1996 FINAL REPORT TO ALMOND BOARD OF CALIFORNIA

Project No. 96-F20 **Pollination**

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Objectives:

1. Develop information 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 1996 bloom season in the Sacramento Valley started in mid February and progressed steadily until mid March. Fog and intermitent rain in mid February, more rain at end of month at and near peak bloom of 4 cultivars at Dixon. Warmest weather was at peak of Mission bloom at Dixon followed by more rain and cool weather just after peak. Bloom progression- Bloom of the five cultivars in our test orchard near Dixon started by mid February and progressed steadily into mid March. Mission did not have significant bloom until the beginning of March when the other four cultivars were already in decline. 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 1996 was greater than in 1995, but somewhat less than in 1994. NePlus, Nonpareil, and Price exhibited strong alternate bearing over a seven 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. The latter two peaked slightly earlier during cooler rainy days. Mission peaked during the warmest days and had the highest set. Orchard mason bees- Adequate populations were trapped in 1995 for release in almond near Dixon on 24 February 1996. New and old nests and active females were removed from the orchard on 17 March and transferred to the original trap site, NE of Madera. Bumble bees- Populations of *Bombus occidentalis* were observed in almond orchards near Dixon and near Ripon, CA. In a repeat of last years experiment, ten limbs, one per tree, in each of three cultivars, Butte, Nonpareil, and Carmel were flagged near and away from four quads (= 16 hives) in an orchard near Dixon. The hives were set at the opposite end of the orchard from last year, reversing near and away plots. Fruit set was significantly higher near the bumble bee hives only in Butte in 1996. In a larger scale non-replicated test near Ripon, an orchard with 2 rows Nonpareil with a row of Merced (interplanted with Carmel as older Merced trees died out) on each side was divided into thirds and supplied with three densities of bumble bees: 2, 4, and 6 hives per acre. Blossom units were counted on one limb each of 30 Nonpareil trees per plot in February to calculate fruit set from April fruit counts. Counts of bees in trees, including background honey bees from neighboring orchards were made during peak bloom. Harvest yields measured in bins filled per plot are adjusted by numbers and sizes of trees per plot. Initial fruit set counts and yield showed no increase with greater densities of bumble bee hives in the three treatment plots. This trial should be repeated with plots reversed to mitigate for potential orchard effects and to provide at least some replication through time.

Introduction

The 1996 bloom season in the Sacramento Valley started in mid February and progressed steadily until mid March. Fog and intermitent rain in mid February, more rain at end of month at and near peak bloom of 4 cultivars at Dixon. Warmest weather was at peak of Mission bloom at Dixon followed by more rain and cool weather just after peak.

Bloom Progression

Bloom of the five cultivars in our test orchard near Dixon started by mid February and progressed steadily into mid March. Mission did not have significant bloom until the beginning of March when the other four cultivars were already in decline.

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 with petals 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 1996 bloom season began early starting by mid February. It progressed steadily into mid March with good overlap in bloom among most of the cultivars except for the latest blooming cultivar, Mission (Fig. 1A-C). The bloom season for most of the cultivars was essentially completed by the first week of March. Mission, the latest blooming of the five cultivars, exhibited the shortest bloom and peaked when most of the other cultivars had declined. The relatively short period of bloom with fog and intermitent rain in mid February, more rain at end of month at and near peak bloom of the four early and mid blooming cultivars effectively narrowed the window of opportunity for bees to pollinate the crop. The warmest weather was at peak of Mission bloom followed by more rain and cool weather just after peak.

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 1996, the bloom progressed steadly and the early blooming cultivars overlapped well providing good opportunity for cross-pollination, with the exception of the latest cultivar, Mission (Fig. 1B). Fog and rain during bloom narrowed windows of opportunity for bee flight. This underscores and reinforces 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 our 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 1996 was greater than in 1995, but somewhat less than in 1994. NePlus, Nonpareil, and Price exhibited strong alternate bearing over a seven 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. The latter two peaked slightly earlier during cooler rainy days. Mission peaked during the warmest days and had the highest set.

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 to obtain bud production in terms of buds per meter.

About 100 buds were counted on one limb on each of 10 trees of the five cultivars and flagged early in the bloom season and these were used as a base for calculating percent fruit set. The trees were in the same rows as those used for our buds per meter data set. Fruits set were counted on 30 April 1996 about 7-8 weeks after bloom ended. Percent fruit set was calculated by dividing the number of large fruits produced and multiplying by 100.

Results: Bud production was generally greater in 1996 than in 1995 for most cultivars and nearly comparable to bud production in 1994 (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).

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 seven 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.

Orchard Mason Bees

Adequate populations were trapped in 1995 for release in almond near Dixon on 24 February 1996. New and old nests and active females were removed from the orchard on 17 March and transferred to the original trap site, NE of Madera for build up for next year.

Methods: Trap-nests containing*Osmia* trapped at a site about 20 miles ENE of Madera in spring 1995 were brought to UC Davis in early November 1995. They were x-rayed to determine the number of potentially viable brood cells and the presence of any parasites or nest destroyers and then placed in a cold room (at about 40°F = 5°C) for the winter. The trap-nests were brought out of cold storage incubated in the laboratory and released in an almond orchard near Dixon on 24 February 1996 for use in almond pollination. Sticks and straws with brood cells and active bees were removed from from the almond orchard and returned to the source site in Madera County on 17 March 1996 to augment the local population and to enhance trap-nesting collections in spring 1996.

Results: Little renesting occurred in the almond orchard in spring 1996, due to late incubation and release. Good build up occurred in the *Osmia* nesting population after they were moved to the source site in Madera County where they continued nesting and were augmented by the local population. The nest season at the source site started slowly in spring 1996 with peak nest fill occurring in late April to mid May. This was virtually the same chronology as observed in 1995. Above normal rainfall occurred at both Davis and the Madera County site in December 1995 and February 1996. More than twice the number of nests and brood cells were produced at the Madera County site in spring 1996 as in spring 1995 (ca 149 nests and 929 brood cells in 1995; and 342 nests and 2,210 brood cells in 1996). These are maximum estimates and do not account for mortality factors which are known to be present such as: predators and nest depredators which include the beetles:*Tribolium*, *Trogoderma*, and *Ptinus*; and parasitoids which include the wasps:*Sapyga*, and *Monodontomerus*; and disease which includes the "chalkbrood" fungus, *Ascosphaera*.

Discussion: The above normal rainfall in February 1996 and above average temperatures from January through June 1996 did not stimulate *Osmia* to nest earlier in the season. However, *Osmia* did continue to exhibit a steady increase in population at the trap site in Madera County, more than doubling their numbers over those trapped in 1995 and with nearly 8 times as many nests and over 12 times as many brood cells as were trapped in the dry spring of 1994. Closer attention needs to be given to the build up and effects of mortality factors on the dynamics of the bee population in future examinations of *Osmia* trapped at source sites. Sufficient numbers of *Osmia lignaria propinqua* were trapped in spring 1996 for use for small scale tests in almond in spring 1997 conditional on adequate overwinter survival and spring emergence.

Bumble Bees

Populations of *Bombus occidentalis* were observed in almond orchards near Dixon and near Ripon, CA. In a repeat of last years experiment, ten limbs, one per tree, in each of three cultivars, Butte, Nonpareil, and Carmel were flagged near and away from four quads (= 16 hives) in an orchard near Dixon. The hives were set at the opposite end of the orchard from last year, reversing near and away plots. Fruit set was significantly higher near the bumble bee hives only in Butte in 1996. In a larger scale non-replicated test near Ripon, an orchard with 2 rows Nonpareil with a row of Merced (interplanted with Carmel as older Merced trees died out) on each side was divided into thirds and supplied with three densities of bumble bees: 2, 4, and 6 hives per acre. Blossom units were counted on one limb each of 30 Nonpareil trees per plot in February to calculate fruit set from April fruit counts. Counts of bees in trees, including background honey bees from neighboring orchards were made during peak bloom. Harvest yields measured in bins filled per plot are adjusted by numbers and sizes of trees per plot. Initial fruit set counts and yield showed no increase with greater densities of bumble bee hives in the three treatment plots.

Methods: As in 1995, bumble bee hives were bound together in groups of four (quads) between plyboards and mounted on 4x4 posts within tree rows. Posts in the orchard near Dixon contained two quads or 8 hives each. Entrances of the hives in each quad faced inward to prevent reduction of activity noted in previous years when some entrances faced prevailing winds. Alleyways for bee movement to the outside were provided by spaces between the hives, but this made it more difficult to evaluate bee activity at individual hive entrances.

At the orchard near Dixon, 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). 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. Numbers of honey bees and bumble bees foraging per tree per minute were counted several times during the bloom season in our flagged trees.

A larger scale non-replicated test was conducted near Ripon, CA. An orchard with 2 rows Nonpareil with a row of Merced (interplanted with Carmel as older Merced trees died out) on each side was divided into thirds and supplied with three densities of bumble bees: 2, 4, and 6 hives per acre. Blossom units were counted on one limb each of 30 Nonpareil trees per plot in February to calculate fruit set from April fruit counts. No honey bee colonies were placed in the test orchard. However, since there were honey bee colonies in adjacent orchards, counts of bees in trees, were made during peak bloom to assess the background populations of honey bee foragers from neighboring orchards in addition to bumble bee foragers. Counts were made in trees in the middle of each plot and a comparison was made of bee activity in the middle versus the west end of each plot for Nonpareil and Carmel. Harvest yields of Nonpareil only were measured by counting bins filled per plot and adjusting these data by numbers and sizes of trees per plot. Historical yields for Nonpareil were obtained from the ranch near Ripon to determine how production fared with only bumble bee colonies being placed in the orchard (plus any honey bees that may forage from hives placed in adjacent orchards versus previous years when colonies of honey bees were rented to pollinate the orchard.

Results: In counts of bees foraging in flagged trees of the three cultivars in our test orchard near Dixon, CA, honey bee activity was significantly lower in trees near the bumble bee colonies in Nonpareil and Butte rows, but not in Carmel rows. Bumble bees were more abundant in trees near the quads than in those 20 rows away (Fig. 6). It was difficult to find bumble bees foraging in almond trees, even though we know they were there due to the fact that almond pollen was being brought in to quads throughout the bloom season. Due to the low numbers of bumble bees seen, our data are graphed on a log scale.

In 1995, in our test orchard near Dixon, CA, we had found that all three cultivars had higher fruit set near the bumble bee quads. In 1996, only Butte exhibited significantly higher nut set near the bumble bee hives in comparison to trees 20 rows away from the hives (Fig. 7).

In the orchard near Ripon, background honey bee counts in the middle of the orchard were inversely related to densities of bumble bee hives, ie., they were consistently highest in the low density plot and lowest in the high density plot for all three cultivars (Fig. 8). These data were not significant for counts made in Nonpareil trees, but were in counts made in Merced and Carmel trees. No significant differences were found in background numbers of honey bees foraging in the center versus west end of plots (Fig. 9) in Nonpareil or Carmel trees. In Nonpareil trees, initial fruit set counts and harvest yield data showed no increase with greater densities of bumble bee hives in the three treatment plots (Figs. 10 A & B). Too few bumble bees were counted in Nonpareil and Merced to test for significant differences. Sufficient numbers of bumble bees were counted in Carmel trees late in the season, but no significant differences in numbers of foragers per tree were found in the three plots of different hive densities.

Annual yields of Nonpareil in meat pounds for the test orchard near Ripon were:

1993: 49,434 with honey bees
1994: 55,125 with honey bees
1995: 38,748 with honey bees
1996: 43,981 with bumble bees (+ honey bees foraging from hives in adjacent orchards).

Discussion: The arrangement of hives with interior facing entrances made it very difficult to monitor activity of bees at the quads. The short season and marginal flight weather further impeded observations of bumble bees at their colonies.

In the orchard near Dixon, 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 a most exciting finding in 1995. However, the results were based on a single trial without replication. Therefore, in 1996, we repeated the test in the same orchard, but with the near and away rows reversed in relation to the position of the bumble bee quads, ie., the quads were placed in the tree rows considered as the "Away" plots in 1995. Although bee counts showed higher bumble activity in the rows nearest the quads (Fig. 6), the fruit set data did not reflect this difference as strongly as in 1995. Only one of the cultivars, Butte, had significantly higher fruit set near to versus away from bumble bee colonies in 1996. The fact that honey bee activity was significantly lower in the near trees suggests that this increase may be attributed to pollination by bumble bees.

In the orchard near Ripon, the lack of increases in fruit set and yield relative to greater densities of bumble bee hives may be due to the background populations of honey bees or it may be an orchard effect. Honey bee foraging activities were inversely related to densities of bumble bee hives (Fig. 8). The slight differences in fruit set and yield show a direct correlation with differences in honey bee foraging (cf. Figs. 10A & B with Fig. 8). This pattern also shows a north-south increase in yield and fruit set which may suggest some orchard effect. It is recommended that a similar test be conducted in the future with the bumble bee colony densities reversed as was done near Dixon to mitigate for potential orchard effects and to provide some replication through time.

Fluctuations in historic yields may be due to many factors in addition to pollination and may be interpreted in many ways. However, it seems appropriate to suggest that the yield in 1996 with bumble bees colonies as only pollination units placed in the orchard, supplemented by honey bees that entered presumably from colonies placed in adjacent orchards were sufficient to produce a crop which fell well within the range of variation of production of prior years when honey bees alone were used.

Publications

Thorp, R. W. 1996. Bee management for pollination. pp. 132-138, 143. *In*: Micke, W. C., ed. Almond Production Manual. University of Califoria, Division of Agriculture and Natural Resources, Publication 3364. 289 pp.

DeGrandi-Hoffman, G. R., R. W. Thorp, G. Loper, and D. Eisikowitch. 1996. Describing the progression of almond bloom using accumulated heat units. Journal of Applied Ecology 33(4):812-818.

Figure Captions:

Fig. 1A. Bloom progression for five cultivars in an orchard near Dixon, CA for February and March 1996. Buds.

Fig. 1B. Bloom progression for five cultivars in an orchard near Dixon, CA for February and March 1996. Flowers.

Fig. 1C. Bloom progression for five cultivars in an orchard near Dixon, CA for February and March 1996. Senescent Flowers.

Fig. 2. Buds per meter produced by five cultivars in an orchard near Dixon, CA measured over six years: 1990 through 1996.

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 1996 (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 1996.

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. Bumble bee and honey bee foraging activity in trees of three cultivars near to and about 20 rows away from four quads (16 colonies) of *Bombus occidentalis* in an almond orchard near Dixon, CA. Log decimal scale.

Fig. 7. Comparisons of fruit set in three cultivars near four quads (16 colonies) of the western bumble bee, *Bombus occidentalis*, and about 20 rows away from the quads in an almond orchard near Dixon, CA. Near and away plots reversed from 1995 trial.

Fig. 8. Background numbers of foraging honey bees in the middle of each plot in an almond orchard supplied with bumble bee densities of 2, 4, or 6 hives per acre near Ripon in 1996.

Fig. 9. Background numbers of foraging honey bees in the middle versus west end of each plot in an almond orchard supplied with bumble bee densities of 2, 4, or 6 hives per acre near Ripon in 1996. Blank bars = Middle of orchard; Hatched bars = West end of orchard.

Fig. 10. Fruit set (A) and Yield (B) in plots with bumble bee densities of 2, 4, or 6 hives per acre near Ripon in 1996.

1996 BLOOM PROGRESSION (at Dixon, CA)

BUDS

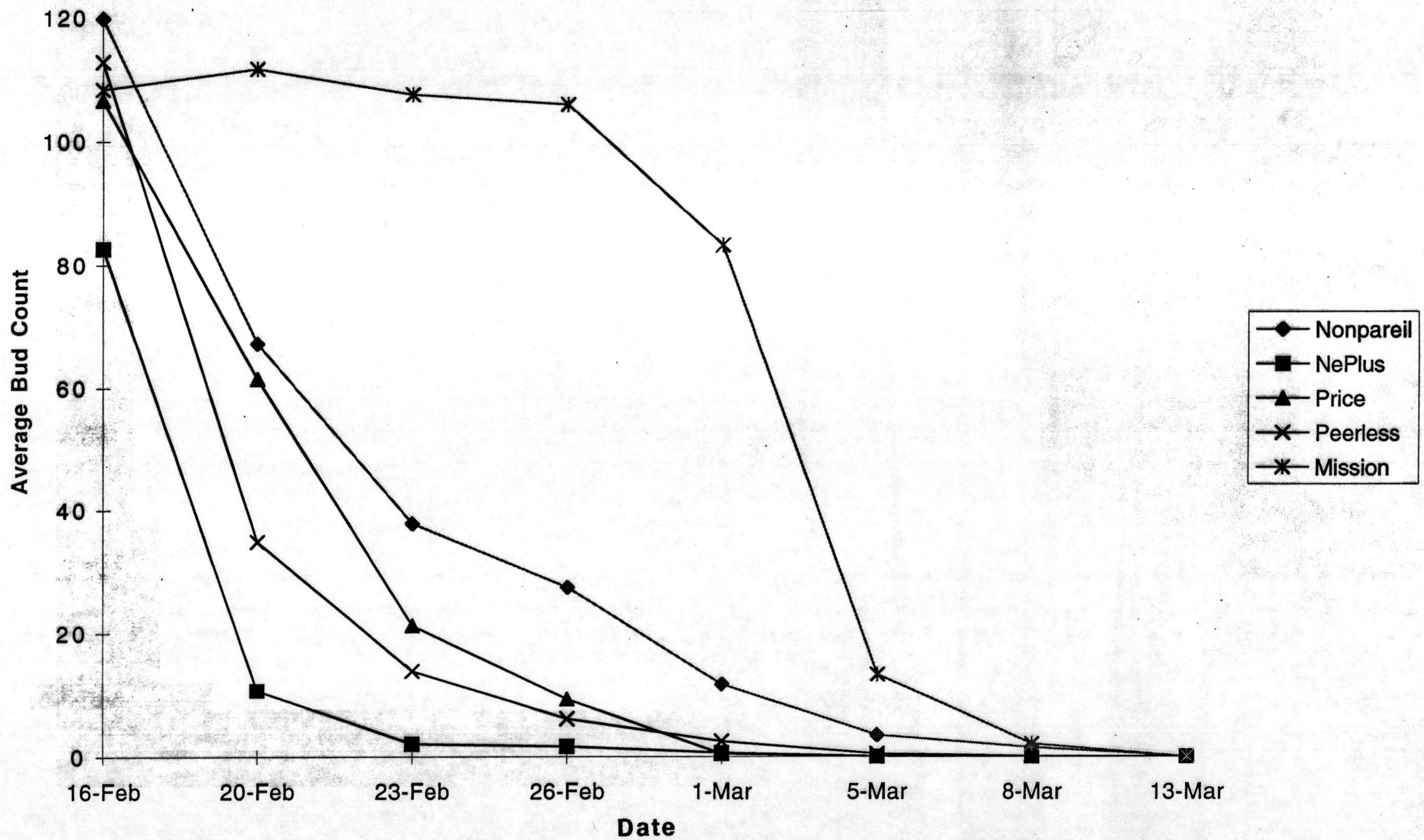

Fig. 1A. Bloom progression for five cultivars in an orchard near Dixon, CA for February and March 1996. Buds.

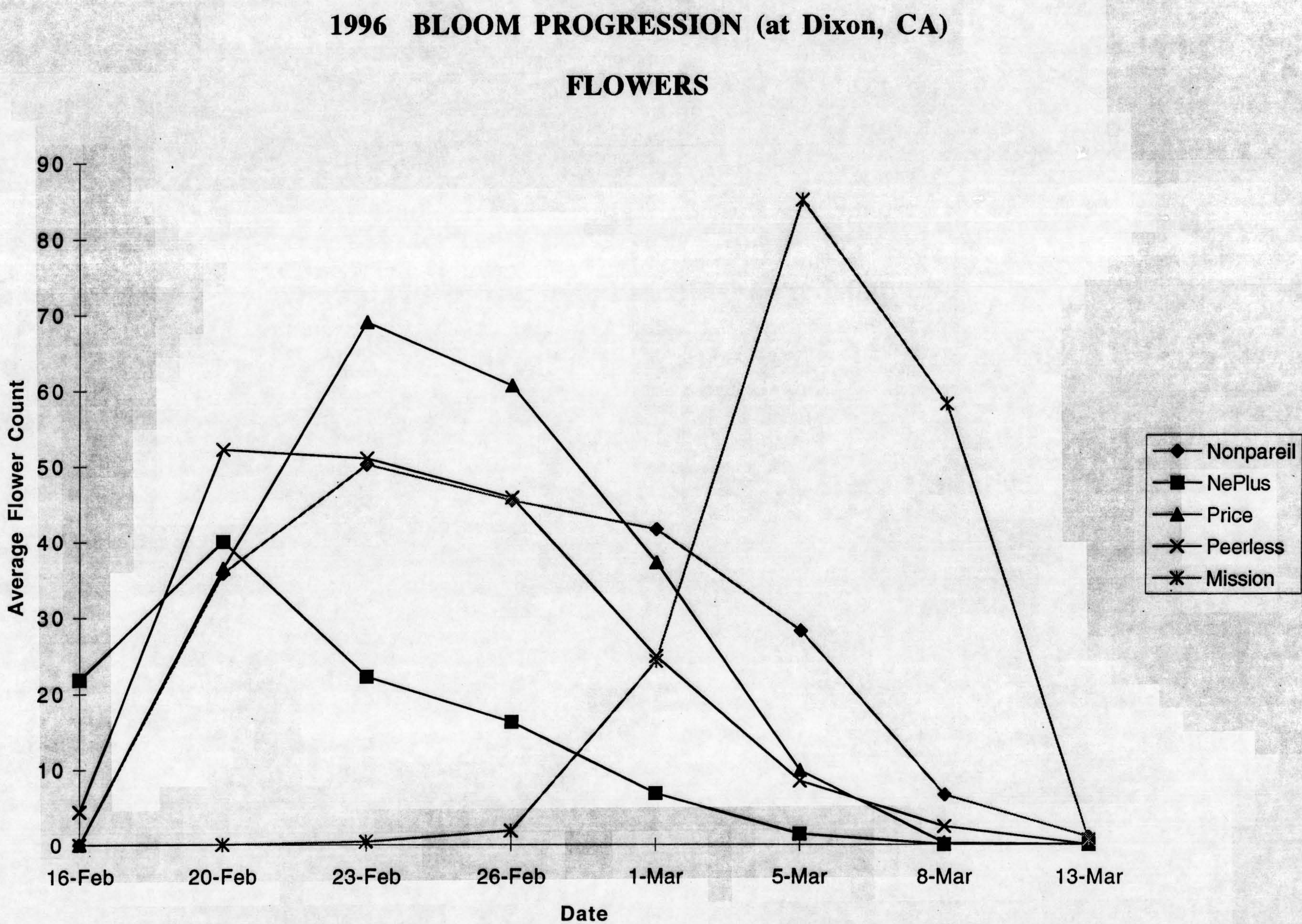

Fig. 1B. Bloom progression for five cultivars in an orchard near Dixon, CA for February and March 1996. Flowers.

1996 BLOOM PROGRESSION (at Dixon, CA)

SENESCENT FLOWERS

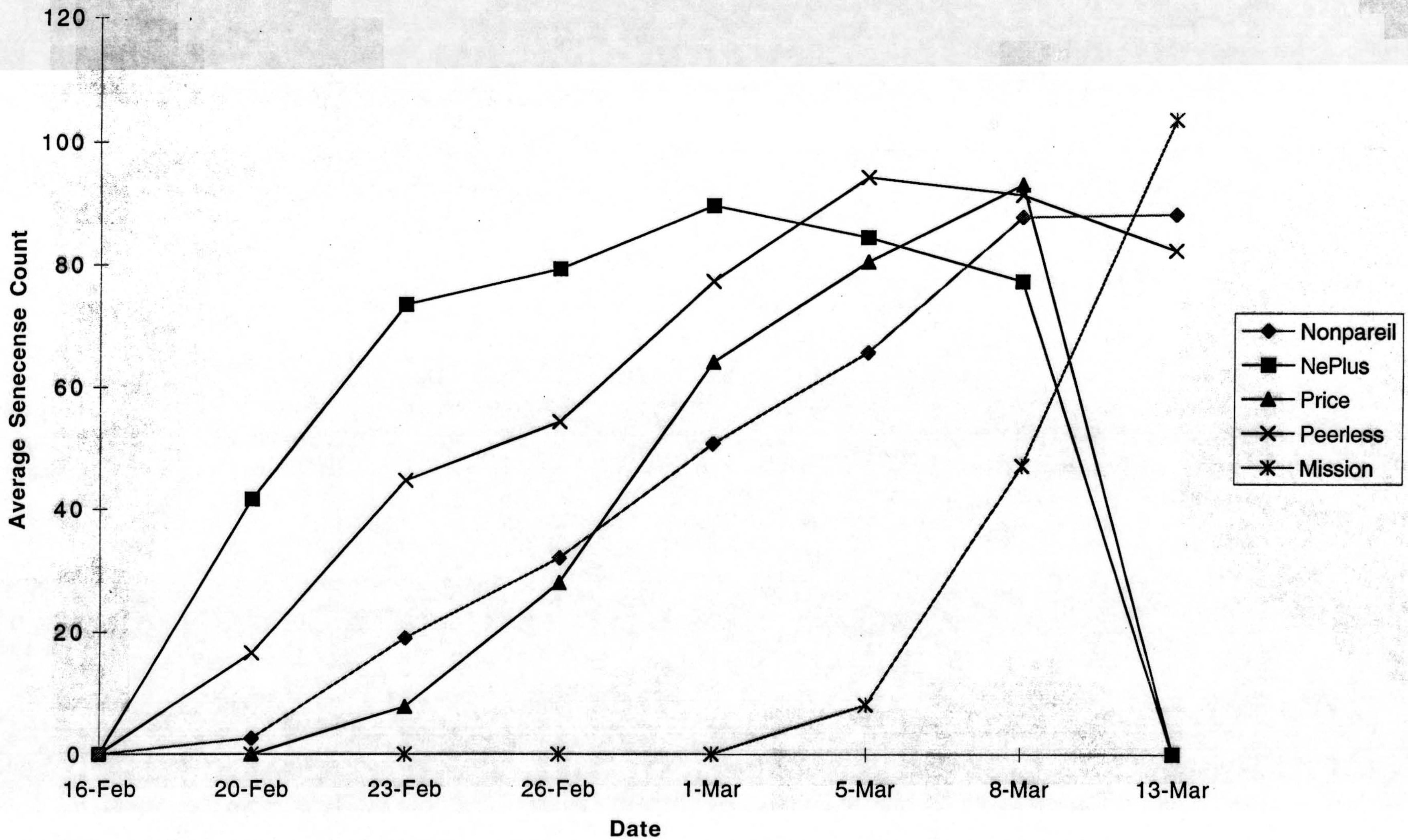

Fig. 1C. Bloom progression for five cultivars in an orchard near Dixon, CA for February and March 1996. Senescent Flowers.

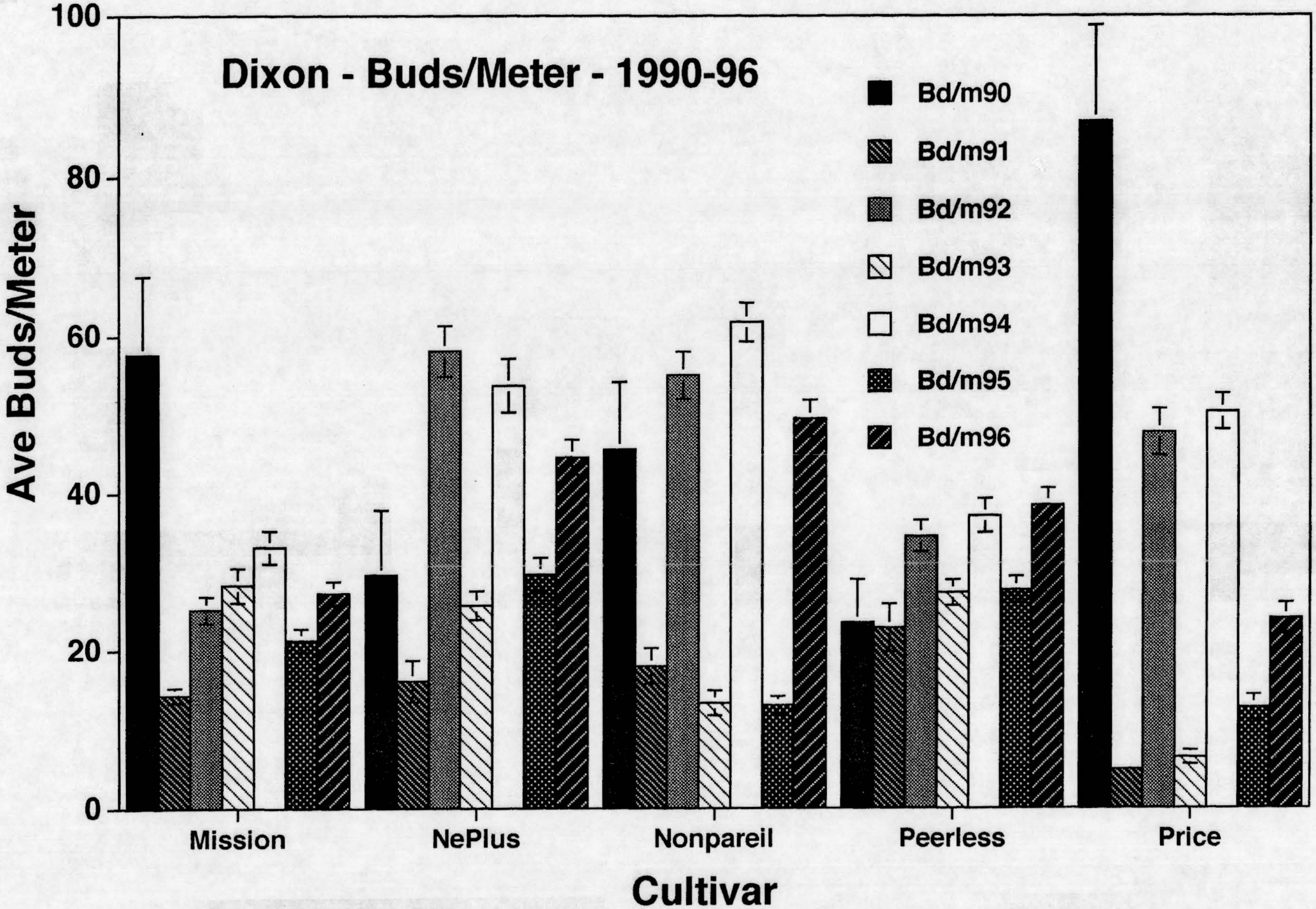

Fig. 2. Buds per meter produced by five cultivars in an orchard near Dixon, CA measured over six years: 1990 through 1996.

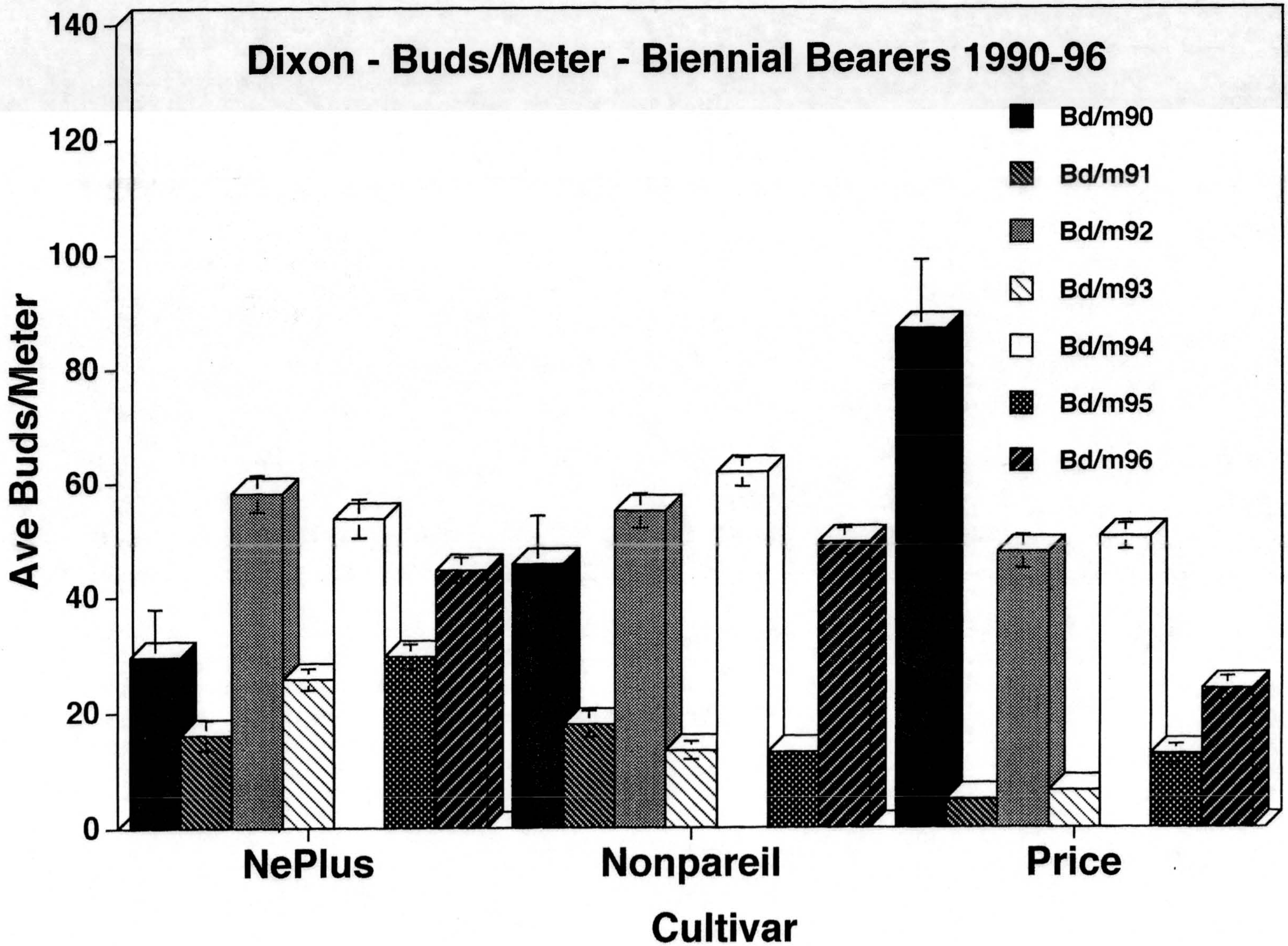

Fig. 3. Buds per meter produced by three of five cultivars showing the strongest biennial patterns in an orchard near Dixon, CA measured over six years: 1990 through 1996 (a subset of data shown in Fig. 2).

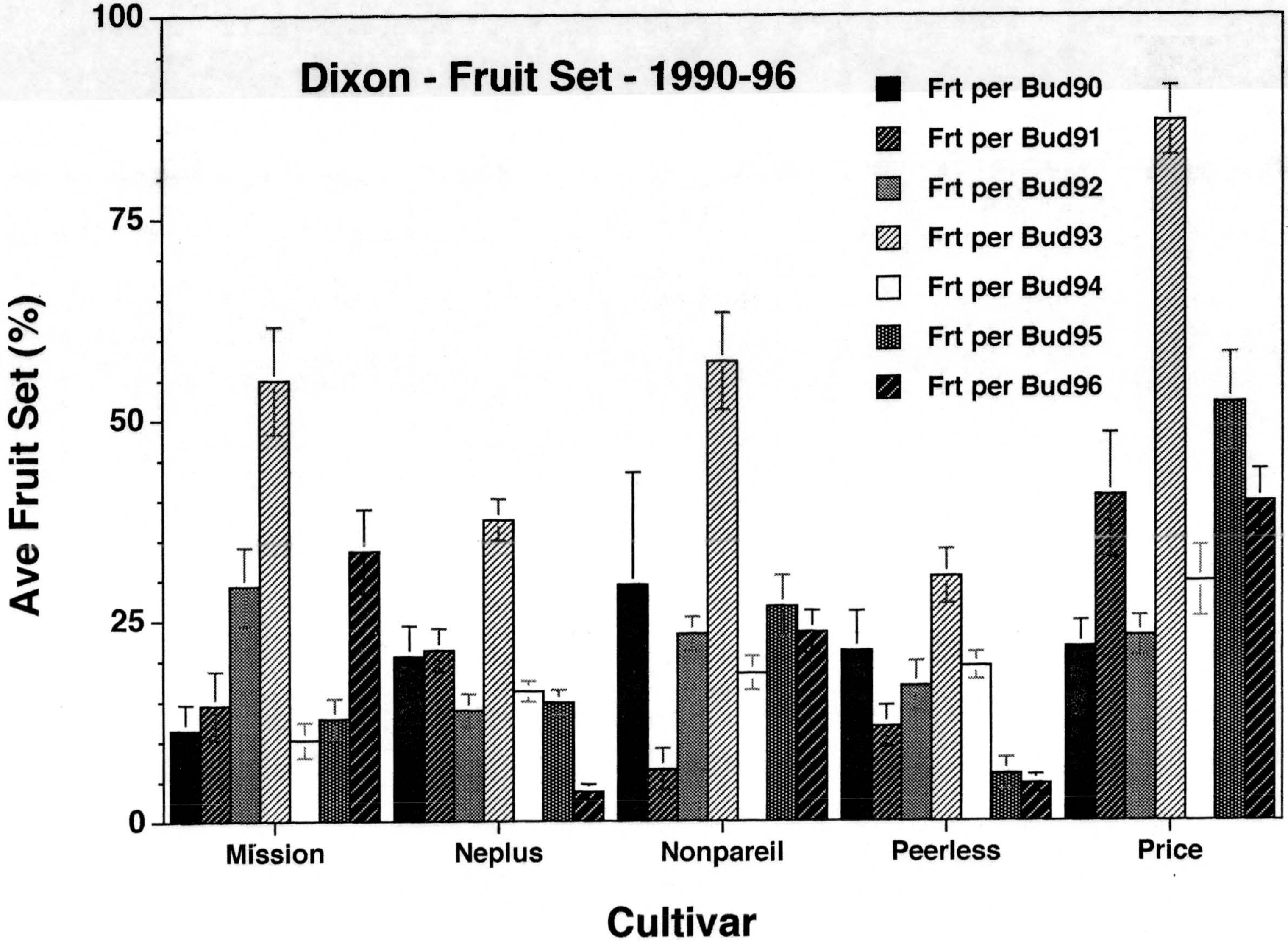

Fig. 4. Fruit set for five cultivars in an orchard near Dixon, CA measured over six years: 1990 through 1996.

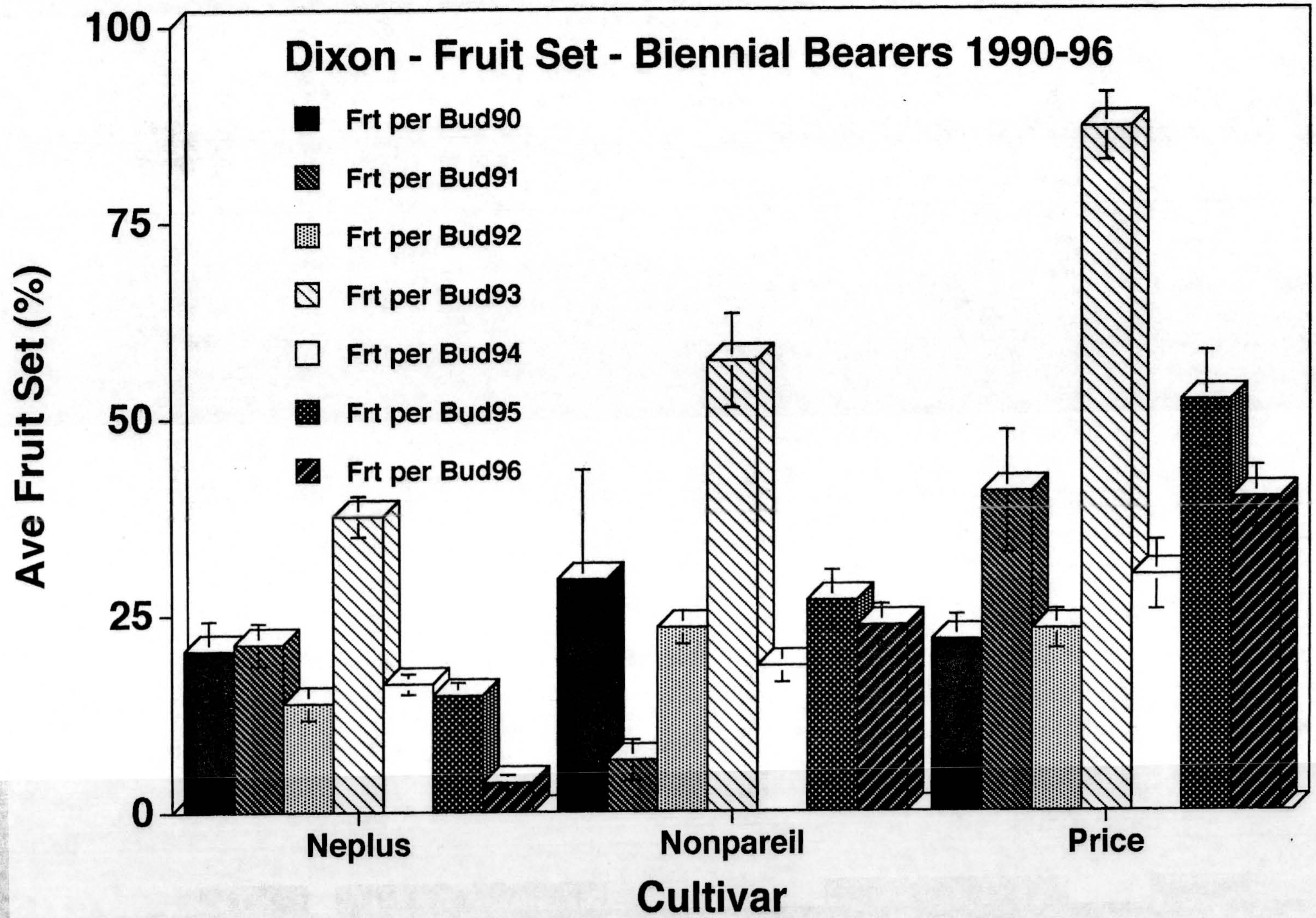

Fig. 5. Fruit set for three of five cultivars showing the strongest biennial patterns of bud production in an orchard near Dixon, CA measured over six years: 1990 through 1995 (a subset of data shown in Fig. 4).

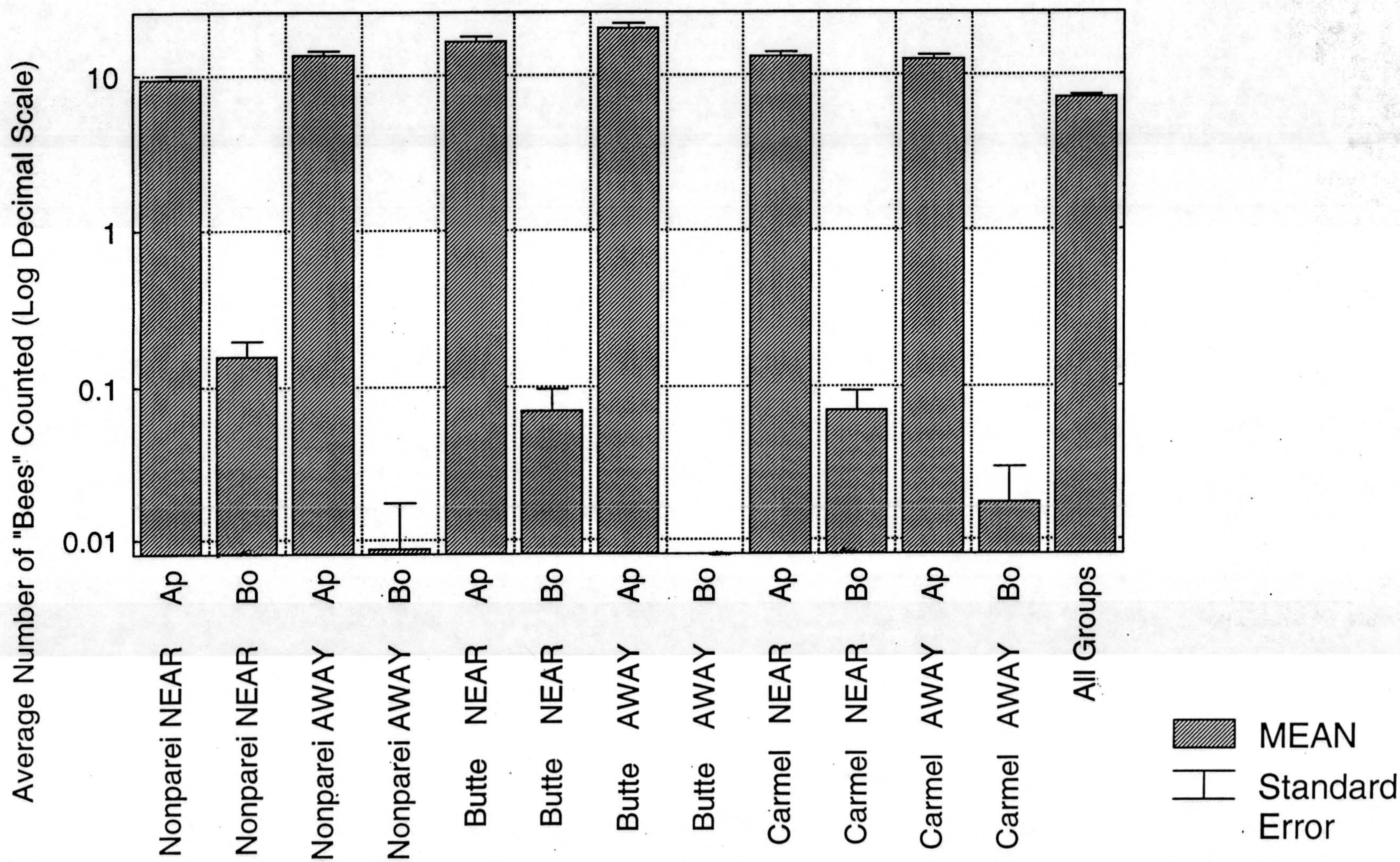

Fig. 6. Bumble bee and honey bee foraging activity in trees of three cultivars near to and about 20 rows away from four quads (16 colonies) of *Bombus occidentalis* in an almond orchard near Dixon, CA. Log decimal scale.

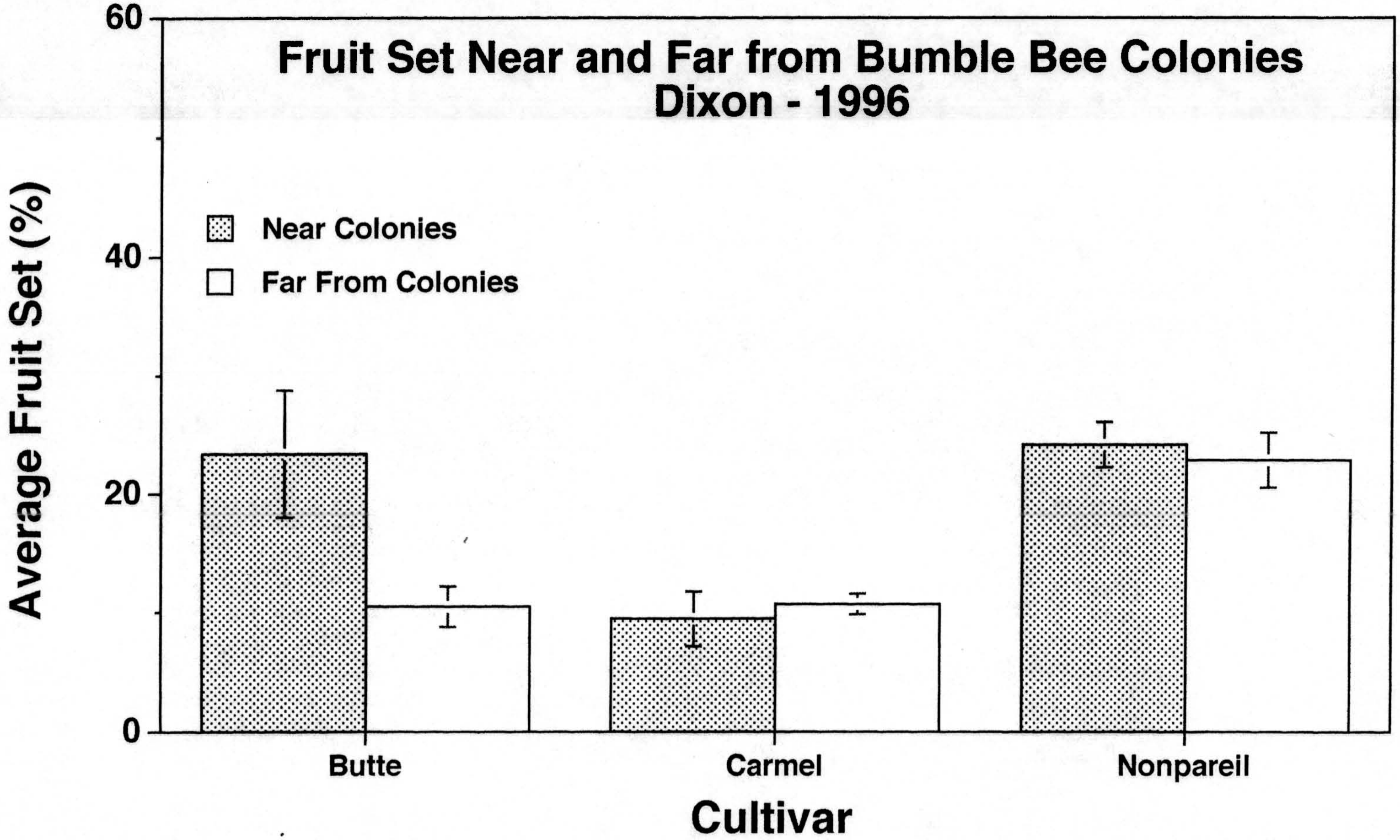

Fig. 7. Comparisons of fruit set in three cultivars near four quads (16 colonies) of the western bumble bee, *Bombus occidentalis*, and about 20 rows away from the quads in an almond orchard near Dixon, CA. Near and away plots reversed from 1995 trial.

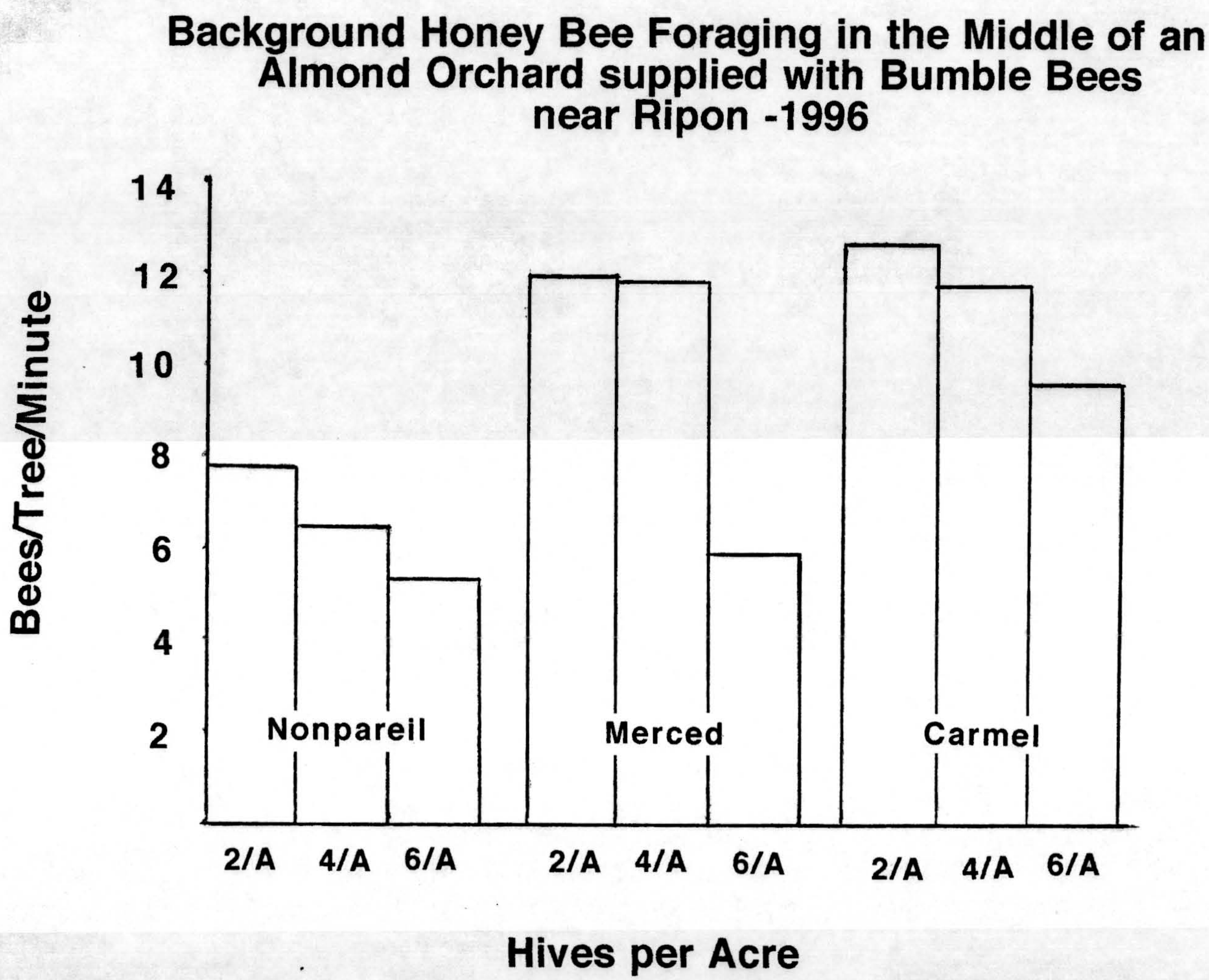

Fig. 8. Background numbers of foraging honey bees in the middle of each plot in an almond orchard supplied with bumble bee densities of 2, 4, or 6 hives per acre near Ripon in 1996.

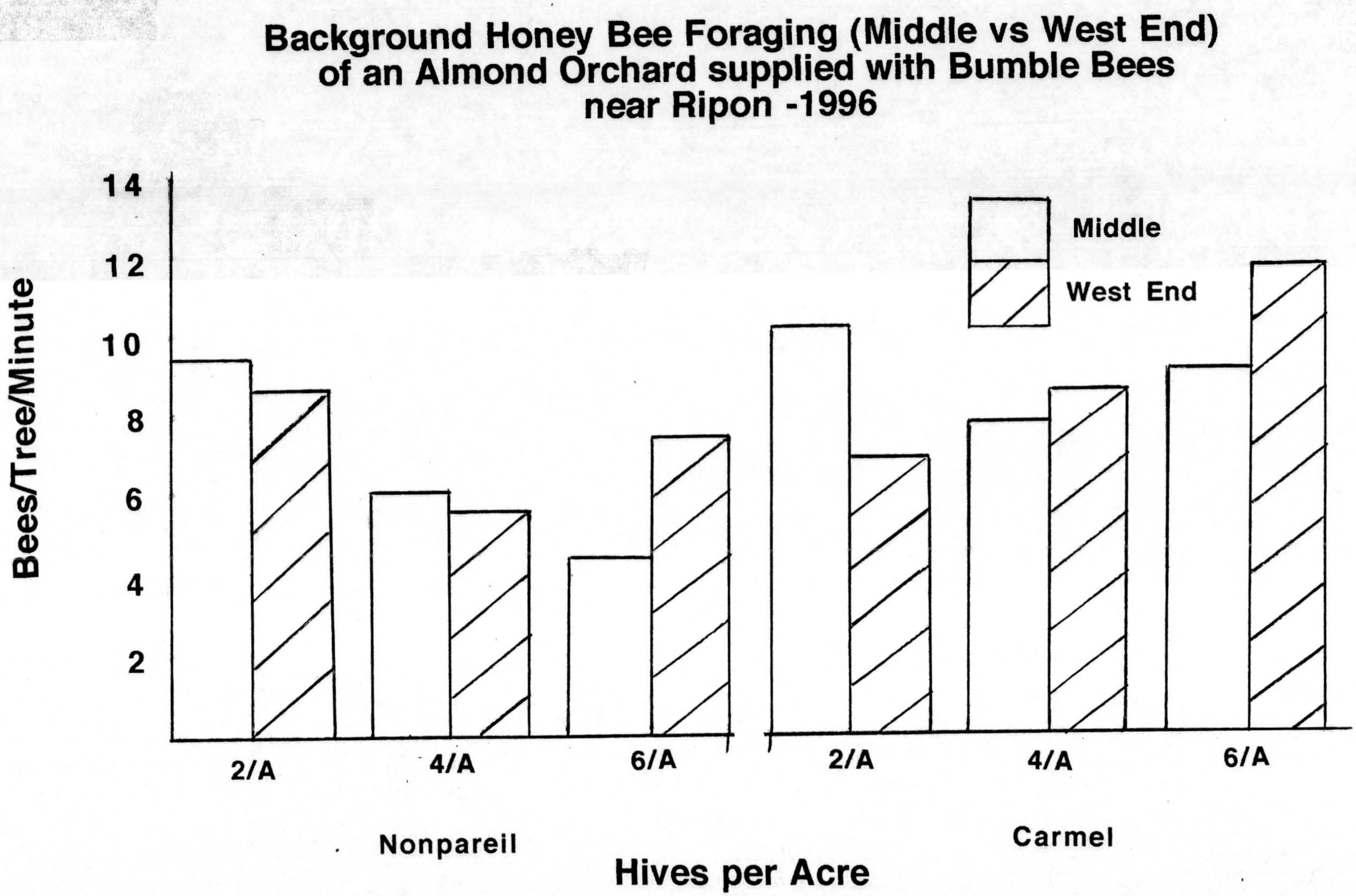

Fig. 9. Background numbers of foraging honey bees in the middle versus west end of each plot in an almond orchard supplied with bumble bee densities of 2, 4, or 6 hives per acre near Ripon in 1996. Blank bars = Middle of orchard; Hatched bars = West end of orchard.

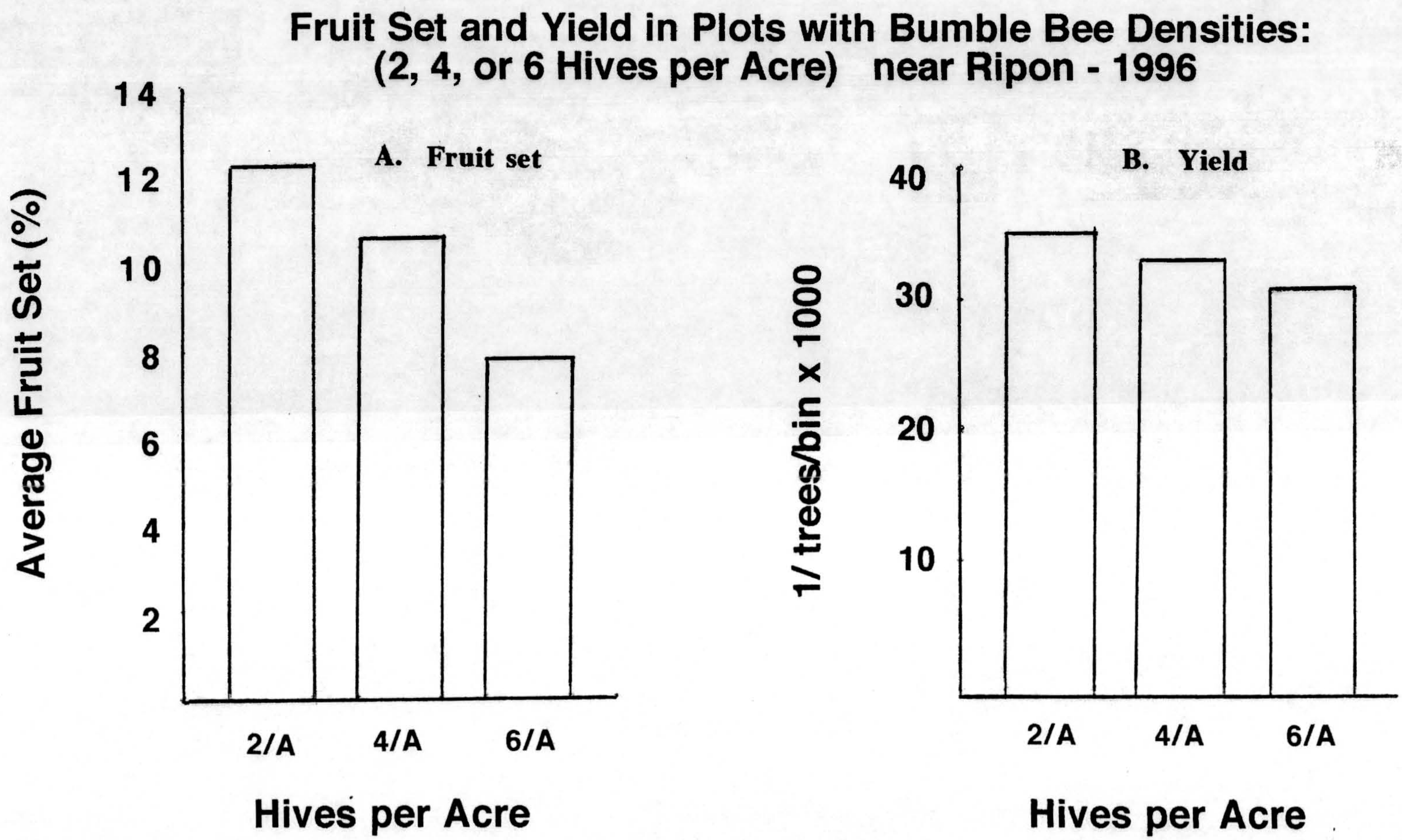

Fig. 10. Fruit set (A) and Yield (B) in plots with bumble bee densities of 2, 4, or 6 hives per acre near Ripon in 1996.