1995 FINAL REPORT TO ALMOND BOARD OF CALIFORNIA

Project No. 95-F20 Pollination

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Objectives:

1. Develop informatin on pollination by bees that will result in increased efficiency and greater grower returns.
2. Improve pollination efficiency of rented honey bee colonies.
3. Evaluate and improve management of alternative pollinators.

Summary

Weather- The 1995 bloom season in the Sacramento Valley started in early February and progressed rapidly. Bloom was preceded by greater than normal January rainfall. These rains caused considerable flooding in low areas,destroyed many honey bee colonies and delayed movement of colonies into many orchards. Saturated ground and moderate temperatures resulted in dense fog throughout much of the Central Valley during peak bloom, further diminishing honey bee pollination. Strong winds and heavy rains in March blew over many trees throughout the state, especially in older orchards.

Bloom progression- Bloom of the five cultivars in our test orchard near Dixon started early and progressed rapidly during the moderate weather of February. Most of the cultivars overlapped well, but the foggy weather during peak bloom limited bee flight.

Buds per meter- In a test orchard near Dixon, buds per meter counts were made among five cultivars as part of a long-term study initiated in 1990. Bud production in 1995 was generally lower than in 1994 for all cultivars. NePlus, Nonpareil, and Price exhibited strong alternate bearing over a six year period. This pattern was apparent to a lesser extent in Peerless. Percent fruit set showed an inverse relation to bud production in Nonpareil and Price, but not in Peerless or NePlus.

Queen mandibular pheromone (QMP)- "Fruit Boost", a QMP product from Canada, was applied twice to an orchard near Chico to determine whether it would increase honey bee foraging activity, fruit set, and harvest yield. Bees were somewhat more abundant in treated trees on the afternoon of the treatments, 6-8 hours post-treatment especially following the second treatment. There were no significant increases in fruit set or harvest yield in treated plots.

Orchard mason bees- Since only extremely small populations were available from trappng in 1994, none were released in almonds this year. Surviving bees were returned to the source site to enhance trap-nest captures in 1995.

Bumble bees- Small populations of *Bombus occidentalis* were observed in almond orchards near Dixon and near Arbuckle, CA. Ten limbs, one per tree, in each of three cultivars, Butte, Nonpareil, and Carmel were flagged near and away from 4 quads in an orchard near Dixon. Blossom units were counted on these limbs to calculate fruit set from April fruit counts. Fruit set was consistently and significantly higher in each cultivar near the bumble bee hives versus set in trees away. Evaluations of colonies at Arbuckle showed that most had increased their populations during the brief bloom period.

Introduction

The 1995 bloom season in the Sacramento Valley started in early February and progressed rapidly. The bloom was preceded by greater than normal rainfall in January. These rains caused considerable flooding in low areas and delayed the movement of honey bee colonies into many orchards. Many honey bee colonies were destroyed by the floods. The saturated ground and moderate temperatures resulted in dense fog throughout much of the Central Valley during peak bloom, further diminishing the ability of honey bees to pollinate the crop. Strong winds accompanying heavy rains in March blew over many trees throughout the state, especially larger trees in older orchards. Our QMP test orchard near Chico also showed effects of the disease Anthracnose (*Colletotrichium* spp.)which was apparently enhanced by the cold damp spring.

Bloom Progression

Bloom of the five cultivars in our test orchard near Dixon started early and progressed rapidly during the moderate weather of February. Most of the cultivars overlapped well, but the foggy weather during peak bloom limited bee flight.

Methods: Bloom progression counts were made every 2 to 4 days along a diagonal (NE-SW) transect across the orchard using one limb on each of five trees for each of the five cultivars. More than 100 buds per limb per tree were counted from the tip and a color coded flag of engineers tape was placed at the base of the section of intial buds counted. Bloom units were classified into three categories: bud (small buds through popcorn stage with petals showing but not separating); flower (from anthesis withpetals just opening enough so tat a bee can enter and contact the stigma = "cup-shaped," through initial petal drop); and senescent flower (with most petals gone, anthers empty, and stigma and style tip darkened.

Results: The 1995 bloom season began early starting in early February. It progressed rapidly with strong overlap in bloom among most of the cultivars (Fig. 1). The bloom season was essentially completed by the end of February. Mission, the latest blooming of the five cultivars, exhibited the shortest bloom and overlapped only with the decline of the other four cultivars. The short period of bloom and fog during bloom effectively narrowed the window of opportunity for bees to pollinate the crop.

Discussion: Previous experience suggested that early bloom is often followed by a straggled long bloom season with poor overlap among cultivars. However, despite the early onset of bloom in 1995, the bloom progressed rapidly and overlapped well providing good opportunity for cross-pollination (Fig. 1). Foggy weather during bloom narrowed windows of opportunity for bee flight. Difficulty in getting bees into orchards due to flooding in January further depressed opportunity for good bee flight. All these factors underscore and reinforce our recommendations regarding the need for adequate numbers of strong bee colonies at the onset of bloom to maximize bee flight during the windows of opportunity for foraging.

Buds Per Meter and Fruit Set

In a test orchard near Dixon, buds per meter counts were made among five cultivars as part of a long-term study initiated in 1990. Bud production in 1995 was generally lower than in 1994 for all cultivars. NePlus, Nonpareil, and Price exhibited strong alternate bearing over a six year period. This pattern was apparent to a lesser extent in Peerless. We hope to be able to compare our long-term data set with historical yield records for the cultivars in this orchard to look for any relationships among bud production, fruit set, and harvest yield and to determine whether the apparent biennial patterns of bud production may affect yield.

Methods: This is a continuation of a long-term study started in 1990. Buds per meter were counted on one limb of each of 10 trees in one row of each cultivar. Starting at the tip of each branch, a meter tape was run toward the base, measuring along each major spur and branch until one meter was reached. A clothes pin was clamped to the branch at that point and all buds were counted from the apex of each limb. A color coded flag of engineers tape replaced the clothes pin and was numbered using a sharpie pen to identify each tree.

Buds counted on the limb on each of the 10 trees of the five cultivars and flagged early in the bloom season for buds per meter data were also used as a base for calculating percent fruit set. Fruits set were counted on 24 April about 8 weeks after bloom ended. Percent fruit set was calculated by dividing the number of large fruits produced and multiplying by 100. Harvest yield data for all five cultivars from 1990 through 1995 have been requested from the grower cooperator, but are not yet available.

Results: Bud production was generally lower in 1995 than in 1994 for most cultivars and nearly comparable to bud production in 1993 (Fig. 2). Three of the five cultivars examined, NePlus, Nonpareil, and Price, continued to show strong patterns of biennial bud production (Fig. 3). Peerless exhibited a more subtle, but apparent biennial bud production pattern (Fig. 2). Fruit set continued to show an inverse relationship to bud production, at least for Nonpareil and Price (Figs. 4 & 5). Harvest yield data are not yet available.

Discussion: At least three of the five cultivars examined, NePlus, Nonpareil, and Price, continued to show strong patterns of biennial bud production over the past six years (Figs. 2 & 3) . Peerless also exhibited a more subtle, but apparent biennial bud production pattern (Fig. 2). This alternate bearing may influence the bee/flower ratio and percent fruit set. The alternate bearing expressed by these cultivars often resulted in increased percent fruit set in low bud production years (Figs. 4 & 5). This was reversed in years of high bud production and often accompanied by increased fruit drop in about June. This suggests that trees with low bud densities can compensate by devoting more resources to retain developing fruit. Trees with low bud and subsequent flower densities may also be more effectively pollinated due to more bees per flower producing more rapid depletion of pollen and nectar resources each day. This could cause increased bee flights between trees and therefore better movement of out-cross pollen in the orchard. However, it suggests that growers should consider renting more bees during years of high bud densities or other means of increasing bee activity during these years to ensure an adequate bee/flower ratio and to obtain even better fruit set in years of heavy flowering. Harvest yield data are not yet available for comparison.

Queen Mandibular Pheromone (QMP)

With funding from Phero Tech Inc. of Canada, we established test plots at Almont Orchards of Durham, near Chico, CA. "Fruit Boost", a QMP product from Canada, was applied twice to the orchard to determine whether it would increase honey bee foraging activity, fruit set, and harvest yield. Two treatments: 0 (control) or 400 queen equivalents (QE), were each replicated six times. One limb per tree on six trees in the center of each plot was used determine percent fruit set. Bee-in-tree counts were made prior to, immediately after, and one day following each spray application to measure bee activity. Fruit set was measured in April and June and harvest yield data were taken in August.

Methods: Queen mandibular pheromone (QMP) produced by Phero Tech Inc. of Canada under the trade name, "Fruit Boost," was applied twice to a row of 29 trees of Nonpareil in each of six plots in an orchard near Chico (Fig. 6). Another six plots were left untreated as controls. The orchard contained four cultlivars, Nonpareil, Carmel, Butte, and Peerless. Nonpareil was every other row with a row of Carmel on one side and a row of Butte and Peerless trees alternating in same row on the other side.

Materials were applied early in the morning and counts of bees visiting flowers were initiated within two hours after application. The first application was on 17 February, the second on 21 February. Bee in tree counts were made prior to applications and twice a day after applications. In addition, counts of 20 to 30 bees collecting pollen or nectar were made in the afternoons to determine whether ratios of forager activity were influenced by the sprays.

About 100 buds and/or flowers were counted and flagged on one limb on each of five trees in in the middle of each of the 12 test rows as a basis for calculating fruit set. One limb on a sixth tree in each of the 12 test rows was selected for bloom progression (phenology) counts. About 100 bloom units were counted and flagged on these limbs and the numbers of buds, flowers, and old (senescent) flowers were counted at one to three day intervals. Fruit counts were made on 17 April and 20 June. Fruit set was determined by dividing the number of original bloom units into the fruits and multiplying by 100.

Missing trees were determined and mapped on 8 August. After nuts were shaken, we hand raked nuts at the ends of the 12 test rows in preparation for pickup on 29 August. Fruits from each of the 12 test rows were vacuumed into individual bins and the bins were weighed at a nearby field weighing station. Harvest data were provided to us by the grower cooperator on 1 September. All plots were color coded and the identity of treated versus untreated plots were maintained by the grower until after all bee and fruit set counts were made to prevent observer bias.

Results: Bloom in Nonpareil started slightly later in these plots than it did near Dixon (cf. Figs. 1 &7). Nonpareil bloom progressed rapidly at Durham and had good overlap with the other cultivars (Carmel, Butte, and Peerless) in the orchard. Bees were somewhat more abundant in treated trees on the afternoon of the treatments, 6-8 hours post-treatment, and also on the second afternoon, ca 30 hours, after the second treatment (Fig. 8). There were slight increases in the ratio of pollen versus nectar foragers in treated plots on the two days following each treatment (Fig.9). This also extended to a third day (February 23) after the second treatment where the average P/N ratio for treated trees (1.35) was slightly higher than that for untreated trees (1.01). Both were lower than the previous afternoon. There were no significant increases in fruit set or harvest yield in treated plots (Figs. 10 & 11). The number of missing and nonproductive "runt" trees per test row varied from zero to seven increasing the variance of our analyses. However, even when yield was recalculated on a per tree basis, there were no significant differences between treated versus untreated test rows.

Discussion: In 1994 we tested several doses and found the best increase in bee activity in plots treated with a dose of 400 queen equivalents (QE). Since this was also the standard dose used in other pollination trials we decided to focus on this dose and increase the plot size and number of replicates for our 1995 trial. As in 1994 we found some increase in bee activity in treated trees. In 1995, this was especially true the afternoon following each treatment and into the second afternoon after the second treatment. We also found some increase in pollen foraging activity in the afternoons following treatments. However, these increases in foraging activity did not translate into increases in fruit set or yield.

There may be a number of reasons for the lack of increase in fruit set or yield in these trials. In both 1994 and 1995, the bloom progressed rapidly even though it started nearly a month earlier in 1995. This presented very narrow windows of opportunity for bee activity and pollination. However, we were able to apply two sprays as recommended in our 1995 trial.

Trials with other crop plants conducted by Dr. Mark Winston in Canada have shown both increased bee activity and increased crop yield. Part of the problem in our studies with almond may be due to its self-incompatibility system and need to move pollen between cross-compatible trees. Thus, increasing bee activity in almond trees may not be sufficient without some means of increasing movement between trees of cross-compatible cultivars. Our spray applications included the Nonpareil test trees and the adjacent cross-compatible cultivars. But could our spray applications have enhanced cultivar fidelity among honey bees at the expense of foraging movements between cultivars? Is it possible to devise some method of applying materials to enhance inter-tree movement, especially between trees of different cultivars? These questions pose some interesting problems for the future, but after two years of trials the current methods of crop treatment with QMP to enhance pollination and yield do not seem promising in almond.

Orchard Mason Bees

Since only extremely small populations were available from trappng in spring 1994, none were released in almond this year. Surviving overwintered bees from 1994 were returned to their source site to enhance trap-nest captures in 1995.

Methods: Sticks and straws with brood cells from 1994 were added to empty trap-nests at a site about 20 miles ENE of Madera in February 1995 to augment the local population and to enhance trap nesting collections. Trap-nests were collected in early November 1995. They were returned to Davis where they were x-rayed to determine the number of potentially viable brood cells and the presence of any parasites or nest destroyers. The trap nests are currently in cold storage to be brought out in spring 1996 for use in almond pollination.

Results: Although the nesting season got off to a slow start, over four times as many nests of *Osmia lignaria propinqua* were trapped in spring 1995 as compared to spring 1994 (ca 184:44). And the 1995 nests contained over six times as many brood cells as did nests in 1994 (ca 929:149). These are maximum estimates and do not account for mortality factors.

Discussion: Dispite a wetter than normal rainfall season for 1994-95, the wild bee populations have not recovered as rapidly from previous drought years as anticipated. However, after a slow start in spring 1995, the nesting season did progress much better than in spring 1994. Sufficient numbers of *Osmia lignaria propinqua* were trapped in spring 1995 for use for small scale tests in almond in spring 1996 conditional on adequate overwinter survival and spring emergence.

Bumble Bees

Small populations of *Bombus occidentalis* were observed in almond orchards near Dixon and near Arbuckle, CA. Both orchards were fully stocked with honey bees. A four colony "quad" was established at the Bee Biology Facility on the UCD campus for use in cage studies by Dr. James D. Thomson, SUNY, Stony Brook, NY. Dr. Thomson is initiating tests of models of bee visitation to flowers to compare their efficiency in removal of pollen from anthers, and in deposition of pollen on stigmas.

Methods: Bumble bee hives were bound together in groups of four (quads) between plyboards and mounted on 4x4 posts within tree rows. Some posts contained two quads each for a total of 16 hives per post. In 1995, entrances of the hives in each quad were facing inward to prevent reduction of activity noted in previous years from entrances facing prevailing winds. Alleyways for bee movement to the outside were provided by spaces between the hives. Colonies at Arbuckle were evaluated for strength at the end of the pollination season.

Ten limbs, one per tree, in each of three cultivars, Butte, Nonpareil, and Carmel were flagged near and away (20 rows) from two double quads (16 hives) in an orchard near Dixon. Blossom units were counted on these limbs to calculate percent fruit set from April fruit counts. All rows of trees were approximately equidistant from sets of honey bee hives.

After a number of discussions, Dr. James Thomson who was on Sabbatical leave at U. C. Berkeley from his home institution (SUNY, Stony Brook, NY, conducted initial trials to compare the pollination efficiency of honey bees versus bumble bees. He plans to test removal and deposition of pollen in almond flowers. He set up a cage with a quad of *Bombus occidentalis* at the Bee Biology Facility, U. C. Davis. He also made some observations of bees in trees and presented cut flowers to bumble bees in the quads established in an almond orchard near Dixon, CA. His primary effort was to develop methods to compare how much pollen is removed from almond flowers and how much is delivered to their stigmas by honey bees and bumble bees when collecting either pollen or nectar.

Results: Honey bees frequently robbed bumble bee colonies, especially where the liquid feeders were leaking. It was still difficult to find bumble bees working in almond trees, even though almond pollen was being brought in to quads during the bloom season. Most of the bumble bee colonies at Arbuckle had increased their population sizes over what they were at introduction.

All three cultivars in the test orchard near Dixon, CA exhibited consistent and significantly higher nut set in each row near the bumble bee hives in comparison to the rows away from the hives (Fig. 12).

Dr. Thomson tried flowers on cut branches for presentation to foraging bees and found it difficult to manipulate individual flowers without contaminating stigmas with pollen. Field caught bees introduced to a cage could be trained to feed at cut flowers, but only for nectar. In the orchard stocked with bumble bees and honey bees, he was unable to find sufficient numbers of bumble bees foraging and was unable to attract honey bees from trees with Butte flowers to the cut branches of Mission flowers. He did succeed in getting bumble bees to forage for pollen on flowers on cut branches when a single hive was moved into a screen flight cage. No data were collected.

Discussion: The arrangement of hives with interior facing entrances made it very difficult to monitor activity of bees at the quads. The short season, robbing by honey bees, and marginal flight weather further impeded observations of bumble bees at their colonies. Colony evaluations at Arbuckle showed that most of the colonies had increased their populations despite the brief bloom period.

The consistent and significantly higher nut set in each of the three cultivars near the bumble bee hives in contrast to 20 rows away was our most exciting finding (Fig. 12). However, these results are based on a single trial without replication and should be repeated at least one more year in the same site with the bumble bee quads positioned in the tree rows considered away in 1995 and preferably at other sites as well.

Dr. Thomson's findings that bumble bees would forage at flowers on cut branches in a small flight cage. This technique holds promise for future investigations of comparative pollination efficiency of bees on almond. No data were collected, but designs for future tests were established. Empirical tests of his model for comparing pollen removal from anthers and pollen deposition on stigmas by different types of pollinators on different crops will provide important insights to differences in pollination efficiency. Future tests on almond will be worthwhile.

Publications

Thorp, R. W. Bee management for pollination. UC DANR Almond Production Manual. pp. 132-139. [In press, due 1996].

DeGrandi-Hoffman, G., R. Thorp, G. Loper, and D. Eisikowitch. Describing the progression of almond bloom using accumulated heat units. J. Appl. Ecology. [In press, due 1996].

Figure Captions:

Fig. 1. Bloom progression for five cultivars in an orchard near Dixon, CA for February 1995. Top: Buds. Middle: Flowers. Bottom: Old (Senescent) Flowers.

Fig. 2. Buds per meter produced by five cultivars in an orchard near Dixon, CA measured over six years: 1990 through 1995.

Fig. 3. Buds per meter produced by three of five cultivars showing the strongest biennial patterns in an orchard near Dixon, CA measured over six years: 1990 through 1995 (a subset of data shown in Fig. 2).

Fig. 4. Fruit set for five cultivars in an orchard near Dixon, CA measured over six years: 1990 through 1995.

Fig. 5. Fruit set for three of five cultivars showing the strongest biennial patterns of bud production in an orchard near Dixon, CA measured over six years: 1990 through 1995 (a subset of data shown in Fig. 4).

Fig. 6. Orchard plot layout for Queen Mandibular Pheromone trial near Chico, CA for 1995.

Fig. 7. Bloom progression in Nonpareil test trees in treated and untreated plots for Queen Mandibular Pheromone trial near Chico, CA for 1995: a) Buds; b) Flowers; c) Senescence (old flowers).

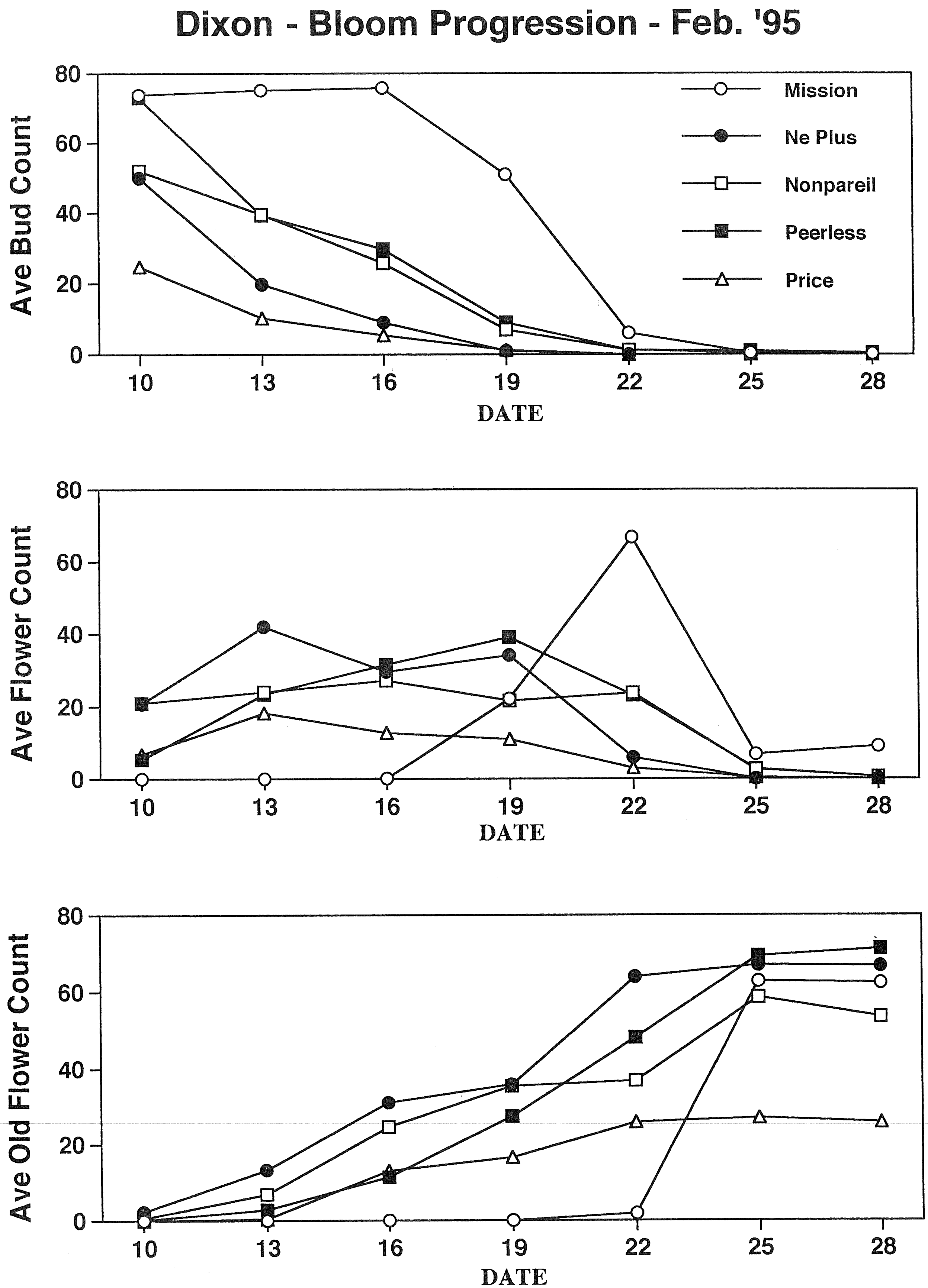
Fig. 8. Honey bee visitation to Nonpareil trees treated or untreated with Queen Mandibular Pheromone near Chico, CA. Treatments applied in early morning on 17 and 21 February 1995 (see arrows).

Fig. 9. Ratios of pollen to nectar foraging honey bees in relation to almond trees treated or untreated with Queen Mandibular Pheromone near Chico, CA. Treatments applied in early morning on 17 and 21 February 1995 (see arrows).

Fig. 10. Average percent fruit set on Nonpareil trees treated or untreated with Queen Mandibular Pheromone near Chico, CA.

Fig. 11. Average harvest yields of Nonpareil test rows treated or untreated with Queen Mandibular Pheromone near Chico, CA.

Fig. 12. Comparisons of fruit set in three cultivars near two double quads (16 hives) of the western bumble bee, Bombus occidentalis, and about 20 rows away from the hives in an almond orchard near Dixon, CA.



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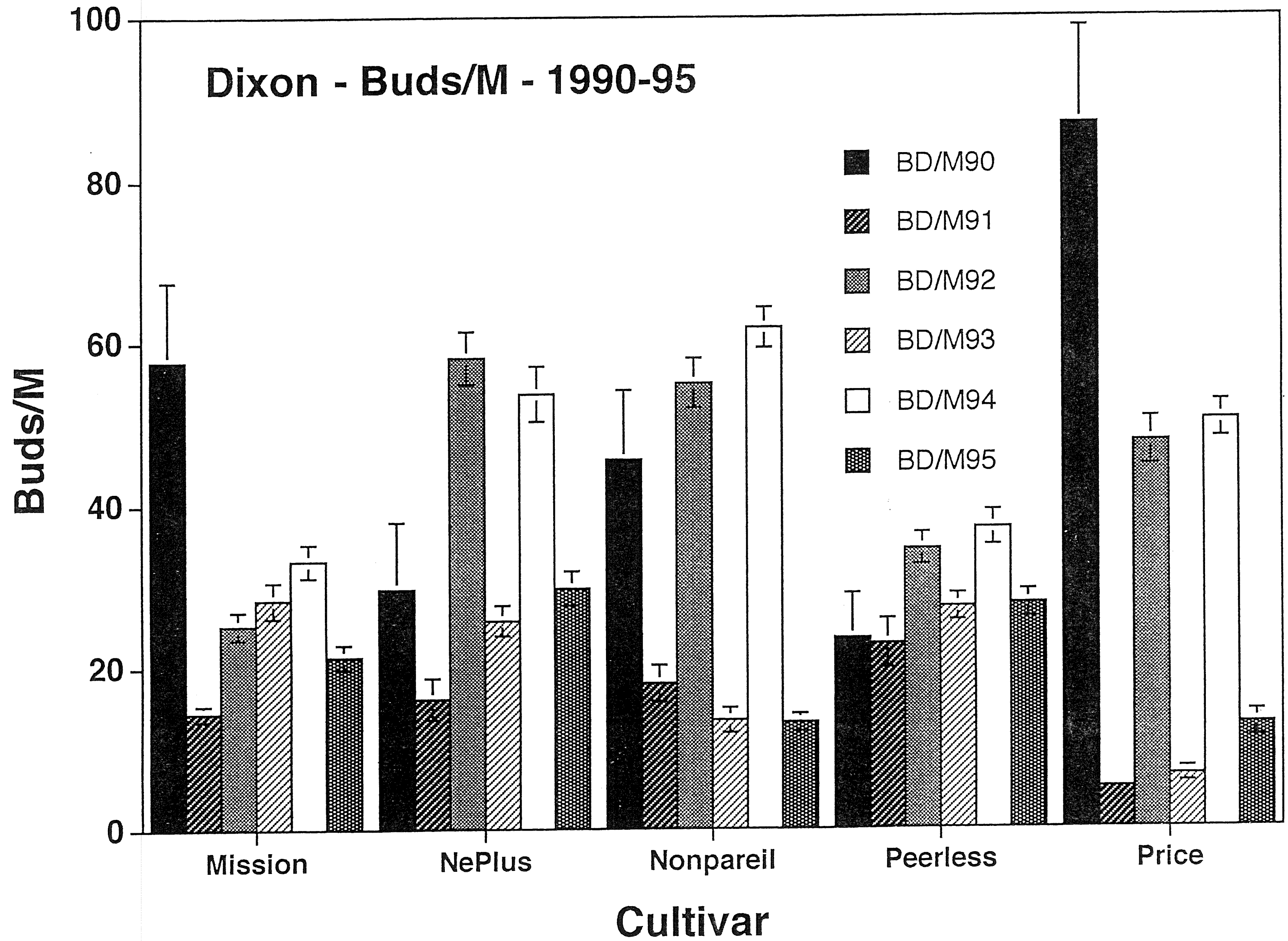

Fig. 2. Buds per meter produced by five cultivars in an orchard near Dixon, CA measured over six years: 1990 through 1995.

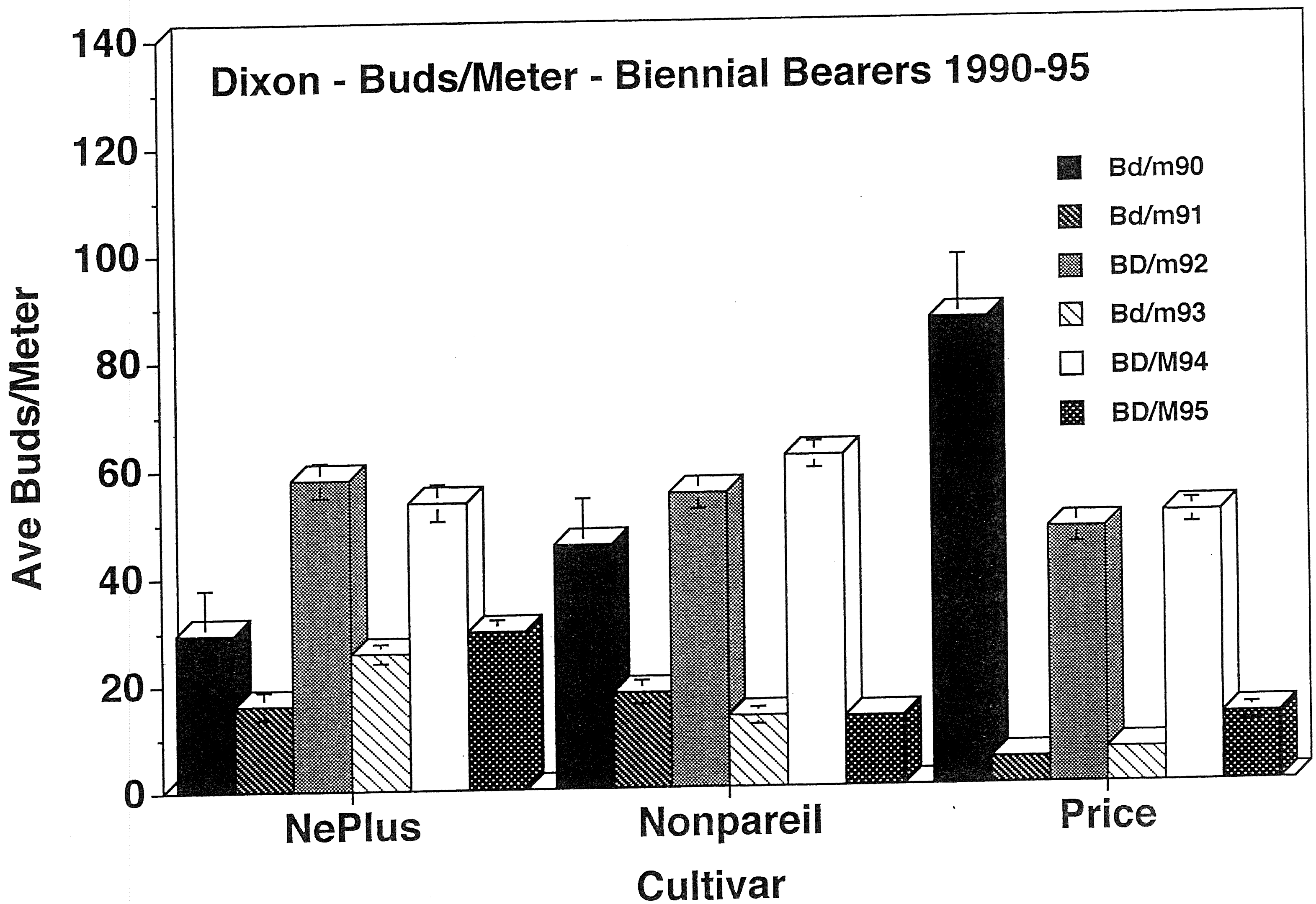

Fig. 3. Buds per meter produced by three of five cultivars showing the strongest biennial patterns in an orchard near Dixon, CA measured over six years: 1990 through 1995 (a subset of data shown in Fig. 2).

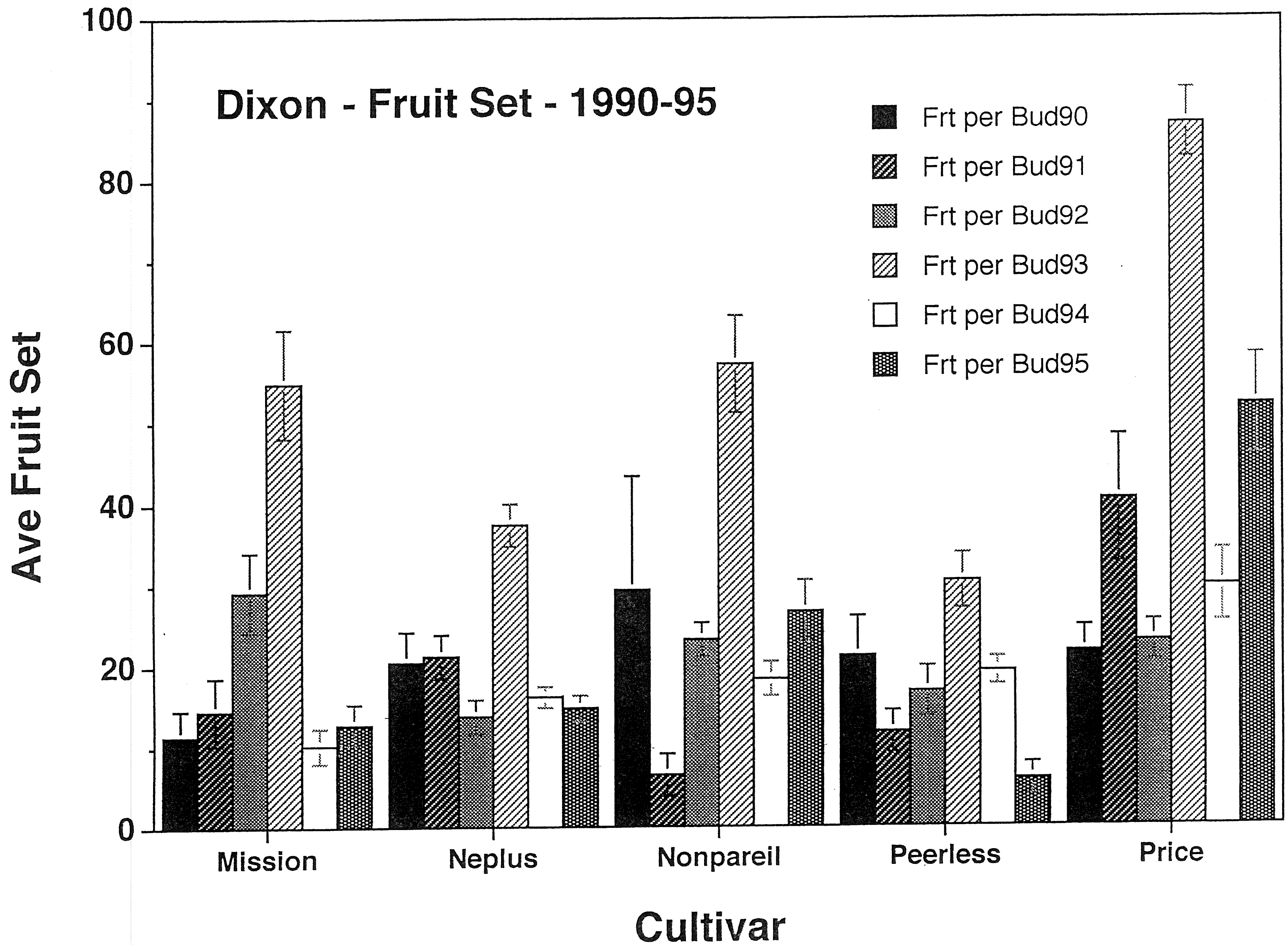

Fig. 4. Fruit set for five cultivars in an orchard near Dixon, CA measured over six years: 1990 through 1995.

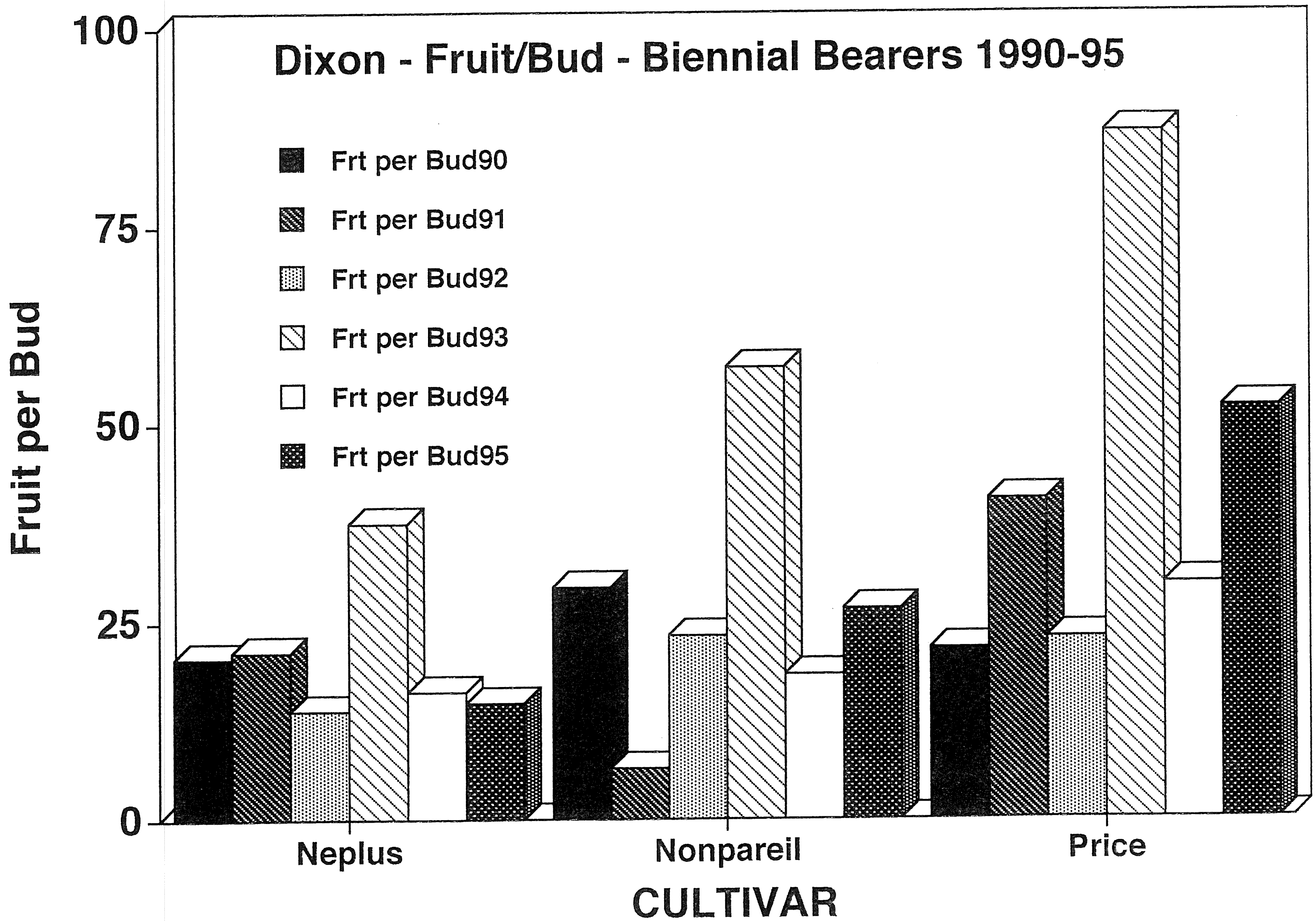

Fig. 5. Fruit set for three of five cultivars showing the strongest biennial patterns of bud production in an orchard near Dixon, CA measured over six years: 1990 through 1995 (a subset of data shown in Fig. 4).

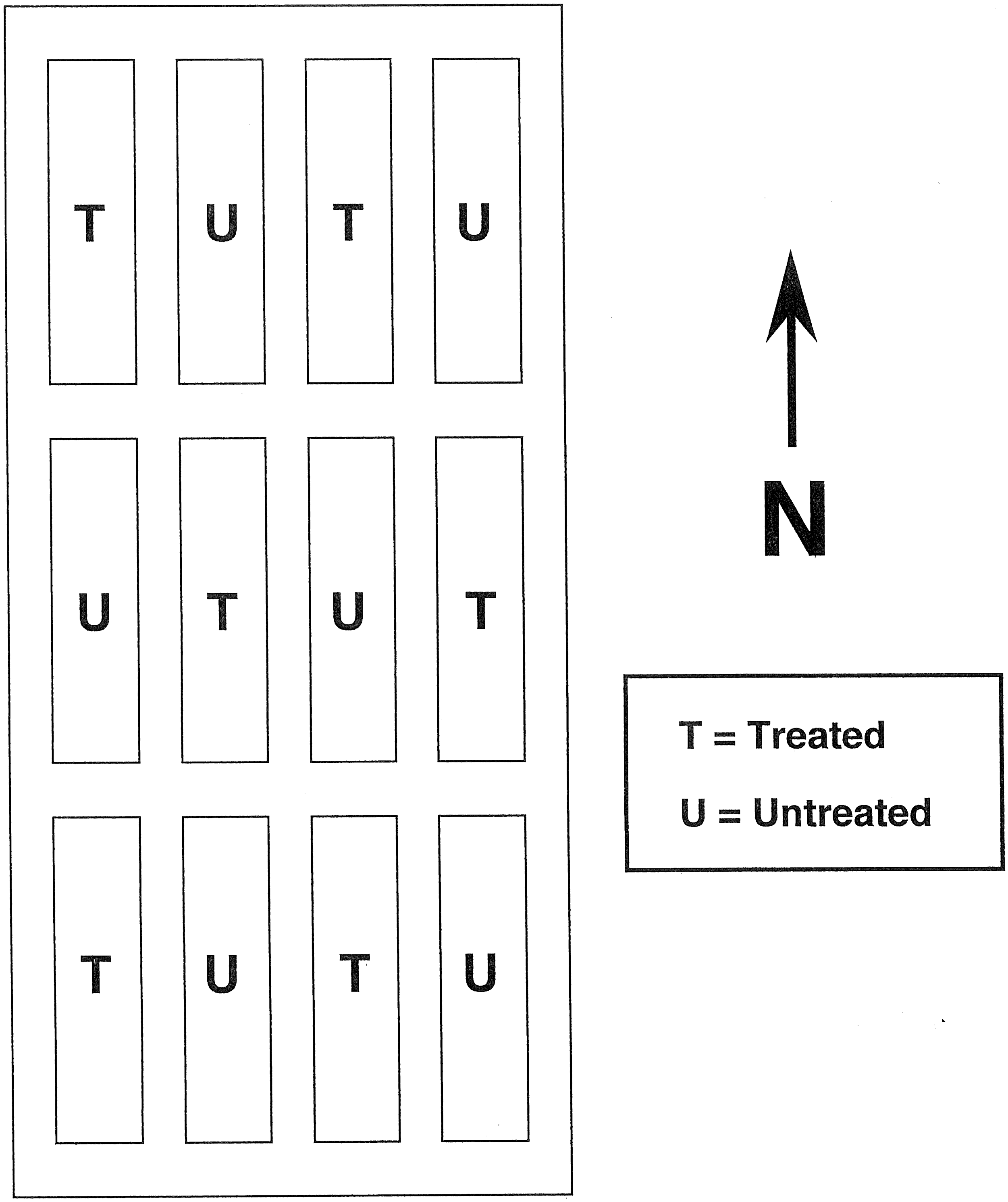

Fig. 6. Orchard plot layout for Queen Mandibular Pheromone trial near Chico, CA for 1995.

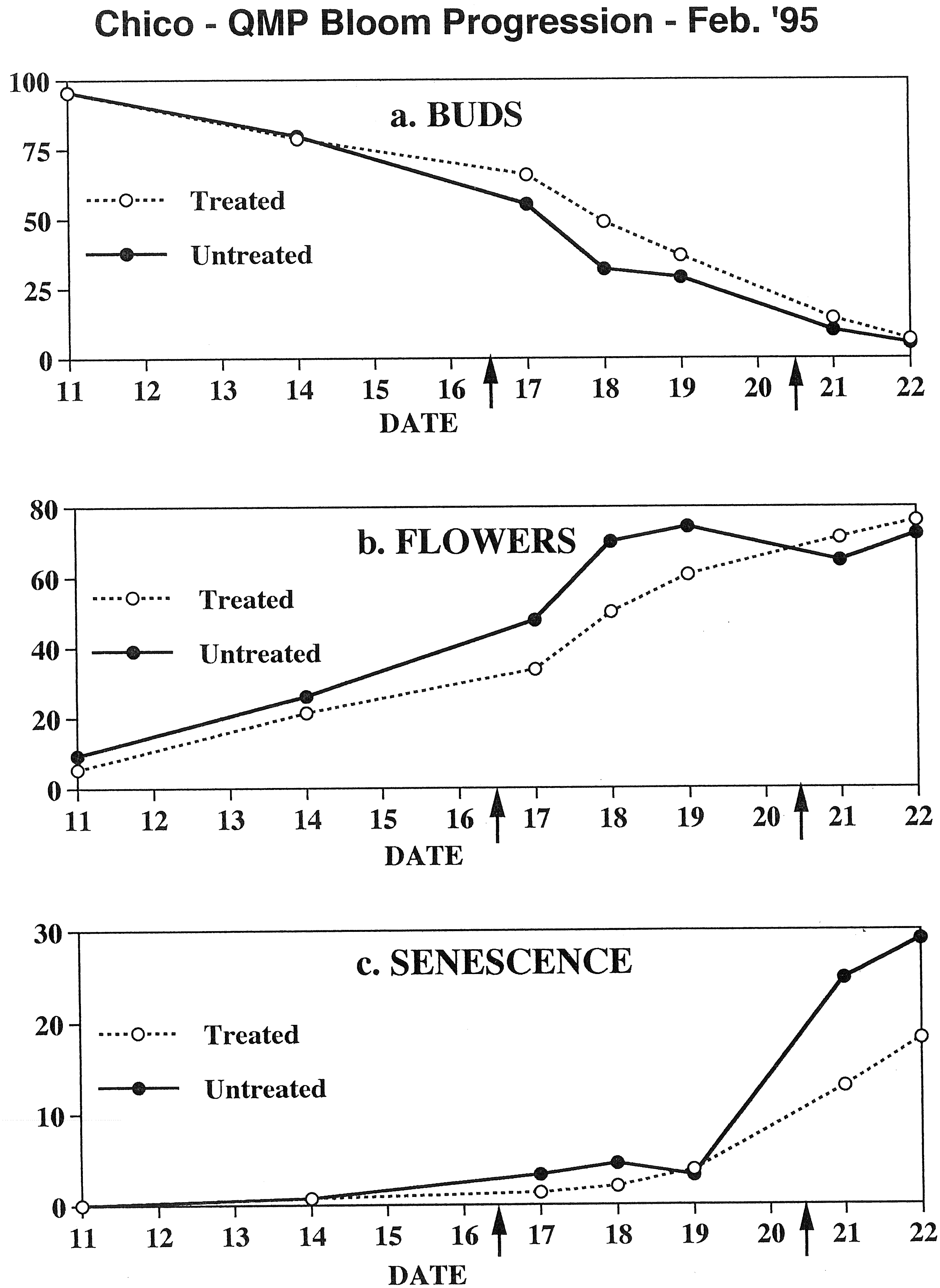

Fig. 7. Bloom progression in Nonpareil test trees in treated and untreated plots for Queen Mandibular Pheromone trial near Chico, CA for 1995: a) Buds; b) Flowers; c) Senescence (old flowers).

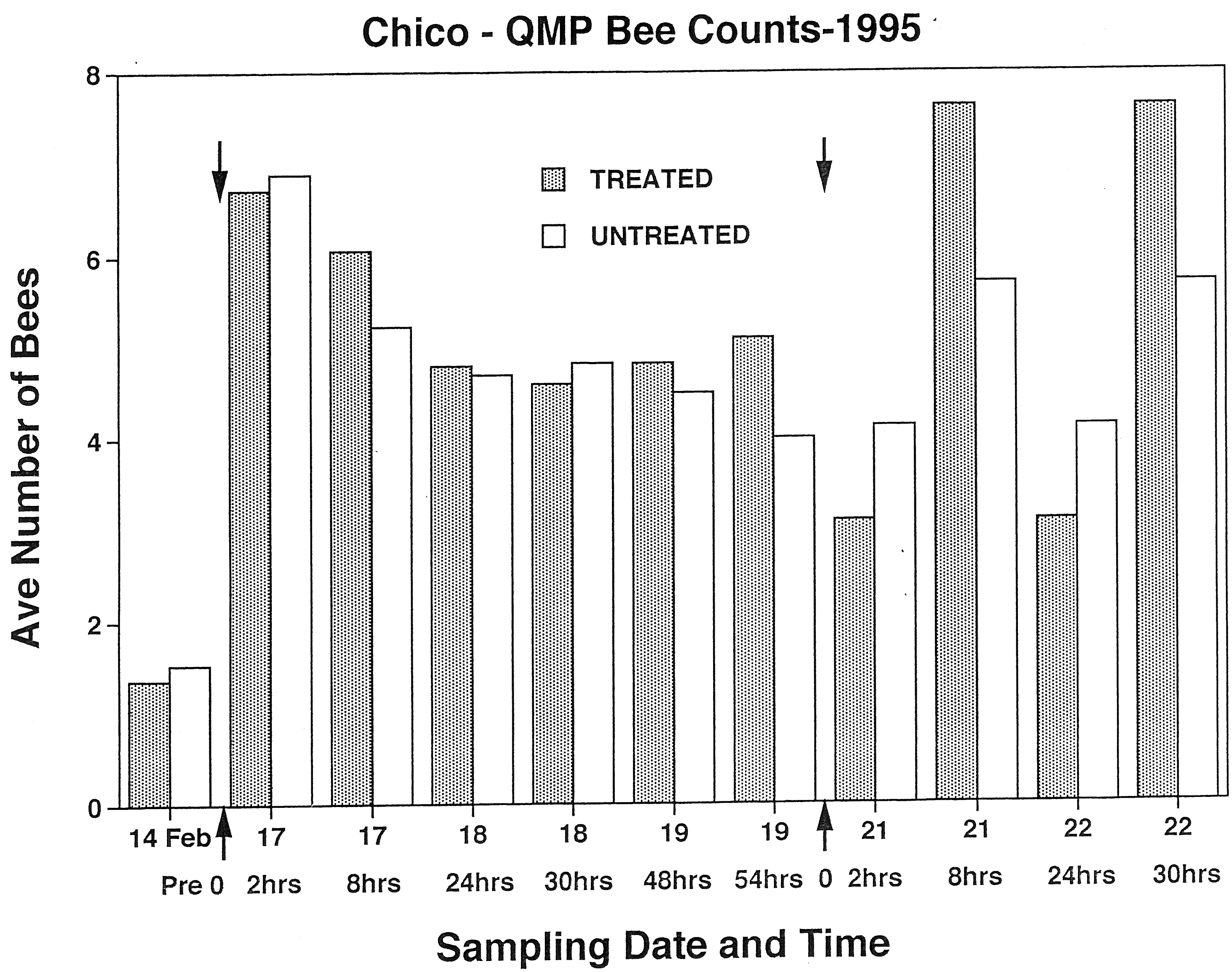

Fig. 8. Honey bee visitation to Nonpareil trees treated or untreated with Queen Mandibular Pheromone near Chico, CA. Treatments applied in early morning on 17 and 21 February 1995 (see arrows).

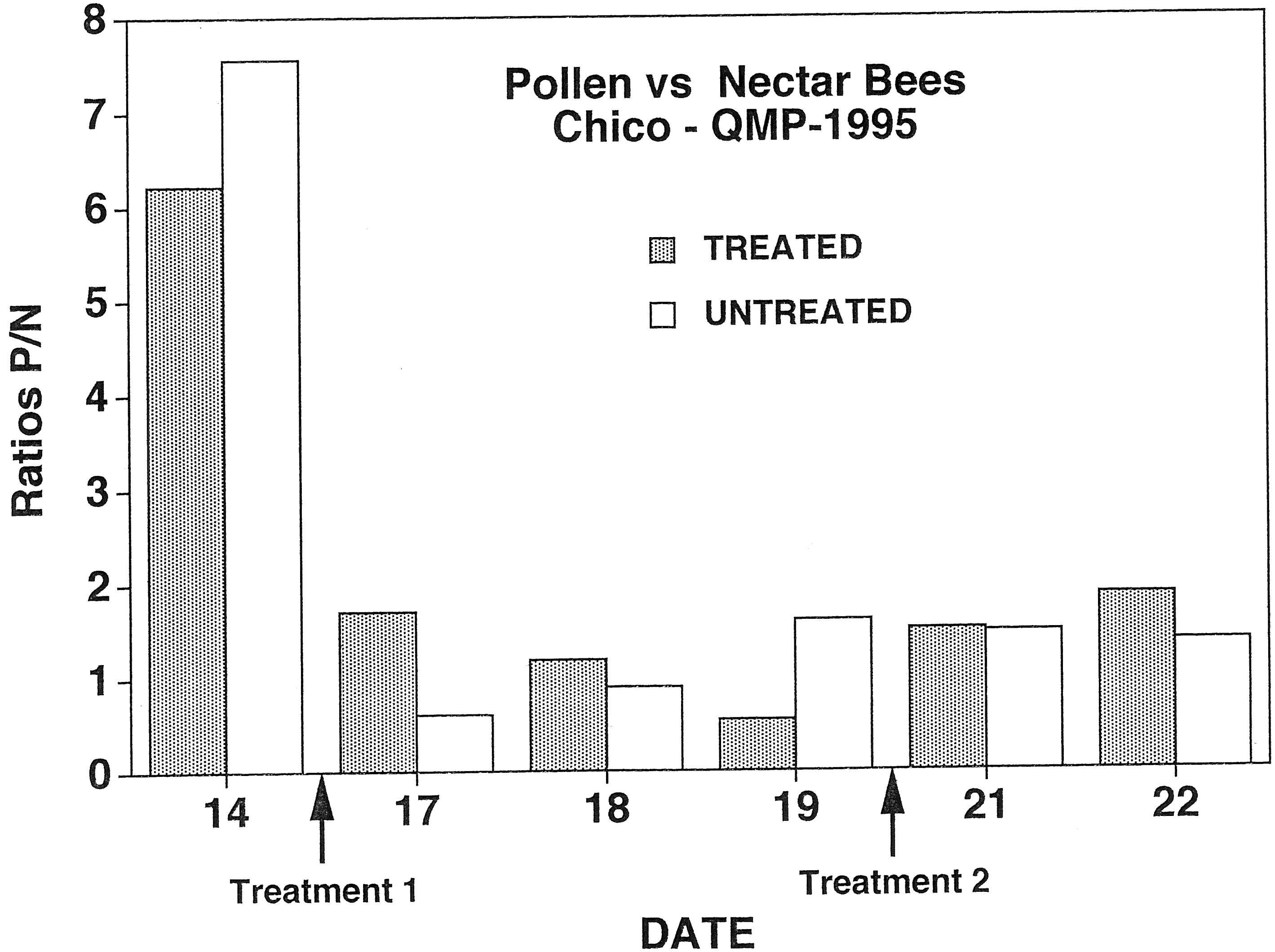

Fig. 9. Ratios of pollen to nectar foraging honey bees in relation to almond trees treated or untreated with Queen Mandibular Pheromone near Chico, CA. Treatments applied in early morning on 17 and 21 February 1995 (see arrows).

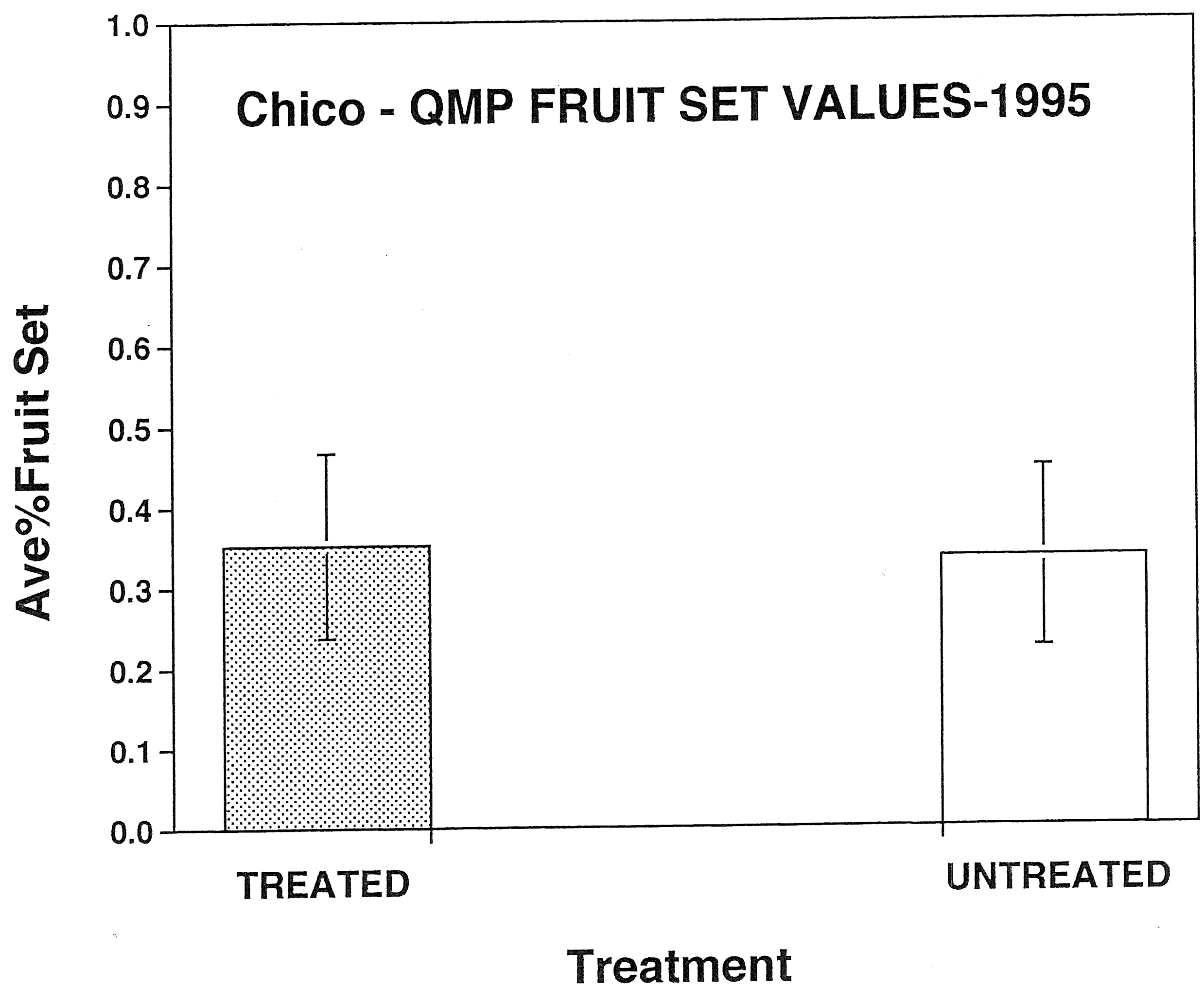

Fig. 10. Average percent fruit set on Nonpareil trees treated or untreated with Queen Mandibular Pheromone near Chico, CA.

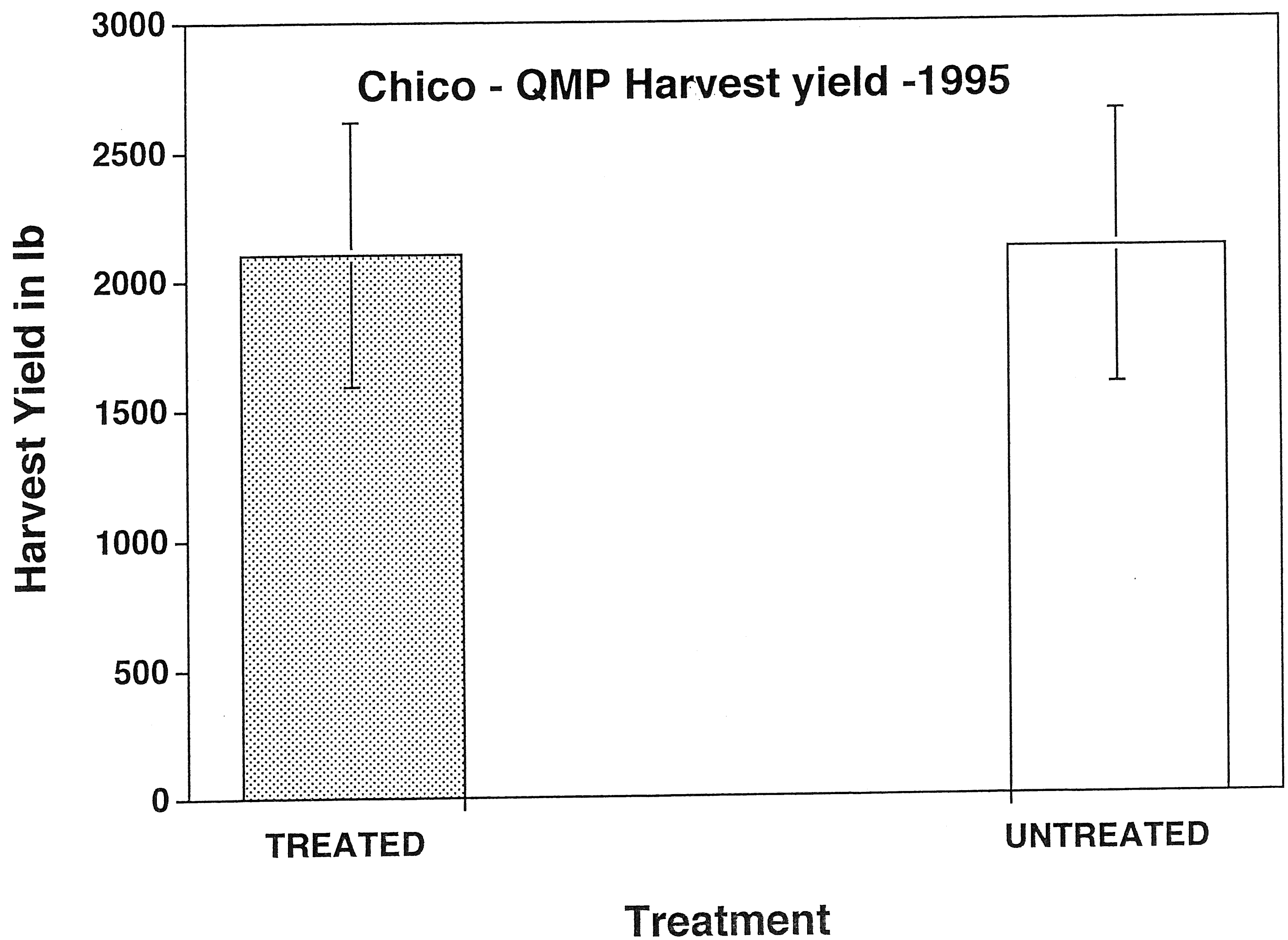

Fig. 11. Average harvest yields of Nonpareil test rows treated or untreated with Queen Mandibular Pheromone near Chico, CA.

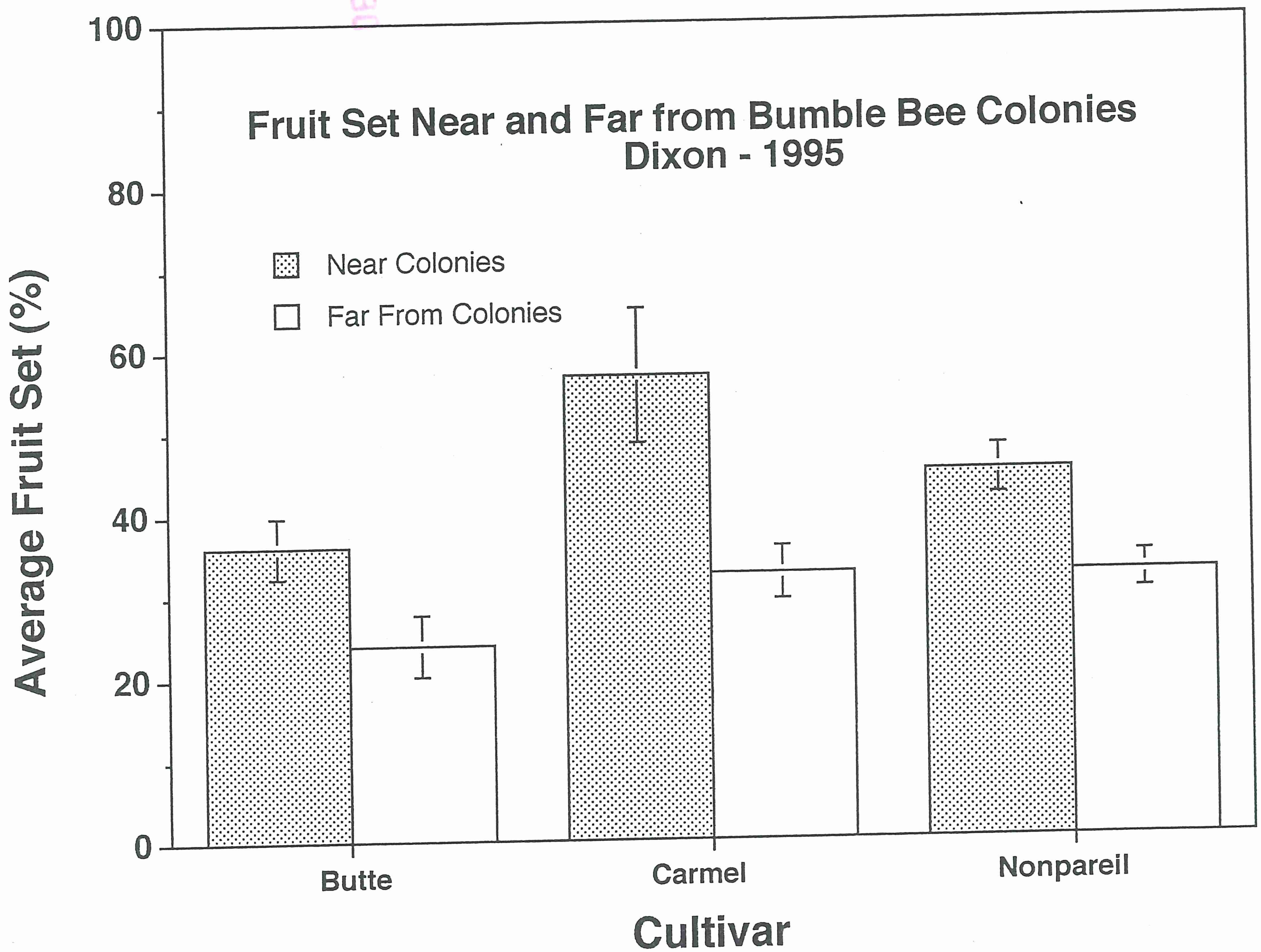

Fig. 12. Comparisons of fruit set in three cultivars near two double quads (16 hives) of the western bumble bee, Bombus occidentalis, and about 20 rows away from the hives in an almond orchard near Dixon, CA.

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DAVIS, CALIFORNIA 95616-8584

27 December 1995

Rick Sousa
Field Representative
Almond Board of California
1104 12th Street
Modesto, CA 95354

Dear Rick:

Enclosed is a copy of my 1995 final report to the Almond Board of California for my Project No. 95-F20 on Pollination. I appreciate all the past suport of the Almond Board for pollination and bee research. Although I am retired, I am still interested in continuing my project and have submitted a proposal to Warren Micke for consideration by the laison committee and eventually by your Research Committee. I feel that there is still much that we need to be learn in the areas of bees and almond pollination. Even the problems presented by Varroa and the Africanized honey bee are not insurmountable. New methods for increasing the efficiency of honey bee pollination and the determination of the potential of non-honey bee species are important avenues to explore.

Sincerely,

Robbin W. Thorp
Professor Emeritus

Enclosure