Project Number: 85-D12

Investigations on Navel Orangeworm and Mites in Almond Orchards

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Summary of Principal Results, 1985

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Project No. 85-D12 - Navel Orangeworm, Mite and Insect Research
Insect and Mite Studies

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Objectives: (1) Develop specific NOW management procedures for later maturing pollinizer varieties like Merced. (2) Continue development of insecticides and miticides. (3) Investigate the effects of water stress on leaf and/or tree canopy temperatures and the resultant development of mite populations. (4) Acquire and analyze data in final preparation for NOW model validation and implementation. (5) Develop information on the carob moth which can be used for its management and control (funded by the California date industry).

Interpretive Summary: Objective 1. A large-scale replicated experiment of chemical control of NOW on Merced almonds was inconclusive, probably because of a late Merced harvest date. Guthion gave better NOW control on Nonpareil almonds than did Lorsban, as compared to unsprayed almonds.

Objective 2: Low population densities of spider mites precluded efficacy evaluation mite suppression by Brigade 10WP (FMC 54800), Brigade 10WP plus Vendex 50WP, and three concentrations of Apollo 50SC. Despite the low populations, a significant resurgence was evident in the Brigade 10WP treatment by the fourth week after spray application.

Objective 3: Effect of water stress on the development of spider mite populations was associated with higher leaf temperatures on water stressed almond trees. A greenhouse study showed a significantly faster developmental time (12%) from egg to first egg on stressed trees for the Pacific spider mite. Measurements of tree canopy temperatures in the field indicated that water stressed trees were significantly hotter than nonstressed trees during daylight hours. Canopy temperature measurements from trees under three irrigation levels had correspondingly higher mean temperatures with decreasing irrigation.

Objective 4: Lower and upper developmental threshold temperatures were determined for the egg and pupal stages of the NOW in laboratory constant temperature studies. The lower threshold temperatures for the egg and pupal stages were 55.9 and 55.2°F, respectively. The upper threshold temperature for both stages was between 90 and 94°F. In separate studies, degree-day accumulations for each NOW instar were determined for development on both mummy and new crop almonds. Biological data on NOW development have been voluntarily provided to UC/IPM personnel for a separate model development effort.

Objective 5: Field research studies on the carob moth are still underway, with harvest scheduled in mid-November. The annual report on these studies will be available by request by February 1.

Insecticide Trial for Navel Orangeworm Control on Nonpareil and Merced Almonds, 1985

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A large scale, replicated experiment was conducted to compare the performance of Guthion and Lorsban for navel orangeworm (NOW) control on Nonpareil and Merced almonds. In particular, we wanted to compare the degree of control achieved on Merceds by a single application of Guthion or Lorsban applied at Nonpareil hullsplit initiation, as well as a second spray of Lorsban applied to the Merceds at Merced hullsplit initiation.

Materials and Methods

The orchard in which the trial was conducted consisted of 15- and 16-year-old Nonpareil, Merced, and Texas Mission variety trees, and was located near McFarland, Calif.

The treatments were: (a) Guthion 50W at 2 lb AI/acre applied at Nonpareil hullsplit initiation, (b) Lorsban 50W at 2 lb AI/acre at Nonpareil hullsplit initiation, (c) Lorsban 50W at the previous rate applied at both Nonpareil and Merced hullsplit initiation, and (d) insecticide-free control. Omite 6E at 2.25 lb AI/acre was added to all treatments, including the control.

The experiment was conducted in a randomized block design, with each treatment replicated once in each of six blocks. Each replicate consisted of a ca. 30 acre plot, except those of the controls which were seven acres.

Materials were applied by speed sprayer at a rate of 400 gal/acre. The treatments timed at Nonpareil hullsplit were applied on July 3 and 4, 1985. The second Lorsban spray timed at Merced hullsplit was applied only to the Merced rows on Aug. 5.

The percentage of kernels damaged by navel orangeworm and peach twig borer was estimated from 200-nut harvest samples, collected within 3 days of harvest shake, from each of 8 (Merced) or 10 (Nonpareil) trees located centrally in each replicate. Nonpareil samples were collected on Aug. 26 and 27. Merced samples were collected on Sept. 19.

Both raw and square-root-transformed data were analyzed by analysis of variance, and treatment means were compared using Duncan's new multiple range test.

Results and Discussion

No kernel damage by peach twig borer was detected in any of the Nonpareil or Merced samples. NOW damage was common.

A significant treatment effect ($P < 0.0001$) was detected in both the transformed and raw data of the Nonpareil samples. The comparison of the means of each treatment is presented in Table 1. Nuts from trees sprayed with Guthion had statistically less damage than unsprayed trees. Moreover, the degree of control provided by Guthion (45%) is consistent with the results of many previously conducted field tests. Although nuts from trees sprayed with Lorsban had less damage on average than the unsprayed nuts, their damage level was not statistically different at the 5% level.

There was no significant difference among any of the treatments for NOW control on Merceds. The late harvest date for the Merceds probably contributed to the observed lack of control of any of the treatments.

Observations in June, 1985, showed that in a block where Lorsban, Plictran, Helena Buffer, and No Foam B were applied at Nonpareil hullsplit in 1984 (see 1984 report), severe mite damage had developed early the following (1985) season, as compared with a similar treatment but using Guthion. In the latter plot, immediately adjacent, no mite outbreak occurred in early season.

Mite population levels will be monitored in these plots in the spring of 1986. Also compared will be a 30-acre plot in this same orchard which was sprayed with Ambush at 0.1 lb AI/acre at Nonpareil hullsplit initiation in 1985.

Table 1. Results of a large scale experiment on the efficacy of insecticides for navel orangeworm control on 'Nonpareil' and 'Merced' almonds, Kern County, 1985.

Treatment	Lb AI/ acre	Date(s) of application[a]	Avg. % damage at harvest[b, c]	
			'Nonpareil'	'Merced'
Guthion 50W	2	7/3 and 4	3.9 a	34.4 a
Lorsban 50W	2	7/3 and 4	5.8 b	33.9 a
Lorsban 50W	2	7/3 & 4, 8/5	-	28.7 a
Control	-	-	7.1 b	28.8 a

[a] Applied at Nonpareil or Merced hullsplit initiation by speed sprayer at 400 gal/acre. Replicated in 6, 30-acre plots per treatment. Control plots were 7 acres.

[b] Based on 200-nut samples taken randomly from each of 8 Merced or 10 Nonpareil trees centrally located on each plot. Nonpareils sampled 8/26 and 27, and Merceds sampled 9/19.

[c] Means in the same column followed by the same letter are not statistically different at the 5% level, as measured by Duncan's NMRT.

Development Rates of the Navel Orangeworm (Lepidoptera: Pyralidae) at Various Constant Temperatures

J.P. Sanderson and M.M. Barnes

This study was conducted as a part of the synthesis of a degree-day model to predict seasonal development of the navel orangeworm (NOW), Amyelois transitella (Walker), in California almond orchards. The present goal was to obtain development rate data over a wide range of temperatures which could be used to estimate the lower and upper developmental threshold temperatures, and the thermal constant for development, for the egg and pupal stages, and for development from neonate larva to adult eclosion.

Previous studies have measured development rates of various life stages of this species in the laboratory (Wade 1961, Gal 1978, Engle and Barnes 1983, Seaman 1983). However, each of these studies lacked data necessary to estimate upper developmental threshold temperatures, and was inadequate as well for at least one of the following reasons: (a) only studied one life stage; (b) used insects from inbred laboratory cultures; (c) inadequate frequency of experimental observations; (d) used an artificial rearing diet; or (e) did not adequately control humidity. Therefore the present studies were conducted to provide a more complete determination of the developmental rate response of

this species to a wide range of constant temperatures.

Materials and Methods

Egg Stage

Wild NOW females which emerged from mummy almonds collected in Kern Co., CA, in January and February, 1985, were placed in battery jars lined with paper toweling and allowed to oviposit for ca. 5 hours. Strips of paper toweling containing known numbers of eggs were then suspended above a saturated solution of NaCl inside a 40 dr. clear plastic vial. The saturated NaCl solution in the sealed vials maintained a relative humidity of ca. 75% over all temperatures (Winston and Bates 1960). Three vials, each containing ca. 18 eggs, were placed into each of five chambers, which maintained temperatures of 36.7 +/- 0.5°C, 34.4 +/- 0.5°C, 32.2 +/- 0.5° C, 26.7 +/- 0.5°C, and 21.1 +/- 0.1°C. A sixth chamber, set at 16.7 +/- 1.6°C held two such vials. The photoperiod in each chamber was 14L:10D. The eggs were checked every six hours for eclosion.

Pupal Stage

Two separate studies were conducted with the pupal stage. In the first study, NOW larvae produced by field-collected adults were reared at 26.7°C on a diet of red wheat bran, glycerin, and honey (Finney and Brinkman 1967). Last instar larvae were checked inside their cocoons every

six hours for pupation. Any cocoons containing newly-pupated individuals were then placed into individual 12 dr. plastic vials which were sealed with screened lids to allow airflow. Each vial was then placed into a chamber set at either 37.8 +/- 1.0°C, 34.4 +/- 0.5°C, 32.2 +/- 0.5°C, 29.4 +/- 1.0°C, 26.7 +/- 0.5°C, or 23.9 +/- 0.5°C. The time of pupation was recorded for each individual. Twenty-four vials were placed into each chamber. Pans of water were added to the chambers to increase humidity, which ranged from 50 to 90% RH. The photoperiod in each chamber was 14L:10D. Each vial was checked every three hours for eclosion and the adults were sexed.

The results of this first study indicated a possible diel periodicity of adult eclosion. This periodicity could influence the calculated mean duration of development, producing inaccurate results. For example, if eclosion usually occurs between 8 and 9 PM, the recorded duration of development of an individual which has actually developed to the point of eclosion at 1 AM could be as much a s 20 hours in error, because this individual would not eclose until the following night. The measured duration of the pupal stage at a given temperature could change, depending on the time of day when most of the individuals reared at that temperature pupated.

For this reason, and to examine development rates at several other temperatures, the study was repeated. The

same procedure was followed, with the following modifications. The vials containing individual pupae were placed in a rack suspended over one liter of a saturated NaCl solution inside a 35.5 x 26 x 16.5 cm plastic box which was covered with a lid. The saturated NaCl solution maintained ca. 75% RH over all temperatures as was measured by a psychrometer. Groups of 8 to 16 vials, comprised of individuals which had pupated within 6 hours of one another, were placed in the boxes. Four to five of these groups, each representing a different initial time of pupation, were included at each temperature. This procedure eliminated error due to eclosion periodicity by including groups of individuals which pupated at different times of day. The temperatures used were 36.7 +/- 0.5°C, 34.4 +/- 0.5°C, 32.2 +/- 0.5°C, 29.4 +/- 1.0°C, 26.7 +/- 0.5°C, 25.5 +/- 0.5°C, 21.1 +/- 1.0°C, and 16.7 +/- 1.6°C. Each individual was checked every three hours from 7 AM to 1 AM for eclosion. Emerged adults were sexed. The data from both experiments were combined for the analysis.

First Instar to Adult Eclosion

Mummy almonds, in which the NOW overwinters in various larval stages, were collected from orchards in Kern Co., CA, in February, 1985, and frozen for 24-48 hours to kill any larvae present. Only those mummies that appeared to be uninfested were used. Eggs, produced by wild moths as previously described, were allowed to hatch at 26.7°C. Two of

the resulting neonate larvae were placed into each mummy. The mummy kernels had been punctured to facilitate larval establishment. The artificially infested mummies were then placed individually into a 12 dr. plastic vial and covered with a screened lid. Forty-eight such vials were placed into plastic boxes as described in the pupal stage study. One box was then placed into each of eight chambers at the same temperatures and relative humidity used in the second pupal stage study. The vials were checked daily for emerged adults.

Data Analysis

The duration of development of each individual was measured in hours for the egg and pupal stage studies, and in days for the first instar to adult eclosion study. All measurements were then converted to days for analysis. Development rate was expressed as the reciprocal of duration. Graphs of mean development rate versus temperature were generated, and the rate data from those temperatures which appeared linearly related to development rate were regressed on temperature to estimate the lower developmental threshold temperature by the x-intercept method of Arnold (1959). The upper developmental threshold, defined as that temperature above which development rate decreases, was estimated directly from each graph. The theoretical thermal constant for development was calculated as the reciprocal of the slope of each regression equation (Morris and Fulton

1970). The theoretical thermal constants were compared to observed estimates of average degree-days required for development at each temperature, calculated as the product of duration of development times the number of centigrade degrees above the lower threshold temperature.

Results and Discussion

Egg Stage

Table 1 presents data on percent mortality, average duration of development, and average degree-days required for development at each temperature. Mortality was low at all temperatures except 36.7° C. Average rat e of development per day is plotted against temperature in Figure 1. A regression of development rate on temperatures between 16.7 and 32.2°C produced the following equation:

$$\text{rate}=0.0192(\text{temperature})-0.262$$

with a coefficient of determination of 99.4%. The calculated lower threshold temperature was 13.6°C. The upper tnreshold temperature was between 32.2 and 34.4°C.

The theoretical thermal constant (52 degree-days) is comparable to the average degree-day values reported in Table 1, except at 34.4 and 36.7°C. This discrepancy demonstrates the non-linear relationship between these temperatures and rate of development.

Table 1. Percent mortality, average development time (days), and average degree-days required for development of navel orangeworm eggs at six constant temperatures.

Temperature (°C)	Percent Mortality	No. Surviving	Avg. Time (days) +/- SD	Avg. Degree-days
36.7	53	25	3.4 +/- 0.15	78
34.4	4	44	2.9 +/- 0.15	60
32.2	10	53	2.8 +/- 0.10	53
26.7	5	56	3.9 +/- 0.11	52
21.1	10	46	7.2 +/- 0.23	54
16.7	3	35	17.1 +/- 0.38	53

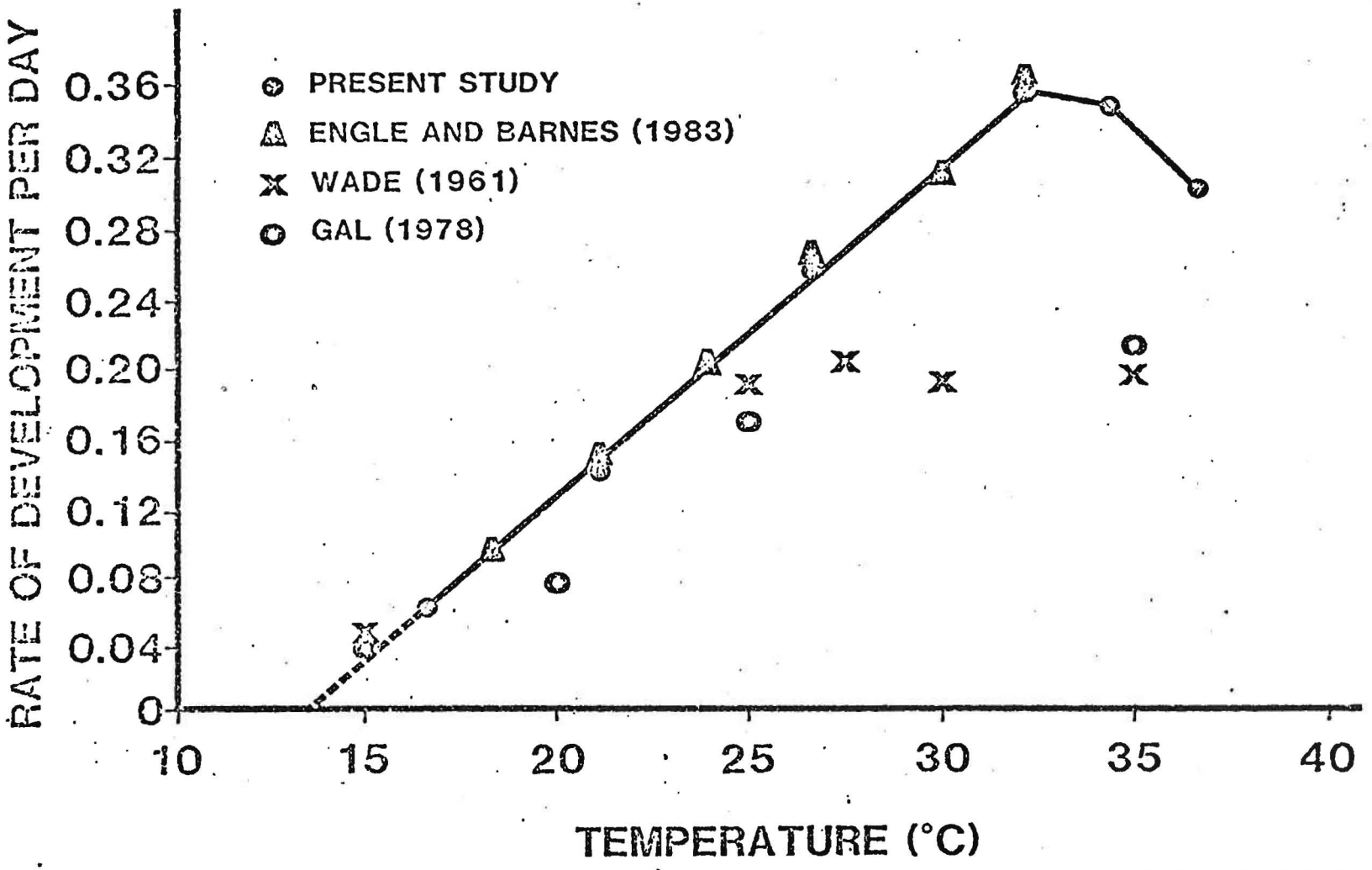

Fig. 1. Rate of navel orangeworm egg development (1/days) vs. constant temperature. Data calculated from other sources included for comparison. Solid line connects the data of the present study. Dashed line extrapolates to the lower threshold temperature (13.6°C).

Development rates calculated from the data of Wade (1961), Gal (1978), and Engle and Barnes (1983) were plotted for comparison in Figure 1. The development rates of the present study are comparable to those of Engle and Barnes (1983) at comparable temperatures. The discrepancy between these results and th ose of Wade (1961) and Gal (1978) is probably because eggs were observed only once daily in both of the latter studies. Engle and Barnes (1983) calculated a lower threshold temperature of 12.8°C, which is probably not biologically different from the present estimate. The thermal constant calculated by Engle and Barnes (1983) (1,332 degree-hours) is also very close to the present estimate.

Linear regression of the average rate data derived from Engle and Barnes (1983) combined with the present data yielded the following equation:

$$rate=0.0188(temperature)-0.250$$

with a coefficient of determination of 99.0%. The lower threshold temperature and thermal constant were 13.3°C and 53 degree-days, respectively.

Engle and Barnes (1983) developed a thermal summation procedure to predict spring egg hatch of NOW. Spring temperatures in the San Joaquin Valley of California remain primarily within the range of temperatures which are linearly related to development rate. Thus their forecast system works well in spring. However, during late spring and summer, temperatures frequently rise above the upper

threshold temperature. With temperatures in this range, their forecast system would not be valid unless modified in some way to account for the non-linear relationship between high temperatures and development rate (e.g., incorporation of a upper threshold cutoff).

Pupal Stage

Percent mortality, average duration of development, and the average degree-days required for development of the pupal stage at each temperature are shown in Table 2. Figure 2 illustrates the relationship between temperature and average development rate. Development rates calculated from the data of Wade (1961), Gal (1978), and Engle and Barnes (1980) were also plotted for comparison. Regressing development rate data from the present study on temperatures from 16.7 to 32.2°C produced the following equation:

$$rate=0.00899(temperature)-0.116$$

The coefficient of determination was 96.1%. The calculated lower threshold was 12.9°C. The upper threshold temperature was between 32.2 and 34.4°C. The theoretical thermal constant was 111 degree-days.

Gal (1978) and Engle and Barnes (1980) reported pupal lower threshold temperatures of 12.5 and 13.1°C, respectively, both of which are comparable with the present value. Thermal constants of 119 and 109 degree-days, reported by Gal (1978) and Engle and Barnes (1980), respectively, are

Table 2. Percent mortality, average development time (days), and average degree-days required for development of navel orangeworm pupae at ten constant temperatures.

Temperature (°C)	Percent Mortality	No. Surviving	Avg. Time (days) +/- SD	Avg. Degree-days
37.8	100	0	---	---
36.7	28	29	6.3 +/- 0.28	150
34.4	2	63	5.9 +/- 0.36	127
32.2	6	58	6.0 +/- 0.39	116
29.4	3	62	6.6 +/- 0.40	108
26.7	6	60	8.1 +/- 0.42	112
25.6	3	33	8.2 +/- 0.34	104
23.9	0	24	9.5 +/- 0.40	104
21.1	5	37	14.0 +/- 0.49	115
16.7	2	39	33.5 +/- 1.28	127

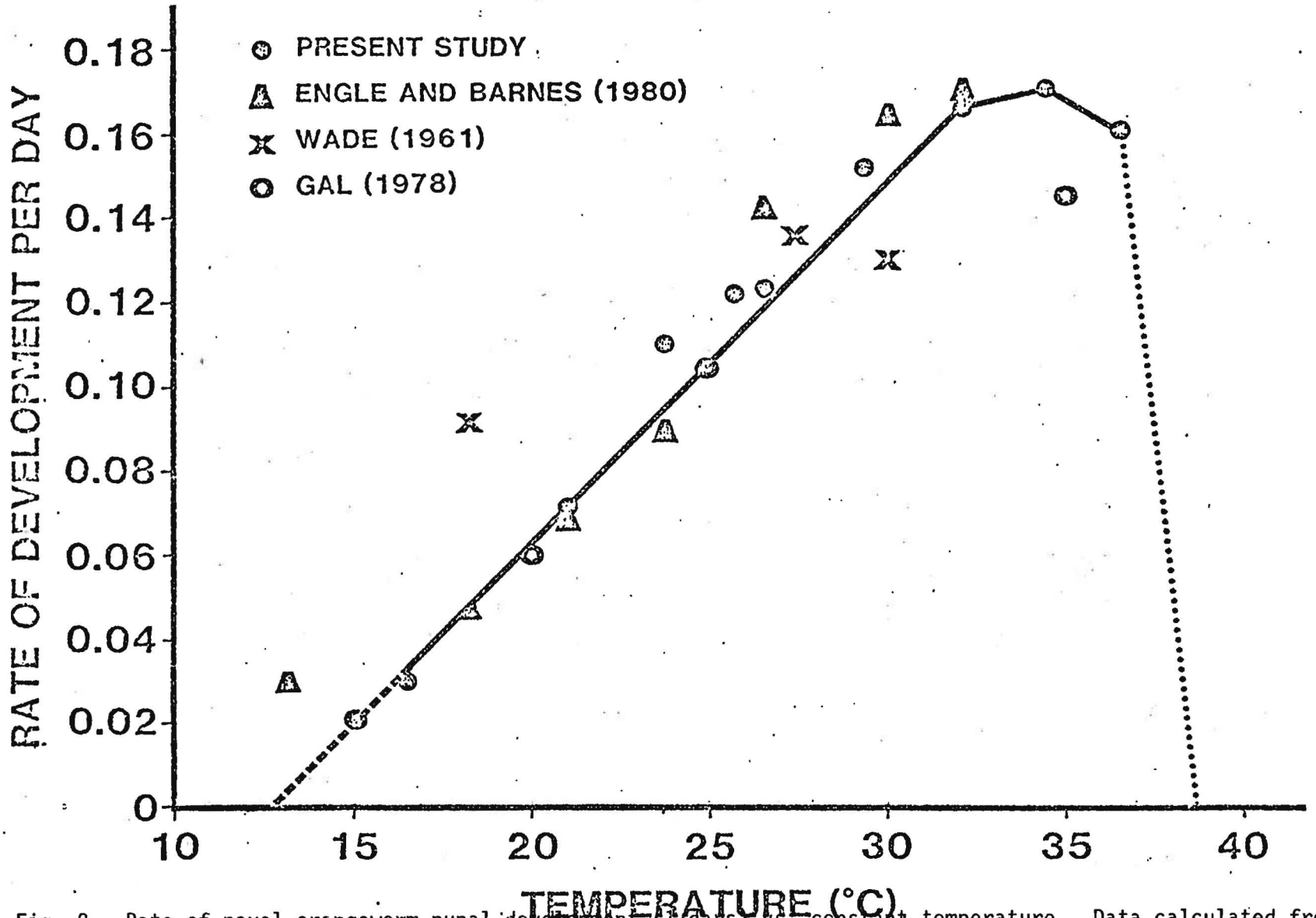

Fig. 2. Rate of navel orangeworm pupal development (1/days) vs. constant temperature. Data calculated from other sources included for comparison.. Solid line connects data of present study. Dashed line extrapolates to lower threshold temp. (12.9°C). Dotted line indicates 100% mortality at 37.8°C.

also both close to the present value. The average development rates calculated from the data of Wade (1961), Gal (1978), and Engle and Barnes (1980) were combined with the present data and regressed on temperatures from 15 to 32.2°C (Figure 2). The resulting regression equation was:

rate=0.00886(temperature)-0.114

with a coefficient of determination of 95.4%. The lower threshold temperature and thermal constant were 12.9°C and 113 degree-days, respectively.

The average degre-day accumulation at temperatures of 21.1 to 32.2° C (Table 2) are comparable to the theoretical thermal constant. Degree-day accumulations at temperatures outside this range deviate from the thermal constant, due to the non-linear temperature-rate relationship at these temperatures.

Mortality was low at temperatures from 16.7 to 34.4° C, but increased markedly at 36.7°C and was 100% at 37.8°C. Half of the adults which emerged at 36.7° C had partially expanded wings, difficulty walking, and were clearly unhealthy. The individuals kept at 37.8° C developed apparently normally inside their pupal cases, but for some reason never emerged.

Students t-test analysis revealed no significant difference (p=0.01) in average development times of male and female pupae at any temperature.

To examine the possible diel periodicity of eclosion, the eclosion times of all individuals at all temperatures of the second study were combined and expressed in terms of hours before or after lights off. Lights went off in the different chambers at 8 PM, 9 PM, or 2AM. The results are illustrated in Figure 3. Eighty-five percent of all individuals eclosed between 3 hours before and 5 hours after lights off, with peak eclosion just after lights off. Andrews et al. (1980) observed eclosion no earlier than about one hour before sunset in the field. They reported that most eclosion occurred "just before darkness fell." Their observations, coupled with the present results, indicate that NOW adult emergence has a diel periodicity.

First Instar to Adult Eclosion

Abnormal behavior of a majority of the prepupal individuals at all temperatures precluded legitimate calculations of average development times in this study. These individuals remained in the last larval instar for an unusually long period of time, spinning extensive emergence tunnels and/or several partially completed cocoons. Their size decreased with time. No feeding was observed. Some individuals pupated, yet never eclosed; many shriveled and died as larvae. The extensive webbing produced by these larvae has never been observed under field situations. Unfortunately, the identification of those individuals exhibiting this behavior was not recorded during the study. Therefore,

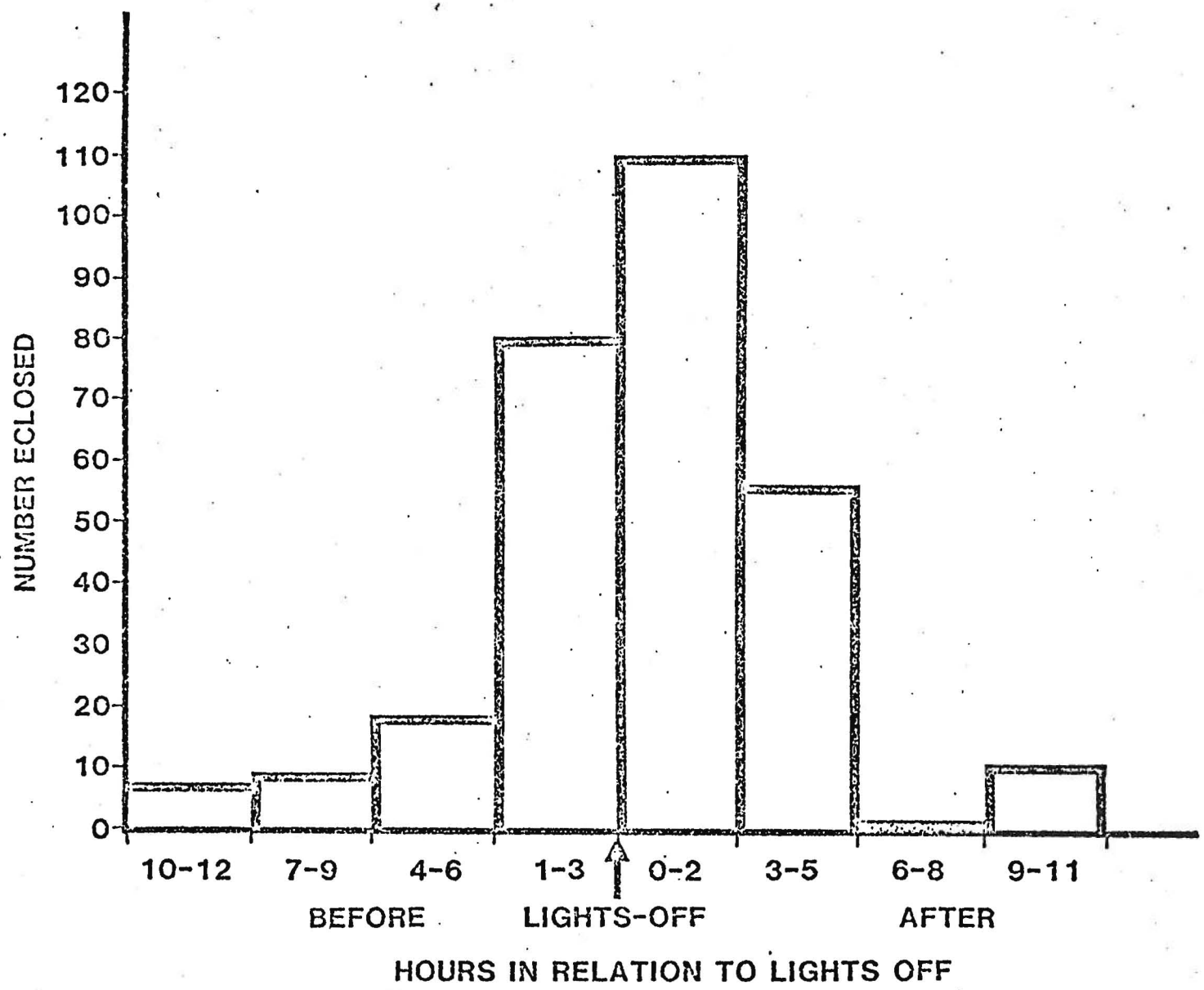

Fig. 3. Numbers of eclosed NOW adults found during 3-h time periods in relation to lights off.

there was no way to determine which individuals to exclude from the calculations.

Seaman (1983) did not mention the appearance of this behavior in his laboratory studies. However, he placed individual almonds into larger chambers (5 x 4.3 x 4 cm) than the vials used in the present study. Perhaps some aspect of the experimental enclosure such as volume in some way caused this unusual behavior.

The average duration of development from first instar to adult eclosion at each temperature is presented in Table 3, although again, these data may be misleading. Further calculations of development rates, etc. from these data could be erroneous.

Mortality levels (Table 3) increased rapidly above 34.4° C.

Males developed slightly faster than females, on average, although t-test analysis revealed no significant difference ($p>0.01$) in development times.

In a related observation, the duration of the pupal stage of several individuals at all temperatures except 16.7 and 36.7°C was noted to the nearest day, and compared with the findings of the previous pupal stage study. At all temperatures, the observed average development times of the two studies were in agreement. Thus, the duration of the pupal

Table 3. Percent mortality and average development time (days) of navel orangeworms reared from neonate larvae to eclosed adults on mummy almonds at eight constant temperatures.

Temperature (°C)	Percent Mortality	No. Surviving	Avg. Time (days) +/- SD
36.7	98	2	40.5 +/- 0.7
34.4	53	45	39.9 +/- 7.2
32.2	35	62	40.6 +/- 12.5
29.4	38	60	37.1 +/- 13.5
26.7	27	70	37.3 +/- 10.9
25.6	36	61	38.8 +/- 9.1
21.1	47	51	63.0 +/- 10.9
16.7	17	80	125.4 +/- 13.1

stage apparently is not related to the diet of the larva, since the larval diets of the previous and present studies were bran media and mummy almonds, respectively.

General Discussion

Seaman and Barnes (1984) conducted field studies of NOW thermal summation, from first instar to adult eclosion, using a lower developmental threshold temperature of 12.8°C. Their use of 12.8° C as a lower threshold temperature was based on the results of Engle and Barnes (1983) for the egg stage. Gal (1978) reported lower threshold temperatures of ca. 13°C for various immature stages. The lower threshold temperatures reported herein for the egg and pupal stages confirm these prior results. For the purposes of degree-day calculations for the NOW, a lower threshold temperature of ca. 12.8°C should be used.

Seaman and Barnes (1984) also explored the use of an upper threshold temperature in their calculations. They sought an upper threshold temperature which was biologically meaningful and produced consistant results in field data from two seasons which contrasted considerably in temperature. The use of both horizontal and vertical cutoffs were examined. The horizontal cutoff produced the most consistent results at an upper threshold temperature between 26 and 30°C, which was rejected because available laboratory data for NOW indicated this was an unrealistic range for the

upper developmental threshold temperature. With a vertical cutoff, an upper threshold of 34.4°C produced consistent results between the two season's data for both mean and range of thermal summation, modelling their field data in superior fashion.

The development rates at the higher temperatures observed herein for the egg and pupal stages adequately confirm the use of an upper threshold temperature in the range of 32.2-34.4°C.

Thermal Summation During Individual Stadia of the Navel Orangeworm

J. P. Sanderson and M. M. Barnes

Studies of the thermal summation for each instar of the NOW on both mummy and newly-hullsplit almonds were conducted to provide necessary data for the NOW population simulation model of Dr. J. K. Oddson. These data could also be used to predict adult emergence from field samples of immature NOW.

Materials and Methods

Studies were conducted in 1983, 1984, and 1985, with two studies on each of the two almond substrates. For studies on newly-hullsplit almonds, unsplit new crop almonds still attached to mature Nonpareil trees in Kern Co. were individually caged in 1983 and 1984 to prevent infestation by wild NOW. Upon dehiscence, each nut was artificially infested with two neonate larvae. In 1983, these larvae were primarily from a lab colony. In the 1984 study they were the progeny of wild moths.

For studies on mummies, Nonpareil mummies were collected from Kern Co. orchards in the winters of 1983-84 and 1984-85. Uninfested mummies were each inoculated with two neonate larvae, produced by wild NOW females, placed into cages at 10 nuts per cage, and hung in March in the canopies of 5-6 year-old Nonpareil trees in the UCR Biocontrol orchard.

Nuts were destructively sampled periodically during the course of the population development. Samples were collected daily in the 1984 new crop study, and every 2-3 days in the 1985 mummy study. Samples were taken at infrequent intervals in the 1983 new crop and 1984 mummy studies. Each sample of the 1984 new crop and 1985 mummy studies consisted of 5 nuts. The samples

of the other studies consisted of 10-15 nuts per sample.

The head capsule widths of the larvae recovered in each sample were measured with a dissecting microscope fitted with an ocular micrometer. A frequency distribution of these measurements was constructed for each study and analyzed statistically to determine the range of head capsule measurements for each observed instar.

In all studies, a portion of the nuts were not sampled to allow some individuals to develop to the adult stage. These cages were checked daily for adult emergence.

The inoculation date and the date on which each sample was taken (or adults emerged) were recorded, along with concurrent maximum-minimum temperature measurements taken at the study sites. The thermal summation from inoculation date to sampling date was calculated from these data, using lower and upper threshold temperatures of 12.8 and 34.4°C, respectively, double triangulation, and a vertical upper cutoff.

To determine the thermal summation for each instar, the proportion of individuals of the subsequent instar present in each sample will be regressed on accumulated degree-days. The data within each substrate were combined, and separate linear regressions will be performed on mummy and new crop data. These regressions will be used to produce an estimate of the physiological time required for 50% of the individuals of one instar to molt to the next.

Data are presently being analyzed and final analysis of these data will be completed in December, 1985.

1985 Acaricide Efficacy Trial

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Field evaluation of Brigade 10WP (FMC-54800) and Apollo 50SC on spider mite and spider mite predator populations on almond trees in the southern San Joaquin Valley was conducted from June 25 to August 20, 1985. Brigade 10WP, Brigade 10WP plus Vendex 50WP, and three concentrations of Apollo 50SC were compared with a Vendex 50WP standard and a water check. Since a spreader-sticker, Triton B-1956, was mixed with all treatments, a Triton B-1956 check was also included in the evaluation.

Materials and Methods

The experimental plot was located in Ranch 25 of the Superior Farming Company, approximately 1.5 miles north of Kimberlina Rd. on Zerker Rd. in Kern County, Calif. Treatments were laid out in a randomized complete block design consisting of eight, single-tree replications that were blocked by almond variety. Trees were drip-irrigated, four-year-old Nonpareil and Carmel variety almonds. Treatments were applied on June 26 with a high pressure handgun (#8 disc) at an application rate of 800 gal/acre. Each tree was sprayed until runoff (approx. 8.75 gal/tree). Treatments are listed in Tables 1 and 2.

To assess spider mite and spider mite predator populations, five leaves were randomly removed, between the heights of 4 and 7 ft, from the four directional quadrants of each tree. Thus, a total of 20 leaves/tree was

examined with a dissecting microscope to obtain counts of spider mite and spider mite predators for all stages excluding eggs. Samples were taken weekly for six weeks, except for the last sample which was taken eight weeks after spraying. Visual observations for phytotoxicity were made on each sampling date.

Spider mite populations from the pretreatment samples consisted primarily of Tetranychus spp. The citrus red mite, Panonychus citri, was also present but accounted for only about 6% of the spider mites. Postspray counts of spider mites consisted of 78% Tetranychus spp. and 22% P. citri. The majority of the spider mite predators observed were the sixspotted thrips, Scolothrips sexmaculatus, and the phytoseiid mites, Metaseiulus occidentalis and M. mcgregori.

Due to the low spider mite and spider mite predator counts, nonparametric analyses were used — Friedman's two-way analysis of variance (a nonparametric analog to the two-way analysis of variance) and a nonparametric multiple comparison procedure[1] similar to Tukey's honest significant difference procedure (a mean separation test such as Duncan's new multiple range test). Data were transformed into ranks to allow for nonparametric analyses.

Results and Discussion

Pretreatment populations were statistically equivalent across all treatments with averages of 6.4 spider mites and 0.4 spider mite predators per 20-leaf sample. By the second week after treatment applications, only treatments

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[1] Wayne W. Daniel, Applied Nonparametric Statistics (Boston: Houghton Mifflin, 1978), p. 231.

that contained Vendex 50WP exhibited significantly lower spider mite counts than the checks. From weeks 3 to 8, spider mite counts were very low and not significantly different among all treatments and checks, except for the Brigade 10WP treatment. The Brigade 10WP treatment had significantly higher counts in weeks 5 and 8. Week 6 also had a higher count, but this count was not significantly higher since spider mites were found in only three of the replicates (Table 1). Predator counts were very low and not significantly different throughout the trial (Table 2). No evidence of phytotoxicity was observed from any of the treatments.

Spider mite and spider mite predator populations remained at very low levels throughout the trial to preclude any meaningful conclusion about the effectiveness of the Apollo 50SC or Brigade 10WP compounds in suppressing spider mite populations. It should be noted that counts presented in Tables 1 and 2 are per 20-leaf sample per tree. However, despite these low counts, a relative trend of spider mite resurgence was evident in the Brigade 10WP treatment by the fourth week after treatment application. This trend is consistent with our results in 1984, where resurgence was evident in the Brigade treatments after two weeks, under conditions of high spider mite densities. The Brigade 10WP plus Vendex 50WP treatment did not exhibit significant increases in spider mite counts.

Table 1. Mean[a] number of spider mites (all stages except eggs) per 20-leaf sample on Nonpareil and Carmel almonds, Kern County, Calif. 1985.

Treatment	Rate (ai/acre)[b]	Sample date: Pretrt[d] (6/25)	Week 1 (7/4)	Week 2 (7/10)	Week 3 (7/17)	Week 4 (7/24)	Week 5 (7/31)	Week 6 (8/7)	Week 8 (8/20)
1. Brigade 10WP	.10 lb	7.0 a	0.1 ab	1.4 abc	0.9 a	4.0 a	7.3 a	10.4 a	19.8 a
2. Brigade 10WP + Vendex 50WP	.10 lb + .75 lb	4.5 a	0.0 b	0.0 c	1.4 a	0.1 a	1.6 ab	1.3 a	1.0 ab
3. Apollo 50SC	.125 lb	5.0 a	3.9 ab	9.4 abc	0.8 a	0.3 a	0.0 b	1.0 a	0.0 b
4. Apollo 50SC	.25 lb	5.8 a	3.1 ab	2.9 abc	0.4 a	0.3 a	0.1 b	0.0 a	0.3 b
5. Apollo 50SC	.50 lb	5.8 a	2.5 ab	2.9 abc	0.6 a	0.1 a	0.0 b	0.1 a	0.0 b
6. Vendex 50WP	.75 lb	5.3 a	0.0 b	0.6 bc	0.6 a	0.5 a	0.0 b	0.0 a	0.1 b
7. Triton B-1956	6.2 oz[c]	8.6 a	3.5 a	11.3 ab	0.7 a	0.6 a	0.1 b	0.3 a	0.0 b
8. Water	-	9.0 a	2.5 ab	15.1 a	1.0 a	0.3 a	0.0 b	0.0 a	0.1 b

[a] Means based on 8 single tree replicates of total counts from 20 leaves per tree; means for each sample date followed by same letter are not significantly different at .10 experimentwise error rate using a non-parametric multiple comparison test on rank transformed data.

[b] Applied at 800 gal/acre by high pressure handgun, treatment 7 added to all treatments except no. 8.

[c] 1 oz formulated per 100 gal, 77% ai.

[d] Treatments applied 6/26/85.

Table 2. Means[a] of spider mite predators[b] (all stages except eggs) per 20 leaf sample, on Nonpareil and Carmel almonds, Kern County, CA, 1985.

Treatment	Rate (ai/acre)[c]	Sample date: Pretreat.[e] (6/25)	Week 1 (7/4)	Week 2 (7/10)	Week 3 (7/17)	Week 4 (7/24)	Week 5 (7/31)	Week 6 (8/7)	Week 8 (8/20)
1. Brigade 10WP	.10 lb	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.1
2. Brigade 10WP + Vendex 50WP	.10 lb + .75 lb	0.4	0.0	0.0	0.0	0.3	0.0	0.1	0.0
3. Apollo 50SC	.125 lb	0.3	0.0	0.4	0.1	0.3	0.0	0.0	0.0
4. Apollo 50SC	.25 lb	0.6	0.1	0.3	0.0	0.0	0.0	0.0	0.0
5. Apollo 50SC	.50 lb	0.1	0.1	0.0	0.1	0.0	0.3	0.0	0.0
6. Vendex 50WP	.75 lb	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7. Triton B-1956	6.2 oz[d]	0.3	0.3	1.0	0.1	0.3	0.0	0.0	0.0
8. Water	-	0.8	0.1	1.5	0.3	0.4	0.0	0.0	0.0

[a] Means based on 8 single tree replicates of total counts from 20 leaves per tree; all means for each sample date were not significantly different at a .10 experimentwise error rate using a nonparametric multiple comparison test on rank transformed data.

[b] Sixspotted thrips and phytoseiid mites.

[c] Applied at 800 gal/acre by high pressure handgun; treatment 7 added to all treatments except no. 8.

[d] 1 oz formulated per 100 gal, 77% ai.

[e] Treatments applied 6/26/85.

Effect of Water Stress in Potted Almond Trees on the Developmental Time of the Pacific Spider Mite

D. H. Oi, J. P. Sanderson, R. R. Youngman and M. M. Barnes

Spider mite populations have been observed to increase rapidly during the summer in almond trees, especially when trees were water stressed. A 1984 study found that there was no increase in fecundity of the Pacific spider mite, Tetranychus pacificus McGregor, on potted, water stressed, almond trees. However leaf surface temperatures were noted to be 9 degrees F hotter on the water stressed trees than on the non-water stressed, control, trees. Since development rates of spider mites are temperature dependent, this study examined the effect of water stressed, potted almond trees on the egg to first egg developmental time of the Pacific spider mite with respect to leaf surface temperatures.

Materials and Methods

Twenty, 1/2 inch diameter, dormant, Texas Mission variety almond trees on Nemaguard rootstock were transplanted into 12 gal. pots, and allowed to break dormancy in a greenhouse at the University of California, Riverside. Trees of similar size were paired and placed together to allow for 10 paired comparisons between water stressed and non-water stressed (control) trees.

The water stressed tree in each pair was generally kept in a continuous state of wilt diurnally, by maintaining the potted tree at an average of 79% of its saturated soil weight (weight after saturating with water then draining overnight). Control trees were maintained at an average of 96% of their saturated weight throughout the experiment.

Pacific spider mites, obtained from a laboratory culture at the University of California at Riverside, were used for the study. A mature female was placed within a 11 mm diameter arena, punched from double sided carpet tape (2.5 X 3.5 cm), to allow for oviposition. One arena was positioned on the upper surface of an individual leaf, with 10 arenas per tree. Arena locations were standardized among paired trees, usually being placed 5 leaves below the apex of a branch. Females were removed within 9 hours, and all arenas had a maximum of three eggs. Each arena was examined every eight hours to determine the developmental time from the egg to the first egg oviposited by the new adult female. Since several arenas contained males, the egg to first egg developmental times from virgin females and females having males in the arena were compared. No significant difference was found between these developmental times, so all developmental times were included in the analyses.

Ten thermistors (5 mm dia.) were used to detect leaf surface temperatures on five pairs of trees. One thermistor per tree was attached to the upper surface of a leaf in the proximity of the arenas. Thermistors were shaded with foil to prevent excessive temperature measurements due to direct sunlight, and were placed on leaves oriented in the same direction within each pair of

trees. Temperatures were recorded hourly for each tree using a tele-thermometer (Yellow Springs Instrument Co.). Temperature readings were taken sequentially so that temperatures for trees within pairs were measured within five minutes of each other. Accumulated heat unit (degree hours) were calculated using a lower developmental temperature threshold of 12 degrees C.

After determining developmental times, a tissue analysis to determine the nutrient levels of the leaves was performed by the University of California Cooperative Extension Service. Levels of nitrogen, phosphorus, potassium, calcium and magnesium were determined for the water stressed and control trees.

Paired t-tests were used to compare average egg to first egg developmental times of mites, accumulated degree hours, and leaf nutrient levels from the water stressed and control trees. A 5% significance level was used for all analyses.

Results and Discussion

Pacific spider mites developed significantly faster on the water stressed almond trees. The average egg to first egg developmental time for the mites on the water stressed trees was 6 days 7 hrs. (152 hrs.), and 7 days 3 hrs. (171 hrs.) for the mites on the control trees (Fig. 1). Accumulated centigrade (C) degree hours for mites from both the water stressed and the control trees were not significantly different, averaging 2866 and 2888 C degree hours respectively. Analyses of the leaf nutrient levels revealed that average nitrogen levels in the control trees at 3.0% were significantly higher then the 2.6%

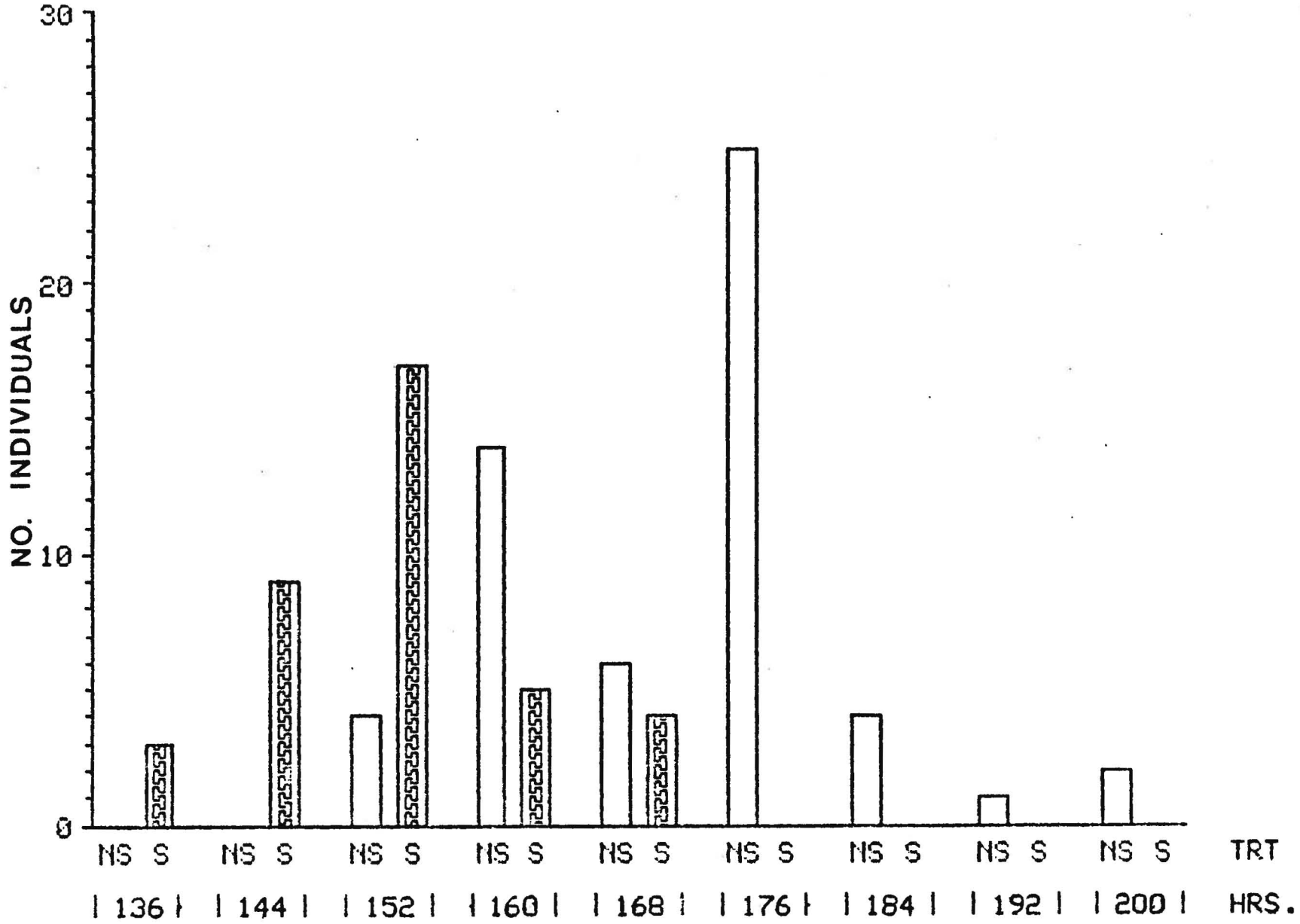

Fig. 1. Frequency distribution of egg to first egg developmental times (hrs.) of Pacific spider mites on water stressed (S) and non-water stressed (NS) potted, almond trees.

Table 1. Mean[1] measurements obtained from 1985 greenhouse study of Pacific spider mite development on potted almond trees.

Trt.	Pct. of Saturated Soil Weight	Developmental Time (hours)	Accum. C Deg. Hours	% Leaf Nit.
Stress	79	152 a	2866 a	3.0 a
Control	96	171 b	2888 a	2.6 b

[1]Means followed by the same letter are not significantly different at the 5% level.

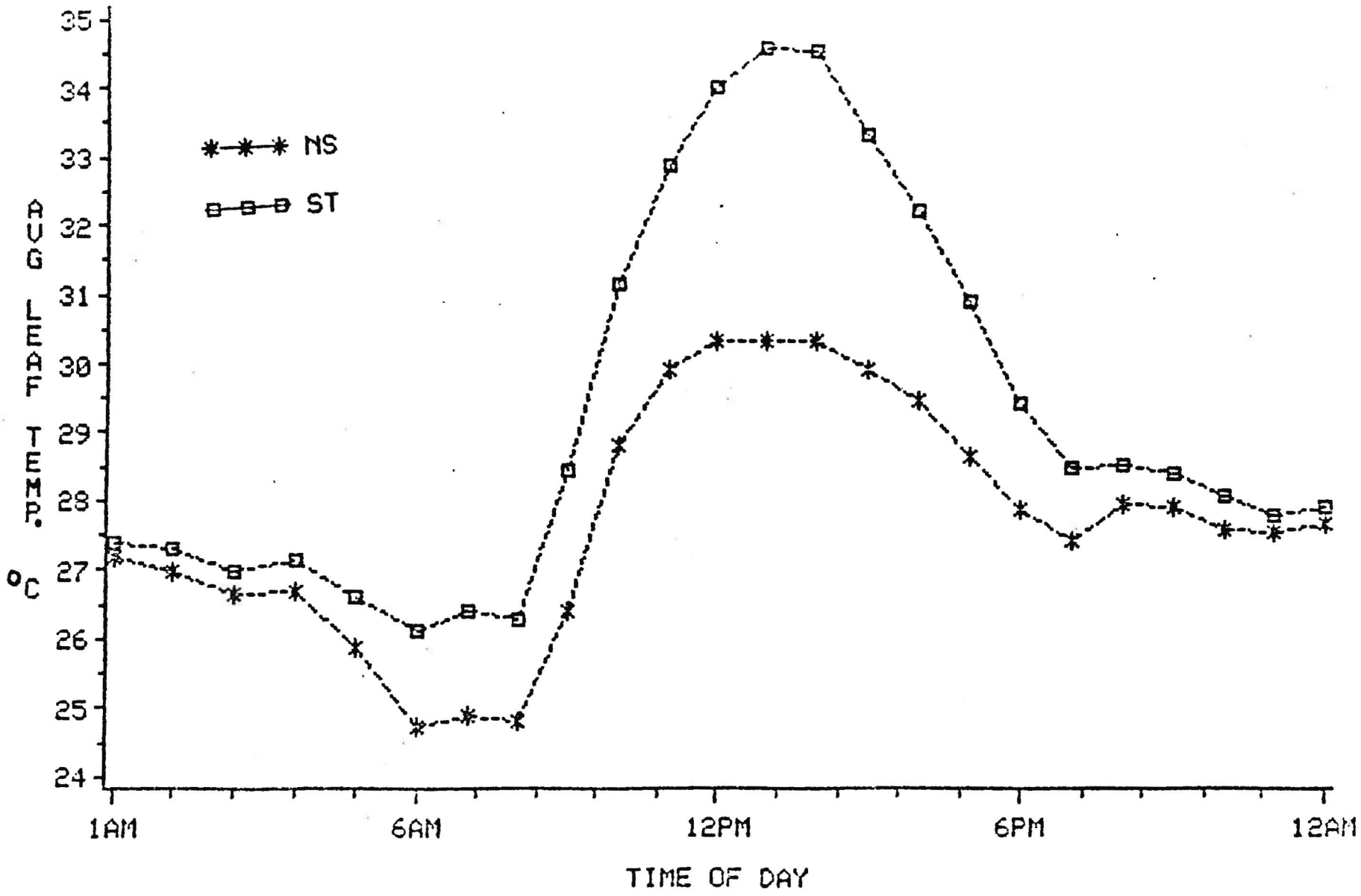

Fig. 2. Hourly leaf surface temperatures measured from 5 water stressed and 5 non-water stressed potted, almond trees, averaged over an eight-day period.

the leaf. Thus the water status of a plant can influence leaf surface temperatures, through which it can also effect spider mite microenvironments.

Field Measurements of Leaf-Canopy Temperatures from Water Stressed and Non-Water Stressed Almond Trees

D. H. Oi and M. M. Barnes

Almond trees typically become water stressed during the summer when harvesting practices necessitates the witholding of irrigation. A 1985 greenhouse study associated faster Pacific spider mite, Tetranychus pacificus McGregor, developmental times with potted, water stressed, almond trees. Since higher leaf temperatures were recorded for the water stressed trees, almond tree leaf canopy temperatures were measured under field conditions to determine if a similar phenomena would occur.

Materials and Methods

Two studies were undertaken to document water stress effects on almond tree leaf canopy temperatures. Spider mite populations were also monitored, but no appreciable populations developed during the studies. The first study (1) compared diurnal leaf canopy temperatures between water stressed and non-water stressed (control) trees, while the second study (2) compared leaf canopy temperatures of trees under three different levels of irrigation.

Study (1). Diurnal leaf canopy temperatures were measured from four year old, drip irrigated, Nonpareil almond trees, located on Zerker Rd., approximately 1.5 miles north of Kimberlina Rd., in Ranch 25 of the Superior Farming Company, in Kern County, CA. Trees were water stressed by replacing drip emitters with

standard plugs, on July 16 and 17, while the control trees were maintained on the normal irrigation cycle. Since trees were spaced in 25 x 25 ft. squares, and tree canopies did not overlap, adjacent trees were paired according to size and leaf canopy densities along a row. The water stress and control treatments were randomly assigned within eight pairs of trees.

The water status of the water stressed and control trees was quantified by measuring predawn leaf water potentials using a pressure bomb (PMS Instrument Co.). Predawn leaf water potentials gave an indication of the amount of soil moisture available to the tree based on the assumption that the leaf water potential equilibrated with the soil water potential during the night when stomata were closed and water transpiration was practically nil. The more negative leaf water potentials indicated less available soil moisture. Leaf water potentials were determined from the average of four pressure bomb readings, made on individual leaves that were selected from the four directional quadrants of each tree.

Average leaf surface temperatures from three ft. diameter areas of the tree leaf canopy surface were measured using an infrared thermometer (Everest Interscience Inc.), which was set at an emissivity of 0.98. Measurements were taken from the sunlit and shaded portions of each tree at 7am, 11am, 1pm, 3pm, and 6:30 pm. The sunlight and shade readings from each tree were averaged together to provide an estimate of each tree's leaf canopy temperature at the specified recording time. Daily leaf canopy temperatures for individual trees were determined by averaging the leaf canopy temperatures of each tree obtained

throughout the day.

Leaf canopy temperature and leaf water potential readings were taken from four pairs of trees on successive days that coincided with the beginning and ending of the weekly irrigation cycles (water on Monday thru Thursday), from July 16 to August 12, 1985. On August 8 and 12 the leaf water potentials of only the control trees were recorded to document water stress levels after the weekly irrigation cycle had been stopped, on July 29, for harvest preparation.

A paired t-test was used to determine any differences between daily leaf canopy temperatures, which were averaged over readings taken from July 21 thru August 5, from the water stressed and control trees. A linear correlation was determined between the difference in daily leaf canopy temperatures, and the difference in the daily leaf water potentials, from the paired water stressed and control trees. A 5% significance level was used for all analyses.

Study (2). Leaf canopy temperatures were measured from 12 year old, Nonpareil almond trees, which were part of an irrigation trial of the Dept. of Pomology, University of California, Davis and the Kern County Farm Advisors' Office. The trial was located in a sprinkler irrigated orchard operated by Kern Farm Co., approximately 1/4 mile west of Wallace Rd., on Zerker Rd., in Kern County, CA. Irrigation levels of 100% (control), 85%, and 55% of the estimated water use of the trees (ET) were administered through differential flow rates in rainbird sprinkler heads. ET was determined from the soil moisture profile monitored by neutron probes. Treatments were set up in a

randomized complete block design, consisting of four single tree replicates. Treatment levels were applied to clusters of nine trees, comprised of three trees within three rows, with the center tree of each treatment being measured. At least three trees, receiving 100% ET, buffered each treatment within a row.

Leaf canopy temperature measurements were taken weekly from July 24 to Aug 7, and on August 20, 1985, between 12:45 pm and 4pm. Afternoon measurements were chosen in order to coincide with maximum diurnal leaf canopy temperature differences among the treatments. Treatments were blocked within a row and according to measurement times. Five measurements of leaf surface temperatures, from 1 to 1.5 ft. diameter, sunlit sections, were made across the tree canopy. Since trees were relatively tall, and in order to measure consistent foliage densities, a ladder was used to take measurements at a height of approximately 11 feet. Measurements were taken with an infrared thermometer with emissivity set at 0.98.

The five leaf canopy temperature measurements were averaged for each tree, and a 2-way analysis of variance and Duncan's multiple range test were used to determine differences in leaf canopy temperatures averaged over all dates at a 5% significance level.

Results and Discussion

Study (1). Figure 1 shows the change in average leaf water potentials during the study, where the overall average leaf water potentials for the water stressed and control trees were -16.7

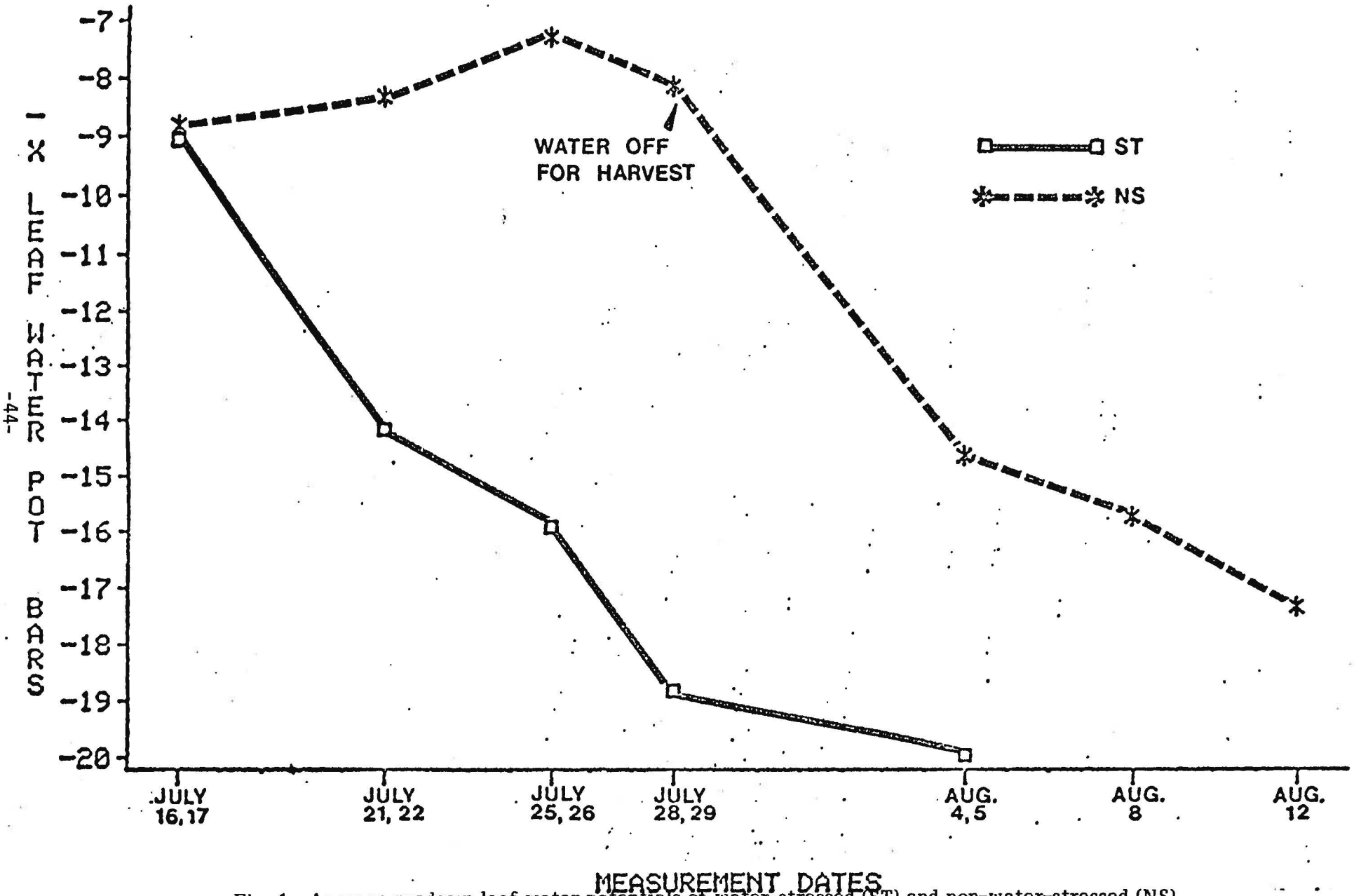

Fig. 1. Average predawn leaf water potentials of water-stressed (ST) and non-water-stressed (NS) Nonpareil almond trees measured during the study.

and -9.7 bars respectively between July 21 and August 5. Leaf canopy temperatures of the water stressed trees were significantly hotter than the control trees (Table 1). Water stressed trees were recorded to have leaf canopy temperatures that ranged from -0.9 to 9.7 degrees F hotter than the control trees. The average leaf canopy temperature of the water stressed trees was 88.3 degrees F, while for the control trees it was 85.5 degrees F. The difference of less than 3 degrees F between average leaf canopy temperatures seemed relatively small, however average differences can be misleading since the variation in diurnal leaf canopy temperature cycles among paired trees may reduce the magnitude of the difference. Thus while the average difference was small, the fact that average leaf canopy temperatures were consistently hotter on water stressed trees throughout the day (Fig. 2), and that a maximum difference of 9.7 degrees F had been recorded, indicated that water stress could have a significant effect on leaf canopy temperatures.

A significant coefficient of correlation (r=.85) was found between the difference in daily leaf canopy temperatures and the difference in daily leaf water potentials, for the paired water stressed and control trees. This indicated that as the difference in leaf water potentials between the water stressed and control trees increased, the difference in leaf canopy temperatures, between water stressed and control trees, also increased in a partially linear manner (Fig. 3), with the the water stressed tree canopies being hotter than the control canopies as water stress levels increased.

Study (2). Leaf canopy temperatures from the trees irrigated at

Table 1. Summary of average leaf canopy temperatures and leaf water potentials, Nonpareil almond trees, Kern County, CA, 1985.

	Superior (1) Ranch-25		Kern (2) Farm Co		
Treatment :	Water Stress	Control	55%ET	85%ET	(control) 100%ET
Avg. Leaf Canopy Temp. (F) :	88.3 **	85.5	89.2 a[1]	85.3 b	84.1 b
Avg. Leaf Water Pot. (bars) :	-16.7	-9.7			

** Significantly different (.01>P>.001) using a paired t-test.
[1] Means followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

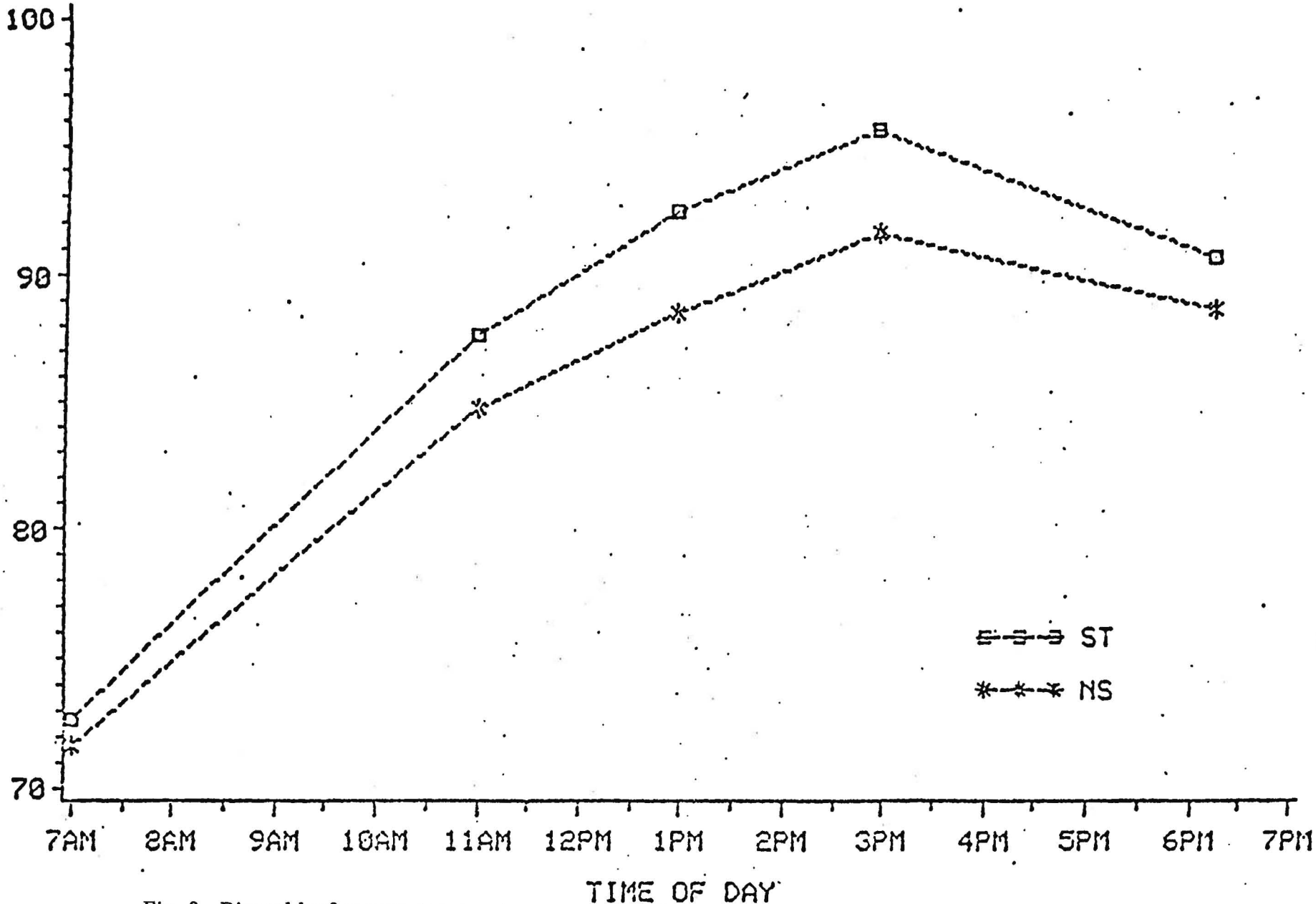

Fig. 2. Diurnal leaf canopy temperatures measured from water-stressed (ST) and non-water-stressed (NS) Nonpareil almond trees averaged over 8 dates.

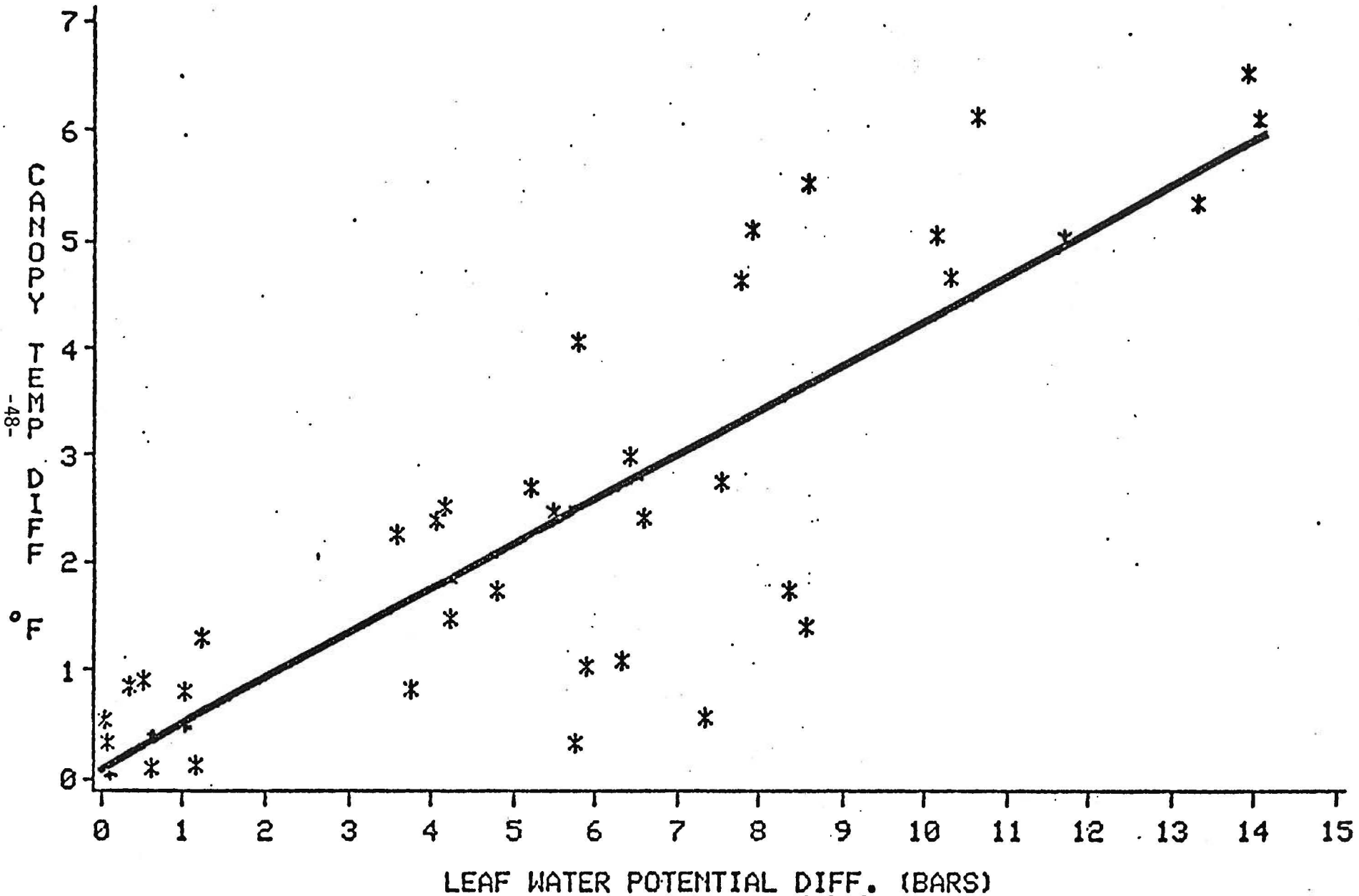

Fig. 3. Linear correlation of the difference in average daily leaf canopy temperatures and the difference in average leaf water potentials, between paired water-stressed and non-water-stressed trees (r=.85).

55% ET were significantly higher than the trees irrigated at 85 and 100% ET. The average leaf canopy temperature from the 55% ET treatment was 89.2 degrees F, while for the 85 and 100% ET levels the average leaf canopy temperatures were 85.3 and 84.1 degrees F respectively (Table 1). Even though measurements were taken in the afternoon, in order to detect maximum leaf canopy temperature differences, the differences among treatments were less than 4 degrees F. However the large, mature trees used in the experiment probably had root systems that extended past the treatment areas, and as a result probably reduced the amount of water stress effects on leaf canopy temperatures. Nevertheless, differential irrigation levels were shown to influence leaf canopy temperatures.

The two studies indicated that water stress does significantly effect leaf canopy temperatures of almond trees in the field. Leaf canopy temperatures were higher as trees became more water stessed. When irrigation was withheld for harvest, leaf water potentials decreased rapidly (Fig.1), resulting in a water stress situation, and a concurrent increase in leaf canopy temperatures (Fig.4). This relationship suggests that water stress could be a factor in the development of spider mite populations through increased leaf canopy, and hence spider mite microenvironment, temperatures.

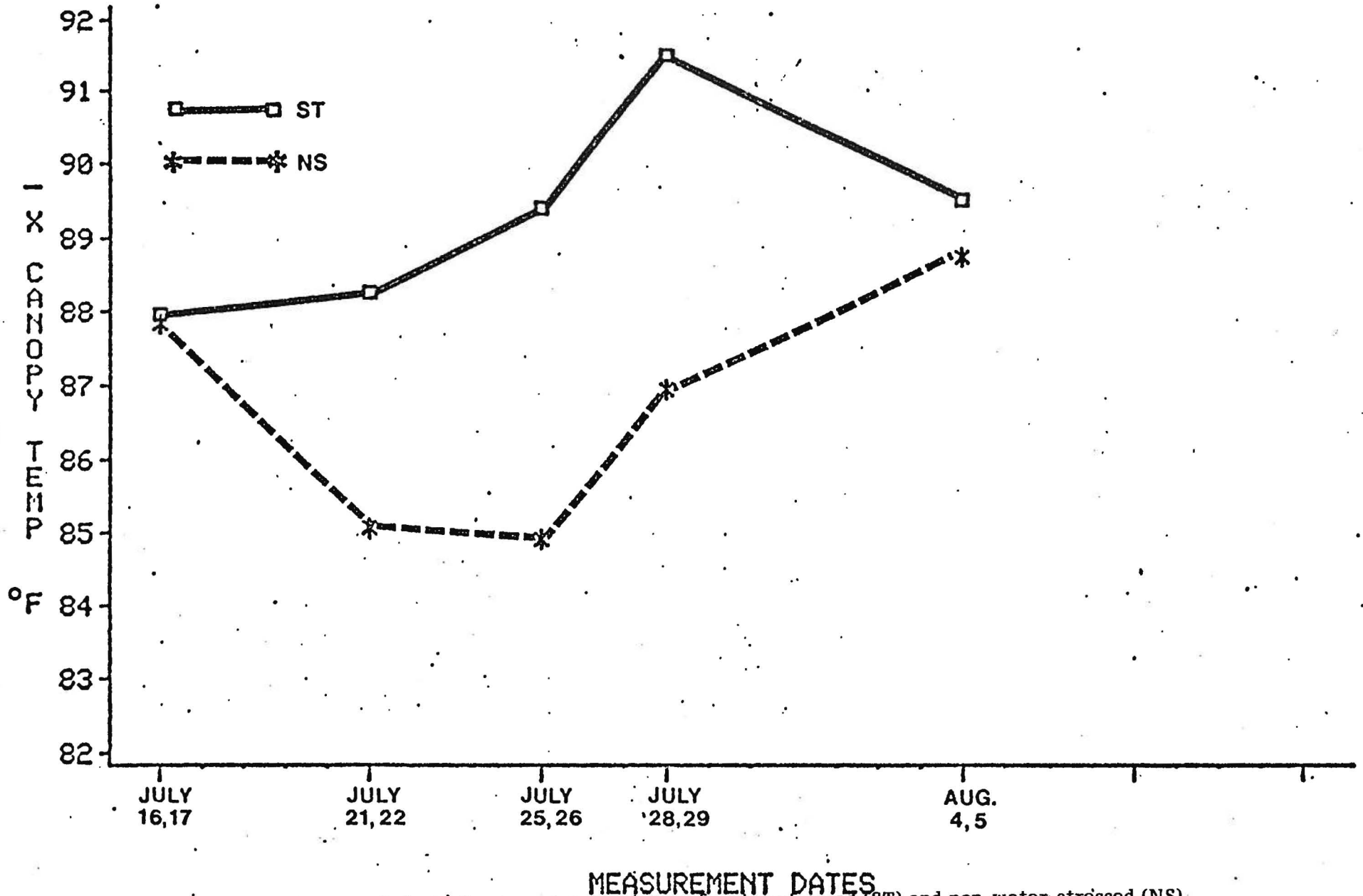

Fig. 4. Average daily leaf canopy temperatures of water-stressed (ST) and non-water-stressed (NS) Nonpareil almond trees measured during the study.