21 December 1990

1990 ANNUAL RESEARCH REPORT TO ALMOND BOARD OF CALIFORNIA

Project No. 90-F15 - Tree Research: Pollination

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Objectives: To develop information on pollination by bees which will result in increased production and greater grower returns.

Interpretive Summary

We conducted studies on seasonal patterns of honey bee colony strength, pollen foraging, and flight activity. We collected data on weather, bee activity in trees, floral phenology, and initial and final nut set to validate the ALMOPOL model.

Colony strength--Honey bee colonies lost strength in February due to cold weather and lack of almond bloom. Initial colony strength did not correlate well with flight activity due to differential colony growth. Flight activity was not significantly different between colonies starting with 4 and 6 frames of bees (NOF). Colonies with 8 NOF had significantly greater flight activity.

Seasonal pollen income--Almond pollen represented about 90% or more of the pollen income between 1 and 16 March.

Pollen foraging--Cumulative numbers of bees returning with pollen was not highly correlated with initial colony strength. The least variation occurred in the 6 NOF group.

Intertree flight--Only a small proportion of foragers on almonds move between trees. We found little difference in intertree flights between versus within cultivar rows, except in early and late bloom when difference in bloom availability was greatest. Canopies of trees of different cultivars were often closer than those in rows of the same cultivar in the hexagonal planting of our study orchard.

ALMOPOL model--ALMOPOL is a nut set prediction computer model designed for use in almond orchards. ALMOPOL will generate site specific nut set predictions based upon weather and orchard conditions in a given year and site. In 1990, data were collected to test the accuracy of ALMOPOL nut set predictions as well as predictions from individual components of the model. These include predictions on the progression of bloom as a function of bloom period, temperature, and honey bee foraging activity which is predicted as a function of temperature, wind velocity, solar radiation, and rainfall. Currently ALMOPOL is located on the mainframe VAX computer at the University of Arizona, and users can access it if they have a modum connected to their personal computer. Our goal in 1991 is to convert the mainframe ALMOPOL program into a software program for IBM compatible personal computers, and distribute the program to growers, extension agents, and to the Almond Board of California.

Introduction

Our studies in the 1990 bloom season were conducted in the same 30 acre orchard located near Davis, CA as our studies of the past several years. The orchard contained five cultivars: NePlus, Nonpareil, Peerless, Price and Mission. The average initial strength of 60 colonies based on cluster counts (NOF) was 5.16 $\pm$ 3.24 (S.D.). A rented weather station provided readings on temperature, solar radiation, relative humidity, wind speed, wind direction and precipitation from 1 February through 23 March 1990. The extremely cold weather through most of February delayed first bloom until the end of the month and set back colony populations from our initial measures. Rain occurred on two days in early March just after all the cultivars except Mission had initiated bloom. Weather improved steadily after 10 March. Bloom started and finished the latest in 1990 in comparison to 1987 through 1989.

Colony Strength

This year we initially surveyed colonies to estimate strength during almond bloom using our cluster method based on numbers of frames covered with bees (NOF) (Nasr et al. 1990). Flight activities, counts of bees returning to these hives with and without pollen were made on a total of 21 colonies, seven each in three strength groups (4, 6 and 8 NOF). These were added to our cumulative database on foraging activity in relation to colony strength and air temperature that may provided a simplified method allowing growers to assess colony strength without opening hives.

Methods: NOF measures were made on 60 colonies on 7, 8 and 10 February 1990. From these, 21 were selected on the basis of NOF counts on 10 February with 7 colonies in each of three strength groups (4, 6 and 8 NOF). Weekly cluster counts (NOF) were made on these colonies to determine the seasonal pattern of population change.

Results: Following the initial strength counts made on 8 February, all colonies lost population (Fig. 1). They quickly recovered and increased through the season leveling off or slightly decreasing after 16 March (Fig. 2A-C). Decrease at the last measure was most consistent in the 6 NOF initial strength group (cf. Figs. 1, 2B). Following initial strength counts, colony NOF variability increased within each strength group (Fig. 3A-C). Percent increase in strength was greatest for the 4 NOF colonies (Table 1).

Discussion: The decrease in colony populations in late February is probably attributable to the cold weather (Fig. 4A) and delayed bloom (Fig. 5A) following our initial colony strength evaluations. Shortly after the onset of bloom, about 26 February, colony populations increased rapidly (Figs. 1, 3). Weekly measures showed a dramatic increase in variability of colony populations within each group (Figs. 3A-C). This produced problems with other analyses attempting to correlate other measures to initial strength groups. As in previous years where we found highest correlations with end of season strength measures. Leveling off or decrease in populations after the 16 March colony strength estimates is presumably due to reduction in availability of food at the end of the bloom season (Fig. 5A, B). Although colonies in the 4 NOF category showed the greatest percent of increase as for previous years (Table 1), they also showed the greatest range of variation at the end of the season (Fig. 3). The higher percentage rate of increase is due to the fact that they started with smaller populations. The need is for more bees at the beginning of the bloom season in order to keep pace with the rapid increase in bloom as occurred in early March this year.

Seasonal Flight Activity

Flight activity based on numbers of bees returning to the hive during 30 second intervals at different times of day and partitioned into bees with versus without pollen loads were taken under varying weather conditions and related to weekly measures of colony strength. This year we also estimated colony strength at weekly intervals to see if we could determine why previous correlations of entrance flight with initial strength measures had been weaker than when compared with final strength assessments.

Methods: Incoming flight activities were monitored several times a day for 24 days during the almond bloom season. Bees returning during 30 second periods were recorded. Correlations with weekly strength groups were made.

Results: ANOVA analyses showed that flight activity was not significantly different between colonies starting with 4 and 6 frames of bees (NOF) nor between colony strength groups at different temperatures. However, colonies with 8 NOF produced significantly greater flight activity than did colonies of lower strength groups.

Discussion: Seasonal flight activity of returning foragers did not correlate well with initial colony strength groups due to variability in growth rates among colonies within each strength group.

Seasonal Pollen Income

This study was an attempt to determine the proportion of pollen being brought into hives that actually came from almond flowers throughout the bloom season.

Methods: Entrance type pollen traps were placed on 10 colonies and activated for single-day observation periods on seven days throughout the almond bloom period. Pollen pellets were sorted by color and classed as to whether they came from almond or not.

Results: On 26 February, when NePlus was in about 1.3% bloom and Nonpareil was less than 1 bloom, colonies averaged less than half of their pollen from almonds (Fig. 6). However, from 1 through 16 March, the peak of bloom for most of the cultivars in the orchard, colonies averaged 90% or more almond pollen. On 19 March while Mission was at peak, but the other cultivars were waning, colonies averaged only about 75% almond pollen.

Discussion: Almonds provide a strongly attractive pollen source due to availability and abundance during peak bloom of the major cultivars. Pollen foragers quickly switch to almond flowers as they become available and track the bloom through flowering of the latest cultivar.

Pollen Foraging and Colony Flight Profiles

The proportion of pollen foragers among all bees returning to the hive is important in determining the pollination efficiency of colonies in almond orchards.

Methods: Incoming flight activities were monitored several times a day for 24 days during the almond bloom season. Bees returning during 30 second periods were tallied according the presence or absence of pollen on their hind legs.

Results: Pollen foragers represent only a small portion of the bees returning to hives throughout the season (Fig. 5C). Peak of pollen foraging occurred on 5 March corresponding with the peak of NePlus bloom and increase in the mid-blooming cultivars (Fig. 5A) and with the peak of activity in NePlus trees (Fig. 5B). Total activity at hive entrances increased throughout the bloom season, tapering off about 17 March when bloom of the first four cultivars was on the wane. Cumulative profiles of returning pollen foragers relative to colony strength groups also illustrate the sharp upswing in pollen collection from 3 through 6 March (Fig. 7A-C). Colonies in the 4 NOF and especially 8 NOF strength groups exhibited the greatest variability in cumulative numbers pollen foragers, especially by the end of the season (Figs. 7A, C).

Discussion: Although almond pollen is highly attractive and readily collected by pollen foragers the proportion of pollen foragers in commercial colonies tends to be small. This is likely due to the long term selection beekeepers have been performing for high honey production. Genetic selections can alter ratios of pollen versus nectar (honey) hoarding (R. E. Page, personal communication). Evaluations of the pollination efficiency of high versus low pollen hoarding strains need to be conducted in almond orchards.

Bees in Trees Seasonal Patterns

Patterns of bee activity in trees were examined to determine correspondence with bloom curves and weather patterns.

Methods: Bees were counted during a 60 second walk around 5 trees each of the 5 cultivars.

Results: Bees were active primarily in NePlus trees in the early season and in Mission trees late in the season. During the middle of the season bees were most active in the mid-blooming cultivars with greatest activity in Peerless trees (Fig. 5B).

Discussion: Activity of bees in trees corresponds closely with abundance of bloom, especially through peak bloom. Peerless appears to be the most attractive of the mid-blooming cultivars.

Intertree Flight

Pollen movement between trees of different cultivars is most important for efficient pollination in almonds. We have shown that distance and between trees and similarity in stage of bloom are important determinants as to where a bee will fly when it leaves flowers of a tree. The study orchard gave us an opportunity to test these ideas in a hexagonal or equilateral planting of 5 cultivars in which every other row is Nonpareil.

Methods: Bees working within trees, flying between trees of the same cultivar and across rows of different cultivars were counted for 60 seconds each. Counts were made using adjacent rows of NePlus and Nonpareil early in the season and using adjacent rows of Nonpareil and Mission late in the season.

Results: Numbers of bees foraging within trees shifted through the season from earlier to later cultivars (Figs. 8B, 9B). The crossover point was nearer the crossover for bloom progression between NePlus and Nonpareil (Fig. 8A, B), but much earlier between Mission and Nonpareil (Fig. 9A, B). Numbers of bees flying between trees were considerably less than those foraging within trees (cf. Figs. 8B-C and Figs. 9B-C). The flight between trees of different cultivars was as great or greater than flight between trees within rows of the same cultivar, except at the beginning and end measures when there was the greatest divergence in bloom stage between cultivars (Figs. 8C and 8C).

Discussion: The hexagonal or equilateral planting of our test orchard resulted in canopies that were as close or sometimes closer together between trees of different cultivars (across rows) than between trees of the same cultivar. Pruning and canopy shape typical of the cultivar (e.g., Mission has a rather erect growth form, while Nonpareil is quite spreading) often result in greater distances between Mission trees than Mission to Nonpareil trees. Distance between trees was not a factor in deterring bee flights between cultivars in this particular planting scheme. Orchard plantings therefore can have a considerable influence on bee-mediated pollen flow between almond cultivars.

ALMOPOL Model

During the 1990 bloom season data were collected to determine the progression of bloom in five almond cultivars. Data required to conduct an ALMOPOL nut set prediction model simulation were also collected. These data include measuring tree height, diameter, trunk height, number of blossom clusters per meter of branch, and number of blossoms per cluster. Weather data (temperature, solar radiation, wind velocity, and rainfall) were collected hourly throughout bloom. The total number of flower buds on limbs of trees of each cultivar were counted and tagged. Six to eight weeks after bloom and immediately before harvest the number of nuts setting on those limbs was counted to obtain estimates of initial and final nut set for each of the cultivars. These nut set estimates were compared with predictions from the ALMOPOL model.

<u>Methods</u>: Data collection to test the accuracy of bloom progression equations and ALMOPOL predictions was conducted in a 30 acre commercial orchard near Davis, CA. The orchard contains rows of Nonpareil trees alternating with rows of Neplus, Price, Peerless, and Mission. Measurements of tree height, diameter, trunk height, and the number of blossom clusters per meter were taken from five trees of each cultivar. The average number of blossoms per cluster was calculated from samples of 40 clusters per cultivar. Counts of blossom clusters per meter and blossoms per cluster were taken from limbs selected at the four cardinal positions on trees of each cultivar.

Limbs at the cardinal points of five trees of each cultivar were tagged and the number of open blossoms was recorded daily (weather permitting). The total number of initial buds on those limbs was also recorded. The number of blossoms setting nuts on the tagged limbs was determined 6-8 weeks after bloom (initial set), and before harvest (final set). The percent nut set for each cultivar was determined using the equation: NS / TB; where NS = the number of nuts counted on the limb at time (t), and TB = the total number of blossoms on the limb. Actual initial and final nut set were compared with predictions from the ALMOPOL nut set prediction model. Information of tree dimensions, orchard design, honey bee foraging activity, and hourly weather conditions collected by an automated micrologger was entered into the ALMOPOL program.

Daily counts of open blossoms from each cultivar were compared with the progression of bloom predicted by pre- and post-peak bloom equations. These equations were derived from daily blossom count data collected in previous years of this study. Bloom progression equations for pre- and post-peak bloom intervals for the five cultivars are: $Y = 2.084x^2 + 1.425x$ and $Y = -21.35x^3 + 52.5x^2 - 42.4$ for NePlus; $Y = 5.71x^2 + 0.0805x$ and $Y = 4.18x^2 - 7.67x + 3.53$ for Nonpareil; $Y = 4.72x^2 + 1.2x$ and $Y = 3.76x^2 - 6.59x + 2.9$ for Peerless; $Y = 14.53x^3 + 12.17x^2$ and $Y = 10.89x^3 + 28.7x^2 - 25.15x + 7.35$ for Price; and $Y = 19.24x^3 + 13.94x^2$ and $Y = 2.716x^2 - 5.65x + 2.944$ for Mission; where Y = the proportion of open blossoms at time (t) and x = the total number of degree days (dd) at time (t) / total number of degree days in the cultivar's bloom period. The base temperature for each cultivar and the total number of dd in each cultivar's bloom period are: NePlus base = 2.22° C with 264 dd in the bloom period, Nonpareil base = 4.0° C and 200 dd in the bloom period, Price base = 4.44° C and 170 dd in the bloom period, Peerless = 4.44° C and 175 dd in the bloom period, and Mission base = 7.78° C and 89 dd in the bloom period.

<u>Result</u>: Correlation coefficients for actual and predicted bloom progression are shown in Table 2. The equations very accurately predicted the progression of bloom during the pre-peak bloom interval in all cultivars. However, the predictions were not as accurate during the post-peak bloom interval.

Nut set predictions from the ALMOPOL model were within the 95% confidence interval for initial set for all the cultivars except Nonpareil where ALMOPOL predicted significantly less nut set than actually occurred (Table 3). Both Price and Peerless lost more nuts between initial and final actual nut set than predicted by the model.

Discussion: Bloom progression equations derived from previous years' data accurately predicted the progression of bloom in all cultivars. The predictions for bloom progression in the post-peak bloom period were not as accurate. A reason for this may be that during the post-peak bloom interval weather conditions other than temperature can strongly affect the length of time blossoms retain their petals. Heavy rains or strong winds can cause blossoms to prematurely drop their petals. Conversely, low wind velocities and post-peak bloom intervals that are free of rain can make blossoms retain their petals. In all cases in this study the bloom progression equations predicted that bloom progressed at a faster rate than actually occurred during the post-peak bloom interval. In 1990 winds were light (less than 8.0 mph) and there was no rain during the post-peak bloom interval. This could have caused the petals to be retained longer than in previous years, and caused the accuracy in our post-peak bloom progression predictions to be reduced.

ALMOPOL accurately predicted initial set in four of the five cultivars at the test site. Actual set in Nonpareil was significantly higher than predictions. This may be due to overestimates of initial bloom based on tree measurement parameters and/or blossom density estimates. The thinning equation used in the ALMOPOL program to predict final nut set as a function of initial nut accurately predicted final nut set in NePlus and Mission and has proven accurate for all cultivars over the past several years. However, unusual conditions such as disease, insect damage, wind or other conditions may cause excess drop before the time of final nut set counts and thus lead to overestimates in predictions by the model.

Publications

Nasr, M. E., R. W. Thorp, T. L. Tyler and D. L. Briggs. 1990. Estimating honey bee (Hymenoptera: Apidae) colony strength by a simple method: measuring cluster size. J. Econ. Entomol. 83: 748-754.

Table 1. Changes in colony strength during the 1990 almond bloom period in an orchard near Davis, CA.

Strength Group [1]	Number Colonies	Colony Strength (Mean & Standard Deviation Begin	End	% Change
4	7	3.86 ±0.35	11.94 ±2.61	209.63%
6	7	5.64 ±0.23	13.13 ±1.99	93.88%
8	7	8.29 ±1.06	15.33 ±2.30	85.0%
Combined	21	5.93 ±1.94	13.47 ±2.71	127.15%

[1] Numbers of frames of bees (NOF) determined by cluster counts

Table 2. Correlation coefficients between actual and predicted bloom progression for five almond cultivars.

Cultivar	Pre-peak bloom Corr. Coef.	Post-peak bloom Corr. Coef.
NePlus	89.3	79.5
Nonpareil	96.8	63.3
Price	95.8	77.1
Peerless	98.9	69.2
Mission	97.9	46.3

Table 3. Actual nut set in five almond cultivars and predicted set using the ALMOPOL nut set prediction model.

Cultivar	Actual Set		Predicted Set	
	Initial ± SE	Final ± SE	Initial	Final
NePlus	19.7 ± 1.2	15.1 ± 1.2	18.97	16.8
Nonpareil	24.6 ± 3.4	21.6 ± 3.2	9.36	9.36
Price	20.7 ± 2.4	17.2 ± 1.8	22.8	21.6
Peerless	19.6 ± 1.8	14.1 ± 1.7	18.8	18.2
Mission	10.6 ± 1.1	9.4 ± 1.2	10.2	10.2

Figure 1. Average changes in strength of colonies based on 3 initial strength groups

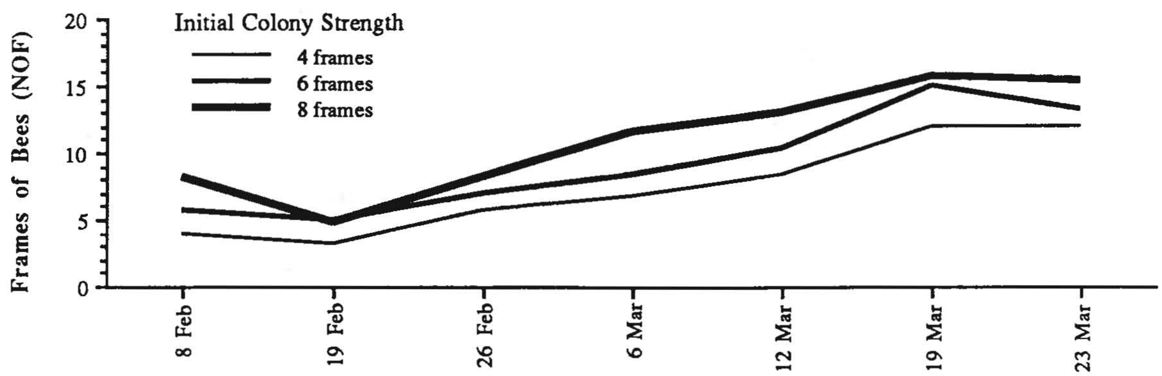
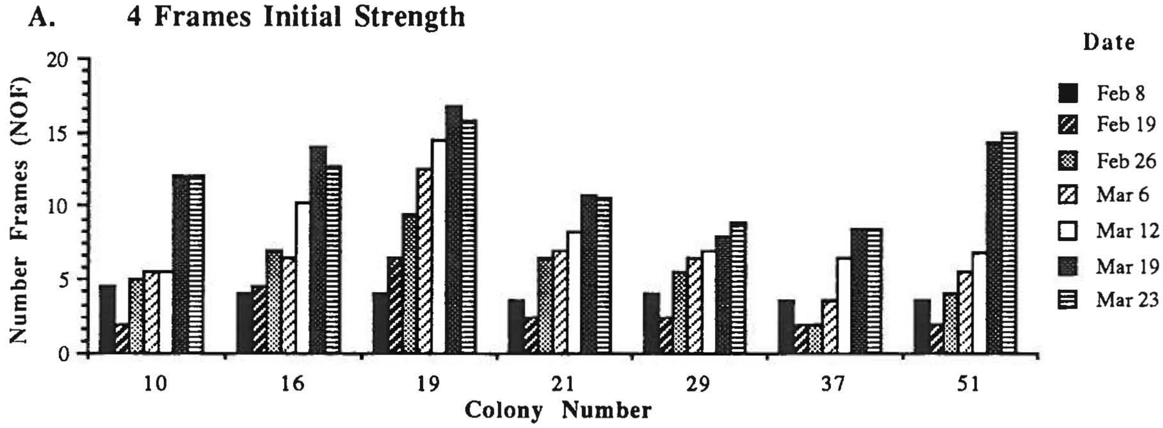
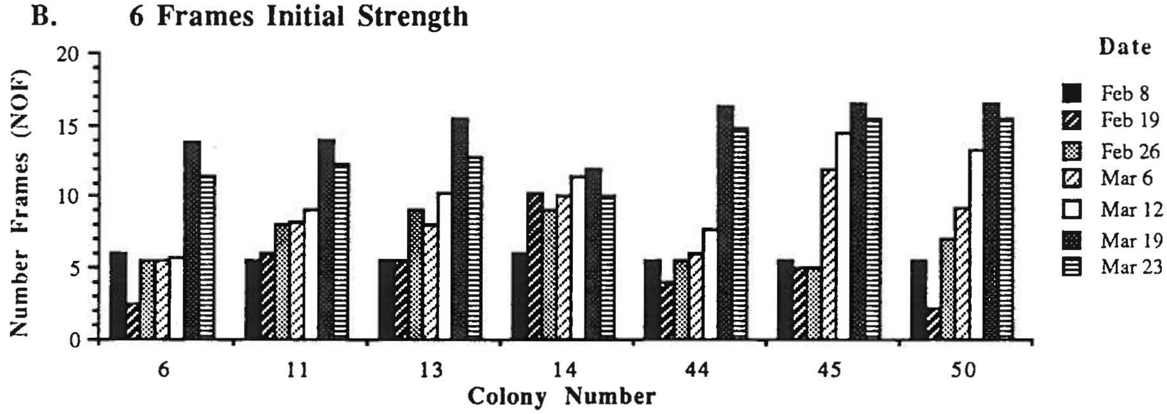


Figure 2. Changes in strength of individual colonies through almond bloom

A. 4 Frames Initial Strength



B. 6 Frames Initial Strength



C. 8 Frames Initial Strength

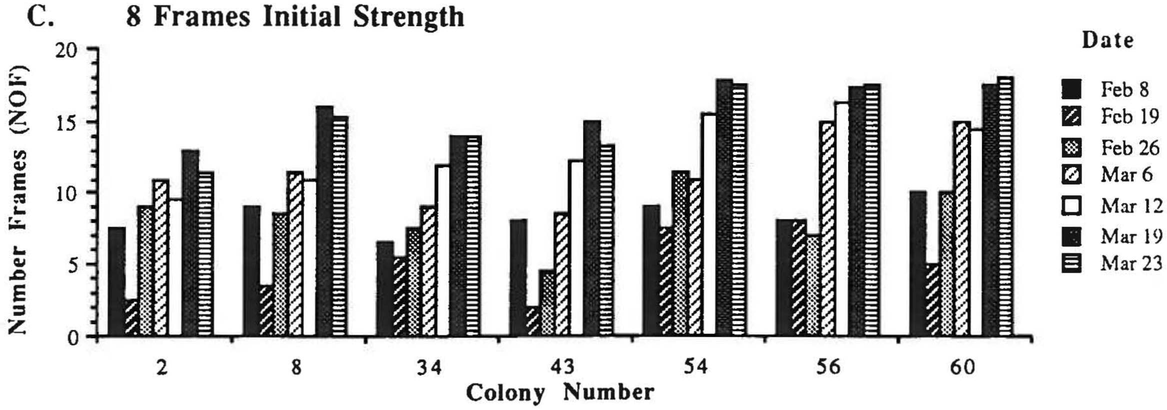


Figure 3. Changes in colony strength by date through almond bloom 1990 in an orchard near Davis, CA.

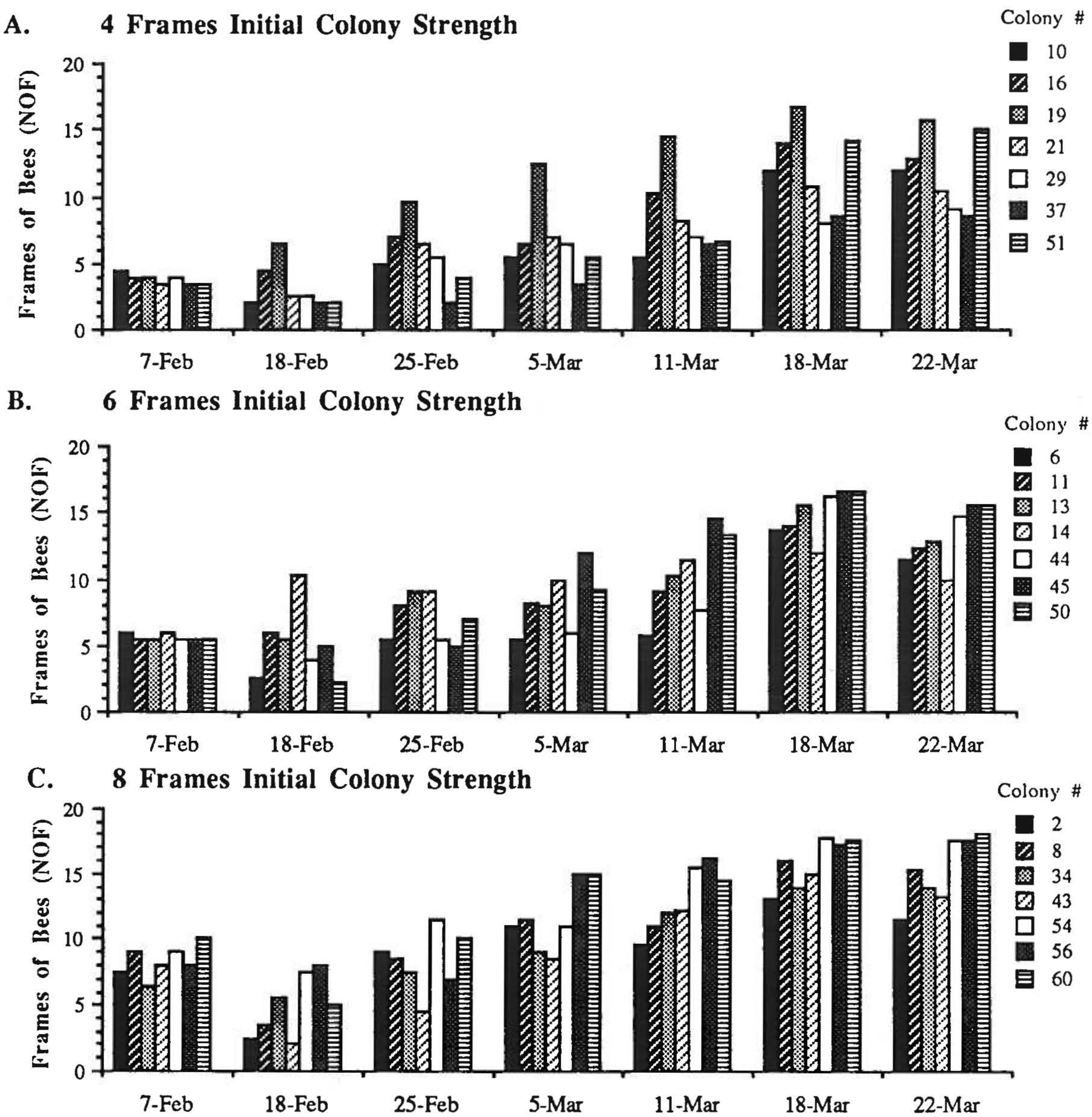


Figure 4. Weather conditions during the almond bloom in an orchard near Davis, CA. 1990.

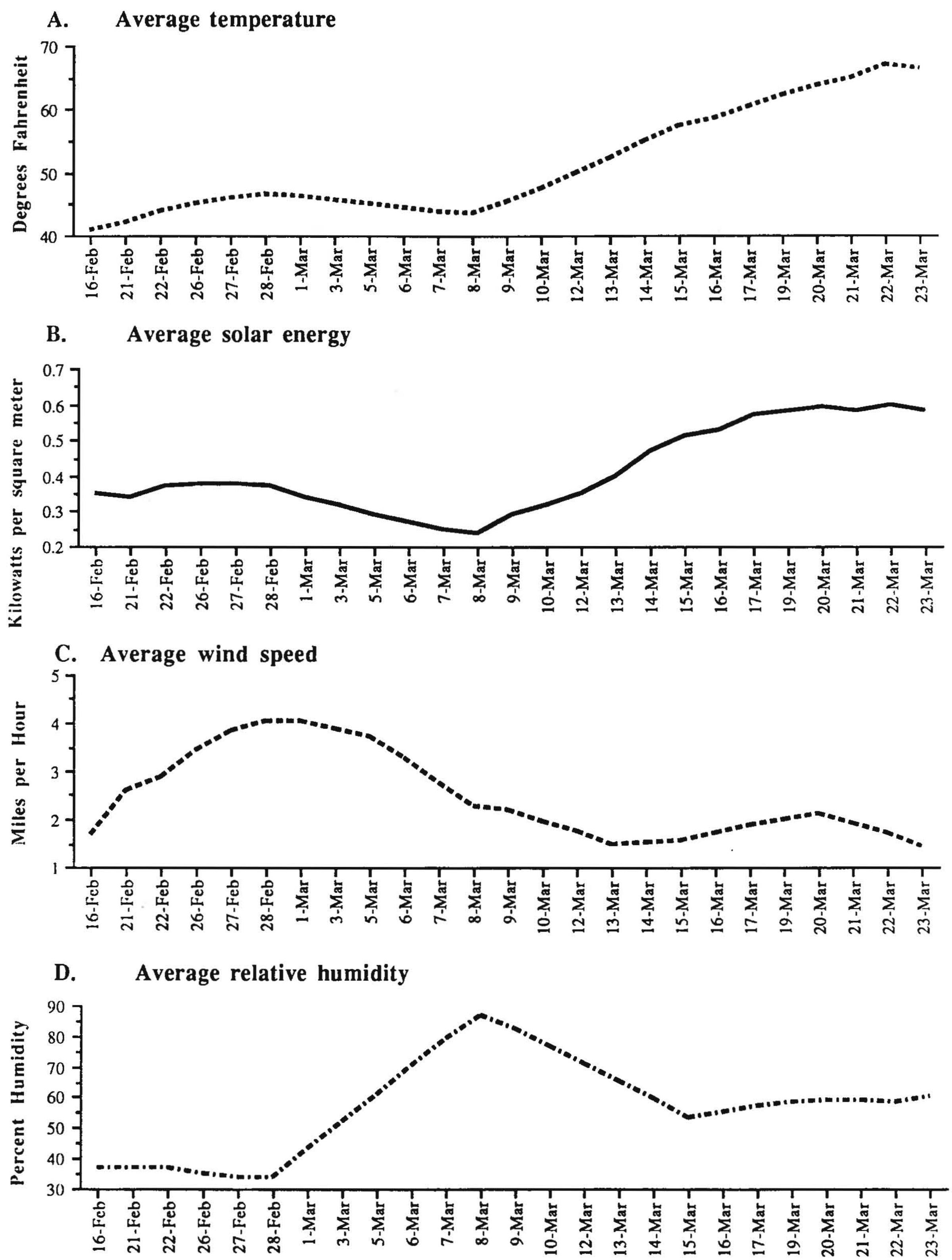


Figure 5. Relationship of honey bee flight activity to bloom phenology of five almond cultivars in an orchard near Davis, CA. 1990.

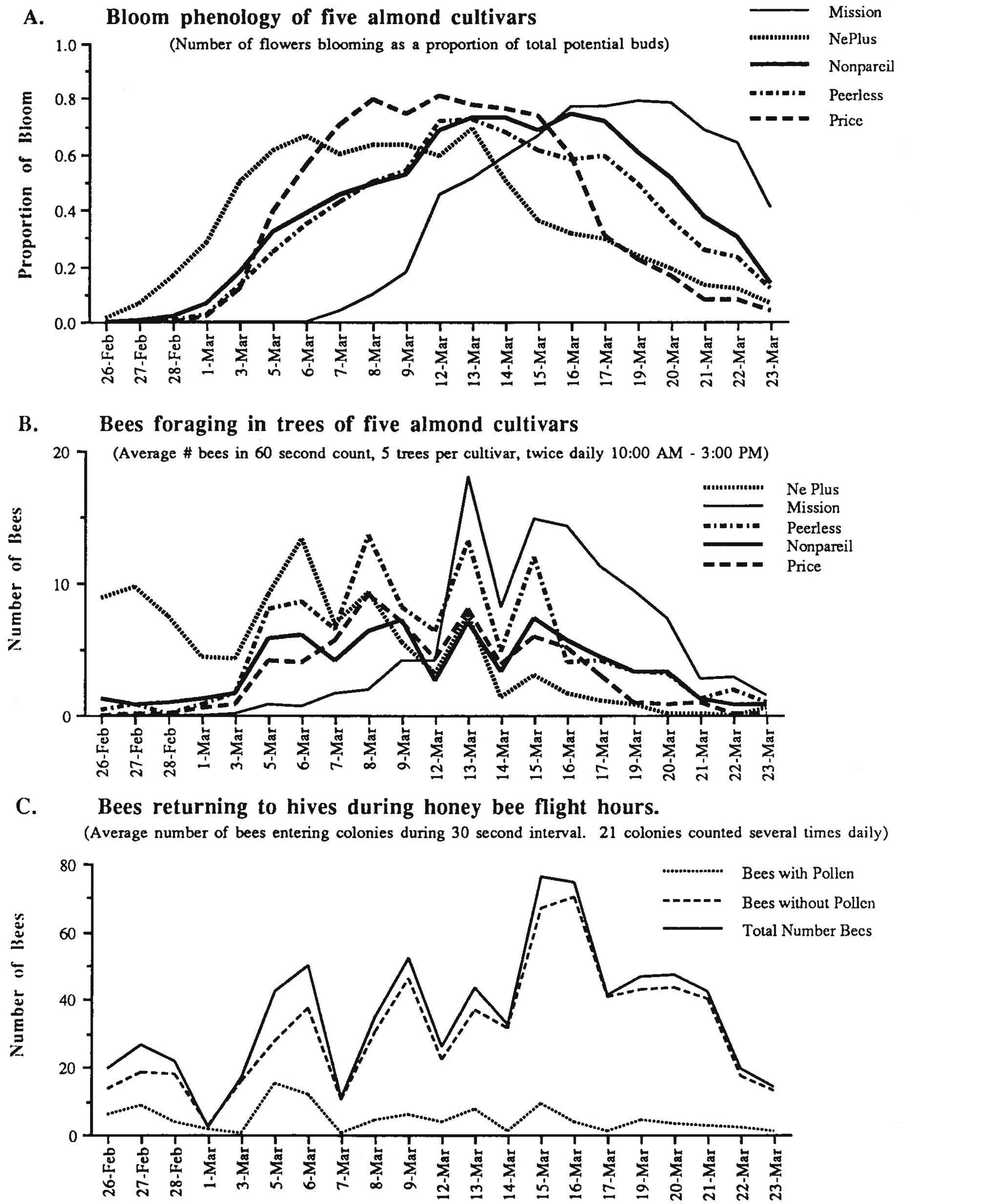


Figure 6. Proportion of almond pollen brought into hives during almond bloom

Average of pollen trapped at 10 colonies twice weekly between 8 AM & 4 PM.

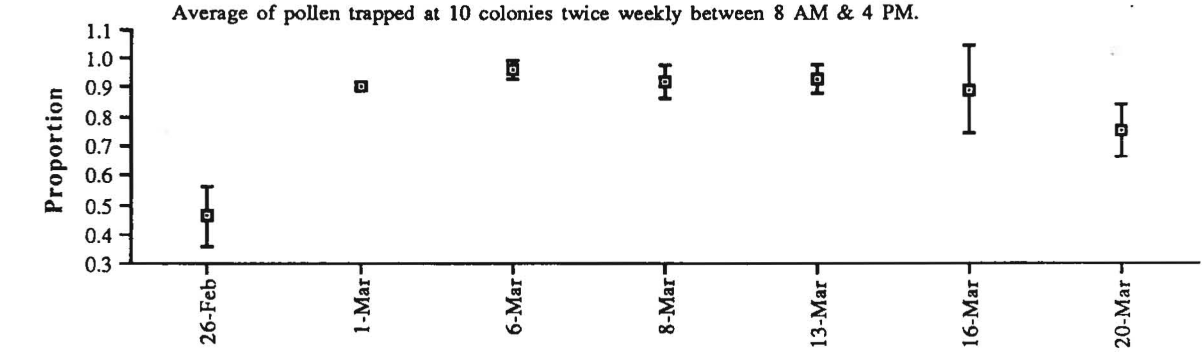
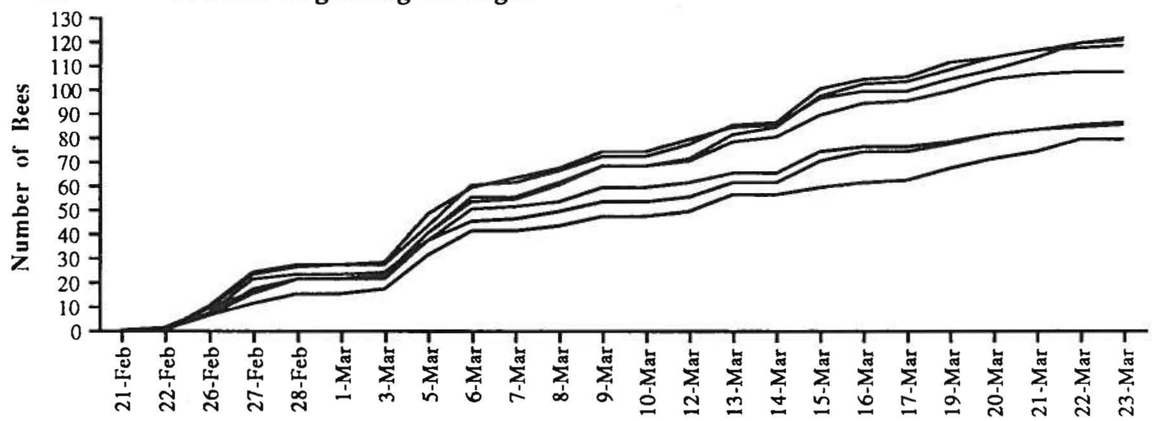


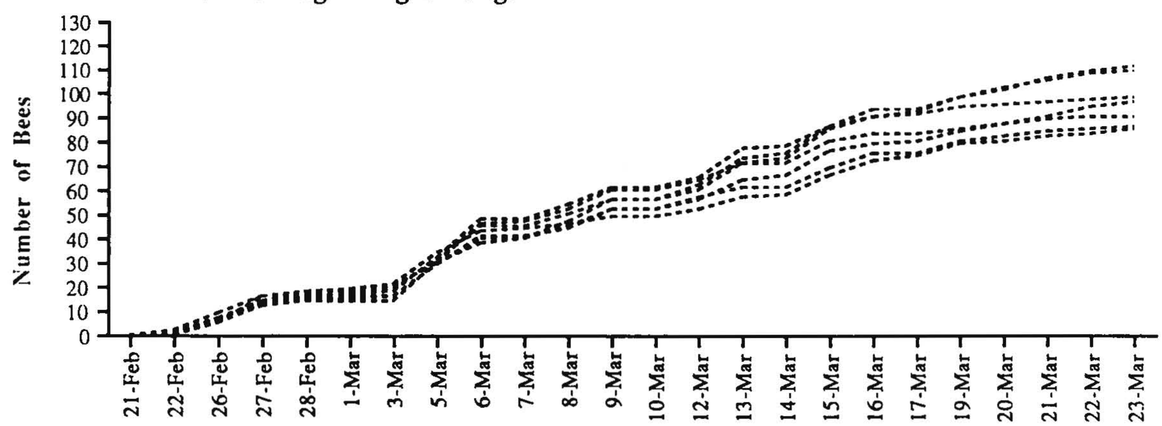
Figure 7. Cumulative daily average number of pollen foragers returning to hives

(Average number of bees counted in 30 second intervals several times daily)

A. 4 Frames Beginning Strength



B. 6 Frames Beginning Strength



C. 8 Frames Beginning Strength

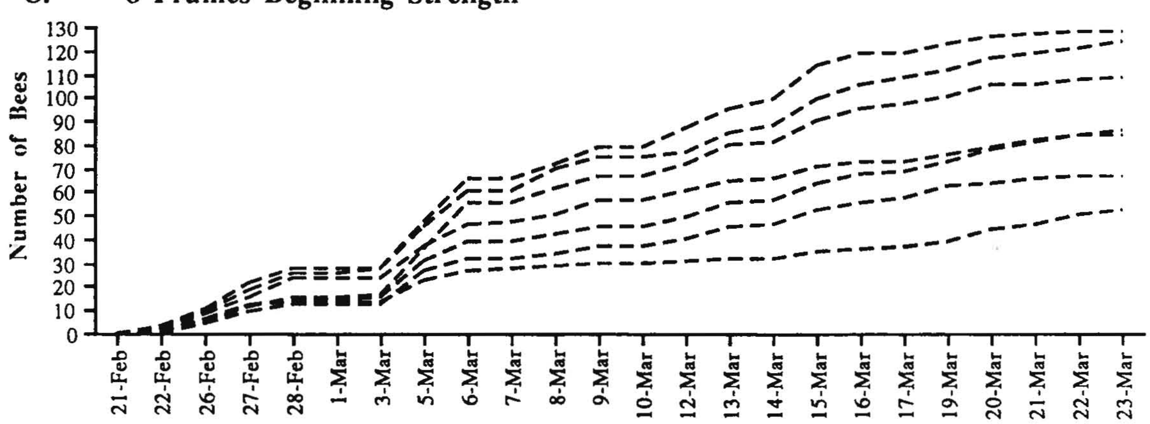
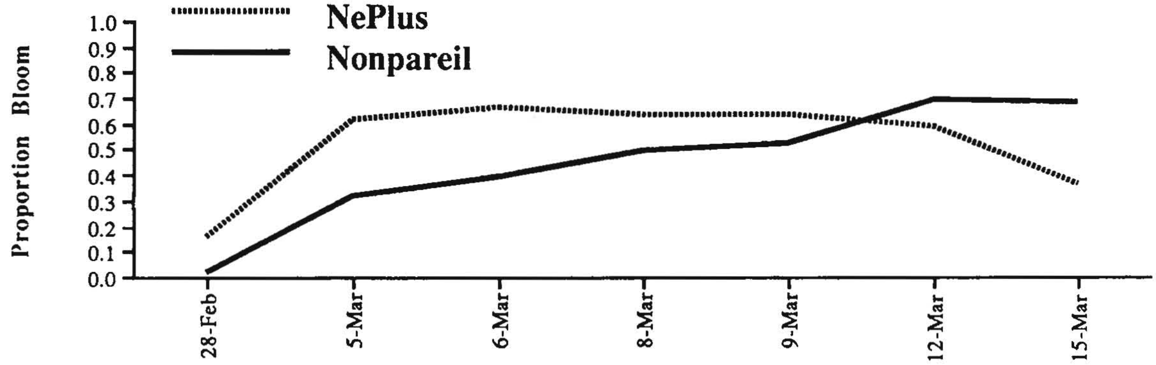


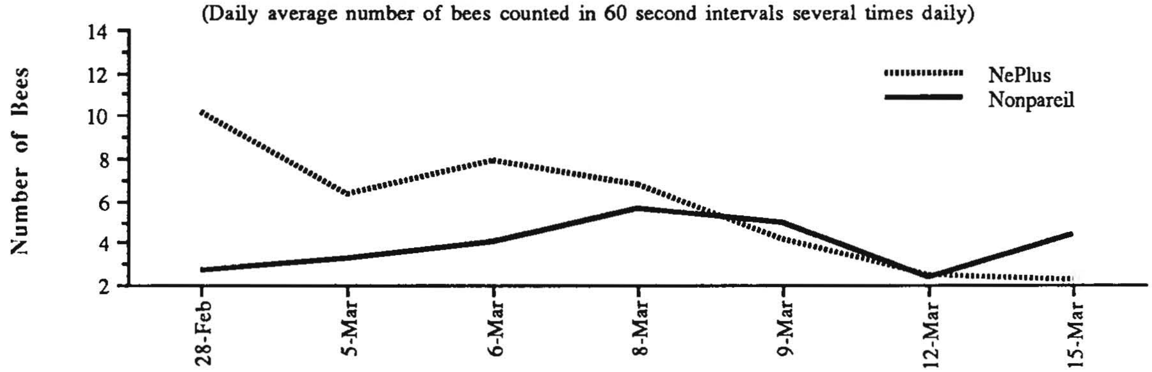
Figure 8. Bee movement between trees: NePlus and Nonpareil cultivars in an orchard near Davis, Ca. 1990.

A. Bloom progression of two cultivars on dates bee movement was monitored



B. Number of bees foraging in single trees of two cultivars

(Daily average number of bees counted in 60 second intervals several times daily)



C. Movement of bees between trees of the same and different cultivars

(Daily average number of bees counted during 60 second intervals several times daily)

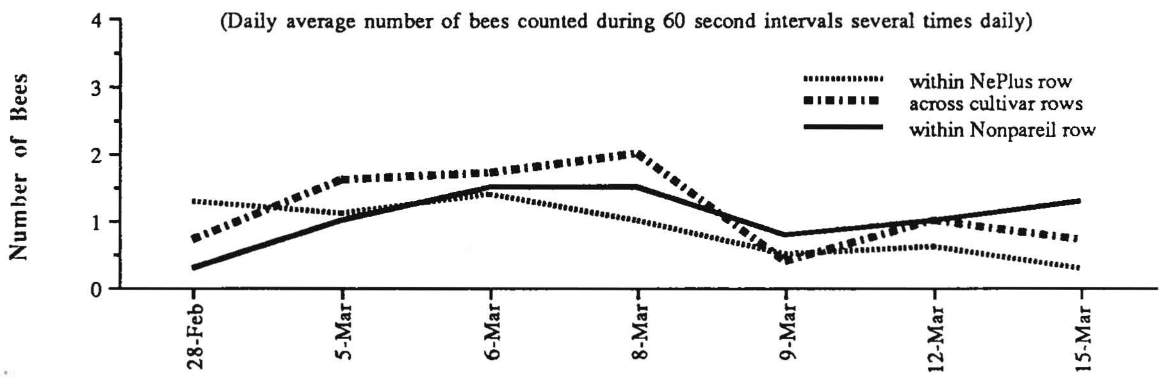
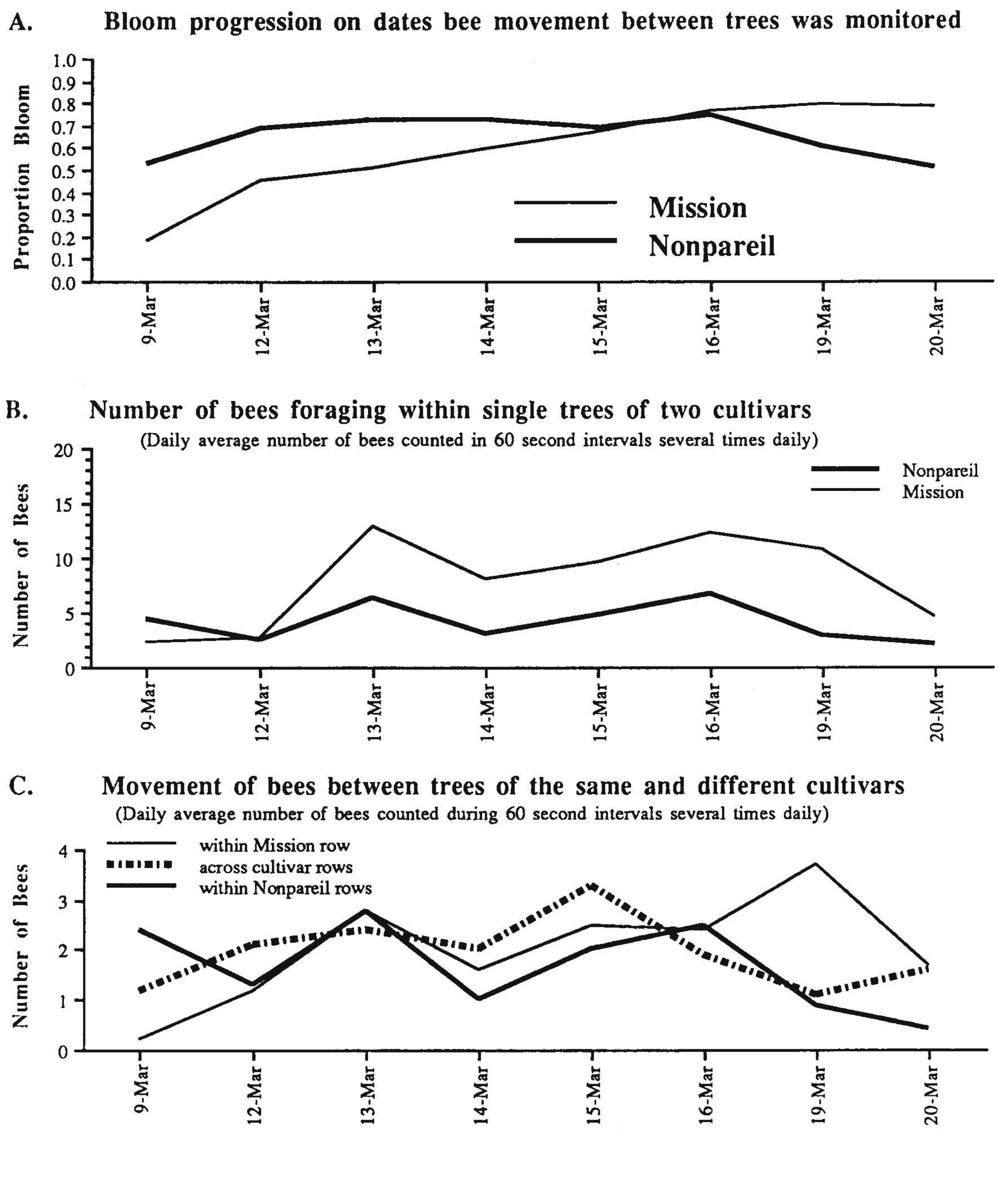


Figure 9. Bee movement between trees: Mission and Nonpareil in an orchard near Davis, CA. 1990.



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Discussion: The decrease in colony populations in late February is probably attributable to the cold weather (Fig. 4A) and delayed bloom (Fig. 5A) following our initial colony strength evaluations. Shortly after the onset of bloom, about 26 February, colony populations increased rapidly (Figs. 1, 3). Weekly measures showed a dramatic increase in variability of colony populations within each group (Figs. 3A-C). This produced problems with other analyses attempting to correlate other measures to initial strength groups. As in previous years where we found highest correlations with end of season strength measures. Leveling off or decrease in populations after the 16 March colony strength estimates is presumably due to reduction in availability of food at the end of the bloom season (Fig. 5A, B). Although colonies in the 4 NOF category showed the greatest percent of increase as for previous years (Table 1), they also showed the greatest range of variation at the end of the season (Fig. 3). The higher percentage rate of increase is due to the fact that they started with smaller populations. The need is for more bees at the beginning of the bloom season in order to keep pace with the rapid increase in bloom as occurred in early March this year.

Seasonal Flight Activity

Flight activity based on numbers of bees returning to the hive during 30 second intervals at different times of day and partitioned into bees with versus without pollen loads were taken under varying weather conditions and related to weekly measures of colony strength. This year we also estimated colony strength at weekly intervals to see if we could determine why previous correlations of entrance flight with initial strength measures had been weaker than when compared with final strength assessments.

Methods: Incoming flight activities were monitored several times a day for 24 days during the almond bloom season. Bees returning during 30 second periods were recorded. Correlations with weekly strength groups were made.

Results: ANOVA analyses showed that flight activity was not significantly different between colonies starting with 4 and 6 frames of bees (NOF) nor between colony strength groups at different temperatures. However, colonies with 8 NOF produced significantly greater flight activity than did colonies of lower strength groups.

Discussion: Seasonal flight activity of returning foragers did not correlate well with initial colony strength groups due to variability in growth rates among colonies within each strength group.

Seasonal Pollen Income

This study was an attempt to determine the proportion of pollen being brought into hives that actually came from almond flowers throughout the bloom season.

Methods: Entrance type pollen traps were placed on 10 colonies and activated for single-day observation periods on seven days throughout the almond bloom period. Pollen pellets were sorted by color and classed as to whether they came from almond or not.

Results: On 26 February, when NePlus was in about 1.3% bloom and Nonpareil was less than 1 bloom, colonies averaged less than half of their pollen from almonds (Fig. 6). However, from 1 through 16 March, the peak of bloom for most of the cultivars in the orchard, colonies averaged 90% or more almond pollen. On 19 March while Mission was at peak, but the other cultivars were waning, colonies averaged only about 75% almond pollen.

Discussion: Almonds provide a strongly attractive pollen source due to availability and abundance during peak bloom of the major cultivars. Pollen foragers quickly switch to almond flowers as they become available and track the bloom through flowering of the latest cultivar.

Pollen Foraging and Colony Flight Profiles

The proportion of pollen foragers among all bees returning to the hive is important in determining the pollination efficiency of colonies in almond orchards.

Methods: Incoming flight activities were monitored several times a day for 24 days during the almond bloom season. Bees returning during 30 second periods were tallied according the presence or absence of pollen on their hind legs.

Results: Pollen foragers represent only a small portion of the bees returning to hives throughout the season (Fig. 5C). Peak of pollen foraging occurred on 5 March corresponding with the peak of NePlus bloom and increase in the mid-blooming cultivars (Fig. 5A) and with the peak of activity in NePlus trees (Fig. 5B). Total activity at hive entrances increased throughout the bloom season, tapering off about 17 March when bloom of the first four cultivars was on the wane. Cumulative profiles of returning pollen foragers relative to colony strength groups also illustrate the sharp upswing in pollen collection from 3 through 6 March (Fig. 7A-C). Colonies in the 4 NOF and especially 8 NOF strength groups exhibited the greatest variability in cumulative numbers pollen foragers, especially by the end of the season (Figs. 7A, C).

Discussion: Although almond pollen is highly attractive and readily collected by pollen foragers the proportion of pollen foragers in commercial colonies tends to be small. This is likely due to the long term selection beekeepers have been performing for high honey production. Genetic selections can alter ratios of pollen versus nectar (honey) hoarding (R. E. Page, personal communication). Evaluations of the pollination efficiency of high versus low pollen hoarding strains need to be conducted in almond orchards.

Bees in Trees Seasonal Patterns

Patterns of bee activity in trees were examined to determine correspondence with bloom curves and weather patterns.

Methods: Bees were counted during a 60 second walk around 5 trees each of the 5 cultivars.

Results: Bees were active primarily in NePlus trees in the early season and in Mission trees late in the season. During the middle of the season bees were most active in the mid-blooming cultivars with greatest activity in Peerless trees (Fig. 5B).

Discussion: Activity of bees in trees corresponds closely with abundance of bloom, especially through peak bloom. Peerless appears to be the most attractive of the mid-blooming cultivars.

Intertree Flight

Pollen movement between trees of different cultivars is most important for efficient pollination in almonds. We have shown that distance and between trees and similarity in stage of bloom are important determinants as to where a bee will fly when it leaves flowers of a tree. The study orchard gave us an opportunity to test these ideas in a hexagonal or equilateral planting of 5 cultivars in which every other row is Nonpareil.

Methods: Bees working within trees, flying between trees of the same cultivar and across rows of different cultivars were counted for 60 seconds each. Counts were made using adjacent rows of NePlus and Nonpareil early in the season and using adjacent rows of Nonpareil and Mission late in the season.

Results: Numbers of bees foraging within trees shifted through the season from earlier to later cultivars (Figs. 8B, 9B). The crossover point was nearer the crossover for bloom progression between NePlus and Nonpareil (Fig. 8A, B), but much earlier between Mission and Nonpareil (Fig. 9A, B). Numbers of bees flying between trees were considerably less than those foraging within trees (cf. Figs. 8B-C and Figs. 9B-C). The flight between trees of different cultivars was as great or greater than flight between trees within rows of the same cultivar, except at the beginning and end measures when there was the greatest divergence in bloom stage between cultivars (Figs. 8C and 8C).

Discussion: The hexagonal or equilateral planting of our test orchard resulted in canopies that were as close or sometimes closer together between trees of different cultivars (across rows) than between trees of the same cultivar. Pruning and canopy shape typical of the cultivar (e.g., Mission has a rather erect growth form, while Nonpareil is quite spreading) often result in greater distances between Mission trees than Mission to Nonpareil trees. Distance between trees was not a factor in deterring bee flights between cultivars in this particular planting scheme. Orchard plantings therefore can have a considerable influence on bee-mediated pollen flow between almond cultivars.

ALMOPOL Model

During the 1990 bloom season data were collected to determine the progression of bloom in five almond cultivars. Data required to conduct an ALMOPOL nut set prediction model simulation were also collected. These data include measuring tree height, diameter, trunk height, number of blossom clusters per meter of branch, and number of blossoms per cluster. Weather data (temperature, solar radiation, wind velocity, and rainfall) were collected hourly throughout bloom. The total number of flower buds on limbs of trees of each cultivar were counted and tagged. Six to eight weeks after bloom and immediately before harvest the number of nuts setting on those limbs was counted to obtain estimates of initial and final nut set for each of the cultivars. These nut set estimates were compared with predictions from the ALMOPOL model.

<u>Methods</u>: Data collection to test the accuracy of bloom progression equations and ALMOPOL predictions was conducted in a 30 acre commercial orchard near Davis, CA. The orchard contains rows of Nonpareil trees alternating with rows of Neplus, Price, Peerless, and Mission. Measurements of tree height, diameter, trunk height, and the number of blossom clusters per meter were taken from five trees of each cultivar. The average number of blossoms per cluster was calculated from samples of 40 clusters per cultivar. Counts of blossom clusters per meter and blossoms per cluster were taken from limbs selected at the four cardinal positions on trees of each cultivar.

Limbs at the cardinal points of five trees of each cultivar were tagged and the number of open blossoms was recorded daily (weather permitting). The total number of initial buds on those limbs was also recorded. The number of blossoms setting nuts on the tagged limbs was determined 6-8 weeks after bloom (initial set), and before harvest (final set). The percent nut set for each cultivar was determined using the equation: NS / TB; where NS = the number of nuts counted on the limb at time (t), and TB = the total number of blossoms on the limb. Actual initial and final nut set were compared with predictions from the ALMOPOL nut set prediction model. Information of tree dimensions, orchard design, honey bee foraging activity, and hourly weather conditions collected by an automated micrologger was entered into the ALMOPOL program.

Daily counts of open blossoms from each cultivar were compared with the progression of bloom predicted by pre- and post-peak bloom equations. These equations were derived from daily blossom count data collected in previous years of this study. Bloom progression equations for pre- and post-peak bloom intervals for the five cultivars are: $Y = 2.084 x^2 + 1.425x$ and $Y = -21.35 x^3 + 52.5 x^2 - 42.4$ for NePlus; $Y = 5.71x^2 + 0.0805x$ and $Y = 4.18 x^2 - 7.67x + 3.53$ for Nonpareil; $Y = 4.72x^2 + 1.2x$ and $Y = 3.76x^2 - 6.59 x + 2.9$ for Peerless; $Y = 14.53 x^3 + 12.17x^2$ and $Y = 10.89x^3 + 28.7x^2 - 25.15x + 7.35$ for Price; and $Y = 19.24x^3 + 13.94x^2$ and $Y = 2.716x^2 - 5.65x + 2.944$ for Mission; where Y = the proportion of open blossoms at time (t) and x = the total number of degree days (dd) at time (t) / total number of degree days in the cultivar's bloom period. The base temperature for each cultivar and the total number of dd in each cultivar's bloom period are: NePlus base = 2.22° C with 264 dd in the bloom period, Nonpareil base = 4.0° C and 200 dd in the bloom period, Price base = 4.44° C and 170 dd in the bloom period, Peerless = 4.44° C and 175 dd in the bloom period, and Mission base = 7.78° C and 89 dd in the bloom period.

<u>Result</u>: Correlation coefficients for actual and predicted bloom progression are shown in Table 2. The equations very accurately predicted the progression of bloom during the pre-peak bloom interval in all cultivars. However, the predictions were not as accurate during the post-peak bloom interval.

Nut set predictions from the ALMOPOL model were within the 95% confidence interval for initial set for all the cultivars except Nonpareil where ALMOPOL predicted significantly less nut set than actually occurred (Table 3). Both Price and Peerless lost more nuts between initial and final actual nut set than predicted by the model.

Discussion: Bloom progression equations derived from previous years' data accurately predicted the progression of bloom in all cultivars. The predictions for bloom progression in the post-peak bloom period were not as accurate. A reason for this may be that during the post-peak bloom interval weather conditions other than temperature can strongly affect the length of time blossoms retain their petals. Heavy rains or strong winds can cause blossoms to prematurely drop their petals. Conversely, low wind velocities and post-peak bloom intervals that are free of rain can make blossoms retain their petals. In all cases in this study the bloom progression equations predicted that bloom progressed at a faster rate than actually occurred during the post-peak bloom interval. In 1990 winds were light (less than 8.0 mph) and there was no rain during the post-peak bloom interval. This could have caused the petals to be retained longer than in previous years, and caused the accuracy in our post-peak bloom progression predictions to be reduced.

ALMOPOL accurately predicted initial set in four of the five cultivars at the test site. Actual set in Nonpareil was significantly higher than predictions. This may be due to overestimates of initial bloom based on tree measurement parameters and/or blossom density estimates. The thinning equation used in the ALMOPOL program to predict final nut set as a function of initial nut accurately predicted final nut set in NePlus and Mission and has proven accurate for all cultivars over the past several years. However, unusual conditions such as disease, insect damage, wind or other conditions may cause excess drop before the time of final nut set counts and thus lead to overestimates in predictions by the model.

Publications

Nasr, M. E., R. W. Thorp, T. L. Tyler and D. L. Briggs. 1990. Estimating honey bee (Hymenoptera: Apidae) colony strength by a simple method: measuring cluster size. J. Econ. Entomol. 83: 748-754.

Table 1. Changes in colony strength during the 1990 almond bloom period in an orchard near Davis, CA.

Strength Group [1]	Number Colonies	Colony Strength (Mean & Standard Deviation Begin	End	% Change
4	7	3.86 ±0.35	11.94 ±2.61	209.63%
6	7	5.64 ±0.23	13.13 ±1.99	93.88%
8	7	8.29 ±1.06	15.33 ±2.30	85.0%
Combined	21	5.93 ±1.94	13.47 ±2.71	127.15%

[1] Numbers of frames of bees (NOF) determined by cluster counts

Table 2. Correlation coefficients between actual and predicted bloom progression for five almond cultivars.

Cultivar	Pre-peak bloom Corr. Coef.	Post-peak bloom Corr. Coef.
NePlus	89.3	79.5
Nonpareil	96.8	63.3
Price	95.8	77.1
Peerless	98.9	69.2
Mission	97.9	46.3

Table 3. Actual nut set in five almond cultivars and predicted set using the ALMOPOL nut set prediction model.

Cultivar	Actual Set		Predicted Set	
	Initial ± SE	Final ± SE	Initial	Final
NePlus	19.7 ± 1.2	15.1 ± 1.2	18.97	16.8
Nonpareil	24.6 ± 3.4	21.6 ± 3.2	9.36	9.36
Price	20.7 ± 2.4	17.2 ± 1.8	22.8	21.6
Peerless	19.6 ± 1.8	14.1 ± 1.7	18.8	18.2
Mission	10.6 ± 1.1	9.4 ± 1.2	10.2	10.2

Figure 1. Average changes in strength of colonies based on 3 initial strength groups

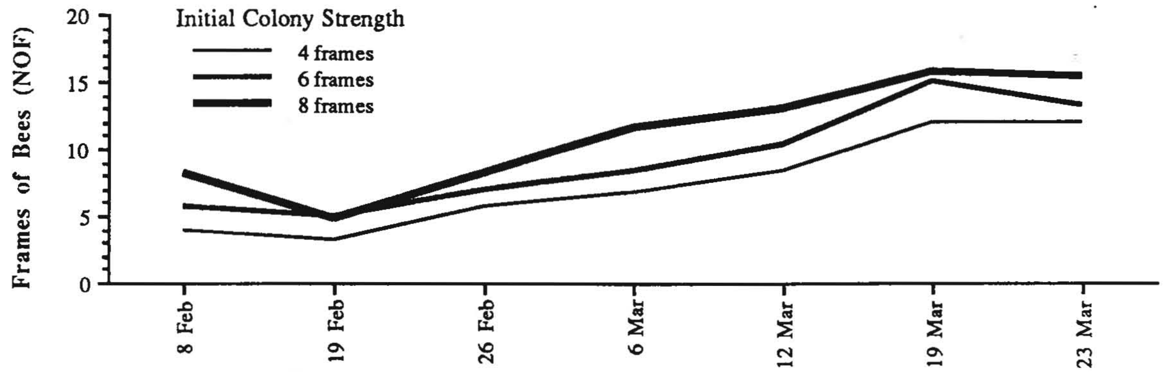


Figure 2. Changes in strength of individual colonies through almond bloom

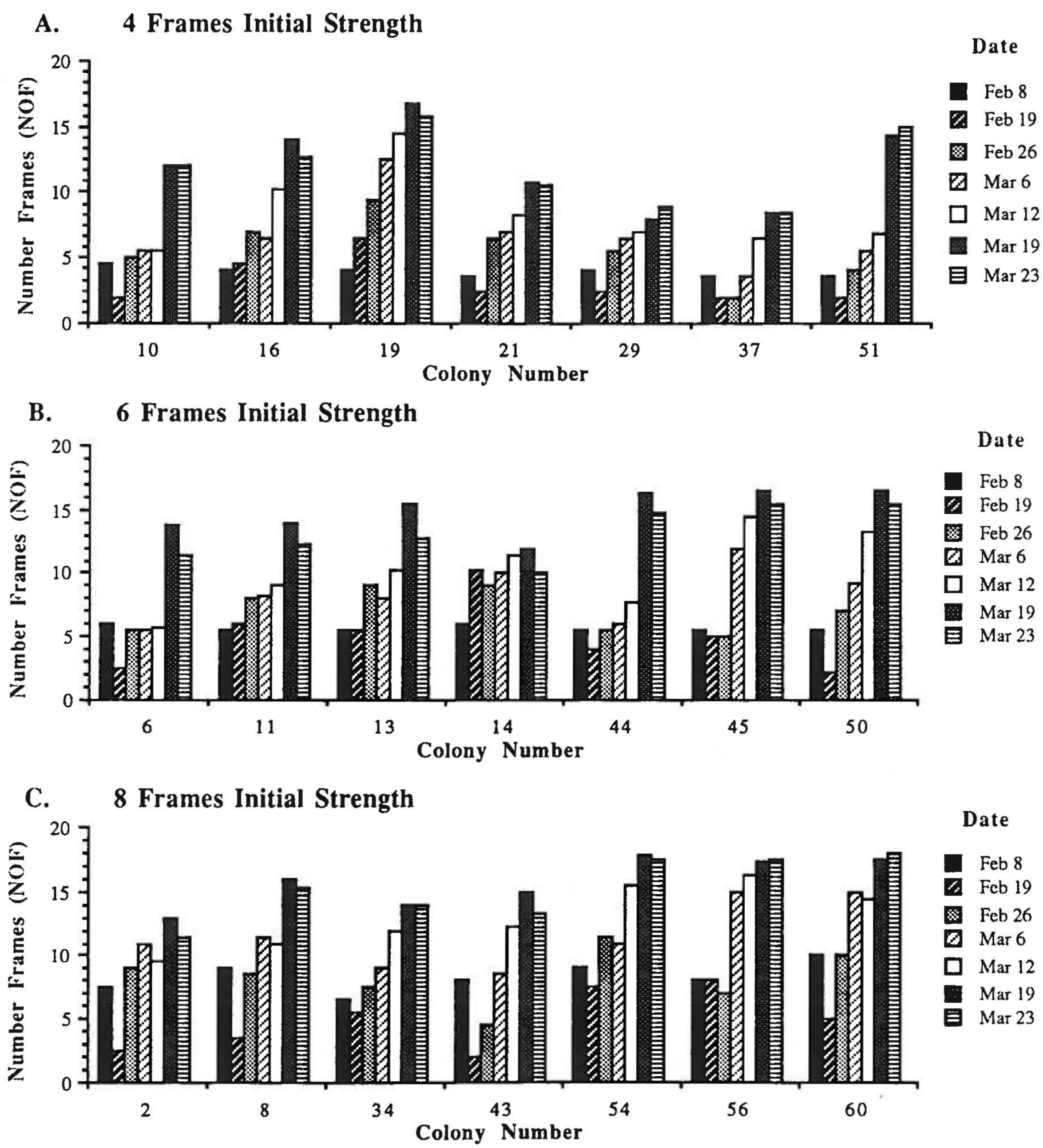


Figure 3. Changes in colony strength by date through almond bloom 1990 in an orchard near Davis, CA.

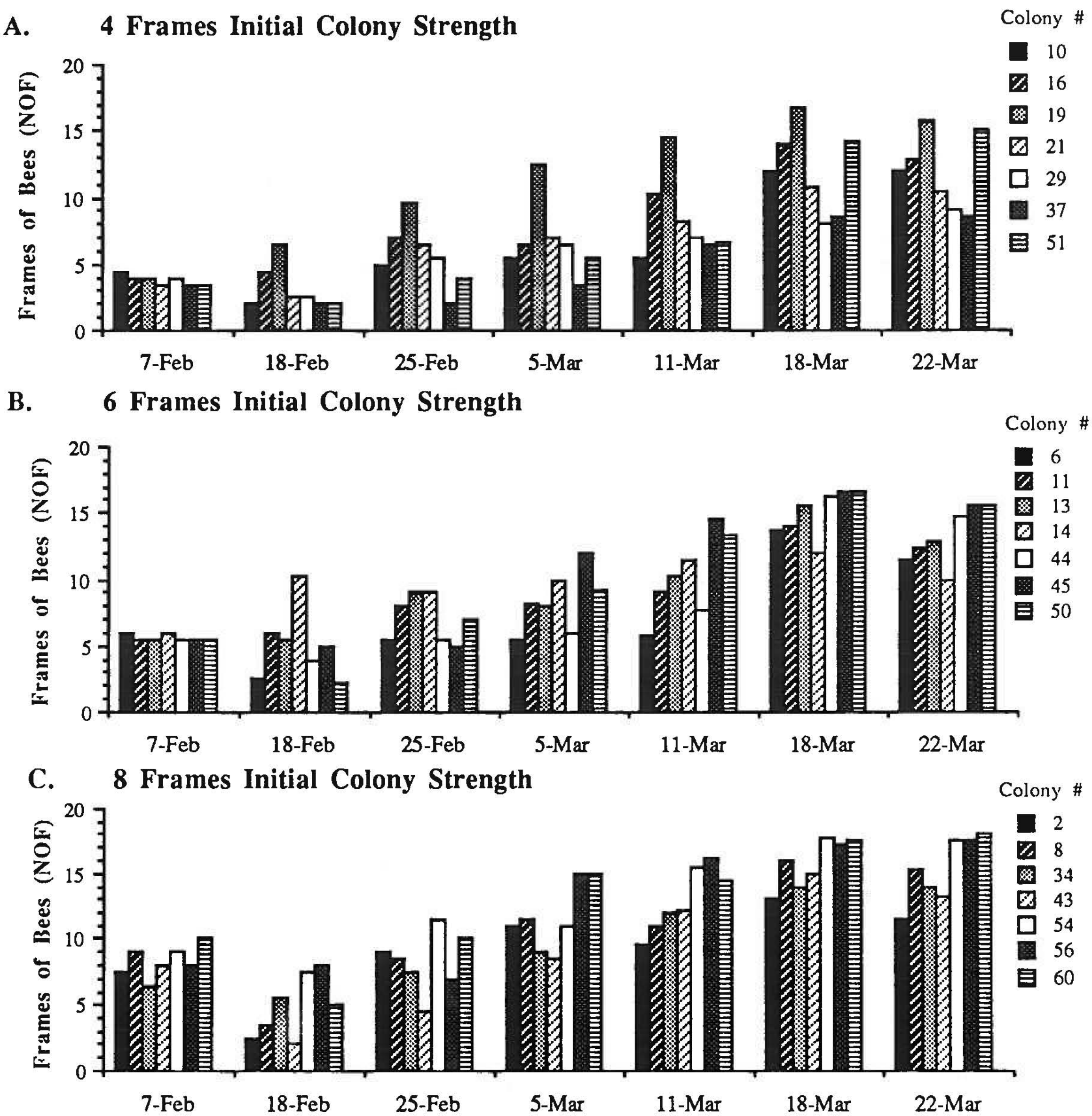


Figure 4. Weather conditions during the almond bloom in an orchard near Davis, CA. 1990.

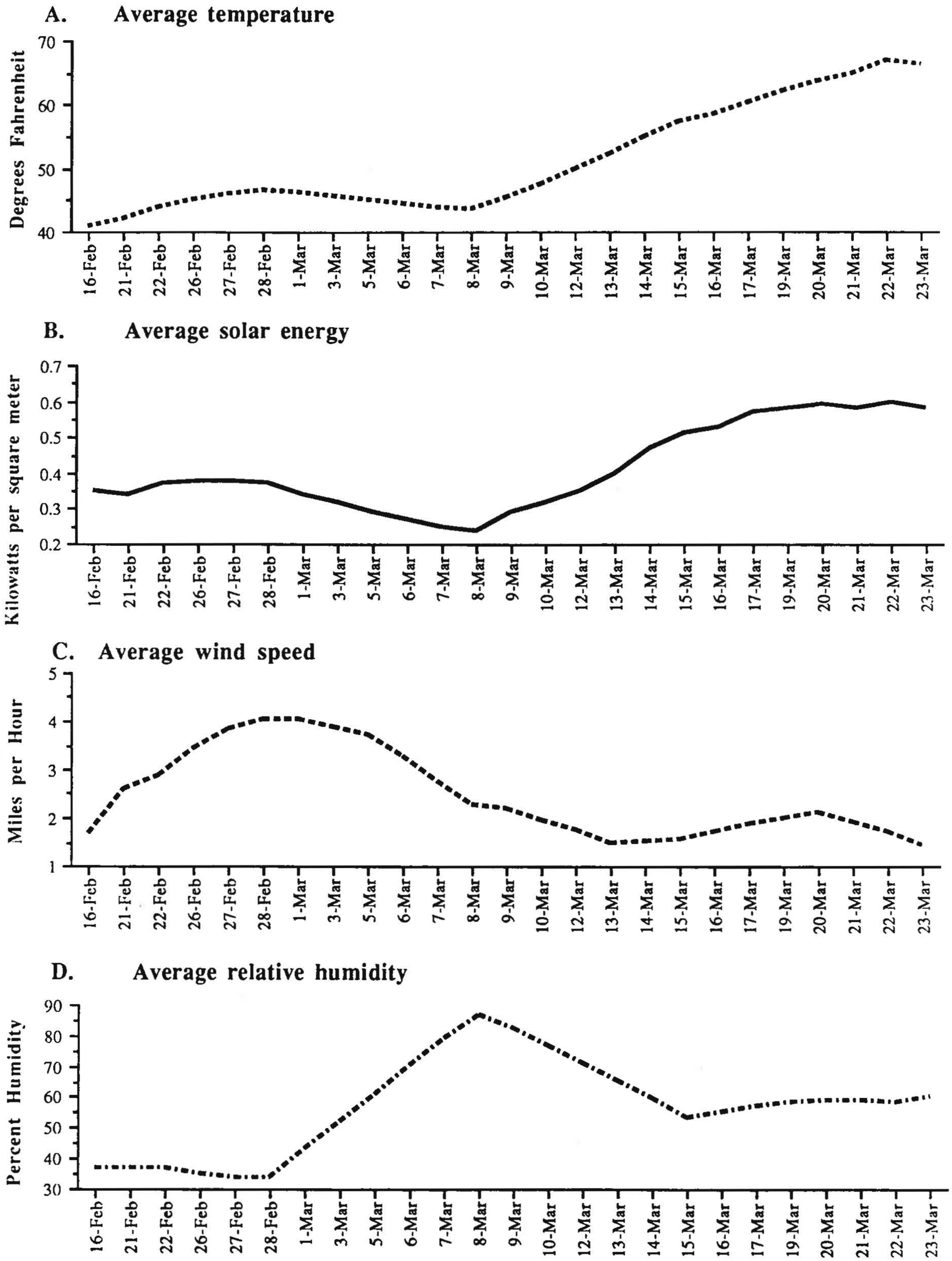


Figure 5. Relationship of honey bee flight activity to bloom phenology of five almond cultivars in an orchard near Davis, CA. 1990.

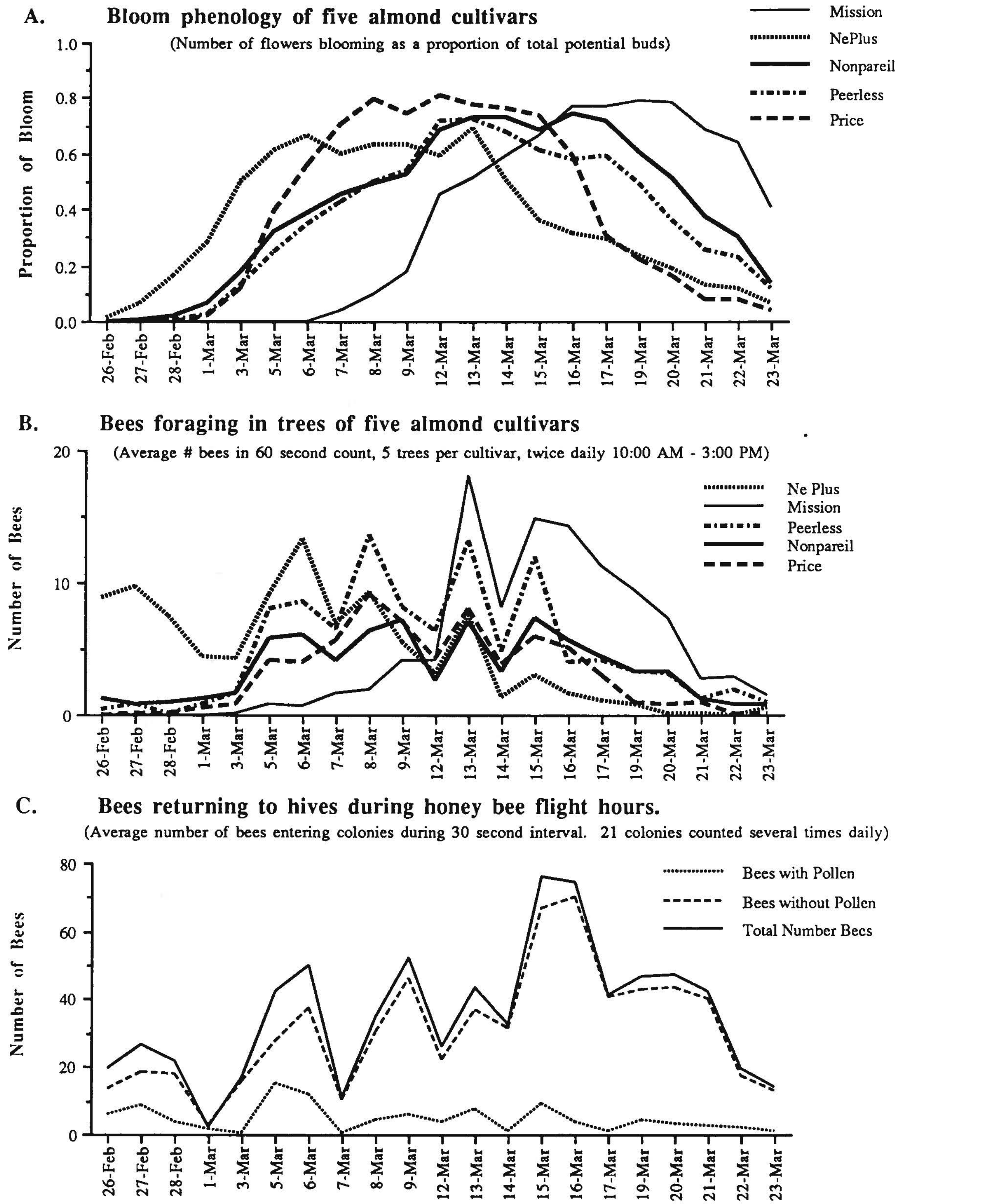


Figure 6. Proportion of almond pollen brought into hives during almond bloom

Average of pollen trapped at 10 colonies twice weekly between 8 AM & 4 PM.

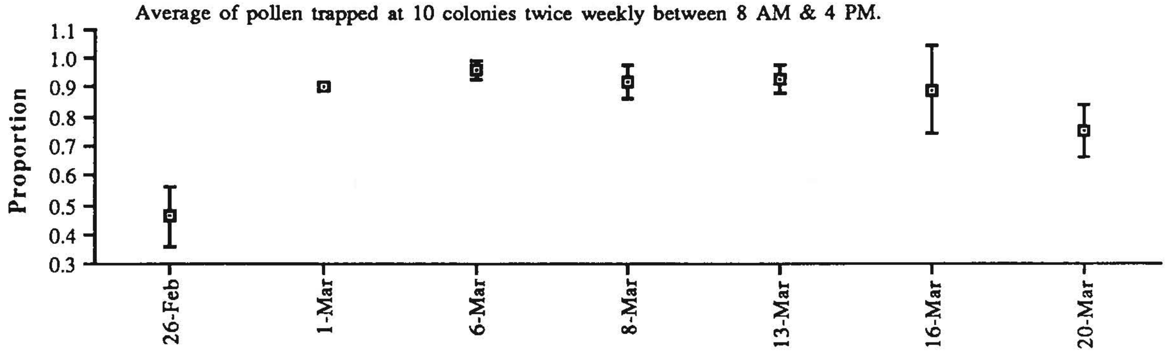
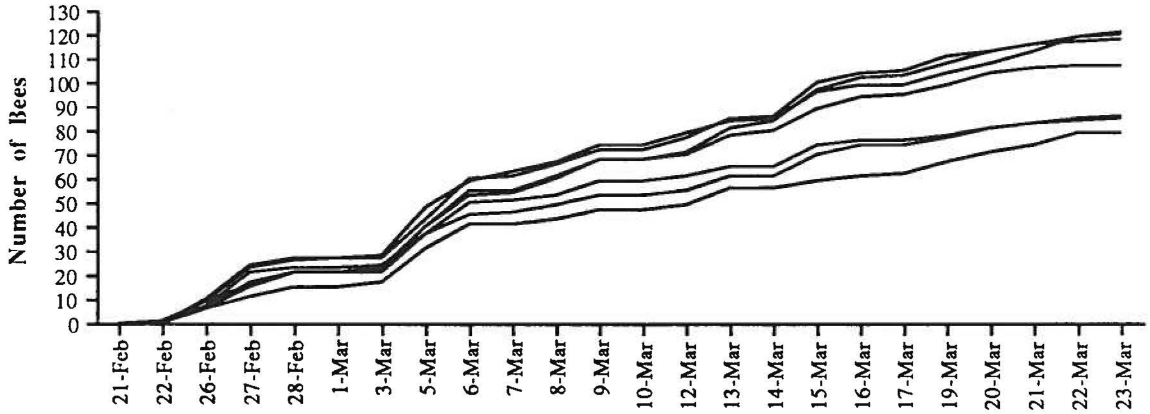


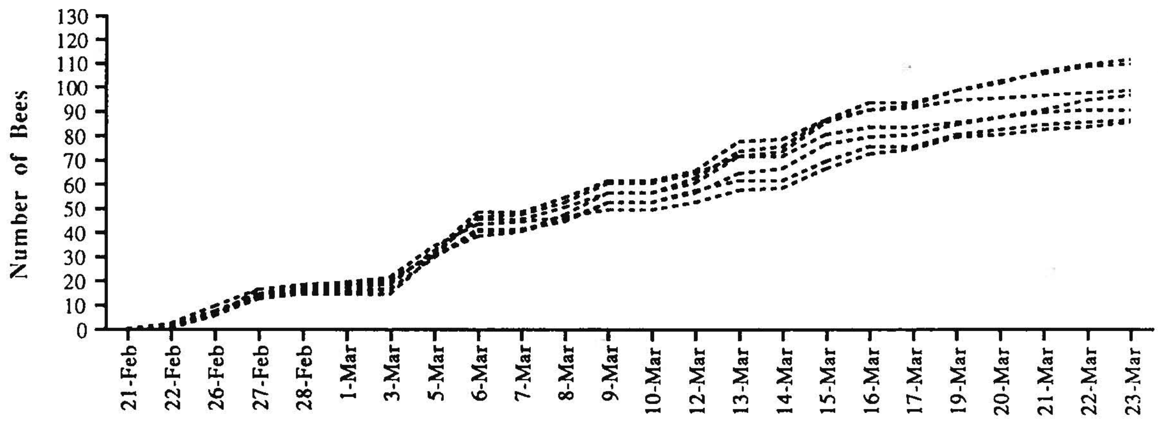
Figure 7. Cumulative daily average number of pollen foragers returning to hives

(Average number of bees counted in 30 second intervals several times daily)

A. 4 Frames Beginning Strength



B. 6 Frames Beginning Strength



C. 8 Frames Beginning Strength

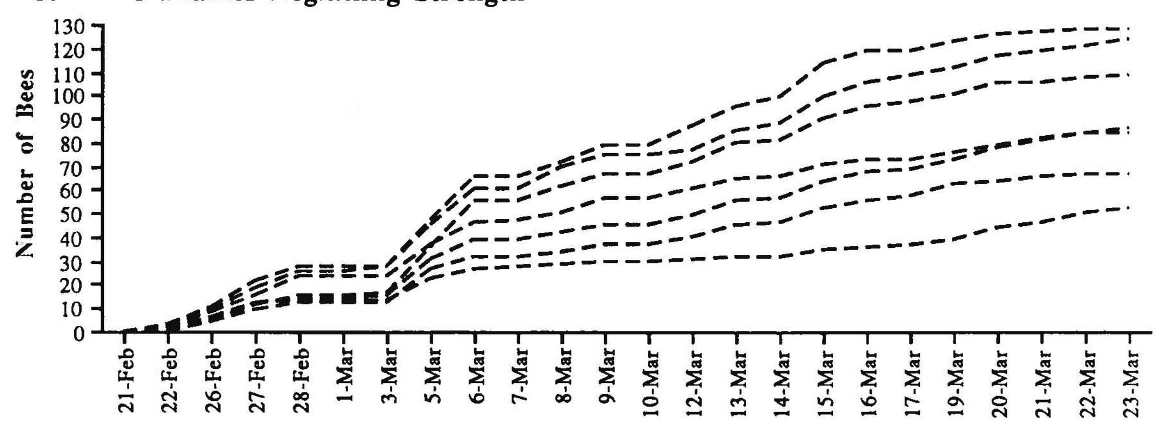
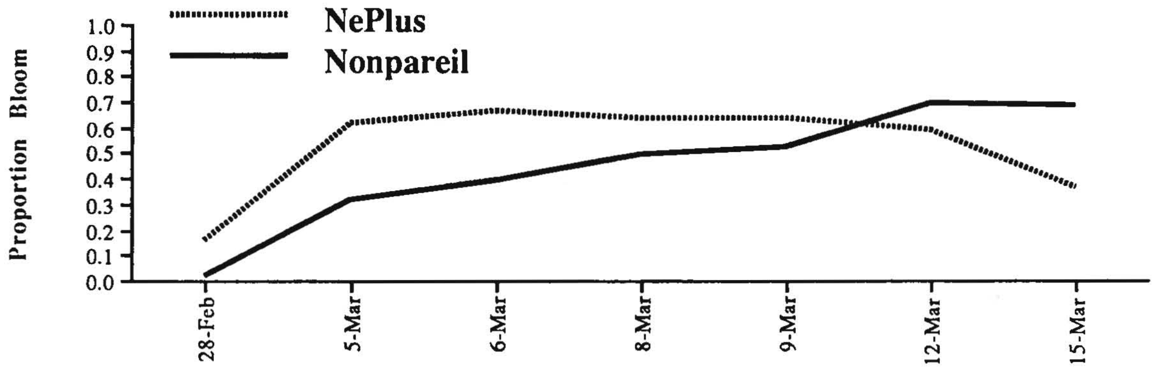


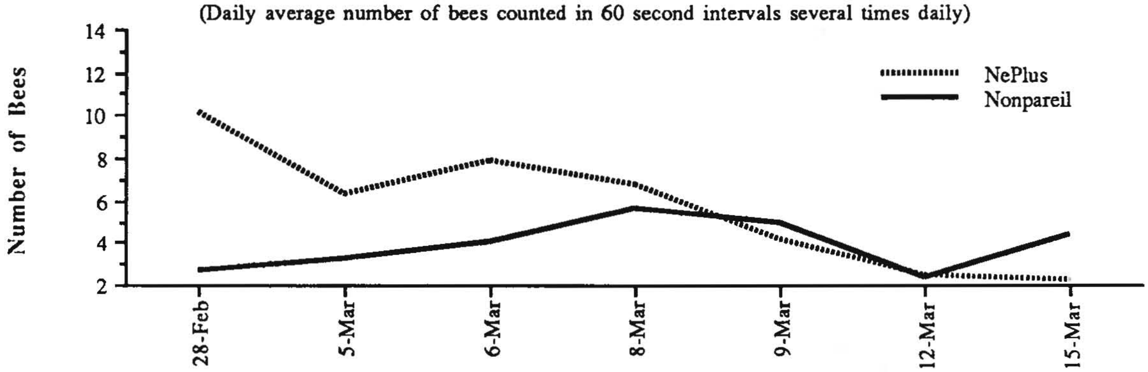
Figure 8. Bee movement between trees: NePlus and Nonpareil cultivars in an orchard near Davis, Ca. 1990.

A. Bloom progression of two cultivars on dates bee movement was monitored



B. Number of bees foraging in single trees of two cultivars

(Daily average number of bees counted in 60 second intervals several times daily)



C. Movement of bees between trees of the same and different cultivars

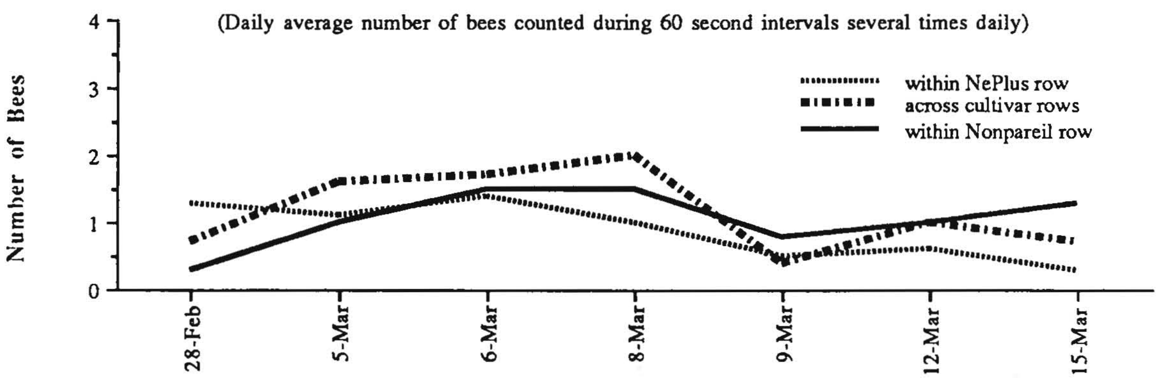
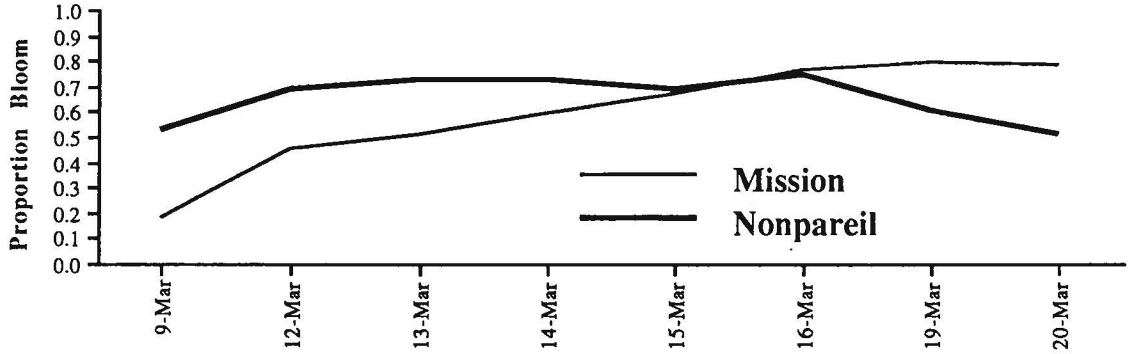


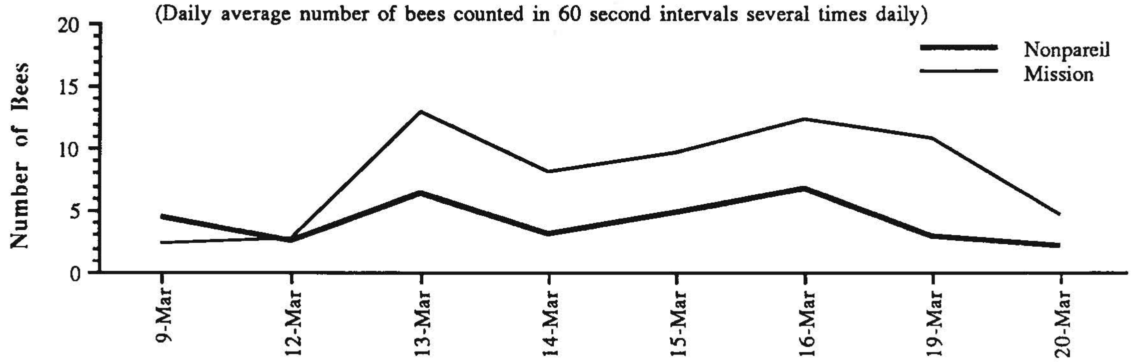
Figure 9. Bee movement between trees: Mission and Nonpareil in an orchard near Davis, CA. 1990.

A. Bloom progression on dates bee movement between trees was monitored



B. Number of bees foraging within single trees of two cultivars

(Daily average number of bees counted in 60 second intervals several times daily)



C. Movement of bees between trees of the same and different cultivars

(Daily average number of bees counted during 60 second intervals several times daily)