Honey Bee Colony Density and Almond Nut Set

Project No.: **11-POLL11-Eischen**

Project Leader: Frank A. Eischen
Research Entomologist
Honey Bee Research Unit
USDA-ARS
Weslaco, TX 78596
956.969.5007
frank.eischen@ars.usda.gov

Project Cooperators and Personnel:
R. Henry Graham, Raul Rivera, and Dr. William G. Meikle, Honey Bee Research Unit, USDA-ARS
Dr. Dale Spurgeon, Cotton Research Unit, USDA/ARS
Lee Brown, South Valley Farms
Dr. Gordon Wardell, Paramount Farming Company
Marty Hein and Carole Fornoff, Westchester Group, Inc.
Grey Wegis, Wegis & Young
Joe Traynor, Scientific Ag
Geordy Wise, Gardiner-King

Objectives:

The objective of this cooperative research project initiated in 2011season is to examine the effectiveness of differing colony densities on pollen transfer and almond nut set.

Interpretive Summary:

We examined the impact of honey bee colony density on almond pollination during the 2012 season. This was carried out on four ranches near Bakersfield, California. Both early and late blooming varieties were tested on each ranch. Blocks of almonds were paired for variety, age, tree density and management. One of the pair had a higher number of colonies per acre placed in or around it prior to bloom. Nominal colony density differed between pairs of orchards by 0.5 - 1.0 colony per acre. Colonies in surrounding orchards out to 1.5 miles were counted and mapped. Their contribution of foragers to test orchards were predicted based on prior work involving the modeling of almond pollen foraging data near Bakersfield, CA. Flower counts and video recordings of bee activity aided in interpreting pollination rates.

In general, orchards with higher colony densities had significantly higher pollination rates. Differences in percent pollination between low and high bee densities ranged from 1.2 to 20.2 percent for the early blooming varieties Nonpareil, Fritz, Monterey, Sonora, and Aldrich. When differences between a pair of orchards were below about 6%, we did not detect a significant difference. Significant increases in

pollination occurred in 60% of the paired early variety blocks. We did not detect a significant increase for the early variety Sonora, but availability of compatible pollen may have been a limiting factor. In the hardshell (late blooming varieties) blocks, 66.7% of high bee density orchards had significantly increased pollination rates. Differences between the low and high density blocks ranged from 1.7 – 17%. Again, when differences were less than about 6%, we did not detect significance.

In some cases, pairs of orchards were slightly out of phase in their bloom time. This together with competing bloom from nearby orchards tended to increase or decrease competition for pollinators and may have been a factor in the different rates of pollination observed.

Video recordings of bee activity on flowers found that foragers in high bee density blocks remained on a flowering branch longer than foragers in low density blocks. They also visited significantly more flowers on a branch. This may be the result of lower rewards (nectar and pollen) in blossoms causing foragers to spend more time collecting loads. Alternatively, foragers in high bee density blocks may have learned a certain expectation of reward. In any case, this increased time spent on a branch helps to explain why a doubling of honey bee colonies generally did not result in a doubling of the pollination rate for pairs of orchards. That is, pollination is more likely to occur when pollinators move from branch to branch.

Observations of bees foraging on adjacent Fritz and Nonpareil trees found that the number of visits to a flower resulted in differing pollination rates. Single visits to a Nonpareil and Fritz flower resulted in 4.6 and 24.0% pollination, respectively. This difference was significant and may help to explain why a variety in a particular year has a higher pollination rate than co-planted varieties.

Commercial nut harvest has yet to be done. Determining the impact that differing pollination rates may have had on harvest will be reported later.

Note: This is shortened version of a larger report with more detail that follows.

Materials and Methods:

Orchards. Pairs of early variety and hardshell orchards were matched as closely as possible for variety, tree age, density (spacing) orchard management, proximity (close enough that climatic conditions are similar, but distant enough to preclude significant bee flight between them). **Table 1** shows the size, varieties, and tree spacing for the 18 orchards. Test orchards had many commonalties, however there were unique attributes. Some of these factors involved missing trees, replanted young trees in an older orchard, and almond plantings in the surrounding area. We will detail known differences and their possible involvement on pollination and harvest in the results and discussion.

Bees. Colony densities located around and in the orchards are shown in **Table 2**. Colony density for a particular orchard is not entirely defined by the number of colonies placed there. We plotted colony placement 1.5 miles distant from the boundaries of test orchards. This information and our model of pollen foraging in almonds allow us to calculate effective colony densities. Effective colony densities were calculated as a function of foraging range observed in almond orchards near Bakersfield, CA during 2009 and 2010 (Eischen et al. submitted). The effective colony densities for test orchards are shown in **Table 2**. Colonies not rented by the grower, but within 1.5 miles of test orchards were plotted but not examined for strength. We made a simplifying assumption that, on average, they met a minimum strength of eight frames of bees. **Table 2** shows the number of additional colonies within 1.5 miles of test orchards.

A representative sample of colonies placed specifically for a test orchard were randomly selected and examined for adult bee strength (n = ≥ 20/orchard). Strength was measured using the standard pollination criteria of frames 70% covered with bees and all stages of brood present. The same colonies were given this examination prior to bloom (during 11 - 14 February 2012) and again at the end of bloom (6 – 9 March 2012). On the King orchards, all colonies were owned by Mr. Ron Spears of Mountain Avenue Bees, Inc. On the Wegis ranch, all colonies were owned by Mr. Ray Marquette. On Premiere/Westchester all colonies were owned either by Mr. Rhea Stroope or Mr. Ray Green. Four different beekeepers had colonies on the South Valley Farms test orchards (Mr. Steve Cantu, CDH Pollination, FL; Mr. Allen Brown, ID; Mr. Boydean Frazier, UT, & Mr. Kelly Keele, UT). We examined a random selection for each of them. The Wegis hardshell south orchard had only 24 colonies rented, i.e. 0.77 colonies/acre. With permission from Mr. Wegis, we applied bottom-style pollen traps. The removal of about 50% of the corbicular pollen loads by these traps causes colonies to double their pollen foraging, thus effectively doubling the number of colonies.

Pollen forager counts at hive entrance. We counted the number of returning pollen foragers at the colony entrance for twenty colonies in each orchard. Colonies were randomly selected for each observation and pollen foragers counted for two minutes.

New blossom counts. Twenty trees per variety in each orchard were monitored for new blossoms. These trees were immediately adjacent to and in the same row as our “pollination rate” tree. One or more branches at or above 10’ were flagged with engineering tape. The flagged branch(s) typically had 100 – 200 large buds. When flowering reached about 1-10% we began counting the number of open blossoms. After counting, these newly opened blossoms were removed.

Paired Flower visitation to Nonpareil and Fritz blossoms. During the 2011 study we observed a higher rate of pollination for Fritz when adjacent trees of Fritz and Nonpareil were monitored. In this study we chose a similar design using adjacent trees of both varieties (n = 8 pairs) in the King NE orchards. Branches of both varieties had a pollinator exclusion device placed over them. When blossoming began the device was opened and blossoms removed. Two days later the device was removed and the number of open blossoms on pairs of trees equilibrated by removing blossoms. Videos were made on 23 February. Bee visits were counted along with number of flowers visited and time spent per flower.

<u>Flower visitations and nut set</u>. On 24 February, branches having about 20 large buds each were bagged with a pollinator-exclusion basket. All open blossoms were removed. Early the next morning exclusion devices were removed. Open blossoms facing the camera position were tagged and numbered; those facing away removed. Exclusion devices were replaced. At 12.00 cameras were positioned, exclusion devices removed, video recording made for 45 minutes. This was repeated on 26 February using the same branch. The time spent/blossom and the number of flowers individual bees visited on the branch recorded. Eight days later, the pollination exclusion device was removed. Nut set was determined on 28 March.

<u>Flower visitation in high and low bee density orchards</u>. We monitored honey bee foraging on Fritz and Butte blossoms. These orchards were located on the King NE and King West orchards. We made 45-minute videos of randomly chosen flowering branches between four and five feet above ground. On 22 February, 10 cameras in each orchard monitored about 36" of 10 branches of Fritz flowers during 11.15 - 12.00. We counted the number of bee foragers, number of flowers visited by each bee and the time spent at each flower. Colony density was at 2.16/per acre on King west and 1.08/acre on King NE. We repeated this experiment using Butte flowers.

<u>Orchard Pollination</u>. Pollination was monitored by selecting 20-30 trees of each variety in each orchard. These were spaced at regular intervals. Each tree had two branches flagged. Both at about 10-14 feet on opposite sides of the tree. Each flagged early-variety branch had 136.6 ± 52.7 well-developed buds. Hardshell varieties had 161.0 ± 45.0 buds. Near the end of the blossoming period (2 – 9 March 2012), the number of open blooms was counted and any bud not in "pink tip" removed. Developing ovaries were examined for proof of fertilization during 25 March – 1 April 2012. Gentle pressure was applied to the side of the embryo. If it came off easily, it was considered unfertilized.

<u>Nut harvest</u>. Mature nuts were counted during the first week of August, but the data has yet to be analyzed.

<u>Pollen foraging Model</u>. We have developed a model for estimating bee density in almond orchards during pollination. The model has two versions, one in Excel and a second in C++. The model extends the capability of ALMOPOL (DeGrandi-Hoffman 1989).

<u>Statistics</u>. All data were analyzed with ANOVA and means evaluated with Fisher's Protected Least Significant Difference (FPLSD). The chi-square statistic was calculated for flower visitation data. All data presented as percentages were log transformed (SAS Institute 1999-2000).

Results and Discussion:

Orchards.
Tree age, density and spacing are shown in **Table 1**. Six of the 18 orchards had some level of replanting. On South Valley Farms, the percentage of replants ranged from 0.84 – 1.13%. On Premiere it was 0.82 – 3.35%. Replants were of varying ages. We have discounted the amount of bloom on trees up to three years old. Bloom for 4 and 5 year-old trees will be adjusted on a variety basis, and our final estimates of the bloom:bee ratio will reflect this.

Tree height was about 25' for both early and late varieties on both the South Valley Farms orchards and the Premiere orchards. Most of our flagged branches were at or above 12'. Nevertheless, the majority of the blossoms were above our test branches. We discovered after the colonies had been placed that the early variety Monterey on King west (high density-2.16 colonies per/acre) had low bud density. Our flower counts confirmed this.

Bees.
Colonies on Wegis had strengths greater than 8.0 frames of adult bees. Those placed on the 2.0 colonies/acre did not expand as much as those on the 1.0 colony/acre ($P < 0.05$, Fisher's Protected Least Significant Difference or FPLSD). Colonies on the King/Gardiner orchards started the trial with 8.0+ frames. Colonies on the 2.16 colonies/acre early variety block grew significantly less than those on the low density blocks ($P < 0.05$, FPLSD). King/Gardiner colonies placed on the hardshell blocks grew less than those on the early varieties, but ended the trial with about the same strength ($P > 0.05$, FPLSD).

Premiere/Westchester colonies were at or slightly less than an 8.0 frame average, excepting those placed on the 2.5 colonies/acre hardshell block. Those had a 6.5 frames of bees' average, however, these differences were not significant ($P > 0.05$, FPLSD). These colonies grew considerably (+1.9 - +3.5 frames), and at the end of the trial their strength was at or near 10 frames of bees, excepting the 2.5 colonies/acre early variety block (+ 0.8 frames).

South Valley Farm (SVF) early variety orchards had an above eight frame average and grew, to about 11.5 frames. The SVF hardshell colonies on the other hand started with about a six-frame average, and grew to 7.8 – 8.9 frames. Even though growth rates were significantly different for the hardshell varieties, their ending size was not. Colonies on the matched pairs were not significantly different either at the beginning or the end of the trial. Six of the checked colonies pollinating the test orchards went queenless during the trial. This was 1.4% of examined colonies.

Our model of pollen foraging found that colony density for several orchards had fewer effective colonies than the number of colonies rented. On the Wegis ranch, this occurred for the 2.0 colonies/acre early variety, and the 1.5 late variety orchard. The likely cause for the reduction at the 2.0 colony/acre orchard was that the balance of the ranch was stocked with 1.0 colony/acre. Five of the six orchards monitored on the King/Gardiner ranch had effective colony densities slightly lower than the stocking rate. Three of the four Premiere-Westchester orchards had effective colony densities higher than the nominal stocking rate. The fourth was slightly less than the stocking rate. This ranch was surrounded by almonds/bees which contributed to the elevated effective colony density. All four of the orchards at South Valley Farms had lower effective colony densities than the nominal stocking rate. The low density hardshell orchard has to its immediate south a large block of land not planted to almonds.

<u>Pollen forager counts at hive entrance</u>.

Returning pollen forager counts varied with colony size, date and time of observation. Prior work in almonds has shown that strength generally accounts for about 60% (correlation coefficients range from 0.7 – 0.8) of the variation of pollen collection. Differing error rates by four observers introduced additional variation into the data and correlation coefficients found between foragers and strength were lower than the expected. In this study their range was 0.268 – 0.525.

<u>New blossom counts</u>.

The number of buds monitored per tree for new blossoms ranged from 46.3 - 144.1 for the early varieties and 69.0 – 156.2 for the late varieties.

Wegis - The number of new flowers for Fritz, Nonpareil, and Monterey peaked near 25 February. Blossoming tended to be earlier at the south orchard and was significantly so for Monterey ($P < 0.05$, FPLSD). On the high bee density orchard 56.5% of Padre buds had opened during 22 – 26 February. This was significantly higher than the 29.8% of Padre blossoming on the Wegis South ($P < 0.05$, FPLSD). Though not significant, blossoming tended to be the reverse of this for Butte on the two orchards.

King - On the King ranch both the hardshell and early variety orchards show a similar pattern of bud counts, i.e., highest on the 1.08 colonies/acre (Fritz and Monterey), intermediate in the 1.33 colonies/acre block and lowest on the 2.16 colonies/acre (Butte and Padre). Significant differences for bloom time by all three early varieties occurred on the King ranch. In general, the King NE block was slower to bloom than the other two blocks. Monterey however, lagged significantly on the West block ($P < 0.05$, FPLSD). Near the end of bloom, most of the differences had disappeared. A similar pattern emerged for the hardshell varieties in that the Northeast block exhibited a significantly delayed bloom. This delay probably resulted in a high bee:bloom ratio as it was the last orchard in bloom. To a lesser extent, this also probably happened for the Padre planted in the west block. In our casual walks through the NE orchard we noticed high bee visitation. As expected, pollination was much higher than the nominal 1.08 colonies/acre. Bloom developed quickly in these blocks; essentially going from no bloom to peak in three days.

Premiere - Bloom times for the high and low bee density Premiere orchards were fairly uniform with no significant differences observed for counts near peak bloom ($P > 0.05$, FPLSD). This was true for both early and late varieties. At the end of bloom, there were small, but significant differences in the number of remaining unopened buds for the early variety Fritz and the late variety Padre ($P < 0.05$, FPLSD).

South Valley Farms - The early variety Monterey in the high bee density orchard had a significantly higher percentage of new blossoms open during the period 22 – 28 February than did the low density orchard ($P < 0.05$, FPLSD). The pair of hardshell orchards bloomed fairly close together. There were relatively small but significant differences in the number of new blossoms that opened near peak bloom for Padre and Mission ($P < 0.05$, FPLSD). These differences in blossom opening for Padre and Mission were still present near the end of the bloom ($P < 0.05$, FPLSD).

These data, though not as complete as we would like, give an estimate of the bloom cycle and helps predict when there was significant overlap between the early and late varieties. We suspect this overlap may be when many flowers are not being pollinated because of inter-variety competition for bee visitation.

<u>Paired Flower visitation to Nonpareil and Fritz blossoms</u>.
Bee visitation to pairs of Nonpareil and Fritz trees were similar. No differences were found for the number of bees foraging on the monitored branches, the number of flowers visited or the number of flowers visited per bee. During the 2011 season, we found that Fritz had significantly higher percentage of flowers pollinated than did Nonpareil.

<u>Flower visitations and nut set</u>.
Nonpareil flowers that were not visited by bees set no almonds. Those receiving one visit set nuts 4.6% of the time. Two bee visits to a blossom resulted in a 38.1% of those flowers to set an almond. This was significantly higher than the pollination/fertilization rate for those flowers receiving one visit ($P < 0.05$, chi-square = 8.31). Similar observations for Fritz flowers found that no nuts were set for unvisited flowers. One visit caused 24.0% of the flowers to set ($P < 0.05$, chi-square = 3.77), two visits resulted in 37.5% of flowers being set, which was not a significantly higher rate than those receiving only one visitor ($P < 0.05$, chi-square = 0.20). Pollination rates for Nonpareil and Fritz differed for those flowers receiving one bee visit (**Table 3**). Fritz had a significantly higher rate ($P < 0.05$, chi-square = 2.72). As mentioned in the previous section, this may explain why we observed a higher nut set for Fritz during the 2011 season.

Flower visitation in high and low bee density orchards.
Significantly more bees foraged on Fritz flowers in a high bee density orchard (2.16 colonies/acre) than they did in a low density orchard (1.08 colonies/acre, P < 0.05, FPLSD, **Table 4**). During a 45 minute video, 15.6 and 9.7 bees foraged on flowers high and low bee density orchards, respectively (P < 0.05, FPLSD). The number of flowers visited was likewise different. In the high density orchard 44.4 flowers were, on average, visited by bees; while 26.3 blossoms received visits in the low density orchard (P < 0.05, FPLSD). The number of flowers visited per bee (2.6 vs. 2.9) was not different (P > 0.05, FPLSD).

Similar data for Butte flowers in a pair of low and high bee density hardshell orchards found that 3.9 and 9.9 bees, respectively foraged on our test branches (P < 0.05, FPLSD, **Table 5**). The number of flowers visited during the 45 minute video was, on average, 6.2 and 28.7 for the low and high bee density orchards, respectively (P < 0.05, FPLSD). Nectar foragers spent 20.6 and 49.0 seconds on the low and high bee density branches, respectively (P < 0.05, FPLSD). Pollen foragers spent 14.0 and 31.5 seconds on the low and high bee density branches, respectively (P < 0.05, FPLSD). On average, pollen foragers spent less time on test branches than did nectar foragers. Though this was not significant, we suspect that our low replicate size (n = 8) caused this (P > 0.05, FPLSD). Pollen foragers spent slightly less time per flower than did nectar foragers in both high and low density blocks, but this was not significant (P > 0.05, FPLSD). It appears clear that more bees in the high-density, late variety orchard visited our test branches, foraged from more flowers, and spent more time on the branch than did bees in the low bee density orchard. Time spent per flower however was about the same. This suggests that the food rewards were about as abundant on both sets of branches, but that bees in the low density orchards were less likely to spend time on any given branch. This may actually work in favor of pollination for low bee density orchards. The bees visiting our test branches had doubtlessly experienced foraging in this orchard and assessed the likelihood of finding areas with richer rewards.

Orchard Pollination: Early Varieties.
Wegis - Nonpareil trees in the high density orchard, had a 5.6% increase in pollination (Table 6). This was not significant and considerably less than the 12.1% increase found in 2011. An 8.2 and 8.1% increase was observed for the high bee density Fritz and Monterey trees, respectively. These were significant (P < 0.05, FPLSD). The pollination rate for Fritz was significantly lower than that of the other two early varieties (P < 0.05, FPLSD, **Table 6**).

King - There were three different bee densities on this ranch. Pollination was significantly higher on the 2.16 colonies/acre block (**Table 6**). The pollination rate for Nonpareil on that block was 78.2% which was significantly higher than that of the low bee density block (1.08 colonies/acre) which was 67.8% (P < 0.05, FPLSD). The pollination rate for the intermediate bee density block (1.33 colonies/acre) was significantly lower (58.0%) than either of the high or low density blocks (P < 0.05, FPLSD). We do not know the cause for this, but the Northeast block (low bee density) may have benefited by a slowed bloom for Nonpareil. It appears that this variety lagged on that block. Fritz pollination on the three blocks followed a similar pattern (**Table 6**). It was significantly higher (82.0%) on the high bee density block (2.16 colonies/acre) compared to 72.3 and 73.1% pollination for the intermediate and low bee density blocks, respectively (P < 0.05, FPLSD). Monterey pollination across the three bee density blocks (66.8 – 73.2%) was not significantly different. However, bloom density and flowering of this variety on this ranch was unusual. Pollination was significantly higher for Fritz on the low bee density block (1.08 colonies/acre) than were the other two varieties. Nonpareil was significantly lower than the other two varieties on the intermediate bee density block (1.33/acre). In general, pollination rates for the early varieties on this ranch were higher than that observed on the other ranches. On five of the six blocks, effective colony density was slightly too marginally lower than the nominal colony density.

Premiere - Early variety pollination tended to be significantly higher on high bee density blocks (**Table 6**). The Nonpareil rate on the high and low blocks (2.5 vs 1.75 colonies/acre) was 57.7 and 49.3%, respectively (P < 0.05, FPLSD, **Table 6**). The difference was larger for Fritz. High and low bee density blocks had 48.0 and 31.7% pollination rates, respectively (P < 0.05, FPLSD). No significant differences were found for the variety Sonora. Nonpareil had a significantly higher pollination rate than did the other two varieties. The effective colony density on Premiere was above the nominal colony density for both high and low density orchards. It is likely that there was a significant elevation for the low density orchard where our model suggests an effective colony density of 2.19 colonies/acre and the nominal stocking levels was at 1.75/acre. Pollination for the early varieties on this ranch was low compared with the other ranches, even though colony density high.

South Valley Farms - Pollination of Nonpareil was high (74.1 and 80.1%, P < 0.05, FPLSD, **Table 6**) on both low and high bee density orchards. Significant differences were not detected between the two orchards. Monterey was comparatively lower at 50.1 and 40.1% for the high and low bee density orchards, respectively. These differences were significant (P < 0.05, FPLSD). Aldrich pollination was similar to Monterey in that high and low bee density orchards had 47.5 and 40.1% levels of pollination (P < 0.05, FPLSD).

<u>Orchard Pollination: Late Varieties</u>.

Wegis - The pollination rate for the hardshell variety Butte in the “high” density orchard (1.5 colonies/acre) was 44.9%, which was significantly different than that of the low (1.0 colonies/acre) bee density orchard (27.9%, P < 0.05, FPLSD, **Table 7**). We qualify the “high” density orchard inasmuch as the nominal colony density was only 0.77 colonies per acre. By pollen trapping, we effectively doubled the amount of pollen collection and thereby raised the nominal colony density to about 1.5 colonies/acre. Even with this, the effective colony density rose only to 1.02, which was less than the 1.16 effective colonies/acre for the low density orchard. The variety Padre had pollination rates similar to those of Butte. The “high”(1.5 colonies/acre) and low bee density (1.0 colonies/acre) orchards had pollination rates of 47.4 and 34.6%, respectively (P < 0.05, FPLSD).

King - The hardshell variety Butte had three levels of bee density. On the 2.16 colonies/acre, the pollination rate was 68.5% which was significantly higher than that found on the low (55.0%) and intermediate (53.6%) bee density orchards (P < 0.05, FPLSD, **Table 7**). Bloom was delayed significantly in the low density NE block (1.08 colonies/acre). Bloom in the surrounding orchards was declining, and it was apparent from our inspections that a high population of bees was foraging in that orchard. We suspect that the pollination rate for both Butte and Padre rose significantly as a result. Padre pollination followed the Butte pattern. On the west 2.16 colonies/acre block, we found that 65.7% of flowers set nuts which were significantly different than that observed for the intermediate colony density block (53.0%) but not different than that for the low density NE block (61.9%). On the low bee density NE block, Butte pollination was significantly lower than that of Padre (P < 0.05, FPLSD).

Premiere - We observed high pollination rates for both the low and high bee density blocks (**Table 7**). No significant difference was observed for Butte on the high and low bee density blocks. Padre had about a 10% higher pollination rate on the high bee density block than on the low block (P < 0.05, FPLSD). Likewise, Mission had a significantly higher rate on the high bee density block (P < 0.05, FPLSD). Butte had the highest pollination rate on both high and low bee density blocks when compared to Padre and Mission. Padre had the second highest and Mission was lowest on this pair of orchards. The rate for Mission was significantly lower than the other two varieties (P < 0.05, FPLSD). Pollination rates were lower than the nominal rate would suggest it should have been (**Table 7**). Starting colony size on the late varieties was smaller than on the other ranches. This was not true for the early variety blocks on this ranch.

South Valley Farms - For Butte and Padre, the high bee density block (3.0 colonies/acre) had significantly higher pollination (**Table 7**) than the low density block (P < 0.05, FPLSD). Overall, Mission had a nominally higher level of pollination, but not significantly so. That is for an unknown reason, Mission had a significantly higher rate of pollination than did Padre on both high and low density blocks. This was also true for Butte on the low density block (P < 0.05, FPLSD).

Research Effort Recent Publications:

None

References Cited:

DeGrandi-Hoffman, G., S.A. Roth, and G.M. Loper. 1989. ALMOPOL: A cross-pollination and nut set simulation model for almond. Jour. Amer. Soc. Hort. Sci. 114: 170-176.

SAS Institute 1999-2000. SAS/STAT User's Guide, 6th ed. SAS Institute, Inc. Gary, NC.
Eischen, F.A., Graham, R.H. and R. Rivera. 2008b. Overwintering nutritionally stressed honey bee colonies infested with *Varroa destructor*. Proc. Amer. Bee Research Conf., American Bee Journal

Table 1. Orchard size, varieties and tree densities.

Orchard	Acres	Varieties	Tree age (yrs)	Trees per acre[1]	Row spacing	Within row tree space
Wegis north Early	160	50% Nonpareil, 25% Fritz, 25% Monterey	7	114	24'	16'
Wegis south Early	160	50% Nonpareil, 25% Fritz, 25% Monterey	7	114	24'	16'
Wegis north Hardshell	160	50% Butte, 50% Padre	7	114	24'	16'
Wegis south Hardshell	32	50% Butte, 50% Padre	7	114	24'	16'
King NE Early	76.5	50% Nonpareil, 25% Fritz, 25% Monterey	7	109	22'	18'
King SE Early	76.0	50% Nonpareil, 25% Fritz, 25% Monterey	7	109	22'	18'
King West Early	76.5	50% Nonpareil, 25% Fritz, 25% Monterey	7	109	22'	18'
King NE Hardshell	17.8	66% Butte, 34% Padre (2 Butte trees alternated with 1 Padre)	7	114	22,	16'
King SE Hardshell	77.6	66% Butte, 34% Padre (2 Butte trees alternated with 1 Padre)	7	114	22,	16'
King West Hardshell	74.9	66% Butte, 34% Padre (2 Butte trees alternated with 1 Padre)	7	114	22,	16'
SVF North Early	40.1	50% Nonpareil, 25% Monterey, 25% Aldrich		85.8	24'	21'
SVF South Early	40.1	50% Nonpareil, 25% Monterey, 25% Aldrich		85.8	24'	21'

Table 1. Orchard size, varieties and tree densities (con't).

SVF North Hardshell	40.8	33.3% Butte, 33.3% Padre, 33.3% Mission		85.8	24'	21'
SVF South Hardshell	45.4	33.3% Butte, 33.3% Padre, 33.3% Mission		85.8	24'	21'
Premiere E Early	58.1	50% Nonpareil, 25% Sonora, 25% Fritz	18	75.2	24'	24'
Premiere W Early	70.6	50% Nonpareil, 25% Sonora, 25% Fritz	18	75.2	24'	24'
Premiere E Hardshell	62.1	50 Butte, 25% Padre, 25% Mission	18	75.2	24'	24'
Premiere W Hardshell	69.5	50 Butte, 25% Padre, 25% Mission	18	75.2	24'	24'

[1]See Appendix D for replant data.

Table 2. The nominal and effective[1] colony density on test orchards.

Orchard: Nominal colony density (colonies per acre) and varieties	Colonies set at orchard	Additional colonies placed ≤ 1.5 miles from test orchard[2]	Effective colony density (per acre)	Effective frames of bees/acre (per acre)[3]
Wegis: 1.0 colony/acre Early varieties	216	5,753	1.12 ± 0.18	
Wegis: 2 colonies/acre Early varieties	308	4,094	1.57 ± 0.26	
Wegis: 1.0 colonies/acre Late varieties	216	5,517	1.16 ± 0.09	
Wegis: 1.5 colonies/acre Late varieties (pollen trapped)	24 (x2)	2,604	1.02 ± 0.22	
King/Gardiner: Northeast 1.08 colony/acre; Early varieties	120	3,746	0.94 ± 0.17	
King/Gardiner: Southeast 1.33 colony/acre; Early varieties	168	2,418	1.29 ± 0.41	
King[1]: West 2.16 colony/acre; Early varieties	336	3,659	1.85 ± 0.31	
King/Gardiner: Northeast 1.08 colony/acre; Late varieties	24	3,844	0.78 ± 0.11	
King[1]: Southeast 1.33 colony/acre; Late varieties	228	2,418	1.54 ± 0.27	
King/Gardiner: West 2.16 colony/acre; Late varieties	324	3,635	1.92 ± 0.30	

(**Table 2** continued on next page.)

Table 2. The nominal and effective[1] colony density on test orchards (con't).

Premiere-Westchester 1.75 colonies/acre; Early varieties	168	6,878	2.19 ± 0.32	
Premiere-Westchester 2.5 colonies/acre; Early varieties	364	7,270	2.60 ± 0.39	
Premiere-Westchester 1.75 colonies/acre; Late varieties	120	5,802	1.91 ± 0.76	
Premiere-Westchester 2.5 colonies/acre; Late varieties	520	7,270	2.44 ± 0.50	
South Valley Farms 2.0 colonies/acre; Early varieties	120	7,730	1.68 ± 0.12	
South Valley Farms 2.5 colonies/acre; Early varieties	152	8,356	2.15 ± 0.15	
South Valley Farms 2.0 colonies/acre; Late varieties	100	7760	1.76 ± 0.18	
South Valley Farms 3.0 colonies/acre; Late varieties	144	7524	2.27 ± 0.18	

[1]Nominal colony density is the number of colonies rented for the orchard. Effective colony density is based on pollen foraging range of bees near Bakersfield, CA during the 2009 and 2010 almond pollination seasons.
[2]Our data indicates that 94.8% of [3]pollen foraging trips were made within 1.5 miles of the colony. We assume colonies beyond the orchard boundaries met an 8-frame average.

Table 3. Comparison of forager visits and nut set for Nonpareil and Fritz

Forager visits	N NP/F	% set Nonpareil	% set Fritz
0	48/17	0 a[1]	0 a
1	22/25	4.6 a[2]	24.0 b
2	21/8	38.1 a	37.5 a
3	3/3	66.7 a	33.3 a

[1]Means in a row followed by the same letter are not significantly different * $P < 0.05$
[2]Chi-square statistic = 2.72

Table 4. Honey bee visitation to Fritz flowers in a low and high honey bee density orchards. (Not all video material has been analyzed)

Variable	Low Density orchard[1] $\bar{x} \pm$ SD	High Density orchard[1] $\bar{x} \pm$ SD
Number of open flowers/branch (branch ca. 36" long)[2]	±	±
Number of bees visiting per branch	9.7 ± 4.2 a[3]	15.6 ± 6.3 b
Number of flowers visited	26.3 ± 13.6 a	44.4 ± 19.5 b
Number of flowers per bee	2.6 ± 0.7 a	2.9 ± 1.0 a
Seconds spent on branch (per bee) nectar & pollen foragers	±	±
Seconds spent on branch (per bee) nectar foragers only	±	±
Seconds spent on branch (per bee) pollen foragers only	±	±
Seconds spent per flower by nectar foragers	±	±
Seconds spent per flower by pollen foragers	±	±

[1]N = 10 branches for the low density orchard (King NE, (1.08 colonies/acre) and 7 for the high density (King West, (2.16 colonies/acre).
[2]Videos were taken on 22 Feb 2012 and were 45 minutes long. Orchards were in about 34 & 42% bloom for NE and West blocks on 20 Feb.
[3]Means in a row followed by the same letter are not significantly different (P > 0.05, FPLSD)

Table 5. Honey bee visitation to Butte flowers in a low and high honey bee density orchard.

Event/variable	Low Density orchard[1] (1.08 colonies/acre) $\bar{x}$ ± SD	High Density orchard[1] (2.16 colonies/acre) $\bar{x}$ ± SD
Number of open flowers/branch (branch ca. 36" long)[2]		
Number of bees visiting branch	3.9 ± 2.3 a	9.9 ± 4.8 b
Number of flowers visited	6.2 ± 4.7 a	28.7 ± 20.0b
Number of flowers/bee	1.5 ± 0.5 a	2.8 ± 0.5 b
Seconds spent on branch (per bee) nectar & pollen foragers	19.3 ± 23.2 a	41.7 ± 49.7 b
Seconds spent on branch (per bee) nectar foragers only	20.6 ± 23.3 a	49.0 ± 55.5 b
Seconds spent on branch (per bee) pollen foragers only	14.0 ± 23.4 a	31.5 ± 39.5 a
Seconds spent per flower by nectar foragers	13.3 ± 12.8 a	15.7 ± 19.9 a
Seconds spent per flower by pollen foragers	10.5 ± 11.0 a	11.0 ± 10.5 a

[1]N = 10 branches for the low density orchard (King NE) and 7 for the high density King West.
Videos were taken on 29 February 2012 and were 45 minutes long.

Table 6. Percent of pollination for early blooming varieties

Ranch Colonies/acre	Nonpareil $\bar{x} \pm SD$	Fritz $\bar{x} \pm SD$	Monterey $\bar{x} \pm SD$	Sonora $\bar{x} \pm SD$	Aldrich $\bar{x} \pm SD$
Wegis North 1.0/acre	59.3 ± 13.7a[1] A[2]	47.6 ± 19.2a B	55.4 ± 20.8a A	N/A	N/A
Wegis South 2.0/acre	64.9 ± 20.8a A	55.8 ± 22.0b B	63.5 ± 19.2b A	N/A	N/A
King/Gardiner 1.08/acre	67.8 ± 10.6a B	73.1 ± 12.0a A	66.8 ± 12.9a B	N/A	N/A
King/Gardiner 1.33/acre	58.0 ± 13.8b B	72.3 ± 15.6a A	65.8 ± 16.7a A	N/A	N/A
King/Gardiner 2.16/acre	78.2 ± 19.6c A	82.0 ± 22.6b A	73.2 ± 21.4a A	N/A	N/A
Premiere 1.75/acre	49.3 ± 13.4a A	31.7 ± 16.8a C	N/A	42.5 ± 12.4a B	N/A
Premiere 2.5/acre	57.7 ± 15.5b A	48.0 ± 19.2b B	N/A	43.7 ± 11.9a B	N/A
South Valley 2/acre	74.1 ± 19.8a A	N/A	40.1 ± 16.3a B	N/A	40.1 ± 16.9a B
South Valley 2.5/acre	80.1 ± 13.4a A	N/A	50.1 ± 14.2b B	N/A	47.5 ± 10.7b B

[1]Means in a column followed by the same lower case letter are not significantly different (P > 0.05, FPLSD).
[2]Means in a row followed by the same upper case letter (blue) are not significantly different (P > 0.05, FPLSD).

Table 7. Percent of pollination for late blooming varieties

Ranch Colonies/acre	Butte $\bar{x} \pm SD$	Padre $\bar{x} \pm SD$	Mission $\bar{x} \pm SD$
Wegis North 1.0/acre	27.9 ± 17.2a[1] B[2]	34.6 ± 12.0a A	N/A
Wegis South 1.5/acre	44.9 ± 14.8b A	47.4 ± 25.6b A	N/A
King/Gardiner, NE 1.08/acre	55.0 ± 12.2a B	61.9 ± 7.1a A	N/A
King/Gardiner, SE 1.33/acre	53.6 ± 13.9a A	53.0 ± 11.0b A	N/A
King/Gardiner, West 2.16/acre	68.5 ± 20.4b A	65.7 ± 23.9a A	N/A
Premiere 1.75/acre	65.4 ± 12.0a A	56.7 ± 11.1a B	40.5 ± 12.4a C
Premiere 2.5/acre	71.3 ± 20.6a A	66.5 ± 19.6b A	48.8 ± 12.4b B
South Valley Farms 2.0/acre	44.8 ± 11.4a B	37.9 ± 10.6a C	54.1 ± 15.6a A
South Valley Farms 3.0/acre	58.4 ± 18.4b A	49.5 ± 16.0b B	58.7 ± 18.9a A

[1]Means in a column followed by the same letter are not significantly different (P > 0.05, FPLSD).
[2]Means in a row followed by the same upper case letter (blue) are not significantly different (P > 0.05, FPLSD)./

Honey Bee Colony Density and Almond Nut Set

LARGER REPORT

Project No.: **11-POLL 11-Eischen**

Project Leader: Frank A. Eischen
Research Entomologist
Honey Bee Research Unit
USDA-ARS
Weslaco, TX 78596
office 956-969-5007
cell 956-514-1786
e-mail frank.eischen@ars.usda.gov

Project Cooperators and Personnel:
Researchers, Growers, and scientific advisors

Mr. R. Henry Graham
Research Technician
Honey Bee Research Unit
USDA-ARS
Weslaco, TX 78596
956-969-5018

Mr. Raul Rivera
Chemist
Honey Bee Research Unit
USDA-ARS
Weslaco, TX 78596
956-969-5018

Dr. William G. Meikle
Acting Research Leader
Honey Bee Research Unit
USDA-ARS
Weslaco, TX 78596
956-969-5019

Dr. Dale Spurgeon
Research Leader
Cotton Research Unit
USDA-ARS
Shafter, CA
661-746-8001

Mr. Lee Brown
South Valley Farms
15443 Beech Ave.
Wasco, CA 93280
661-391-9000

Dr. Gordon Wardell
Paramount Farming Co.
33141 E. Lerdo Hwy
Bakersfield, CA 93308-9767
661-477-0256

Mr. Marty Hein
& Ms. Carole Fornoff
Westchester Group, Inc.
2534 S. Conyer
Visalia, CA 93277
661-428-8108
559-435-5803

Mr. Greg Wegis
Wegis & Young
12816 Jomani Drive
Bakersfield, CA 93312
661-201-0068

Mr. Joe Traynor
Scientific Ag
1734 D Street Suite #2
Bakersfield, CA 93303
661-327-2631

Mr. Geordy Wise
(Gardiner-King)
8226 Rudd Ave.
Bakersfield, CA 93314
661-978-0585

Objectives: The objectives of this cooperative research project is to examine the effectiveness of differing colony densities on pollen transfer and almond nut set during the 2012 season.

Interpretive Summary:

We examined the impact of honey bee colony density on almond pollination. This was carried out on four ranches near Bakersfield, California. Both early and late varieties were tested on each ranch. Blocks of almonds were paired for variety, age, tree density and management. One of the pair had a higher number of colonies per acre placed in or around it prior to bloom. Nominal colony density differed between pairs of orchards by 0.5 - 1.0 colony per acre. Colonies in surrounding orchards out to 1.5 miles were counted and mapped. Their contribution of foragers to test orchards were predicted based on prior work involving the modeling of almond pollen foraging data near Bakersfield, CA. Flower counts and video recordings of bee activity aided in interpreting pollination rates.

In general, orchards with higher colony densities had significantly higher pollination rates. Differences in percent pollination between low and high bee densities ranged from 1.2 to 20.2 percent for the early varieties Nonpareil, Fritz, Monterey, Sonora, and Aldrich. When differences between a pair of orchards were below about 6%, we did not detect a significant difference. Significant increases in

pollination occurred in 60% of the paired early variety blocks. We did not detect a significant increase for the early variety Sonora, but availability of compatible pollen may have been a limiting factor. In the hardshell (late varieties) blocks, 66.7% of high bee density orchards had significantly increased pollination rates. Differences between the low and high density blocks ranged from 1.7 – 17%. Again, when differences were less than about 6%, we did not detect significance.

In some cases, pairs of orchards were slightly out of phase in their bloom time. This together with competing bloom from nearby orchards tended to increase or decrease competition for pollinators and may have been a factor in the different rates of pollination observed.

Video recordings of bee activity on flowers found that foragers in high bee density blocks remained on a flowering branch longer than foragers in low density blocks. They also visited significantly more flowers on a branch. This may be the result of lower rewards (nectar and pollen) in blossoms causing foragers to spend more time collecting loads. Alternatively, foragers in high bee density blocks may have learned a certain expectation of reward. In any case, this increased time spent on a branch helps to explain why a doubling of honey bee colonies generally did not result in a doubling of the pollination rate for pairs of orchards. That is, pollination is more likely to occur when pollinators move from branch to branch.

Observations of bees foraging on adjacent Fritz and Nonpareil trees found that the number of visits to a flower resulted in differing pollination rates. Single visits to a Nonpareil and Fritz flower resulted in 4.6 and 24.0% pollination, respectively. This difference was significant and may help to explain why a variety in a particular year has a higher pollination rate than co-planted varieties.

Commercial nut harvest has yet to be done. Determining the impact that differing pollination rates may have had on harvest will be reported later.

Materials and Methods:

Orchards. Pairs of early variety and hardshell orchards were matched as closely as possible for cultivars, tree age, tree density (spacing) orchard management (water, soil, disease control, and owner), proximity (close enough that climatic conditions are similar, but distant enough to preclude significant bee flight between them). Table 1 shows the size, varieties, and tree spacing for the 18 orchards. Figures 1 - 16 show the geographic locations, approximate dimensions, and shapes of orchards. Test orchards had many commonalties, however there were unique attributes to each. Some of these factors involved missing trees, replanted young trees in an older orchard, almond plantings in the surrounding area, onset of bloom, etc. We will detail known differences and their possible involvement on pollination and harvest in the results and discussion section below.

Bees. Colony densities located around and in the orchards are shown in Table 2. Colony density for a particular orchard is not entirely defined by the number of colonies placed there. We plotted colony placement 1.5 miles distant from the boundaries of test orchards. This information and our model of pollen foraging in almonds allow us to calculate effective colony densities. Effective colony densities were calculated as a function of foraging range observed in almond orchards near Bakersfield, CA during 2009 and 2010 (Eischen et al. submitted; Appendix A). The effective colony densities for test orchards are shown in Table 2. Colonies not rented by the grower, but within 1.5 miles of test orchards were plotted but not examined for strength. We made a simplifying assumption that, on average, they met a minimum strength of eight frames of bees. Table 2 shows the number of additional colonies within 1.5 miles of test orchards.

A representative sample of colonies placed specifically for a test orchard were randomly selected and examined for adult bee strength ($n = \geq 20$/orchard). Strength was measured using the standard pollination criteria of frames 70% covered with bees and all stages of brood present. We have considerable experience evaluating colonies. One of us (RHG) is a former commercial beekeeper who during the past 12 years has worked for the USDA-ARS and has regularly evaluated about 2,000 colonies annually. The same colonies were given this examination prior to bloom (during 11 - 14 February 2012) and again at the end of bloom (6 – 9 March 2012, Table 3). On the King orchards, all colonies were owned by Mr. Ron Spears of Mountain Avenue Bees, Inc. On the Wegis ranch, all colonies were owned by Mr. Ray Marquette. On Premiere/Westchester all colonies were owned either by Mr. Rhea Stroope or Mr. Ray Green. Four different beekeepers had colonies on the South Valley Farms test orchards (Mr. Steve Cantu, CDH Pollination, FL; Mr. Allen Brown, ID; Mr. Boydean Frazier, UT, & Mr. Kelly Keele, UT). We examined a random selection for each of them. The Wegis hardshell south orchard had only 24 colonies rented, i.e. 0.77 colonies/acre. With permission from Mr. Wegis, we applied bottom-style pollen traps. The removal of about 50% of the corbicular pollen loads by these traps causes colonies to double their pollen foraging, thus effectively doubling the number of colonies. We did this to try to boost the pollination rate in this orchard. Though this orchard yielded satisfactorily during the 2011 season, pollination rate was low.

Pollen forager counts at hive entrance. We counted the number of returning pollen foragers at the colony entrance for twenty colonies in each orchard. Colonies were randomly selected for each observation and pollen foragers counted for two minutes. Times of observations varied, i.e., Wegis 2/21, 9.30-10.15, 2/22, 13.30-14.30; King/Gardiner 2/22, 12.15-13.15, 2/23, 13.30-14.30,2/24, 10.30-11.30; Premiere 2/20, 10.45-11.45, 13.45-14.45; South Valley Farms 2/24, 9.30-10.30, 13.14.30; 2/28, 13.30-14.30hrs. Colonies were often placed between early and late variety orchards under observation. We do not present data by ranch ownership, but rather than orchard variety. Because of time constraints, we used four different observers, each of which likely had a different error rate. Our previous work on foraging flights for almonds shows good correlation with strength. We did these observations to determine whether or not foraging in pairs of orchards under observation were significantly different.

New blossom counts. We suspect the blossom to bee ratio (along with weather) is a key factor to understanding the relationship of bee density and pollination rate (as bloom density increases, the likelihood that any given blossom receiving a foraging visit changes). Another way of looking at this is the reward evaluation that bees make while working almonds. High reward typically brings recruits. To get a better understanding of this, we counted the number of new blossoms for each variety in each orchard about every third day. Twenty trees per variety in each orchard were monitored for new blossoms. These trees were immediately adjacent to and in the same row as our “pollination rate” tree. One or more branches at or above 10’ were flagged with engineering tape. The flagged branch(s) typically had 100 – 200 large buds. When flowering reached about 1-10% we began counting the number of open blossoms. After counting, these newly opened blossoms were removed. Because there was a certain amount of unevenness of bloom within orchards, we employed a limited amount of aerial photography to help monitor bloom. We have not yet examined these photos.

Paired Flower visitation to Nonpareil and Fritz blossoms. During the 2011 study we observed a higher rate of pollination when adjacent trees of Fritz and Nonpareil were monitored. In this study we chose a similar design using adjacent trees of both varieties (n = 8 pairs) in the King NE orchard. Branches of both varieties had a pollinator exclusion device placed over it. When it was apparent that blossoms were opening, the device opened and blossoms removed. Two days later the device was removed and the number of open blossoms on pairs of trees equilibrated by removing blossoms. Forty-five minute videos were made of blossoms simultaneously on 23 February. Videos were downloaded to a computer and bee visits counted along with number of flowers visited and time spent per flower. The object of this study was to determine if more bee visits occurred to Fritz flowers than to Nonpareil.

Flower visitations and nut set. Multiple bee visits are beneficial to seed set in other crops. In this study, we monitored the number of bee visitations and resulting nut set for Fritz and Nonpareil flowers. On 24 February, branches (n = 6 Fritz, 11 Nonpareil, King ranch, 2.16 colonies/acre) having about 20 large buds each were bagged with a pollinator-exclusion basket (Appendix B). All open blossoms were removed. Early the next morning (8.30am, 25 Feb.) exclusion devices were removed and a camera position determined. Open blossoms facing the camera position were tagged and numbered. Those facing away were removed. Exclusion devices were replaced. At 12.00 cameras were positioned, exclusion devices removed, video recording made for 45 minutes, and then downloaded to a computer. This was repeated on 26 February using the same branch. The weather was cool on the first run of this experiment and few bees visited the flowers. Individual flowers were given a designation in the video and then numbers of bees visiting that blossom counted. The time spent/blossom and the number of flowers individual bees visited on the branch recorded. Eight days later, the pollination exclusion device was removed. Nut set was determined on 28 March.

Flower visitation in high and low bee density orchards. In this study, we monitored honey bee foraging on the early variety Fritz and late variety Butte blossoms. These orchards were located on the King NE and King West orchards. Early and late variety orchards were adjacent at these two locations. The general methods of tree branch bagging, blossom age, and video recordings were as described above. In brief, We made 45-minute videos of randomly chosen flowering branches between four and five feet above ground. On 22 February, 10 cameras in each orchard monitored about 36” of 10 branches of Fritz flowers during 11.15 - 12.00. We downloaded the videos onto a computer hard drive and then counted the number of bee foragers, number of flowers visited by each bee and the time spent at each flower. Colony density was at 2.16/per acre on King west and 1.08/acre on King NE. Bloom was about 50% complete. The object of this study was to determine if colony density would result in a commensurate number of bee visits. It also served to begin the process of validating our pollen foraging model. We repeated this experiment using Butte flowers during 13.35-14.15, 29 February. Butte was near 80% in bloom.

Orchard Pollination. Pollination was monitored by selecting 20-30 trees of each variety in each orchard. These were spaced at regular intervals (usually 10-12 trees between monitored trees, see Figures 1 - 16 for layout). On north to south planted tree rows, each tree had two branches flagged with engineering tape. One branch was at about 10+ feet on the east side of the tree and a second at about the same height on the west side. One orchard (Wegis South, hardshell) had its trees planted east to west. In this case, monitored branches were flagged on the north and south sides of trees. Each flagged early-variety branch had 136.6 ± 52.7 well-developed buds. Hardshell varieties had 161.0 ± 45.0 buds. Five branches of each variety were randomly selected in each orchard and had a pollination exclusion device placed on it before blooming began. These were removed near the end of the blooming cycle, the number of blossoms counted, and unopened buds removed. These were our negative control blossoms. Near the end of the blossoming period (2 – 9 March 2012), the number of open blooms was counted and any bud not in "pink tip" removed. Developing ovaries were examined for proof of fertilization during 25 March – 1 April 2012. Gentle pressure on its side was applied to the embryo. If it came off easily, it was considered unfertilized and vice versa.

Nut harvest. Mature nuts have not yet been counted, but we plan doing so starting 1 August. Commercial harvesting of nuts will be by cultivar (for the early cultivars but probably not for the hardshells). Actual nut harvest data from the growers will likely be received sometime during late January

2013. This schedule is apparently set by hulling/nut processing mills. Correlations between our counts of harvestable nuts on our flagged branches and actual harvested nuts (by weight) will be made. To insure that correlations are done correctly, we plan to weigh a series of freshly harvested and dried nuts.

Pollen transfer. This part of the proposal was not done due to time constraints. We had planned to monitor pollen transfer on trees immediately adjacent to and in the same row as those trees involved in determining pollination rates. One branch on each tree (about five feet above ground—we did not see large differences in pollination rates on a given tree with respect to height during the 2011 season) will be tagged with engineering tape during the 2013 season. Fifteen blossoms whose pistils and petals show clear sign of senescence will be randomly chosen and their pistils removed and preserved in ethyl alcohol. Pollen attached to the stigma of pistils will be counted. These counts will be used as a measure of bee activity. In hindsight we should have done this as it would serve to validate the pollination model.

Pollen foraging Model. We have developed a model for estimating bee density in almond orchards during pollination.

The model has two versions, one in Excel and a second in C++. Both should run on any computer. The Excel version has the advantage of being easy to understand and to modify, but it has limitations in its application and can be cumbersome due to its size. The C++ version is much smaller and more versatile, but the code can only be modified using C++ software. Appendix B shows how colony density maps are constructed. The model extends the capability of ALMOPOL (DeGrandi-Hoffman 1989).

Statistics.

All data were analyzed with ANOVA and means evaluated with Fisher's Protected Least Significant Difference (FPLSD). The chi-square statistic was calculated for flower visitation data. All data presented as percentages were log transformed (SAS Institute 1999-2000).

Results and Discussion:

Orchards. Tree age, density and spacing are shown in Table 1. Wegis and King orchards were relatively young and denser, while those of Premiere and South Valley Farms were older and less dense. Six of the 18 orchards had some level of replanting in progress (Appendix D). On South Valley Farms, the percentage of replants ranged from 0.84 – 1.13%. On

Premiere it was 0.82 – 3.35%. Replants were of varying ages. We are not yet sure how to incorporate this data into bloom/bee ratio and the harvestable acreage. We have been guided by the Regional Almond variety trials 1998 report for Kern County (Appendix D). This documents the observed vs. predicted harvest for the different varieties by age. Based on this we discounted the amount of bloom on trees up to three years old. Bloom for four and five year-old trees will be adjusted on a variety basis, and our final estimates of the bloom : bee ratio will be adjusted accordingly. This calculation will be done after harvest.

Tree height was about 25′ for both early and late varieties on both the South Valley Farms orchards and the Premiere orchards. Most of our flagged branches were at or above 12′. Nevertheless, the majority of the blossoms were above our test branches. We discovered after the colonies had been placed that the early variety Monterey on King west (high density-2.16 colonies per/acre) had low bud density. Mr. Wise thought it likely that an Alternaria fungal infection was on that block and that Monterey seemed more susceptible to it. Our flower counts confirmed the low bud density. The harvest data for Monterey on this block may be deleted later.

Bees. At the beginning of the trial, colonies on the Wegis orchards had, on average, strengths greater than 8.0 frames of adult bees (Table 3). Those placed on the 2.0 colonies/acre early varieties did not expand their populations as much as those on the 1.0 colony/acre ($P < 0.05$, Fisher's Protected Least Significant Difference or FPLSD). Colonies on the King/Gardiner orchards likewise started the trial with above 8.0 frame averages. Those colonies on the 2.16 colonies/acre early variety block grew significantly less than those on the low density blocks ($P < 0.05$, FPLSD). King/Gardiner colonies placed on the hardshell blocks grew less than those on the early varieties, but ended the trial with about the same strength ($P > 0.05$, FPLSD). Premiere/Westchester colonies were at or slightly less than an 8.0 frame average, excepting those placed on the 2.5 colonies/acre hardshell block. Those had a 6.5 frames of bees average at the beginning of the trial, however, these differences were not significant ($P > 0.05$, FPLSD). These colonies grew considerably (+1.9 - +3.5 frames), and at the end of the trial their strength was at or near 10 frames of bees, excepting the 2.5 colonies/acre early variety block (+ 0.8 frames). South Valley Farm (SVF) early variety orchards had an above eight frame average and grew, on average to about 11.5 frames. The SVF hardshell colonies on the other hand started with about a six-frame average, and grew to 7.8 – 8.9 frames. Even though growth rates were significantly different for the hardshell varieties, their ending size was not. In fact, colonies on the matched pairs (or triply matched) orchards were not significantly different either at the beginning or the end of the trial. Six of the checked colonies pollinating the test orchards went queenless during the trial. This was 1.4% of examined colonies. Typically, these colonies collect reduced amounts of pollen, but because they were distributed over three of the four growers, we think it was not a significant factor in pollination.

Our model of pollen foraging (Appendix B) found that the effective colony density for several orchards had fewer effective colonies than the number of colonies rented (Table 3). On the Wegis ranch, this occurred for the 2.0 colonies/acre early variety, and the 1.5 late variety orchard. The likely cause for the reduction at the 2.0 colony/acre orchard was that the balance of the ranch was stocked with 1.0 colony/acre. Thus, many of the foragers at that orchard went beyond it. The hardshell orchard (32 acres) was stocked with 24 colonies. We have good evidence that pollen trapping doubles the number of pollen foragers. Even with this, the effective colony density was only 1.02 and not the nominal 1.5

per acre. We think the main cause for this was that there were no colonies/almonds to the south. Those almonds to the east were not owned by Wegis and few colonies were placed there. Still, pollination rate for this hardshell orchard rose from about 29% observed in 2011 (same number of colonies then) to 44% for 2012. We think this is largely due to the pollen trapping.

Five of the six orchards monitored on the King/Gardiner ranch had effective colony densities slightly lower than the stocking rate. Because colonies are placed between early and late variety blocks, it is not always possible to calculate the precise nominal stocking rate. It is likely that differences were not significant for all orchards excepting the two high density (2.16 colonies/acre) blocks on the west side of the ranch. There were no almonds/bees to the south and all the almonds to the east were stocked at lower rates.

Three of the four Premiere-Westchester orchards had effective colony densities higher than the nominal stocking rate. The fourth was slightly less than the stocking rate. This ranch was surrounded by almonds/bees which contributed to the elevated effective colony density.

All four of the orchards at South Valley Farms had lower effective colony densities than the nominal stocking rate. The low density hardshell orchard has to its immediate south a large block of land not planted to almonds. This same block of apparently unfarmed land affects the effective colony density for the high density hardshell orchard. The early variety orchards are near Kimberlina Rd. Almond plantings nearly surround these orchards, but to the south are younger orchards not owned by SVF and not stocked with as many colonies per acre.

Pollen forager counts at hive entrance. Returning pollen forager counts varied with colony size, date and time of observation (Table 4). Prior work in almonds has shown that strength generally accounts for about 60% (correlation coefficients range from 0.7 – 0.8) of the variation of pollen collection. We have not yet measured the other factors that we suspect influences pollen foraging (general colony health, varroa infestation, age structure of the adult population, etc.). We do know that high nosema infections severely reduce almond pollen collection (Eischen et al. 2008a).

Differing error rates by four observers introduced additional variation into the data and correlation coefficients found between foragers and strength were lower than the expected 0.7 – 0.8. In this study their range was 0.268 – 0.525. We have done numerous counts of pollen foragers in the past using just one observer with satisfactory results (high correlations with colony strength). Because of this, we present past work with the belief that they are applicable to this work (Appendix E).

New blossom counts. The number of buds monitored per tree for new blossoms ranged from 46.3 - 144.1 for the early varieties and 69.0 – 156.2 for the late varieties (Tables 5 and 6). In some pairs of orchards significant differences were observed. It is possible that this is the outcome of our random selection of branches to monitor. We think this unlikely, however. On the King ranch both the hardshell and early variety orchards show a similar pattern of bud counts, i.e., highest on the 1.08 colonies/acre (Fritz and Monterey), intermediate in the 1.33 colonies/acre block and lowest on the 2.16 colonies/acre (Butte and Padre). Early variety and late variety blocks were adjacent. This suggests that flower density was significantly higher and may be related to that area of the ranch. Alternatively, orchard blocks may have gotten out of phase with each other with respect to “up” year “down” year. We have not yet inspected the yield history of these blocks. A significant difference was found on the Wegis ranch for the late variety Padre. On the Wegis South (1.5 colonies/acre) we tagged branches with 156.2 buds/tree and Wegis North (1.0 colonies/acre) there were 120.8 ($P < 0.05$, FPLSD). We do not know if this is of importance at this stage.

Wegis; early varieties. The number of new flowers for Fritz, Nonpareil, and Monterey peaked near 25 February (Fig. 21). Blossoming tended to be earlier at the south orchard (Figs. 22 - 24) and was significantly so for Monterey ($P < 0.05$, FPLSD, Table 7). The onset of new blossoms for Wegis hardshell varieties Butte and Padre seemingly developed similarly (Fig. 25). However, this is probably not the case. On the high bee density orchard (Wegis South; Figs 26-27) 56.5% of Padre buds had opened during 22 – 26 February. This was a significantly higher than the 29.8% of Padre blossoming on Wegis North ($P < 0.05$, FPLSD, Table 8). Though not significant, blossoming tended to be the reverse of this for Butte on the two orchards. In general appearance, these two orchards had a similar bloom, but by variety on the two blocks, they were not. The significance of this may be minor. Had there been an effect, we would expect to see a pollination rate difference for the variety that reached peak bloom soonest.

The potential overlap with remaining early variety blooms would have been greatest then.

Significant differences for bloom time by all three early varieties occurred on the King ranch (Figs. 28 – 31 and Table 7). In general, the King NE block (low bee density) was slower to bloom than the two blocks. Monterey however, lagged significantly on the West block ($P < 0.05$, FPLSD). Near the end of bloom, most of the differences had disappeared (Table 9). A similar pattern emerged for the hardshell varieties (Butte and Padre) in that the Northeast block exhibited a significantly delayed bloom (Figs. 32 – 34 and Table 8). This delay probably resulted in a high bee : bloom ratio as it was the last orchard in bloom. To a lesser extent, this also probably happened for the Padre planted in the west block. In our casual walks through the NE orchard we noticed high bee visitation. We expected pollination to be much higher than the nominal 1.08 colonies/acre and this proved to be the case (see pollination section below). Bloom developed quickly in these blocks; essentially going from no bloom to peak in three days.

Bloom time for the high and low bee density Premiere orchards were fairly uniform with no significant differences observed for counts near peak bloom ($P > 0.05$, FPLSD, Tables 8 & 9 and Figures 35 – 42). This was true for both early and late varieties. At the end of bloom, there were small, but significant differences in the number of remaining unopened buds for the early variety Fritz and the late variety Padre ($P < 0.05$, FPLSD, Tables 9 & 10).

On South Valley Farms, the early variety Monterey in the high bee density orchard had a significantly higher percentage of new blossoms open during the period 22 – 28 February than did the low density orchard ($P < 0.05$, FPLSD, Table 7 and Figures 43 – 46). The pair of hardshell orchards bloomed fairly close together (Table 8 and Figures 47 – 50). There were relatively small but significant differences in the number of new blossoms that opened near peak bloom for Padre and Mission ($P < 0.05$, FPLSD). These differences in blossom opening for Padre and Mission was still present near the end of the bloom ($P < 0.05$, FPLSD, Table 10).

These data, though not as complete as we would like, give an estimate of the bloom cycle and helps predict when there was significant overlap between the early and late varieties. We suspect this overlap may be when many flowers are not being pollinated because of inter-variety competition for bee visitation. Bloom density is roughly predicted by these blossom counts. This is an area that we need better information to adequately determine the blossom to bee ratio.

Paired Flower visitation to Nonpareil and Fritz blossoms. Bee visitation to pairs of Nonpareil and Fritz trees were similar (Table 11). No differences were found for the number of bees foraging on the monitored branches, the number of flowers visited or the number of flowers visited per bee. During the 2011 season, we found that Fritz had significantly higher percentage of flowers pollinated than did Nonpareil. The current work was an attempt to find out why. In short, we do not know. It is apparently not caused by differences in attractiveness. It may be that pollen transfer is more efficient for Fritz flowers. Alternately, Fritz may be more readily fertilized than is Nonpareil. The data of the next section indicates that one of these is the case.

Flower visitations and nut set. Nonpareil flowers that were not visited by bees set no almonds (Table 12). Those receiving one visit set nuts 4.6% of the time. Two bee visits to a blossom resulted in a 38.1% of those flowers to set an almond. This was significantly higher than the pollination/fertilization rate for those flowers receiving one visit ($P < 0.05$, chi-square = 8.31). During our 45 minute videos, only three flowers received three visits and two those set nuts (66.7%), though that was not significantly different from those flowers who received two visits. Similar observations for Fritz flowers found that no nuts were set for unvisited flowers (Table 13). One visit caused 24.0% of the flowers to set ($P < 0.05$, chi-square = 3.77), two visits resulted in 37.5% of flowers being set, which was not a significantly higher rate that those receiving only one visitor ($P < 0.05$, chi-square = 0.20). Only one of three flowers visited three times was set (33.3%). Pollination rates for Nonpareil and Fritz differed for those flowers receiving one bee visit (Table 14). Fritz had a significantly higher rate ($P < 0.05$, chi-square = 2.72). As mentioned in the previous section, this may explain why we observed a higher nut set for Fritz during the 2011 season.

<u>Flower visitation in high and low bee density orchards</u>. Significantly more bees foraged on Fritz flowers in a high bee density orchard (2.16 colonies/acre) than they did in a low density orchard (1.08 colonies/acre, $P < 0.05$, FPLSD, Table 15). During a 45 minute video, 15.6 and 9.7 bees foraged on flowers high and low bee density orchards, respectively ($P < 0.05$, FPLSD). The number of flowers visited was likewise

different. In the high density orchard 44.4 flowers were, on average, visited by bees; while 26.3 blossoms received visits in the low density orchard ($P < 0.05$, FPLSD). The number of flowers visited per bee (2.6 vs. 2.9) was not different ($P > 0.05$, FPLSD). This report will be updated after we have completed our analyses.

Similar data for Butte flowers in a pair of low and high bee density hardshell orchards found that 3.9 and 9.9 bees, respectively foraged on our test branches ($P < 0.05$, FPLSD, Table 16). The number of flowers visited during the 45 minute video was, on average, 6.2 and 28.7 for the low and high bee density orchards, respectively ($P < 0.05$, FPLSD). Nectar foragers spent 20.6 and 49.0 seconds on the low and high bee density branches, respectively ($P < 0.05$, FPLSD). Pollen foragers spent 14.0 and 31.5 seconds on the low and high bee density branches, respectively ($P < 0.05$, FPLSD). On average, pollen foragers spent less time on test branches than did nectar foragers. Though this was not significant, we suspect that our low replicate size ($n = 8$) caused this ($P > 0.05$, FPLSD). Pollen foragers spent slightly less time per flower than did nectar foragers in both high and low density blocks, but this was not significant ($P > 0.05$, FPLSD). It appears clear that more bees in the high-density, late variety orchard visited our test branches, foraged from more flowers, and spent more time on the branch than did bees in the low bee density orchard. Time spent per flower however was about the same. This suggests that the food rewards were about as abundant on both sets of branches, but that bees in the low density orchards were less likely to spend time on any given branch. This may actually work in favor of pollination for low bee density orchards. The bees visiting our test branches had doubtlessly experienced foraging in this orchard and assessed the likelihood of finding areas with richer rewards. Bees in the low density orchards by their shorter times on the branch may have learned to seek more rewarding forage sites by spending less time on a given branch. We are still examining the videos for evidence of how bees are making choices.

Orchard Pollination: Early Varieties.

On the Wegis ranch, Nonpareil trees in the high bee density orchard (2.0 colonies per acre), we found only a 5.6% increase in pollination (Table 17). This was not significant and considerably less than the 12.1% increase found in 2011 (68.1 vs. 56.0, high vs low density, 2011) on the same blocks. An 8.2 and 8.1% increase was observed for the high bee density Fritz and Monterey trees, respectively. These were significant increases in pollination ($P < 0.05$, FPLSD). The pollination rate for Fritz was significantly lower than that of the other two early varieties ($P < 0.05$, FPLSD, Table 17). The effective colony density on the early variety blocks was slightly higher than the nominal colony density (Table 2), while the reverse was true for the hardshell varieties.

There were three different bee densities on the King/Gardiner ranch. Pollination was significantly higher on the 2.16 colonies/acre block (Table 17). The pollination rate for Nonpareil on that block was 78.2% which was significantly higher than that of the low bee density block (1.08 colonies/acre) which was 67.8% ($P < 0.05$, FPLSD). The pollination rate for the intermediate bee density block (1.33 colonies/acre) was significantly lower (58.0%) than either of the high or low density blocks ($P < 0.05$, FPLSD). We do not know the cause for this, but the Northeast block (low bee density) may have benefited by a slowed bloom for Nonpareil. It appears that this variety lagged on that block by a day or two (Figure 29). Fritz pollination on the three blocks followed a similar pattern (Table 17). It was significantly higher (82.0%) on the high bee density block (2.16 colonies/acre) compared to 72.3 and 73.1% pollination for the intermediate and low bee density blocks, respectively ($P < 0.05$, FPLSD). Monterey pollination across the three bee density blocks (66.8 – 73.2%) was not significantly different. However, bloom density and flowering of this variety on this ranch was unusual (Figure 30) and we considered deleting it from the data, but have included it in the interest of completeness. Pollination was significantly higher for Fritz on the low bee density block (1.08 colonies/acre) than were the other two varieties. Nonpareil was significantly lower than the other two varieties on the intermediate bee density block (1.33/acre). In general, pollination rates for the early varieties on this ranch were higher than that observed on the other ranches. On five of the six blocks, effective colony density was slightly to marginally lower than the nominal colony density. Only the 1.5 colony/acre Southeast block had an effective colony density slightly higher than the nominal rate (Table 2).

Early variety pollination on the Premiere ranch followed the same pattern described above, i.e. pollination tended to be significantly higher on high bee density blocks (Table 17). The Nonpareil rate on the high and low blocks (2.5 vs. 1.75 colonies/acre) was 57.7 and 49.3%, respectively ($P < 0.05$, FPLSD, Table 17). The difference was larger for Fritz. High and low bee density blocks had 48.0 and 31.7% pollination rates, respectively ($P < 0.05$, FPLSD). No significant differences were found the variety Sonora. This variety was earliest to bloom and compatible pollen may be a limiting factor in its pollination as the two early (co-planted) varieties had barely begun to bloom while it had it highest onset of new blossoms (Figures 35 & 37). We observed that pollen inserts were applied to colonies in these orchards. It would seem that this could be a worthwhile practice if compatible pollen is applied early. Nonpareil had a significantly higher pollination rate than did the other two varieties. Results like this may not be interpretable unless the history of an orchard is known. The effective colony density on Premiere was above the nominal colony density for both high and low density orchards. It is likely that there was a significant elevation for the low density orchard where our model suggests an effective colony density of 2.19 colonies/acre and the nominal stocking levels was at 1.75/acre. Curiously, pollination for the early varieties on this ranch was low compared with the other ranches, even though colony density high. We are still examining the data for hints for its cause.

Nonpareil pollination on South Valley Farms was high (74.1 & 80.1%, Table 17 $P < 0.05$, FPLSD) on both low and high bee density orchards. Significant differences were not detected between the two orchards. Monterey was comparatively lower at 50.1 and 40.1% for the high and low bee density orchards, respectively. These differences were significant ($P < 0.05$, FPLSD). Aldrich pollination was similar to Monterey in that high and low bee density orchards had 47.5 and 40.1% levels of pollination ($P < 0.05$, FPLSD). We do not know why the pollination of Nonpareil was significantly higher than the other two co-planted varieties ($P < 0.05$, FPLSD). Its bloom cycle did lag somewhat (Figure 43).

Orchard Pollination: Late Varieties.

The pollination rate for the hardshell variety Butte in the “high” density Wegis orchard was 44.9%, which was significantly different than that of the low (1.0 colonies/acre) bee density orchard (27.9%, $P < 0.05$, FPLSD, Table 18). We qualify the “high” density orchard inasmuch as the nominal colony density was only 0.77 colonies per acre. By pollen trapping, we effectively doubled the amount of pollen collection and thereby raised the nominal colony density to about 1.5 colonies/acre. Even with this, the effective colony density rose only to 1.02, which was less than the 1.16 effective colonies/acre for the low density orchard. Nevertheless, the pollination rate rose from that observed for the 2011 season wherein the nominal colony density was 0.77 colonies/acre. The variety Padre on the Wegis ranch had pollination rates similar to those of Butte. The “high” and low bee density orchards had pollination rates of 47.4 and 34.6%, respectively ($P < 0.05$, FPLSD).

The hardshell variety Butte on the King/Gardiner ranch had three levels of bee density. On the 2.16 colonies/acre, the pollination rate was 68.5% which was significantly higher than that found on the low (55.0%) and intermediate (53.6%) bee density orchards ($P < 0.05$, FPLSD, Table 18). Bloom was delayed significantly in the low density NE block (1.08 colonies/acre). Bloom in the surrounding orchards was declining, and it was apparent from our inspections that a high population of bees was foraging in that orchard. We suspect that the pollination rate for both Butte and Padre rose significantly as a result. Padre pollination followed the Butte pattern. On the west 2.16 colonies/acre block, we found that 65.7% of flowers set nuts which was significantly different than that observed for the intermediate colony density block (53.0%) but different than that for the low density NE block (61.9%). In general, Butte and Padre had about the same pollination rate on five of the six blocks. On the low bee density NE block, Butte pollination was significantly lower than that of Padre ($P < 0.05$, FPLSD, Table 18).

On Premiere, we observed high pollination rates for both the low and high bee density blocks (Table 18). No significant difference was observed for Butte on the high and low bee density blocks. Padre had about a 10% higher pollination rate on the high bee density block than on the low block ($P < 0.05$, FPLSD). Likewise, Mission had a significantly higher rate on the high bee density block ($P < 0.05$, FPLSD). Butte had the highest pollination rate on both high and low bee density blocks when compared to Padre and Mission. Padre had the second highest and Mission was lowest on this pair of orchards. The rate for Mission was significantly lower than the other two varieties ($P < 0.05$, FPLSD). We do no know the cause for this and the condition was reversed on South Valley Farms.

Pollination rates were lower than the nominal colony stocking rate would suggest it should have been for some of the varieties on South Valley Farms (Table 18). Starting colony size on the late varieties was smaller than on the other ranches. This was not true for the early variety blocks on this ranch. For Butte and Padre, the high bee density block

(3.0 colonies/acre) had significantly higher pollination than the low density block ($P < 0.05$, FPLSD). Mission had a nominally higher, but not significantly so, level of pollination on the high bee density block. For an unknown reason, Mission had a significantly higher rate of pollination than did Padre on both high and low density blocks. This was also true for Butte on the low density block ($P < 0.05$, FPLSD).

Competition for pollinators. We made several two minute observations of early variety orchards and found 1-4 bees visiting trees during the time of peak hardshell bloom. These may have been nectar foragers. We do not know whether the early varieties at this time pose a significant competition for pollinators. This is an area of interest as it may help explain the lower rate of pollination for some hardshell blocks.

Nut harvest. Nut harvest has not yet been done, but mature nuts retained by our “pollination rate branches” will be counted the first week of August 2012. We doubt that our technique for monitoring nut harvest from our pollination branches will accurately predict commercial nut harvest. We suspect that several important variables are not being adequately estimated by our relatively modest percent mature nut counts from our pollination branches. We hope to rectify that in 2013.

Critique. We have confidence in our estimates of pollination. Our 2011 verified our methods. We think it likely that our method of predicting nut harvest is based on too small a sample. This is an area we will try to improve on, but collecting samples when all the varieties are being harvested presents a logistical problem. Ultimately, we may need to hire someone in California to be on site to measure whole tree harvest. We are interested in doing more extensive measurements of bees on flowers using video recordings. This area of behavior measurement, we suspect, will yield insight into why incremental increases in colony density do not result in commensurate increases in pollination. We think video recording colony entrances will give more accurate data on colony performance. Over the years of measuring pollen collection and colony size, we still can only account for about for, at best about 50 – 60% of the variation. There are other factors we are not currently measuring. Tree height in the older orchards presents a challenge. We would like to know if our measuring pollination rates at 12' is an accurate measure of pollination above that. Our 2011 data suggests that it is, but until it is verified, there may be an error in our estimates of these tall trees. Some almond references indicate that 100% pollination should be the goal. We have yet to see this even in young orchards with comparatively high bee density. We would like to know where the target pollination rate should be with respect to economic thresholds. We would like to know the pollination rates of flowers opening at different times. Joe Traynor urged us to look at late opening flowers and their pollination rate. We did a limited sampling (n = 30) and found no pollination. These late opening flowers are scattered and the probability of a bee moving compatible pollen late in the season may decline substantially. We need more data to answer the question of whether some varieties under some conditions are more likely to not be pollinated than other varieties. In short, there is a lot we don’t know.

Research Effort Recent Publications:

Acknowledgements:

We are indebted to Jeff Jones and Perry Traynor (Scientific Ag) who counted and mapped the colonies surrounding the test orchards. Francisco Castro (Scientific Ag) counted trees, placed pollinator exclusion devices on branches, installed pollen traps, and several other chores too numerous to mention. Claudia Pena (USDA-ARS) watched the videos and tabulated the various bee activities on almond flowers. Roy Medrano (USDA-ARS) assisted with tagging buds and counting blossoms. Joe Traynor (Scientific Ag) convinced us that this work needed doing and, as always, made cogent and diplomatic comments on our work. We thank them all.

References Cited:

DeGrandi-Hoffman, G., S.A. Roth, and G.M. Loper. 1989. ALMOPOL: A cross-pollination and nut set simulation model for almond. Jour. Amer. Soc. Hort. Sci. 114: 170-176.

SAS Institute 1999-2000. SAS/STAT User's Guide, 6th ed. SAS Institute, Inc. Gary, NC.

Eischen, F.A. and Graham, R.H. 2008a. Feeding overwintering honey bee colonies infected with *Nosema ceranae*. Proc. Amer. Bee Research Conf., American Bee Journal. 148: 555.

Eischen, F.A., Graham, R.H. and R. Rivera. 2008b. Overwintering nutritionally stressed honey bee colonies infested with *Varroa destructor*. Proc. Amer. Bee Research Conf., American Bee Journal. 148: 555-555

Table 1. Orchard size, varieties and tree densities.

Orchard	Acres	Varieties	Tree age (yrs)	Trees per acre[1]	Row spacing	Within row tree space
Wegis north Early	160	50% Nonpareil, 25% Fritz, 25% Monterey	7	114	24'	16'
Wegis south Early	160	50% Nonpareil, 25% Fritz, 25% Monterey	7	114	24'	16'
Wegis north Hardshell	160	50% Butte, 50% Padre	7	114	24'	16'
Wegis south Hardshell	32	50% Butte, 50% Padre	7	114	24'	16'
King NE Early	76.5	50% Nonpareil, 25% Fritz, 25% Monterey	7	109	22'	18'
King SE Early	76.0	50% Nonpareil, 25% Fritz, 25% Monterey	7	109	22'	18'
King West Early	76.5	50% Nonpareil, 25% Fritz, 25% Monterey	7	109	22'	18'
King NE Hardshell	17.8	66% Butte, 34% Padre (2 Butte trees alternated with 1 Padre)	7	114	22,	16'
King SE Hardshell	77.6	66% Butte, 34% Padre (2 Butte trees alternated with 1 Padre)	7	114	22,	16'
King West Hardshell	74.9	66% Butte, 34% Padre (2 Butte trees alternated with 1 Padre)	7	114	22,	16'
SVF North Early	40.1	50% Nonpareil, 25% Monterey, 25% Aldrich		85.8	24'	21'

Table 1. Orchard size, varieties and tree densities (con't).

SVF South Early	40.1	50% Nonpareil, 25% Monterey, 25% Aldrich		85.8	24'	21'
SVF North Hardshell	40.8	33.3% Butte, 33.3% Padre, 33.3% Mission		85.8	24'	21'
SVF South Hardshell	45.4	33.3% Butte, 33.3% Padre, 33.3% Mission		85.8	24'	21'
Premiere E Early	58.1	50% Nonpareil, 25% Sonora, 25% Fritz	18	75.2	24'	24'
Premiere W Early	70.6	50% Nonpareil, 25% Sonora, 25% Fritz	18	75.2	24'	24'
Premiere E Hardshell	62.1	50 Butte, 25% Padre, 25% Mission	18	75.2	24'	24'
Premiere W Hardshell	69.5	50 Butte, 25% Padre, 25% Mission	18	75.2	24'	24'

[1]See Appendix D for replant data.

Table 2. The nominal and effective[1] colony density on test orchards.

Orchard: Nominal colony density (colonies per acre) and varieties	Colonies set at orchard	Additional colonies placed ≤ 1.5 miles from test orchard[2]	Effective colony density (per acre)	Effective frames of bees/acre (per acre)[3]
Wegis: 1.0 colony/acre Early varieties	216	5,753	1.12 ± 0.18	
Wegis: 2 colonies/acre Early varieties	308	4,094	1.57 ± 0.26	
Wegis: 1.0 colonies/acre Late varieties	216	5,517	1.16 ± 0.09	
Wegis: 1.5 colonies/acre Late varieties (pollen trapped)	24 (x2)	2,604	1.02 ± 0.22	
King/Gardiner: Northeast 1.08 colony/acre; Early varieties	120	3,746	0.94 ± 0.17	
King/Gardiner: Southeast 1.33 colony/acre; Early varieties	168	2,418	1.29 ± 0.41	
King[1]: West 2.16 colony/acre; Early varieties	336	3,659	1.85 ± 0.31	
King/Gardiner: Northeast 1.08 colony/acre; Late varieties	24	3,844	0.78 ± 0.11	
King[1]: Southeast 1.33 colony/acre; Late varieties	228	2,418	1.54 ± 0.27	
King/Gardiner: West 2.16 colony/acre; Late varieties	324	3,635	1.92 ± 0.30	

Table 2. The nominal and effective[1] colony density on test orchards (con't).

Premiere-Westchester 1.75 colonies/acre; Early varieties	168	6,878	2.19 ± 0.32	
Premiere-Westchester 2.5 colonies/acre; Early varieties	364	7,270	2.60 ± 0.39	
Premiere-Westchester 1.75 colonies/acre; Late varieties	120	5,802	1.91 ± 0.76	
Premiere-Westchester 2.5 colonies/acre; Late varieties	520	7,270	2.44 ± 0.50	
South Valley Farms 2.0 colonies/acre; Early varieties	120	7,730	1.68 ± 0.12	
South Valley Farms 2.5 colonies/acre; Early varieties	152	8,356	2.15 ± 0.15	
South Valley Farms 2.0 colonies/acre; Late varieties	100	7760	1.76 ± 0.18	
South Valley Farms 3.0 colonies/acre; Late varieties	144	7524	2.27 ± 0.18	

[1]Nominal colony density is the number of colonies rented for the orchard. Effective colony density is based on pollen foraging range of bees near Bakersfield, CA during the 2009 and 2010 almond pollination seasons.

[2]Figures 17 - 20 show the distribution of these colonies. Our data indicates that 94.8% of [3]pollen foraging trips were made within 1.5 miles of the colony.

We assume colonies beyond the orchard boundaries met an 8-frame average.

Table 3. Adult bee strength at the beginning and end of pollination for a random sampling of colonies. Measurements in standard deep frames of bees.

Orchard: colony density (colonies per acre) and varieties	n	Begin $\bar{x} \pm$ SD	End $\bar{x} \pm$ SD	Change in strength $\bar{x} \pm$ SD
Wegis: 1 colony/acre Early varieties	22	8.9 ± 3.8a[1]	11.8 ± 4.5a	+2.9 ± 3.4a
Wegis: 2 colonies/acre Early varieties	31	9.1 ± 3.9a	9.8 ± 4.7a	+0.5 ± 3.5b
Wegis: 1 colonies/acre Late varieties	22	10.1 ± 3.4a	12.7 ± 4.1a	+2.5 ± 3.0a
Wegis: 1.5 colonies/acre Late varieties (pollen trapped)	24	10.8 ± 3.4a	12.8 ± 4.6a[2]	+2.0 ± 3.7a
King/Gardiner: Northeast 1.08 colony/acre; Early varieties	20	8.5 ± 2.6a	10.4 ± 3.7a	+1.9 ± 2.4ab
King/Gardiner: Southeast 1.33 colony/acre; Early varieties	20	8.2 ± 1.9a	10.3 ± 2.1a	+2.1 ± 2.2a
King[1]: West 2.16 colony/acre; Early varieties	17	8.6 ± 2.5a	9.0 ± 4.2a[3]	+0.4 ± 2.9b
King/Gardiner: Northeast 1.08 colony/acre; Late varieties	20	9.4 ± 2.4a	9.9 ± 2.5a	+0.5 ± 1.7a
King[1]: Southeast 1.33 colony/acre; Late varieties	22	10.6 ± 2.3a	10.6 ± 3.2a	0.0 ± 2.3a
King/Gardiner: West 2.16 colony/acre; Late varieties	20	9.8 ± 3.1a	10.1 ± 3.7a[4]	+0.3 ± 1.8a
Premiere-Westchester 1.75 colonies/acre; Early varieties	20	7.7 ± 2.7a	9.6 ± 3.9a[5]	+1.9 ± 2.4a

Table 3. Adult bee strength at the beginning and end of pollination for a random sampling of colonies. Measurements in standard deep frames of bees (con't)

Premiere-Westchester 2.5 colonies/acre; Early varieties	20	7.9 ± 3.4a	8.7 ± 3.8a[6]	+0.8 ± 1.1a
Premiere-Westchester 1.75 colonies/acre; Late varieties	20	8.1 ± 2.8a	10.2 ± 4.0a	+2.1 ± 2.6a
Premiere-Westchester 2.5 colonies/acre; Late varieties	20	6.5 ± 3.3a	10.0 ± 4.6a	+3.5 ± 2.4a
South Valley Farms 2.0 colonies/acre; Early varieties	26	8.5 ± 1.9a	11.5 ± 2.7a	+3.0 ± 2.4a
South Valley Farms 2.5 colonies/acre; Early varieties	30	9.0 ± 2.8a	11.7 ± 2.9a	+2.7 ± 2.0a
South Valley Farms 2.0 colonies/acre; Late varieties	29	5.9 ± 2.4a	8.9 ± 2.9a	+3.3 ± 2.2a
South Valley Farms 3.0 colonies/acre; Late varieties	36	6.8 ± 3.5a	7.8 ± 3.3a	+1.0 ± 2.2b

[1]Within groups of blue or black data, means followed by the same letter in a column are not significantly different P > 0.05, FPLSD.
[2]One colony found queenless
[3]Two colonies found queenless
[4]One colony found queenless
[5]One colony found queenless
[6]One colony found queenless

Table 4. Correlation between numbers of returning pollen foragers and colony strength.

Orchard	n	Colony strength (frames of bees) $\bar{x} \pm SD$	Returning pollen foragers[1] $\bar{x} \pm SD$	Correlation coefficient (r)	P value
Wegis	40	9.3 ± 3.4	41.1 ± 21.4	0.493	0.0012
King/Gardiner	80	10.9 ± 3.1	122.1 ± 73.1	0.268	0.0163
Premiere	80	7.1 ± 2.0	80.8 ± 45.9	0.525	<0.0001
South Valley Farms	80	7.9 ± 3.1	47.6 ± 34.7	0.436	<0.0001

Table 5. Number of buds monitored for early variety blossoming time.

Ranch Colonies/acre (nominal)	n	Nonpareil $\bar{x} \pm SD$	Fritz $\bar{x} \pm SD$	Monterey $\bar{x} \pm SD$	Sonora $\bar{x} \pm SD$	Aldrich $\bar{x} \pm SD$
Wegis North 1/acre	20	108.0 ± 55.7a	107.4 ± 72.0a	109.8 ± 45.7a	N/A	N/A
Wegis South 1.5/acre	20	99.6 ± 49.5a	96.8 ± 41.6a	92.7 ± 31.5a	N/A	N/A
King/Gardiner 1.08/acre	20	103.5 ± 53.1a	110.4 ± 37.2a	110.3 ± 44.3a	N/A	N/A
King/Gardiner 1.33/acre	20	82.6 ± 32.5a	73.9 ± 31.8b	76.7 ± 35.2b	N/A	N/A
King/Gardiner 2.16/acre	20	92.3 ± 47.7a	69.0 ± 39.8b	46.3 ± 51.3c	N/A	N/A
Premiere 1.75/acre	20	84.2 ± 36.3a	144.1 ± 44.9a	N/A	105.2 ± 27.2a	N/A
Premiere 2.5/acre	20	92.7 ± 42.4a	128.4 ± 50.2a	N/A	112.0 ± 32.0a	N/A
South Valley 2.0/acre	20	47.2 ± 27.9a	N/A	113.8 ± 39.7a	N/A	74.7 ± 30.5a
South Valley 2.5/acre	20	63.9 ± 41.6a	N/A	113.1 ± 67.4a	N/A	94.0 ± 46.8a

[1]Means in a column followed by the same letter are not significantly different ($P < 0.05$, FPLSD)

Table 6. Number of buds monitored for late variety blossoming time.

Ranch Colonies/acre (nominal)	n	Butte $\bar{x} \pm SD$	Padre $\bar{x} \pm SD$	Mission $\bar{x} \pm SD$
Wegis North 1.0/acre	20	109.3 ± 51.4a[1]	120.8 ± 37.6a	N/A
Wegis South 1.50/acre	20	111.8 ± 40.6a	156.2 ± 44.0b	N/A
King/Gardiner 1.08/acre	20	115.6 ± 33.6a	107.6 ± 39.7a	N/A
King/Gardiner 1.33/acre	20	84.8 ± 31.1b	91.2 ± 25.1ab	N/A
King/Gardiner 2.16/acre	20	69.0 ± 32.5b	74.2 ± 24.6b	N/A
Premiere 1.75/acre	20	83.3 ± 30.3a	135.3 ± 64.1a	92.6 ± 42.5a
Premiere 2.5/acre	20	101.6 ± 43.0a	138.4 ± 50.1a	121.4 ± 44.5b
South Valley 2.0/acre	20	118.8 ± 43.5a	81.5 ± 34.4a	100.6 ± 37.6a
South Valley 3.0/acre	20	109.8 ± 33.3a	84.1 ± 39.6a	84.5 ± 34.4a

[1]Means in a column followed by the same letter are not significantly different ($P > 0.05$, FPLSD)

Table 7. Percent of buds open at highest count for early varieties

Ranch Colonies/acre	Date	Nonpareil $\bar{x} \pm SD$	Fritz $\bar{x} \pm SD$	Monterey $\bar{x} \pm SD$	Sonora $\bar{x} \pm SD$	Aldrich $\bar{x} \pm SD$
Wegis North 1.0/acre	25 Feb	47.5 ± 8.6a[1]	56.0 ± 6.9a	62.4 ± 11.3a	N/A	N/A
Wegis South 1.5/acre	25 Feb	42.6 ± 12.9a	47.4 ± 20.0a	51.3 ± 13.2b	N/A	N/A
King/Gardiner 1.08/acre	24 Feb	39.4 ± 10.9a	49.5 ± 13.9a	44.0 ± 17.1a	N/A	N/A
King/Gardiner 1.33/acre	24 Feb	30.1 ± 8.6b	14.2 ± 13.6c	21.8 ± 16.6b[2]	N/A	N/A
King/Gardiner 2.16/acre	24 Feb	34.9 ± 11.8ab	39.5 ± 9.7b	56.1 ± 24.6a	N/A	N/A
Premiere 1.75/acre	23 Feb	34.3 ± 12.3a	38.0 ± 9.4a	N/A	38.4 ± 18.8a	N/A
Premiere 2.5/acre	23 Feb	35.4 ± 12.7a	37.2 ± 12.9a	N/A	34.6 ± 22.7a	N/A
South Valley 2.0/acre	28 Feb	42.8 ± 21.6a	N/A	42.7 ± 20.8a	N/A	39.0 ± 14.6a
South Valley 2.5/acre	28 Feb	46.3 ± 23.0a	N/A	61.0 ± 20.4b	N/A	36.6 ± 13.0a

[12]Means in a column followed by the same letter are not significantly different ($P < 0.05$, FPLSD). [2]Peak bloom count was made on 20 February.

Table 8. Percent of buds open at highest count for late varieties

Ranch Colonies/acre	Date	Butte $\bar{x} \pm SD$	Padre $\bar{x} \pm SD$	Mission $\bar{x} \pm SD$
Wegis North 1.0/acre	26 Feb	46.0 ± 24.9a[1]	29.8 ± 17.4a	N/A
Wegis South 1.5/acre	26 Feb	35.6 ± 19.1a	56.5 ± 20.9b	N/A
King/Gardiner 1.08/acre	25 Feb	26.3 ± 16.4a	26.5 ± 15.3a	N/A
King/Gardiner 1.33/acre	25 Feb	76.9 ± 12.8c	65.2 ± 12.1b	N/A
King/Gardiner 2.16/acre	25 Feb	54.4 ± 22.2b	40.5 ± 21.7c	N\A
Premiere 1.75/acre	28 Feb	42.7 ± 14.9a	53.4 ± 23.6a	54.9 ± 16.8a
Premiere 2.5/acre	28 Feb	49.0 ± 11.6a	64.0 ± 14.8a	59.3 ± 15.9a
South Valley 2.0/acre	27 Feb	81.3 ± 21.3a	84.5 ± 11.5a	93.9 ± 8.2a
South Valley 3.0/acre	27 Feb	72.2 ± 22.1a	71.3 ± 19.4b	80.8 ± 19.2b

[1]Means in a column followed by the same letter are not significantly different ($P < 0.05$, FPLSD

Table 9. Percent of buds not open at last count[1] for early varieties

Ranch Colonies/acre	Date	Nonpareil $\bar{x} \pm SD$	Fritz $\bar{x} \pm SD$	Monterey $\bar{x} \pm SD$	Sonora $\bar{x} \pm SD$	Aldrich $\bar{x} \pm SD$
Wegis North 1/acre	1 Mar	5.5 ± 4.5a	3.7 ± 8.6a	4.0 ± 6.3a	N/A	N/A
Wegis South 1.5/acre	1 Mar	6.6 ± 6.5a	3.7 ± 8.6a	4.0 ± 6.3a	N/A	N/A
King/Gardiner 1.08/acre	29 Feb	1.9 ± 2.6a	0.8 ±1.1a	1.2 ± 3.5a	N/A	N/A
King/Gardiner 1.33/acre	29 Feb	2.4 ± 3.2a	0.2 ± 0.7a	0.2 ± 0.5a	N/A	N/A
King/Gardiner 2.16/acre	29 Feb	7.3 ± 5.5b	2.3 ± 2.7b	2.3 ± 4.7a	N/A	N/A
Premiere 1.75/acre	28 Feb	5.0 ± 4.1a	4.0 ± 4.4a	N/A	0.1 ± 0.4a	N/A
Premiere 2.5/acre	28 Feb	7.6 ± 6.1a	1.5 ± 2.5b	N/A	0.2 ± 0.7a	N/A
South Valley 1.75/acre	28 Feb	9.3 ± 7.4a	N/A	17.4 ± 23.1a	N/A	9.4 ± 6.6a
South Valley 2.5/acre	28 Feb	10.1 ± 10.1a	N/A	8.5 ± 21.0a	N/A	5.4 ± 5.9b

[1]The date of the last count varied by orchard.
[2]Means in column followed by the same letter are not significantly different (P > 0.05, FPLSD)

Table 10. Percent of buds not open at last count for late varieties

Ranch Colonies/acre	Date	Butte $\bar{x} \pm SD$	Padre $\bar{x} \pm SD$	Mission $\bar{x} \pm SD$
Wegis North 1.0/acre	5 Mar	8.0 ± 16.6a[1]	10.9 ± 9.8a	N/A
Wegis South 1.5/acre	5 Mar	15.1 ± 16.6a	4.1 ± 3.8b	N/A
King/Gardiner 1.08/acre	5 Mar	17.3 ± 13.9a	19.8 ± 13.9a	N/A
King/Gardiner 1.33/acre	5 Mar	3.1 ± 3.6b	5.7 ± 4.6b	N/A
King/Gardiner 2.16/acre	5 Mar	4.3 ± 4.1b	15.2 ± 10.0a	N/A
Premiere 1.75/acre	4 Mar	10.5 ± 6.1a	12.4 ± 12.2a	3.7 ± 2.6a
Premiere 2.0/acre	4 Mar	9.7 ± 8.6a	5.2 ± 3.8b	3.5 ± 2.6a
South Valley 2.0/acre	3 Mar	6.2 ± 10.4a	5.7 ± 8.4a	3.6 ± 6.1a
South Valley 3.0/acre	3 Mar	3.7 ± 4.4a	1.6 ± 2.6b	0.3 ± 0.9b

[1]Means in a column followed by the same letter are not significantly different ($P < 0.05$, FPLSD)

Table 11. Honey bee visitation to Fritz and Nonpareil flowers in a low honey bee density orchards. (Not all video material has been analyzed)

Variable	Fritz[1] $\bar{x}$ ± SD	Nonpareil[1] $\bar{x}$ ± SD
Number of open flowers/branch (branch ca. 36" long)[2]	15.2 ± 4.0 a[3]	15.2 ± 4.0 a[4]
Number of bees visiting branch	3.9 ± 2.3 a	4.6 ± 2.8 a
Number of flowers visited	11.0 ± 8.6 a	10.9 ± 8.8 a
Number of flowers/bee	2.4 ± 2.0 a	2.0 ± 0.9 a
Seconds spent on branch (per bee) nectar & pollen foragers	±	±
Seconds spent on branch (per bee) nectar foragers only	±	±
Seconds spent on branch (per bee) pollen foragers only	±	±
Seconds spent per flower by nectar foragers	±	±
Seconds spent per flower by pollen foragers	±	±

[1]N = 7 branches for Fritz and 8 for Nonpareil. Pairs of adjacent trees were observed (King NE). One camera on a Fritz branch malfunctioned.
[2]Videos were taken on 23 March 2012 and were 45 minutes long. Orchards were in 84 and 76% bloom for Fritz and Nonpareil.
[3]Number of open flowers were equalized on the branch.
[4]Means in a row followed by the same letter are not significantly different (P > 0.05, FPLSD)

Table 12. Number of forager visits and nut set for Nonpareil

Forager visits	n	Number set	% set
0	48	0	0 a[1]
1	22	1	4.6 a
2	21	8	38.1 b ***
3	3	2	66.7 b

Means in a column followed by the same letter are not significantly different *** $P < 0.001$;
Chi-square statistic = 8.31.

Table 13. Number of forager visits and nut set for Fritz

Forager visits	n	Number set	% set
0	17	0	0 a[1]
1	25	6	24.0 b*
2	8	3	37.5 b
3	3	1	33.3 b

Means in a column followed by the same letter are not significantly different * $P < 0.05$
Chi-square statistic = 3.77

Table 14. Comparison of forager visits and nut set for Nonpareil and Fritz

Forager visits	N NP/F	% set Nonpareil	% set Fritz
0	48/17	0 a[1]	0 a
1	22/25	4.6 a	24.0 b
2	21/8	38.1 a	37.5 a
3	3/3	66.7 a	33.3 a

[1]Means in a row followed by the same letter are not significantly different * P < 0.05
Chi-square statistic = 2.72

Table 15. Honey bee visitation to Fritz flowers in a low and high honey bee density orchards.
(Not all video material has been analyzed)

Variable	Low Density orchard[1] $\bar{x}$ ± SD	High Density orchard[1] $\bar{x}$ ± SD
Number of open flowers/branch (branch ca. 36″ long)[2]	±	±
Number of bees visiting per branch	9.7 ± 4.2 a[3]	15.6 ± 6.3 b
Number of flowers visited	26.3 ± 13.6 a	44.4 ± 19.5 b
Number of flowers per bee	2.6 ± 0.7 a	2.9 ± 1.0 a
Seconds spent on branch (per bee) nectar & pollen foragers	±	±
Seconds spent on branch (per bee) nectar foragers only	±	±
Seconds spent on branch (per bee) pollen foragers only	±	±
Seconds spent per flower by nectar foragers	±	±
Seconds spent per flower by pollen foragers	±	±

[1]N = 10 branches for the low density orchard (King NE, (1.08 colonies/acre) and 7 for the high density (King West, (2.16 colonies/acre).
[2]Videos were taken on 22 Feb 2012 and were 45 minutes long. Orchards were in about 34 & 42% bloom for NE and West blocks on 20 Feb.
[3]Means in a row followed by the same letter are not significantly different (P > 0.05, FPLSD)

Table 16. Honey bee visitation to Butte flowers in a low and high honey bee density orchard.

Event/variable	Low Density orchard[1] (1.08 colonies/acre) $\bar{x}$ ± SD	High Density orchard[1] (2.16 colonies/acre) $\bar{x}$ ± SD
Number of open flowers/branch (branch ca. 36” long)[2]		
Number of bees visiting branch	3.9 ± 2.3 a	9.9 ± 4.8 b
Number of flowers visited	6.2 ± 4.7 a	28.7 ± 20.0b
Number of flowers/bee	1.5 ± 0.5 a	2.8 ± 0.5 b
Seconds spent on branch (per bee) nectar & pollen foragers	19.3 ± 23.2 a	41.7 ± 49.7 b
Seconds spent on branch (per bee) nectar foragers only	20.6 ± 23.3 a	49.0 ± 55.5 b
Seconds spent on branch (per bee) pollen foragers only	14.0 ± 23.4 a	31.5 ± 39.5 a
Seconds spent per flower by nectar foragers	13.3 ± 12.8 a	15.7 ± 19.9 a
Seconds spent per flower by pollen foragers	10.5 ± 11.0 a	11.0 ± 10.5 a

[1]N = 10 branches for the low density orchard (King NE) and 7 for the high density King West. Videos were taken on 29 February 2012 and were 45 minutes long.

Table 17. Percent of pollination for early varieties

Ranch Colonies/acre	Nonpareil $\bar{x}$ ± SD	Fritz $\bar{x}$ ± SD	Monterey $\bar{x}$ ± SD	Sonora $\bar{x}$ ± SD	Aldrich $\bar{x}$ ± SD
Wegis North 1.0/acre	59.3 ± 13.7a[1] A[2]	47.6 ± 19.2a B	55.4 ± 20.8a A	N/A	N/A
Wegis South 2.0/acre	64.9 ± 20.8a A	55.8 ± 22.0b B	63.5 ± 19.2b A	N/A	N/A
King/Gardiner 1.08/acre	67.8 ± 10.6a B	73.1 ± 12.0a A	66.8 ± 12.9a B	N/A	N/A
King/Gardiner 1.33/acre	58.0 ± 13.8b B	72.3 ± 15.6a A	65.8 ± 16.7a A	N/A	N/A
King/Gardiner 2.16/acre	78.2 ± 19.6c A	82.0 ± 22.6b A	73.2 ± 21.4a A	N/A	N/A
Premiere 1.75/acre	49.3 ± 13.4a A	31.7 ± 16.8a C	N/A	42.5 ± 12.4a B	N/A
Premiere 2.5/acre	57.7 ± 15.5b A	48.0 ± 19.2b B	N/A	43.7 ± 11.9a B	N/A
South Valley 2/acre	74.1 ± 19.8a A	N/A	40.1 ± 16.3a B	N/A	40.1 ± 16.9a B
South Valley 2.5/acre	80.1 ± 13.4a A	N/A	50.1 ± 14.2b B	N/A	47.5 ± 10.7b B

[1]Means in a column followed by the same lower case letter are not significantly different ($P > 0.05$, FPLSD).
[2]Means in a row followed by the same upper case letter (blue) are not significantly different ($P > 0.05$, FPLSD).

Table 18. Percent of pollination for late varieties

Ranch Colonies/acre	Butte $\bar{x}$ ± SD	Padre $\bar{x}$ ± SD	Mission $\bar{x}$ ± SD
Wegis North 1.0/acre	27.9 ± 17.2a[1] B[2]	34.6 ± 12.0a A	N/A
Wegis South 1.5/acre	44.9 ± 14.8b A	47.4 ± 25.6b A	N/A
King/Gardiner, NE 1.08/acre	55.0 ± 12.2a B	61.9 ± 7.1a A	N/A
King/Gardiner, SE 1.33/acre	53.6 ± 13.9a A	53.0 ± 11.0b A	N/A
King/Gardiner, West 2.16/acre	68.5 ± 20.4b A	65.7 ± 23.9a A	N/A
Premiere 1.75/acre	65.4 ± 12.0a A	56.7 ± 11.1a B	40.5 ± 12.4a C
Premiere 2.5/acre	71.3 ± 20.6a A	66.5 ± 19.6b A	48.8 ± 12.4b B
South Valley Farms 2.0/acre	44.8 ± 11.4a B	37.9 ± 10.6a C	54.1 ± 15.6a A
South Valley Farms 3.0/acre	58.4 ± 18.4b A	49.5 ± 16.0b B	58.7 ± 18.9a A

[1]Means in a column followed by the same letter are not significantly different ($P > 0.05$, FPLSD).
[2]Means in a row followed by the same upper case letter (blue) are not significantly different ($P > 0.05$, FPLSD).