ALMOND INSECT AND MITE RESEARCH

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Objectives for 2015-16:

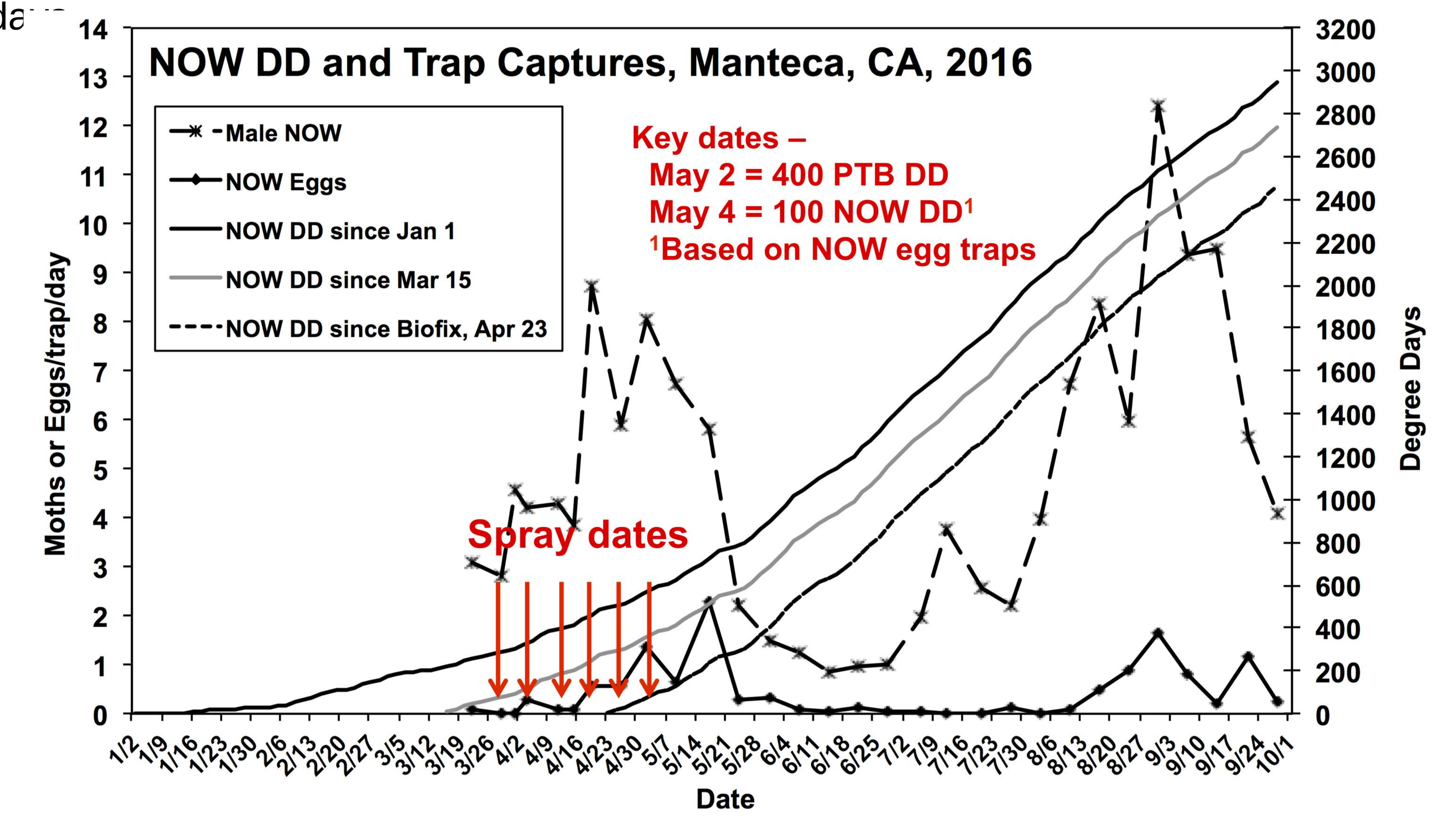
1. Determine treatment timing of bifenthrin, methoxyfenozide, spinetoram, chlornitraniliprone, and flubendiamide for NOW control in spring based on comparison of male trap captures using the Suterra NOW pheromone lure and egg-laying using the traditional black egg traps baited with almond presscake.
2. Evaluate residual efficacy of bifenthrin (Brigade), methoxyfenozide (intrepid), chlornitraniliprone (Altacor), flubendiamide (Belt) and spinetoram (Delegate).
3. Determine if low temperatures delay mating or oviposition by NOW females.
4. Confirm that mummy nuts that were previously infested in fall are more likely to become reinfested in spring

Background. This poster presents results of several studies from the Zalom lab conducted this past year that in some manner focuses on flight and oviposition of the navel orangeworm (NOW) during spring in the more northerly almond production areas. Although we have conducted other studies evaluating efficacy and spring treatment timing for NOW (e.g. Zalom and Nicola 2014; Hamby et al. 2015) and peach twig borer (PTB), our monitoring and treatment timing was based on NOW egg traps (Rice et al. 1976) or PTB pheromone traps (Rice and Jones 1975) and degree-day (DD) phenology models that predict the activity of both insects as has been the case since the 1980s (Engle and Barnes 1983; Sanderson et al. 1989; Brunner and Rice 1984; Zalom et al. 1992). Sex pheromone traps developed as a monitoring tool for male NOW became commercially available in 2013. Field observations clearly show that male moth captures in pheromone traps are consistently greater than the number of eggs in corresponding egg traps. Before the pheromone lure was commercially available, Burks et al. (2011) reported that male moth capture was correlated to proportion of egg traps with eggs present, and that proportion of egg traps with eggs present also correlated to number of eggs per trap. However, we noted that oviposition as recorded in egg traps in more northerly areas began considerably later than did male moth flight. Our studies are aimed at identifying possible mechanisms for these observations as well as relating spring treatment timing to both NOW and PTB pheromone trap captures.

Insect trapping. NOW egg traps, pheromone traps baited with Suterra NOW Biolures, and PTB pheromone traps baited with Trece 'long life' lures were hung on March 14, 2016 in almond orchards near Manteca and Ripon, and monitored to determine the spring flights of NOW and PTB. NOW monitoring results for the Manteca site where thre treatment timing study was also conducted are presented on Figure 1 with notations (in red) for the 100 DD NOW and 400 PTB treatment timings. The PTB biofix date (March 29) was the same in both orchards as was the 400 PTB DD treatment timing. The 100 DD NOW timing based on egg trap captures was on May 4 at the Manteca orchard and May 12 at the Ripon orchard. NOW male moths were caught in both orchards immediately after the traps were deployed in both orchards.

Treatment timing. Twenty uninfested Nonpareil nuts saved from the previous harvest were hot glued to strands of vegetable mesh, and these served as surrogate mummies for\ field studies. In 2016, 290 strands (5800 nuts) were hung in the orchard March 28 which was also the first of 6 weekly treatment dates (noted on Figure 1). Nine strands each were treated with either Altacor, Belt, Intrepid, Brigade, or Delegate on each of these dates, and 20 strands remained untreated as controls. The insecticides were mixed into

Figure 1. Navel orangeworm pheromone and egg trap trap captures at Manteca, 2016, indicating treatment dates and navel orangeworm and peach twig borer degree-da



the equivalent of 100 gal per acre, and included the nonionic surfactant Dyne-amic at 0.25% v/v. The strands were removed from the orchard on May 31 and returned to the lab where they were hand-cracked to determine infestation (nuts with larvae or pupae present) and damage (nuts with larvae, pupae or damage present). Data were analyzed by ANOV following arcsin transformation, with individual treatments and treatment timing compared to the untreated control and treatment means for each product and timing were compared by Students t-test. Results (Table 1) indicated that all treatment timings of all products resulted in reduced NOW infestation when compared to the untreated control. Greater infestation was typically recorded on the May 9 treatment date than on the earlier dates, suggesting that sprays applied after the 100 NOW DD timing was less effective than at the May 3 date.

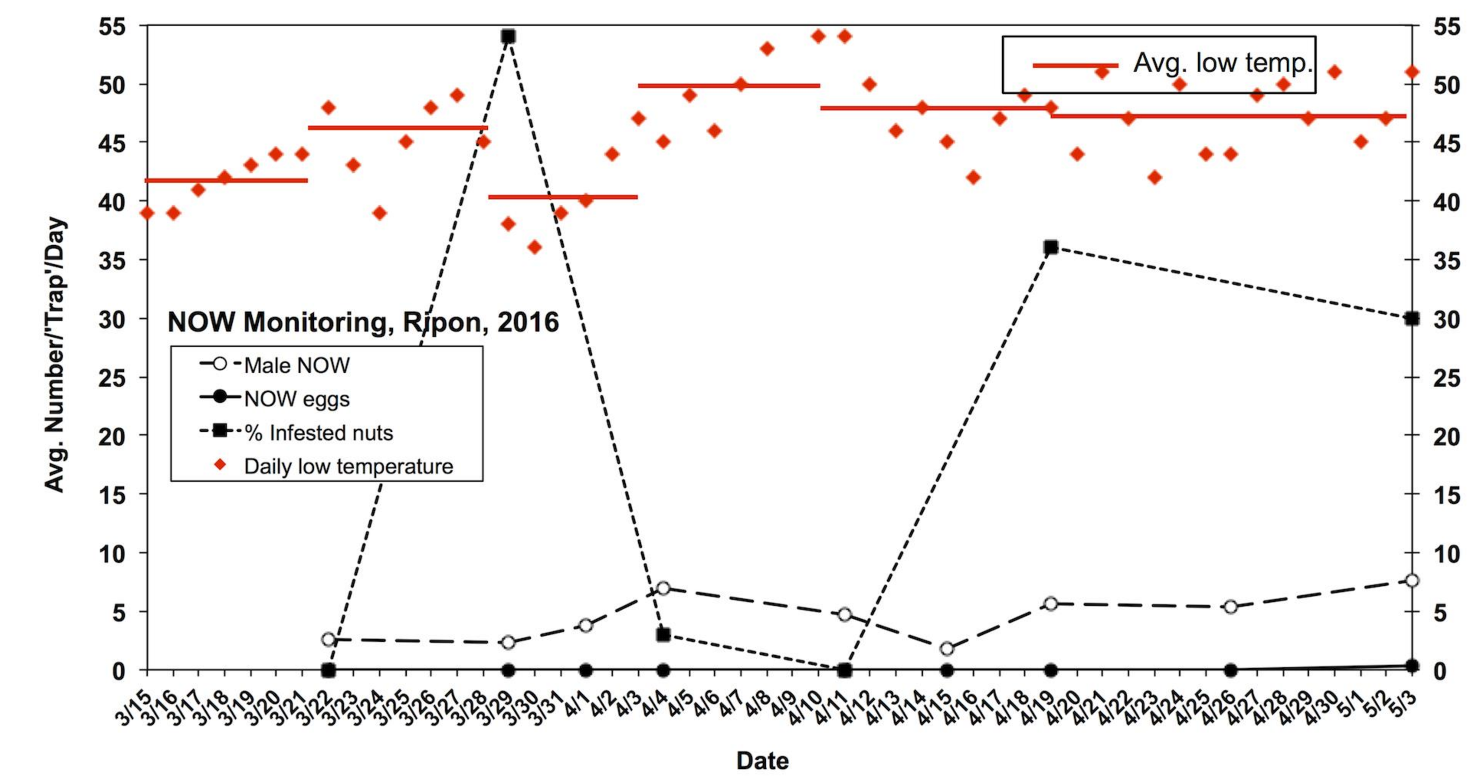
Table 1. Infestation and damage of almond mummies treated with different registered insecticides at weekly intervals starting March 28 2016 at Manteca.

Treatment	n=	Treatment date	Rate/ac	Mean[1,2] % infestation ± SD		Mean[1,3] % damage ± SD	
Control	20	n/a	n/a	3.20 ± 4.87	A	4.31 ± 6.18	A
Altacor	9	4/4/16	4 oz.	0.00 ± 0.00	B	0.92 ± 2.77	B
Altacor	9	4/11/16	4 oz.	0.00 ± 0.00	B	0.62 ± 1.87	B
Altacor	9	4/19/16	4 oz.	0.00 ± 0.00	B	0.00 ± 0.00	B
Altacor	9	4/26/16	4 oz.	0.66 ± 1.97	B	1.28 ± 2.54	B
Altacor	9	5/3/16	4 oz.	0.00 ± 0.00	B	0.56 ± 1.67	B
Altacor	9	5/9/16	4 oz.	0.66 ± 1.97	B	1.80 ± 2.71	AB
Belt	9	4/4/16	4 oz.	0.00 ± 0.00	B	1.18 ± 2.34	B
Belt	9	4/11/16	4 oz.	0.62 ± 1.87	B	2.47 ± 7.40	AB
Belt	9	4/19/16	4 oz.	0.00 ± 0.00	B	1.90 ± 2.91	AB
Belt	9	4/26/16	4 oz.	0.00 ± 0.00	B	0.56 ± 1.67	B
Belt	9	5/3/16	4 oz.	0.00 ± 0.00	B	0.66 ± 1.97	B
Belt	9	5/9/16	4 oz.	0.00 ± 0.00	B	1.11 ± 3.33	B
Intrepid	9	4/4/16	16 oz.	0.00 ± 0.00	B	1.83 ± 2.75	AB
Intrepid	9	4/11/16	16 oz.	0.00 ± 0.00	B	0.59 ± 1.77	B
Intrepid	9	4/19/16	16 oz.	0.00 ± 0.00	B	0.66 ± 1.97	B
Intrepid	9	4/26/16	16 oz.	0.00 ± 0.00	B	1.11 ± 3.33	B
Intrepid	9	5/3/16	16 oz.	0.00 ± 0.00	B	0.00 ± 0.00	B
Intrepid	9	5/9/16	16 oz.	0.59 ± 1.77	B	2.34 ± 3.82	AB
Brigade	9	4/4/16	16 oz.	0.00 ± 0.00	B	1.81 ± 2.74	AB
Brigade	9	4/11/16	16 oz.	0.00 ± 0.00	B	0.74 ± 2.23	B
Brigade	9	4/19/16	16 oz.	0.00 ± 0.00	B	0.56 ± 1.67	B
Brigade	9	4/26/16	16 oz.	0.59 ± 1.77	B	0.59 ± 1.77	B
Brigade	9	5/3/16	16 oz.	0.00 ± 0.00	B	0.00 ± 0.00	B
Brigade	9	5/9/16	16 oz.	0.59 ± 1.77	B	1.79 ± 3.76	AB
Delegate	9	4/4/16	7 oz.	0.00 ± 0.00	B	1.98 ± 4.32	AB
Delegate	9	4/11/16	7 oz.	0.00 ± 0.00	B	1.87 ± 4.08	AB
Delegate	9	4/19/16	7 oz.	0.62 ± 1.87	B	0.62 ± 1.87	B
Delegate	9	4/26/16	7 oz.	0.59 ± 1.77	B	1.14 ± 2.27	B
Delegate	9	5/3/16	7 oz.	0.00 ± 0.00	B	0.56 ± 1.67	B
Delegate	9	5/9/16	7 oz.	0.56 ± 1.67	B	1.18 ± 2.34	B

[1] Means followed by the same letter do not differ significantly at $P=0.05$ by Student's t-test
[2] $F=2.3854$, df=30,289 $P<0.0001$
[3] $F=1.0399$, df=30,289 $P<0.4145$

Low temperatures. Although it is likely that the lower NOW densities present in more northerly almond orchards results in later egg trap captures relative to male moth captures seen farther south in the San Joaquin Valley, another factor may be generally cooler temperatures that tend to occur early spring. Figure 2 presents pheromone and egg trap captures from 2016 together with average number of infested mummy nuts from 10 strands hung during 6 consecutive periods between March 15 and May 3 with associated daily minimum temperatures and average low temperature for each period. Pheromone trap captures averaged 1.7-7.7 moths per trap per night during this period. No nut infestation was observed during the initial period when the average minimum temperature was 41.7ºF and was greatly reduced again during the period from March 29 through April 10. The average daily minimum temperature was 40.7ºF for the period March 29 through April 2.

Figure 2. Navel orangeworm pheromone, egg trap trap and almond mummy infestation during successive spring periods at Ripon, 2016, indicating daily minimum temperatures and average low temperatures for each period of mummy deployment.



Virgin female and male NOW from our laboratory colony were exposed to a series of constant temperatures ranging from 48.2ºF to 57.2ºF, and to a series of variable daily temperatures representing April in the northern San Joaquin and southern Sacramento Valleys, and results indicated a trend with greater egg laying and fertility as temperatures increase (Figure 3). Only 0.7 eggs were laid per female on average at 48.2ºF increasing to as high as 190.8 eggs per female at 55.4ºF, however none of the eggs laid at either 48.2ºF or 50.0ºF were fertile. Eggs laid at the variable temperatures almost doubled at successive warmer regimes, and there were differences in both number of eggs laid and percent fertility. Reproductive success calculated as mean total eggs laid divided by the proportion of those eggs that were fertile also significantly increased. These results have important implications for NOW reproductive success.

Figure 3. Total eggs laid during the first 72 hours after placing 20 NOW virgin females and males in the same container at constant temperatures and fertility of those eggs, and total eggs laid for the 48 hours after the mating period when the females were transferred to 71.6ºF constant temperature. Percent fertility of those eggs was measured after an additional 48 hours.

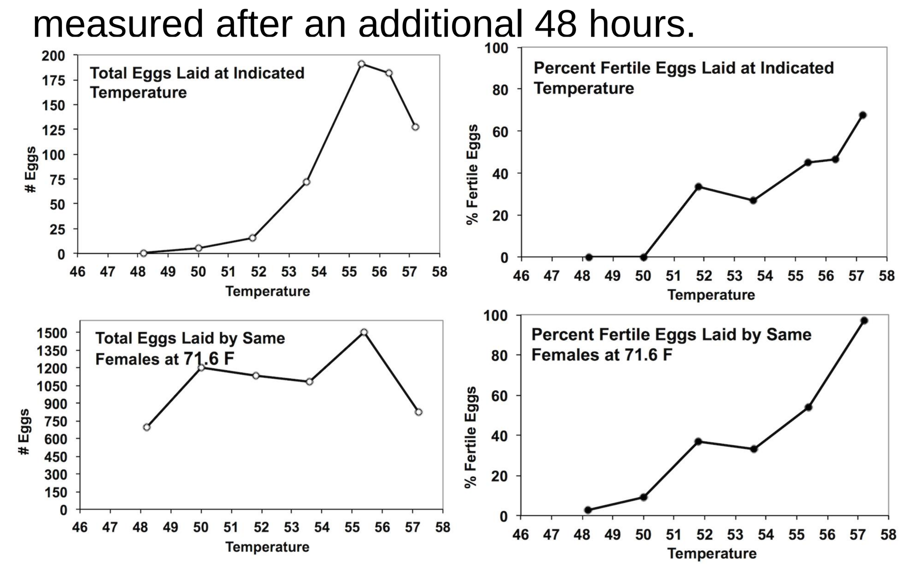


Table 2. Eggs laid by navel orangeworm females during 72 hour exposure to variable temperature, and fertility of those eggs held at 71.6ºF.

Max./Min. Temp (ºF)	Mean Total Eggs ± SD[1,2]		Mean % Fertility ± SD[1,3]		Reproductive Success[1,4]
57.2/37.4	86.8 ± 44.6	B	11.9 ± 8.9	B	10.3
60.8/41.0	171.3 ± 107.2	B	16.4 ± 6.4	B	29.2
64.4/44.6	173.0 ± 74.6	B	24.8 ± 8.5	AB	73.7
68.0/48.2	347.3 ± 41.2	A	44.3 ± 17.9	A	262.6

[1] Means followed by the same letter do not differ significantly at $P=0.05$ by Student's t-test
[2] $F=10.0372$, df=3,11, $P<0.0044$
[3] $F=4.8250$, df=3,11, $P<0.0334$
[4] $F=4.825$, df=3,11, $P<0.0334$

Nut damage and infestation. Previously damaged nuts are more likely to become infested by NOW than sound nuts. Table 3 presents results of a 3 year field study showing that mummy nuts previously infested with NOW larvae are significantly more likely to become reinfested by NOW, confirming the importance of winter mummy removal. These results may also indicate presence of a cue for how females select mummy nuts in which to oviposit.

Table 3. Percent infestation of previously infested and uninfested Nonpareil mummy nuts that were held at -20C for 6 weeks prior to being hung in an untreated orchard in San Joaquin Co. in spring 2013-2016.

Site	Treatment	Year	n=	Dates of NOW exposure	Mean ± SD % infestation
Ripon	Uninfested	2013	20	April 16-June 5	14.4 ± 12.4
Ripon	Preinfested	2013	9	April 16-June 5	36.7 ± 15.5[1]
Manteca	Uninfested	2014	14	April 4-May 28	9.9 ± 16.1
Manteca	Preinfested	2014	14	April 4-May 28	54.6 ± 12.6[2]
Ripon	Uninfested	2016	14	May 3-May 31	19.6 ± 12.9
Ripon	Preinfested	2016	14	May 3-May 31	48.5 ± 15.0[3]
Manteca	Uninfested	2016	14	May 3-May 31	9.1 ± 12.7
Manteca	Preinfested	2016	14	May 3-May 31	54.9 ± 12.1[4]

[1] ANOV statistics, $F=17.2634$, df=1,28, $P=<0.0003$
[2] ANOV statistics, $F=60.2221$, df=1,27, $P=<0.0001$
[3] ANOV statistics, $F=29.8127$, df=1,27, $P=<0.0001$