Biology and Management of the *Ferrisia gilli* Mealybug in Pistachios

David R. Haviland, UCCE Farm Advisor, Kern County; Robert H. Beede, UCCE Farm Advisor, Kings and Tulare Counties; Kent M. Daane, UCCE Specialist, UC Berkeley and Kearney Agricultural Center

Introduction

Ferrisia gilli Gullan is a newly described species of mealybug that is spreading throughout pistachio production regions of California. It was first noticed in pistachios in the late 1990's near the town of Tulare in Tulare County. Initial infestations remained localized for several years and then began to spread rapidly. By 2003 approximately 200 acres on pistachios in Tulare County were infested. As of late 2005, over 3,000 acres of pistachios spread out over at least eight different counties have become infested; by 2006 the number of counties with at least one infested orchard reached eleven.

Due to the new nature of this pest, very little was known about its biology and how it affects the pistachio crop. Even less was known about monitoring and control strategies. As of the 2004 growing season the only control strategies available were in-season applications of Imidan or Sevin. Neither of these products was very effective and mealybug densities per each individual cluster reached into the hundreds.

This project was developed in response to the threat this new pest poses to the California pistachio industry. Objectives center on the development of basic information on the biology and management of the mealybug. These results could then be used for extension education programs that would lead to improved control and decreased spread of this new pest.

Objectives

1) Evaluate the biology of *F. gilli* in pistachio, including information on seasonal biology, within-tree distribution and naturally-occurring biological control
2) Evaluate insecticidal control of *F. gilli* mealybug
3) Determine the effects of *F. gilli* on quality and yield of nuts, and establish preliminary treatment thresholds

Procedures

Trials during 2005 and 2006 were conducted in a mature commercial pistachio orchard near Tipton, Tulare County. This orchard was planted on a 17 by 20 ft spacing with the variety Kerman. Trials for all three objectives of this research project were conducted within this orchard.

<u>Objective 1- Evaluate the biology of *F. gilli* in pistachio, including information on seasonal biology, within-tree distribution and naturally-occurring biological control</u>

Prior to budbreak in 2005 we selected 5 of the most heavily infested pistachio trees on the north edge of the orchard. These trees were chosen based on the amount of white fluff on the trunks and main scaffolds, indicating that the trees were heavily infested the previous fall.

Trees were evaluated biweekly from 18 March through 21 September. On each evaluation date in March and April, a total of 5 branches that each included one cluster were chosen at random from each tree and were evaluated for the total number of mealybugs, what life stage they were in (crawlers, nymphs, or adults), and on what part of the branch they were located (buds, wood, petiole, leaf, rachis, hull). Evaluations from May through August were done similarly except that the sample size was doubled to 10 branches per tree. September evaluations included 20 branches per tree. In 2006 we added two more trees to our evaluations (a total of 7), and did biweekly evaluations of 10 branches per tree from 21 March through 21 September.

Data from each of the evaluation dates were used to calculate averages for the total number of mealybugs per cluster, total number of each life stage present on any given date, and location of the mealybugs. Data were graphed across all evaluation dates to document changes in overall population density, number of generations, life stage structure, and distribution on the tree.

The biology of Gill's mealybug was very similar in both 2005 and 2006. Gill's mealybug has three complete generations per year (Fig. 1). The first generation of crawlers emerges during the early parts of June. These mealybugs pass through their nymphal development and give rise to adults during the early to mid portions of July. The second generation begins when crawlers are born in mid to late July. These mealybugs develop and become adults prior to harvest in early September. Second generation adult females produce crawlers of the third (and overwintering) generation of mealybugs around the middle of September. In some cases these crawlers (when the quality of the pistachio hull in the clusters is still of good quality) will be deposited within the cluster. In other cases, where the hulls begin to degrade prior to harvest, the adult females migrate out of the cluster and onto the trunk and main scaffolds of the tree, where they produce these overwintering crawlers.

Gill's mealybug overwinters as first-instar nymphs (crawlers). They hide deep in cracks and crevices on and underneath the bark, and in knotholes, on the trunk and main scaffolds. As temperatures warm up in the spring, overwintering mealybugs (which can now be first or second instars) migrate to the branch tips to feed at the interface between old wood from the previous year, and new growth from the current year (Fig. 2). In both 2005 and 2006 this migration from overwintering sites up into the canopy coincided with budbreak. During March and April, mealybugs continue to develop at the interface between the old and new wood. In May about three quarters of the mealybugs migrate onto the rachis. In early June (2005), or mid-June (2006), the mealybugs migrate onto the hulls. They remain on the hulls either through harvest, or until the hulls begin to dry down and slip from the shell. At that time they migrate out of the cluster and to their overwintering site.

Overall populations of mealybugs throughout the season are shown in Figure 3. There is a very high rate of mortality during the winter that leads to low populations in the spring. As an example, even without the use of pesticides, trees in the biology experiments with 388, 319, 105, 175, and 314 mealybugs per cluster at harvest in 2005 had averages of 3.2, 3.2, 1.6, 0.8, and 2.7 mealybugs per cluster, respectively in May 2006. Populations in the field begin to increase in early June when the first generation of crawlers appears. Populations at that point maintain fairly even, with some decreases due to mortality of nymphs until crawlers of the second generation are born in mid July. At this point there is a large spike in mealybug density, which decreases due to mortality (both natural and due to biological control) until harvest. The greatest number of mealybugs in a tree occurs just after harvest when adult females produce the overwintering crawlers. However, this number was not quantified during this research project which only evaluated mealybugs in the clusters.

Mealybug densities overall were higher in 2005 than they were in 2006. This was likely caused by several factors. First, cool spring weather resulted in a delay of bud-break and of the corresponding migration of mealybugs from their overwintering sites. This led to each generation being approximately 7 days delayed in 2006 from 2005. This is most notable on figure 3 by looking at the peak crawler dates for the second generation (first week of August in 2005 versus one week later in 2006) and at crawler emergence near harvest, which occurred just before harvest in 2005 and just after harvest (and therefore is not seen in our cluster evaluations) in 2006. A second factor influencing a decrease in mealybug density is likely biological control by lacewings. Large numbers of lacewings built up in the research plots during 2006. It should also be noted that all data were collected as mealybug density per cluster, yet the number of clusters at harvest was greatly reduced from 2005 (an on-year) versus 2006 (an off-year) where yields were approximately one third that of 2005.

<u>Objective 2- Evaluate insecticidal control of *F. gilli* mealybug</u>

a. Evaluate the residual effects of the June 2005 insecticide trial on mealybug density during 2006

During 2005 an insecticide trial was conducted in Tipton, Tulare County to evaluate the effects of 8 insecticides and an untreated control on mealybug densities in pistachio. The trial was set up with single-tree plots organized in a completely randomized design with five replications. Plots were sprayed at crawler emergence on 2 June 2005 using a Shaben gas-powered wand sprayer in a water volume of 200 G.P.A.

Treatments for the 2 June trial included Assail (acetamiprid), two rates of Movento (spirotetramat), Centaur (buprofezin), Imidan (phosmet), two formulations of Provado (imidacloprid), Sevin (carbaryl), and an untreated check. Rates for each insecticide are shown in Table 1. Plots were evaluated prior to application on 24 May 2005 and then again 2 weeks after treatment (WAT) on 15 June, 4 WAT (28 June), 8 WAT (27 July), and 13 WAT (9 September). In the spring of 2006 we noticed that treatment differences were still visible among treatments. Therefore we continued evaluating this trial through harvest in 2006 by evaluating mealybug densities 51, 55, 57, 59, 61, 65, and 67 WAT on 31 May, 29 Jun, 11 Jul, 25 Jul, 9 Aug, 8 Sept and 21 Sept. Data were collected by counting the total number of mealybugs on each of 10 random clusters (20 for the September evaluation in 2005) on each experimental tree.

Data were transformed by the sqrt (value + 0.5) and analyzed by ANOVA with means separated by Fisher's Protected LSD at $\alpha = 0.05$. Data are presented as the mean number of mealybugs per cluster with the *F, P* and LSD values calculated from transformed data.

During 2005 evaluation dates, Assail, both rates of Movento, and Centaur all produced the lowest overall mealybug densities across all evaluation dates. Imidan, both formulations of Provado, and Sevin all resulted in mealybug densities significantly lower than the untreated check on all but the last evaluation data, but that were always numerically (and usually significantly) higher than mealybug densities of the four best treatments.

Similar trends were seen in data during 2006. Centaur continued to have the lowest mealybug densities on all evaluation dates. Assail and the two rates of Movento also resulted in significant reductions in mealybug densities throughout this second season after treatment. Plots treated with Imidan, both formulations of Provado, and Sevin had mealybug densities that were significantly improved compared to the untreated control through the first mealybug generation in early July, but that were in nearly all cases statistically equivalent to the untreated check during evaluations from July through harvest.

The most important general conclusion from this trial is that Centaur, if applied at peak crawler emergence in early June, can provide at least two years of effective mealybug control. Assail and Movento can provide good control for two years. Imidan, Provado and Sevin can all significantly reduce mealybug densities, but this reduction is not as great as the aforementioned insecticides, and the residual effects do not last beyond one season.

b. Evaluate different treatment timings and rates for optimal mealybug control

Research during 2005 documented that early June is an excellent timing for control of Gill's mealybug. However, questions still arose about the value of hull split treatments of Imidan, spring treatments of Centaur (that target overwintering nymphs as they migrate to the new buds and coverage is optimal), and how these compare to June applications of Centaur. Additional questions arose as to whether or not half rates of Centuar and Assail could be utilized as a way to cut application expenses without reducing product efficacy. This insecticide trial was established to answer these questions.

During the fall of 2005 a group of 35 trees were organized into a completely randomized design, with each tree being assigned to one of 7 treatments. Treatments were Imidan in the fall, Centaur in the Spring, full and half rates of Centaur in June, and full and half rates Assail in June (Table 2). Evaluations were made on 5 May, 17 May, 31 May, 15 Jun, 29 Jun, 11 Jul, 25 Jul, 9 Aug, 8 Sept, and 21 Sept, 2006. Treatment methods, data collection methods, and statistical analysis were performed as previously described for the June 2005 insecticide trial.

Results of the trial are shown in Table 2. Mealybug densities in plots treated with Imidan in the fall, or Centaur in the spring were not significantly different than the untreated check during evaluations during May or on June 15. However, mealybug densities beginning 29 June, at the beginning of crawler emergence of the first generation of mealybugs, through the harvest evaluation on 21 Sept were significantly reduced. A comparison of full versus half rates of Centaur and Assail in June revealed that half rates of both products had numerically (an often statictically) increased mealybug densities on all evaluation dates. Data comparing the full rate of Centaur to the full rate of Assail revealed no significant differences among these two best treatments. A comparison of the full rate of Centaur in the spring to the full rate of Centaur in the summer revealed that summer applications are much better than those made in the spring, though plots treated in the spring did still have mealybug densities below that of the untreated check.

Objective 3- Determine the effects of *F. gilli* on quality and yield of nuts, and establish preliminary treatment thresholds

The effects of mealybug density on pistachio yield and quality were evaluated by collecting harvest data from 35 selected trees from the spring insecticide trial under objective 2. We selected plots with the widest range of mealybug densities possible. Mealybug densities in each of these trees were evaluated from May through September, with data used to put trees into six categories based on pest density. For simplification purposes, in this report we only show the categories made for the September evaluations (an average of data collected on 8 and 21 Sept), since they had the greatest likelihood to be correlated to any reductions in yield or quality.

The pistachio trees were harvested on 28 September with a commercial harvester. Trees were shaken individually and the nuts were offloaded into 30 gallon garbage cans. Total yield per tree was weighed and a 20 lb subsample was collected and shipped to Nichols Farms for a standard huller evaluation. Approximately one week after harvest we returned and harvested all remaining nuts by hand. Data of total green weight from mechanical harvest and total green weight of the hand harvest were converted into a percentage of green weight removed during shaking as a measure of harvestability of the trees.

Data were analyzed by regressing a variety of yield and quality parameters against mealybug density in September. In the case that significant differences were found for September dates, additional regressions would have been performed for data on other evaluation dates earlier in the year.

The effects of mealybug density on yield are shown in Table 3. The first column shows the average mealybugs per cluster at harvest. There were no significant correlations among any of the yield parameters evaluated. This included the average green weight per tree, the weight of nuts remaining in the tree during harvest, and the percentage of green weight removed at harvest. There were also no correlations between mealybug density and the average kernel size, the CPC assessed weight, the grower paid weight, or the value of the crop.

Table 4 shows correlations between mealybug density and several quality parameters. In all cases these correlations were not significant, suggesting that even the highest mealybug densities in the research trials in 2006 did not result in a significant loss in pistachio quality.

Conclusions and Practical Applications

We made significant advanced in 2005 and 2006 towards developing an integrated pest management plan for mealybugs in pistachios. We now have an understanding of the general biology of the pest, and from this have been able to identify weak points in its life cycle. For example, we have identified the period in early June as a time when the majority of the mealybug population is in its crawler, and therefore most susceptible to pesticides, developmental stage. At this timing we documented that two pesticide products, Centaur and Assail, are both highly effective against the mealybug. Centaur is already registered for use for pistachios in California and registration for Assail is anticipated some time in 2006. Use of either of these products will keep the crop clean through harvest and into the following winter.

We also documented that mealybugs spend the majority of the summer feeding on the hulls of the pistachios. This feeding resulted in a 7.9% reduction in the total edible split inshell nuts at harvest and a 15.3% overall loss in the value of the crop in 2005. However, these losses were not repeated in 2006 despite similar pest densities. More work is needed to determine the density of mealybugs in the cluster that warrants any insecticide treatment.

Acknowledgements
The authors wish to thank Pat Loftis of Loftis Farms for hosting this mealybug research. We thank Bret Miller and Gary Weinberger for providing general assistance and Jed DuBose, Amanda Shumway, Celine Carlson and Minerva Gonzalez their assistance in data collection. We also thank Nichols Farms for their assistance with harvest and nut processing.

Figure 1. The average number of crawler, nymph, and adult mealybugs per cluster. Tipton, 2005-6

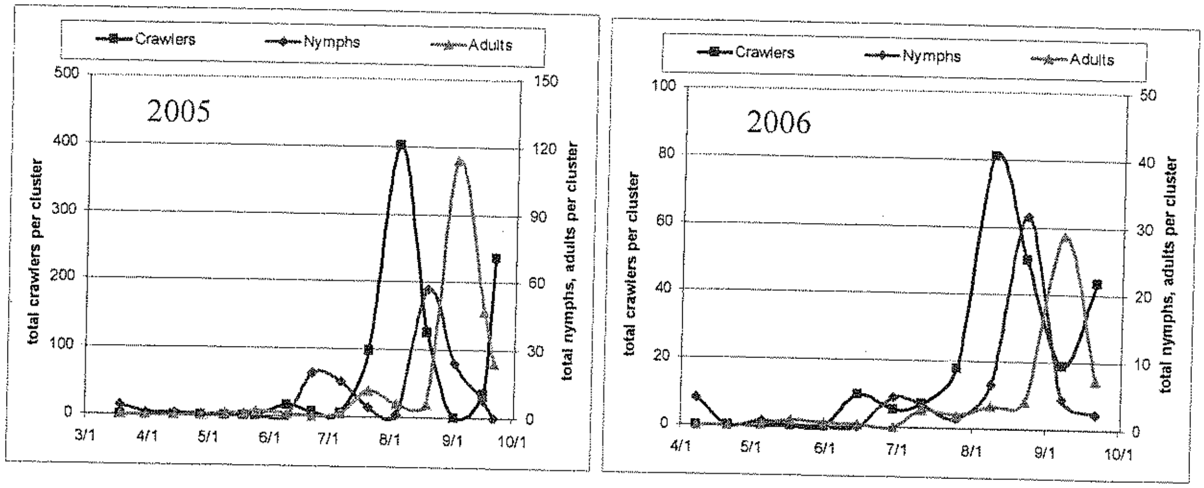

Figure 2. Percentage of the total mealybug population feeding at various locations on a pistachio branch. Tipton, 2005-6.

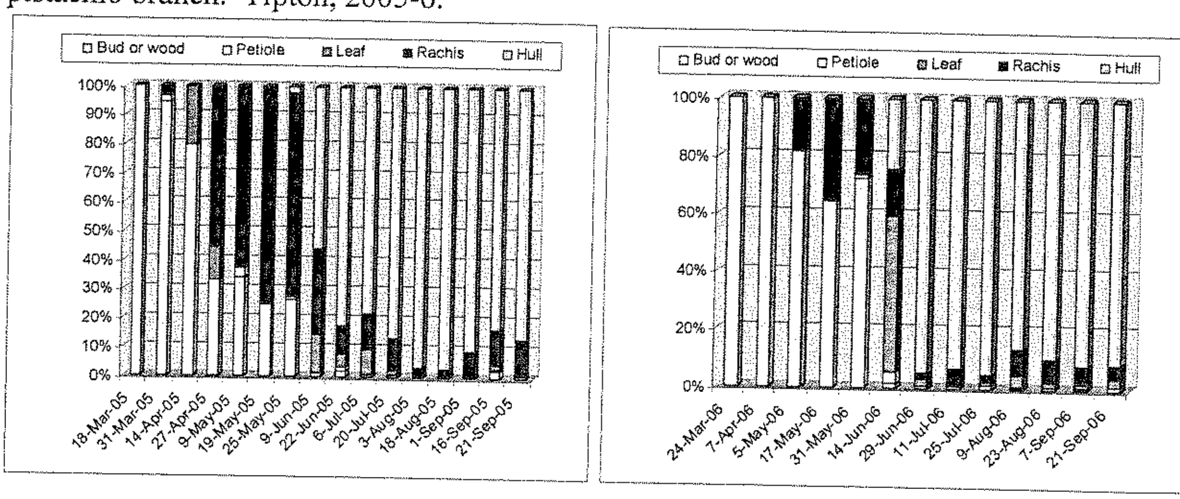

Figure 3. Average mealybugs per branch containing a cluster. Tipton, 2005.

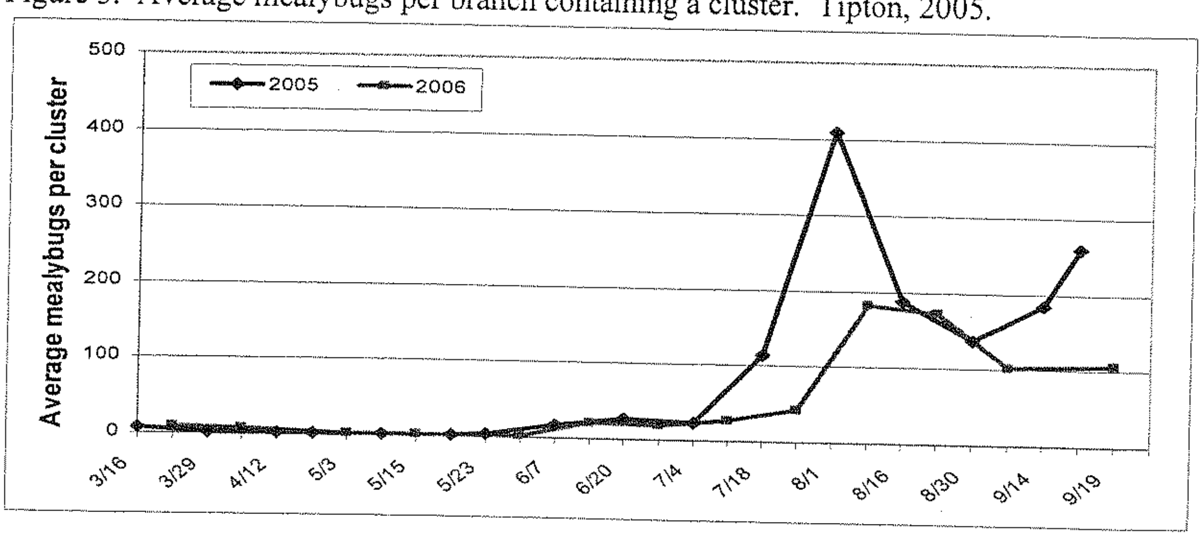

Table 1. The effects of insecticide treatments on 2 June, 2005 on the average number of mealybugs per cluster during the spring and summer of 2005 and 2006. Tipton, Tulare County, CA.

Treatment	Rate per acre	Average mealybugs per cluster (2005)					
		Precounts 24 May adults	2 WAT 15 Jun nymphs	4 WAT 28 Jun nymphs	8 WAT 27 Jul adults	8 WAT 27 Jul crawlers	13 WAT 9 Sep mixed
Assail 30SG	8 oz.	0.6 a	0.1a	0.6 abc	0.2 ab	17 a	0.5 a
Movento	8 oz.	0.8 a	0.4 a	0.0 a	0.0 ab	4 a	0.3 a
Movento	12 oz.	0.6 a	0.1 a	0.0 a	0.0 a	0 a	0.7 a
Centaur	2.14 lb.	0.4 a	0.0 a	0.1 ab	0.0 ab	0 a	0.6 a
Imidan	5 lb.	0.8 a	1.8 a	1.7 bc	0.6 ab	64 a	7.9 b
Provado 1.6F	8 fl oz.	0.9 a	1.7 a	1.4 abc	1.0 ab	181 b	8.7 b
Provado 70WG	2.25 oz.	0.8 a	1.3 a	2.5 c	0.8 ab	120 b	10.6 bc
Sevin XLR	5 qt.	0.7 a	1.2 a	1.8 c	1.0 b	125 b	8.4 bc
Untreated		0.5 a	4.1 a	5.0 d	2.8 c	323 c	17.3 c

cont'd	Average mealybugs per cluster (2006)						
	51WAT 31 May	55WAT 29 Jun	57WAT 11 Jul	59WAT 25 Jul	61WAT 9 Aug	65WAT 8 Sep	67WAT 21 Sep
Assail 30SG	0.01 a	1.2 ab	1.4 ab	18 abc	44 ab	40 a	77 bc
Movento	0.20 ab	1.7 ab	2.3 ab	45 abcd	99 bc	103 abc	61 b
Movento	0.04 a	1.9 ab	1.0 a	16 ab	75 bc	48 ab	71 bc
Centaur	0.01 a	0.2 a	0.7 a	10 a	8 a	38 a	13 a
Imidan	0.33 bc	6.3 c	6.4 de	116 d	328 e	134 cde	144 cd
Provado 1.6F	0.58 cd	5.7 c	3.4 bcd	92 bcd	135 c	160 cde	190 d
Provado 70WG	0.79 d	8.6 c	5.7 cd	94 cd	325 de	230 e	189 d
Sevin XLR	0.59 cd	2.6 b	3.6 bc	82 cd	161 cd	126 bcd	129 bcd
Untreated	1.38 e	12.9 d	9.7 e	98 d	399 e	247 e	170 d

Means in a column followed by the same letter are not significantly different ($P > 0.5$, Fisher's protected LSD) after square root (x + 0.5) transformation of the data. Untransformed means are shown.

Table 2

Treatment	Rate per acre	App. Date	Mean no. mealybugs per cluster (italicized numbers indicate precounts)									
			5 May	17 May	31 May	15 Jun	29 Jun	11 Jul	25 Jul	9 Aug	8 Sept	2 Sept
Imidan 70W	5 lb	???Fall 2005	0.1a	0.1a	0.2a	1.2a	0.9a	1.4a	20.3a	47.1ab	13.5ab	61.7ab
Centaur 7WP	2.14 lb	19 Apr 2006	*0.1a*	0.1a	0.8a	4.6ab	3.6abc	3.0a	31.1a	58.2ab	28.3ab	99.2b
Assail 30SG	8 oz	15 Jun 2006				*21.9bc*	3.3abc	1.5a	15.2a	20.5a	8.3a	31.8ab
Assail 30SG	4 oz	15 Jun 2006				*27.7c*	8.2cd	9.6bc	22.4a	117.0b	31.4ab	116.5bc
Centaur 7WP	2.14 lb	15 Jun 2006				*18.9bc*	1.9ab	2.8a	1.9a	8.2a	11.2a	8.6a
Centaur 7WP	1.07 lb	15 Jun 2006				*23.7bc*	6.8bcd	5.5ab	6.0a	50.1ab	38.1bc	117.1bc
Unt. check			1.3a	1.0a	1.3a	14.4abc	14.5d	16.7c	33.8a	423.2c	94.7c	233.1c

Means in a column followed by the same letter are not significantly different ($P > 0.5$, Fisher's protected LSD) after square root $(x + 0.5)$ transformation of the data. Untransformed means are shown.

Table 3. The effects of mealybug density on pistachio quality. Tipton 2006

Mealybug density rating at harvest	Average Mealybugs per Cluster (Sept)	Harvest Data from Individual Trees			Average Oz Count	Per Acre Yields and Value[1]		
		Green weight removed at shaking (lb/tree)	Green weight remaining in tree (lb/tree)	Green weight removed (%)		CPC Assessed Weight (lbs/acre)	Grower Paid Weight (lbs/acre)	Value
1	10	17.0	3.3	16.2	19.6	1,719	1,703	$3,106
2	46	43.3	7.4	14.5	19.8	1,661	1,646	$3,292
3	95	63.8	8.4	11.6	20.2	1,859	1,847	$3,694
4	153	48.3	9.0	15.7	20.0	1,706	1,694	$3,388
5	198	49.4	7.5	13.1	20.3	1,483	1,471	$2,943
6	263	34.6	5.6	13.9	20.1	1,602	1,583	$3,165
P		0.650	0.623	0.557	0.096	0.703	0.692	0.692
R^2		.057	0.07	0.09	0.54	0.04	0.04	0.04

Values followed by the same letter are not significantly different based on Fisher's Protected LSD at P>0.05.
P and R^2 values are measurements of the correlation in a regression analysis of the value in the column against the average mealybugs per cluster in September.
[1]Based on 2,256 lb gross dry weight per acre average across all research plots at a value of $2.00 per lb.

Table 4. The effects of mealybug density on pistachio yields and crop value. Tipton 2006

Mealybug density rating at harvest	Average Mealy-bugs per Cluster (Sept)	Split InShell (% dry weight)			Shelling Stock (% dry weight)			Closed Shell (% dry weight)		
		Un-stained	Light Stain	Total Edible	Ad-hering Hull	Dark Stained	Total Edible Kernel	Total	Blank	Total Edible Kernel
1	10	60.7	6.6	67.4	0.1	0.2	0.2	25.8	10.2	10.2
2	46	60.8	9.1	69.9	0.0	0.3	0.2	23.4	7.7	10.0
3	95	63.2	13.8	77.0	0.0	0.3	0.2	17.0	6.5	6.2
4	153	65.9	8.8	74.7	0.0	0.2	0.2	20.8	6.7	8.7
5	198	59.8	9.3	69.1	0.0	0.2	0.2	24.9	8.7	10.5
6	263	58.2	9.9	68.1	0.0	0.3	0.3	24.4	7.2	9.5
P		0.596	0.664	0.907	0.205	0.877	0.125	0.904	0.413	0.992
R^2		0.08	0.05	0.00	0.36	0.01	0.48	0.00	0.17	0.00

Values followed by the same letter are not significantly different based on Fisher's Protected LSD at P>0.05.
P and R^2 values are measurements of the correlation in a regression analysis of the value in the column against the average mealybugs per cluster in September.