined with the model, if other factors are kept constant.

Temperature. Exposure to high temperature increases the rate of change in BF-potential as shown both by experimental evidence and field experience. The model has allowed Dr. Lou Fenton to show mathematically that the BF hazard rate is directly proportional to the accumulated annual exposure to temperatures of 80°F or higher. (Fig. II-7). Further analyses using degree-day information, (UC-IPM computer network) showed that the more effective temperature range for increasing the rate of BF-potential change was 80° to about 95° (Fig. II-8).

Continuous increase in rate has been produced in the greenhouse by exposing plants to consecutive cycles of high temperature in the range of 80 to 100°F (Kester, et. al., 1976, prior reports).

Growth. The temperature studies, along with prior experiments and observations, supports the idea that the change in BF-potential involves both (a) growth and (b) exposure to high temperature. Fig. II.2 showed the amount of vegetative growth during the critical early years of the orchard tree and the seasonal exposure to temperatures over 80°F.

Factors affecting temperature exposure. The analysis focuses attention on the early years (first 5-7 years) in the development of the tree as vulnerable periods for shifts in BF-potential due to increased interactions between growth and high temperature. Several experiments and observations (e.g., see Fig. I- ) have shown that increase in the growth period in the nursery has resulted in decrease in the age at which symptoms had begun to appear (i.e., increase the BF-potential of the orchard tree). The total exposure to heat can be affected by both

LOCATION OF THE ORCHARD and INDIVIDUAL SEASON. Figs. II-9 shows comparisons of seasonal accumulations of temperatures above 80°F for four locations ranging from Davis to Bakersfield for each of the years from 1981 to 1985. These data are compared to the 30 year average for those sites and show strong differences among locations and seasons. Bakersfield had the highest, followed by Fresno with Davis the lowest.

Highest temperature accumulations have occurred in 1981, 1984, 1985, 1983 and 1982 in that order. (Table ). The patterns during the year have varied somewhat. In 1984, high temperatures started early and continued throughout the entire season. In contrast, in 1985, relatively high temperatures occurred early in the season - May, June, first half of July - but were less pronounced in the latter part. In 1981, high temperatures prevailed throughout the season. These two years, 1981 and 1984 have, in general, been associated with significant increases in BF affected trees the following spring and have to be considered a factor in the increase in the BF problem in recent years. Note that the average accumulated temperatures above 80°F for the past five years appears to be significantly higher than that of the 30 year average.

4. Age

Age has two connotations in relation to the BF problem. On the one hand, age refers to the chronological years of growth of the individual trees in the orchard. The other aspect (clonal age) is the difference in the physiological age of the clone from its first growth as a seedling plant.

(a) The relationship between annual growth and exposure to temperature (Fig. II-2) appears to directly affect the age at which symptoms appear. This pattern is reflected in the time of symptom development, the proportion and location of the tree affected and the severity of the BF symptoms in the individual trees. Fig. II.10 compares typical patterns of BF expression within trees, largely related to where in the tree the symptoms first begin to appear. If symptoms appear within the first few years, then subsequent growth from that point will tend to produce BF and the symptoms are considered severe. If symptoms appear later, they tend to develop higher in the tree and only affect subsequent growth in that area of the tree. If symptoms appear even later in time, then only small branches in the top of the tree may develop symptoms. If the tree makes little extension growth, symptoms may not appear at all, but if the tree is sharply pruned to stimulate new growth then large shifts in BF-potential may begin to appear if hot temperatures occur. Once symptoms have begun to develop and produce vigorous new growth then repetition of the symptoms is likely to continue but this may depend on the season.

(b) Clonal age and scion generations. In the derivation of the model for the 'Carmel' orchard, as well as in other orchard situations described in Part II, there was an increasing "hazard rate" resulting from gradual changes in the inherent BF-potential with time. If one then uses that particular orchard as a new bud-wood source, the hazard rate of the new progeny orchard should be expected to increase to produce trees that develop symptoms at a younger age than the source orchard had done. This sequence is the basis of the PROGENY ORCHARD SOURCE which is commonly utilized in commercial nursery propagation. If the same source is utilized continously in consecutive propagation cycles, it is almost inevitable that increasing percentages of BF affected trees could begin to appear at younger and younger ages.

## MOISTURE STRESS AND OTHER FACTORS

Moisture stress has been associated with the onset of symptoms in orchards but it is unclear how much stress resulted in change in rate of BF development or in the increased expression of symptoms.

In experiments carried out earlier for this project, the onset of bud necrosis in stressed trees was shifted to mid-July from late September in nonstressed trees but the overall percentage was not affected. In this instance, it appeared that the susceptibility of the buds was established during the earlier part of the season but the symptoms were not induced until the time of leaf senescence.

Moisture stress also may have a direct effect on increasing the temperature exposure. Earlier experiments (Weinbaum, et. al. 1980) showed that the stomates of a BF affected plant did not function properly to allow the leaves to carry out the same cooling effect due to transpiration that the nonaffected plant did.

## CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The significance of the models is to provide a way to describe and to analyze factors that affect the BF phenomenon. A principal concept that emerges is that BF is an industry-wide problem (Nursery and almond growers) in that the production of BF trees results from a gradual increase in BF-potential with time in both source and progeny orchards at different rates depending upon both location and management.

## A. VERIFICATION OF MODEL

One of the immediate needs is to verify the model by applying it to the development of BF within such varieties as Carmel where the entire historical pedigree can be traced from the original source tree of the variety and the relationships can be established between source trees of different ages and progeny orchards.

To do this will require the cooperation of the commercial nursery industry as well as participating growers. It can be done in specific stages:

1. Tracing the pedigree of the variety from the original source tree through its various progeny sources to current nursery usage.
2. Survey of the original source and sufficient numbers of progeny source orchards to establish their current BF status.
3. Survey sufficient numbers of progeny orchards to verify patterns of BF development not only in relation to source but also to location of orchard, year propagated and planted and specific conditions of management. According to the model, differences may be expected in time of planting (stored vs. non-stored), pruning (heading vs. non-heading), level of vigor, irrigation regime, etc.
4. Compare specific sources under controlled test conditions of different histories, and clonal age to measure differences in BF-potential. Methods may include vegetative progeny tests, micropropagation, proline level, etc.

## II. APPLICATION TO SOURCE MANAGEMENT

It is envisaged that to maintain better control of the BF problem in the long run, some modification of the source selection procedure and the distribution practices may be required. The following concepts follow from the description of the model but should not be considered to be recommendations.

### 1. Selection of source

A first decision is whether to select (a) a SINGLE TREE SOURCE and develop a source-clone with low BF-potential or (b) to select an ORCHARD SOURCE where somewhat greater variation in BF-potential is expected. A key point in the source orchard is that the selection be based on the entire orchard and not just the portion of the trees from which budwood is to be used. In the absence of direct indexing tests for BF-potential, selection may be based on:

a. early "clonal age" -- selecting from the original seedling tree or from the earliest generation.

b. source orchard in which no (or very few) trees show symptoms and from which there has been a record of little or no BF in progeny orchards. This requires that a certain amount of visual inspections need to be carried out on a regular basis on both progeny orchards and original source orchards.

c. Direct information from vegetative progeny testing

### 2. Maintenance of source

Although using a commercial orchard source has been a predominant method of commercial nurserymen, we may need to consider the use of special scion orchards for selected sources in which the trees are kept pruned back on a regular basis to avoid the kind of consecutive growth flushes from year to year that are associated with the progressive increase in BF-potential. Budwood to establish this block may best come from the base of the source trees, taken for fall budding rather that June budding, with the top of the nursery plant pruned back severely and headed fairly severely during the first couple of years to retain the part of the shoot that grew during its first flush.

The source block should probably be located in a mild temperature summer area although it may be possible that if one follows the described sequence that location might not be as important as if one were doing consecutive orchard handling.

Re-establishment of source blocks would not be made from progeny orchards but from the base of original source trees.

3. Multiplication and production of nursery trees

Where large numbers of buds are required, a second step of multiplication may be necessary. This would be the case where a central source of budwood (Mother Block) would be utilized. The same principles of collection and handling would apply with the main emphasis being to keep sequential propagation to a minimum. The major principle that should be adhered to would be always to return to the original source block for material to re-establish the block.

4. Other methods

The possibility of maintaining and multiplying selected clones by micropropagation needs to be explored. See Section IV.

These steps are geared to the selection, maintenance and distribution of trees against BF. Other potential problems of selection also have to be considered, including varietal mixups, mutations and bud-sports and virus diseases. Each of these also have to be given consideration but will be the subject of other reports.

THE IDEAS PROVIDED ARE NOT RECOMMENDATIONS FOR IMMEDIATE IMPLEMENTATION BUT NEED TO BE TESTED WITH APPROPRIATE SAFEGUARDS AGAINST THE EMERGENCE OF OTHER PROBLEMS.

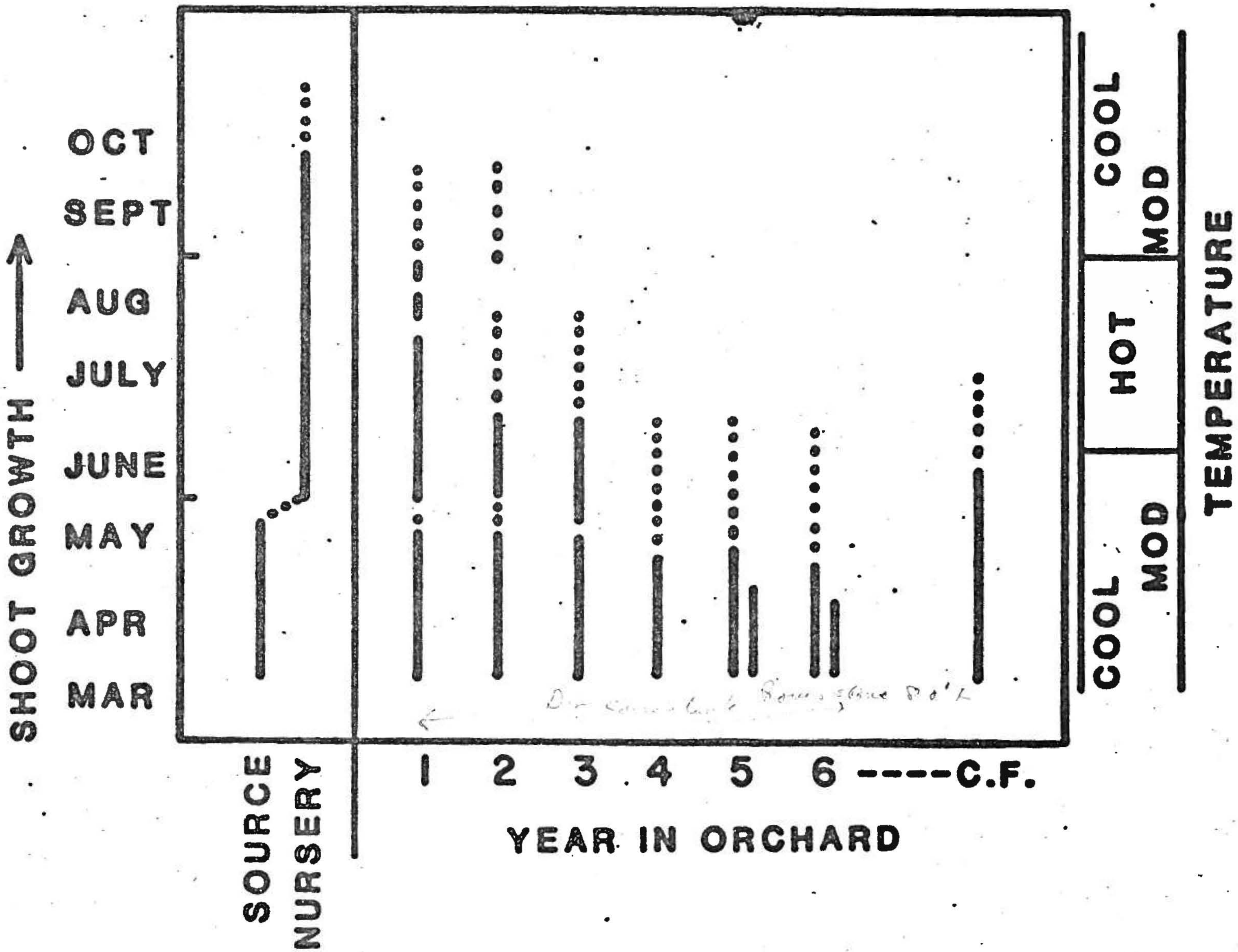



Fig II-2 Interaction between amount of shoot growth and ambiant temperature exposure in California in nursery and first six years in the orchard. C.F = crop failure

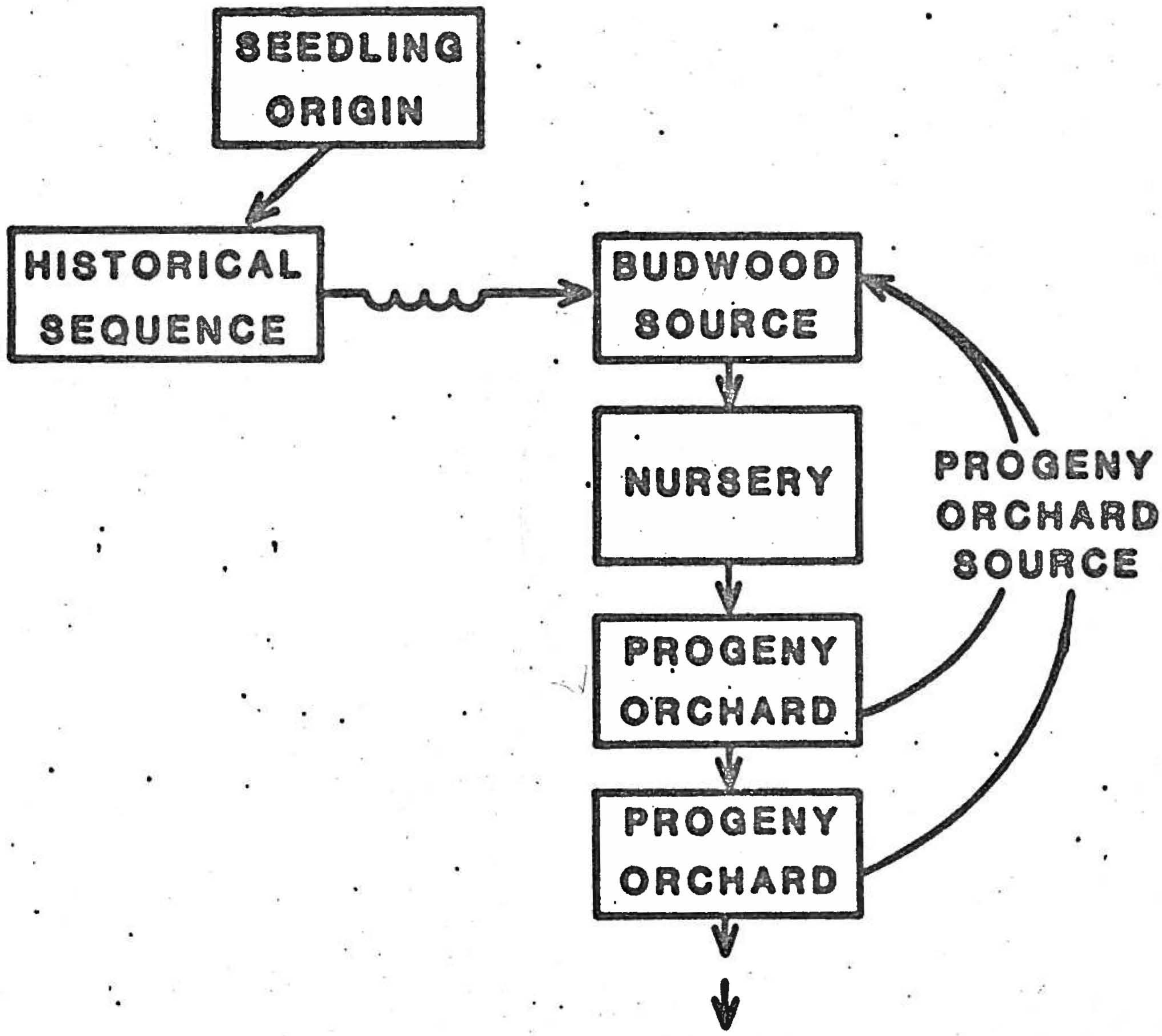



Fig. II-1. Introduction and subsequent sequence of propagation of an almond variety for commercial distribution.