# SUBLETHAL EFFECTS OF INSECTICIDES ON COTTON APHID REPRODUCTION

**D. L. Kerns**
**Department of Entomology,**
**University of Arizona**
**Yuma, AZ**
**S. D. Stewart**
**Department of Entomology and Plant Pathology**
**Mississippi State University**
**Raymond, MS**
**C. L. McKenzie**
**FMC Corporation**
**Yuma, AZ**

## Abstract

Insecticides are often implicated in causing outbreaks of cotton aphids through stimulation of reproduction. In this study we report the sublethal effects of dosages of Capture, Orthene, Furadan or Knack on cotton aphid reproduction. We could not detect any increase or decrease in the intrinsic rate of increase of cotton aphids exposed to Capture, Orthene of Furadan. However, we did detect slight differences in the net reproductive rate of aphids treated with Capture justifying further investigation of the effect on reproduction by this insecticide. Trends based on simple linear regression models suggest that sublethal dosages of Capture or Furadan have a negative impact on aphid population growth as dosages increase. These data suggest that stimulation of reproduction by these insecticides may not play a major role in cotton aphid outbreaks or resurgence. Knack is a juvenoid insecticide currently used for control of whiteflies in cotton. It demonstrated significant activity towards cotton aphid in our bioassays. Knack caused sterility in most aphids exposed to dosage exceeding 1 ppm, and reduced aphid longevity by about 50%. Modifying aphid population structure and growth through the use of juvenoid insecticides such as Knack, may prove to be an effective proactive approach to pest control without adversely impacting beneficial organisms and minimizing pest resurgence.

## Introduction

The cotton aphid, *Aphis gossypii* Glover, is a destructive pest of cotton throughout many of the World's cotton producing regions (Blackman and Eastop 1984). In the United States, high cotton aphid populations in cotton have resulted in a yield reductions of as much as a 150 lbs of lint per acre (Fuchs and Minzenmayer 1995). Presently, cotton aphids are controlled in cotton using broad spectrum insecticides. Insecticide resistance has rendered many insecticides used for aphid control ineffective (Grafton-Cardwell 1991, Kerns and Gaylor 1992a, O'Brien et al. 1992). There is now evidence suggesting that where insecticide resistant aphids are prevalent, the use of some insecticides once used for aphid control may result in higher population densities (Fuson et al. 1995).

The sublethal effects of insecticides on insect pests is an important consideration when making an insecticide selection. Although some outbreaks of cotton aphids have been attributed to the destruction of natural enemies, others appear to involve insecticide mediated stimulation of aphid reproduction (Dunnam and Clark 1941, Slosser et al. 1989, Kerns and Gaylor 1993ab, Rummel and Kidd 1994). Stimulation of aphid reproduction may be invoked through hormoligosis or trophobiosis. Hormoligosis involves direct stimulation of reproduction following contact by the insect with the insecticide, while trophobiosis involves indirect stimulation of reproduction through plant conditioning following the plant's exposure to insecticides. Hormoligosis has not been demonstrated with aphids, but has been found to occur with phytophagous mites (Jones and Parella 1984). However, evidence of trophobiosis with aphids has been documented (Maxwell and Harwood 1960, Lowery and Sears 1986, Kerns and Gaylor 1993a, Hutt et al. 1994). Trophobiosis is most often associated with improved nutrition of the insect's host plant (Wilson et al. 1988, Kerns and Gaylor 1993a, Hutt et al. 1994).

Not only may sublethal doses of insecticides cause a stimulation in insect populations, but many may result in a suppression of reproduction (Kerns and Gaylor 1992b). Juvenoid insect growth regulators have demonstrated the ability to regulate populations of sucking pests in cotton, and may offer an important alternative to cotton aphid management based on curative insecticide applications (Ansolabehere et al. 1995, Satoh et al. 1995). In 1996 and 1997, growers and researchers in Arizona and California noticed a subtle reduction in cotton aphid populations in cotton treated for whiteflies with the juvenoid insecticide Knack (pyriproxyfen). However, it was not certain whether the reduction was due to the preservation of natural enemies or the action of the insecticide on the aphids. The purpose of this research was to determine if sublethal doses of some cotton insecticides speculated in simulating aphid reproduction affect cotton aphid reproduction under controlled laboratory conditions. It was also the objective of this research to determine if Knack has potential in regulating cotton aphid reproduction.

## Materials and Methods

### Laboratory Assays

Cotton aphids were acquired from a colony maintained by the University of California - Davis. From these aphids a single apterous, parthenogenically reproducing female was selected to establish a parent colony. This colony was used as a source for all aphids used in our laboratory assays. The colony was maintained in a environmentally-controlled

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cabinet at 21 ± 2°C and a photoperiod of 14:12 (L:D) on 'Deltapine 5461' cotton.

Reproductive assays were conducted on 'Deltapine 5461' cotton at the two-leaf stage. Cotton was grown in a greenhouse in 4.0 inch plastic pots in standard potting soil. Plants were brought into the laboratory where the pot was removed and soil washed from the roots. Assay cup cages were prepared by melting 1.0-cm diameter hole in the bottom of 300-ml T-10 Comet Brand clear plastic cups. Plants were placed in these cups with the roots protruding from the hole in the bottom. The cotton plants were then secured in place by molding gray-green modeling clay about the stem of the plant and filling the hole. The cups containing the plants were then placed into a 230 ml T-8T Comet Brand clear plastic cup forming a hydroponic reservoir containing approximately 30 ml of a 10% balanced fertilizer solution made from Peter's Soluble 20-20-20.

Prior to placing the plants in the assay cages, the plants were treated with insecticides by submerging their foliar portions into concentrations of each insecticide for 5 sec. Insecticides were prepared by dissolving commercially formulated in de-ionized water containing 0.01% v/v of the non-ionic spreader-sticker Kinetic. Insecticides evaluated included Capture 2EC (bifenthrin; FMC Corporation), Furadan 4F (carbofuran; FMC Corporation), Orthene 90S (acephate; Valent USA Corporation) and Knack 0.83EC (pyriproxyfen; Valent USA Corporation). Concentrations of Capture tested included 0, 0.03, 0.045, 0.06, 0.075, 0.09, 0.105, 0.135 and 0.165 ppm active ingredient. Furadan was evaluated at 0, 0.125, 0.250, 0.375, 0.500, 0.625, 0.750 and 0.875 ppm active ingredient. Orthene was tested at 0, 50, 80, 100, 200, 500 and 1000 ppm active ingredient. Knack was evaluated at 0, 0.1, 0.5, 1, 2, 3, 5, 8, 15, 25, 30, 80,150, 250, 300, 400, 450 and 600 ppm active ingredient. Concentrations exceeding 0.165, 0.875 and 1000 ppm of Capture, Furadan and Orthene respectively, resulted in excessive aphid mortality to evaluate sublethal doses. Control plants (0.0 ppm) were treated with de-ionized water containing 0.01% v/v Kinetic. Each insecticide-dose was replicated six to eight times. Data from alate aphids was not included in the analysis, nor was data used when the cotton plant's health deteriorated.

Following treatment, plants were allowed to dry at room temperature for approximately 30 min and then transferred to cup cages. Five adult cotton aphids were then placed on each plant and the cups were sealed with ventilated clear plastic lids. After 24 hours, the adult aphids were removed leaving only the newborn nymphs. Forty-eight hours later, all but one nymph was removed from each cage leaving the test aphid. The remaining nymphs were monitored every 24 hours. Data recorded included, the number of days to reproductive maturity or generation time, longevity, and the number of progeny produced on a daily basis. Newborn aphids removed from each cup after counting. From these data the following life-table statistics were derived: intrinsic rate of increase ($r_m$), net reproductive rate ($R_O$), mean generation time ($G$) and longevity ($L$) (Krebs 1985). Where there was no reproduction, a $r_m$ value of 0 was assigned.

All reproductive assay data were analyzed as randomized complete block designs using PROC GLM. Mean comparisons within each insecticide were made using an Ryan-Einot-Gabriel-Welsch multiple F test ($P < 0.05$) (SAS Institute Inc. 1989). Trends in the effects of Capture, Furadan and Orthene on aphid population growth potential were identified using a simple linear regression model ($Y = \alpha + \beta X$) where $Y$ = dosage (ppm) and $X$ = life table statistic (SAS Institute Inc. 1989).

**Field Efficacy**

Cotton 'SureGrow 125', planted 04 June 1997 at the Brown Loam Experiment Station, Mississippi State University, Hinds County, MS on 38 inch rows. Plots were 8 rows wide and 50 ft in length. The test was a randomized complete block design with four replicates. Treatments included an untreated check, Furadan 2F at 0.5 lbs ai/A and Knack at 8 oz / acre. Applications were applied using a tractor sprayer traveling 3 mph. The sprayer had two TX-6 nozzles per row calibrated to deliver 7.2 gal/A at 30 psi. The applications were made on August 27, 1997.

Cotton aphid populations were evaluated within each plot by counting the number of aphids from 10 leaves from each, the upper and middle one-third portions of the plant canopy. Evaluations were made at 2, 4, 7, 11 and 15 days after treatment (DAT). At 15 DAT, 20 middle canopy leaves were sampled; no leaves were sampled from the upper canopy. Data were analyzed using a PROC ANOVA and an F-protected Duncan's Multiple Range Test ($P <$ 0.05) (SAS Institute Inc. 1989).

In addition to aphid counts, differences in population structure between the untreated check and Knack treatments were estimated by sampling 10 leaves in each treatment and counting the numbers of small nymphs ($1^{st}$ and $2^{nd}$ instar), medium nymphs ($3^{rd}$ instar), large nymphs ($4^{th}$ and $5^{th}$ instar) and adults. Differences in population structure between treatments were determined using a multivariant $X^2$ contingency table (SAS Institute Inc. 1989).

## Results and Discussion

**Laboratory Assays**

The $r_m$ is used as a comparative statistic of aphid reproductive potential across dosages within each insecticide, and examination of factors contributing to $r_m$ may provide insight into population growth patterns (Kieckhefer and Elliott 1989). There were no significant differences in $r_m$ values for cotton aphids among dosages of Capture, Furadan or Orthene, suggesting that sub-lethal dosages of these insecticides do not promote cotton aphid population growth (Tables 1, 2 and 3). Although we did not detect differences in $r_m$ among dosages of Capture, there were some differences in $R_O$ (Table 1). Aphids reared on plants treated with 0.075 ppm of Capture produced significantly more offspring than those treated at 0.165 ppm, but did not differ from 0 ppm. The biological significance of this observation is questionable, but does justify further investigation into the effects of this insecticide on cotton aphid reproduction. Other pyrethroid insecticides have been implicated as having positive impacts on aphid population growth. Rummel and Kidd (1994), found that applications of the pyrethroid Karate (cyhalothrin) led to increased cotton aphid population growth that did not appear to be due to destruction of natural enemies. A surfactant included with the pyrethroid Cymbush (cypermethrin) has been found to enhance plant growth and subsequent reproduction of the black bean aphid, *Aphis fabae* Scopoli on broad bean (Hutt et al. 1994). However with Capture, instead of increasing the reproductive potential of cotton aphid, there appears to be a trend towards an overall decrease in reproductive potential with increasing sublethal dosages (Table 4). A similar trend was observed for Furadan , but there was not significant trend for Orthene (Tables 5 and 6).

Knack had significant impacts on cotton aphid reproduction and survival (Table 7). Dosages exceeding 1 ppm had the greatest impact on $r_m$, never exceeding a potential of 0.09 aphids per adult per day, compared to a $r_m$ of 0.74 for untreated aphids . These dosages also had the greatest incidence of sterility (Table 8). Against aphids, juvenoid insecticides have been found to inhibit embryogenesis resulting in death to the embryo or the first nymphal instar (Sehnal 1983). Juvenoid insecticides can also cause reproductive failure in aphids by inhibiting germ cell differentiation (Mittler et al. 1979), or by affecting differentiation of the insect's ovaries, and sometimes causes resorption of the egg folicles (Masner 1969, Rohdendorf and Sehnal 1973).

Not only did Knack significantly impact cotton aphid reproductive potential, but it also significantly influenced aphid longevity (*L*). Cotton aphids reared on plants treated with dosages exceeding 0.1 ppm, had significantly shorter life spans than untreated aphids (Table 7). Untreated aphids lived on average 38 days, while those treated with $\geq$2 ppm Knack lived approximately 14 days. Fourteen days is sufficient time to reach reproductive maturity, *G* is usually 6 to 7 days (Table 7). Thus it appeared that cotton aphids treated with Knack primarily died as sterile adults. Adult whiteflies feeding on Knack treated cotton often produce sterile eggs and fail to emerge from the pupae (Ellsworth et al. 1997). However, Knack does not kill adult whiteflies (Palumbo and Hannan 1997).

**Field Efficacy**

Under field conditions Furadan quickly reduced the cotton aphid population compared to the untreated check and the Knack-treated plots (Table 9). By 7 days after treatment (DAT), aphid populations in the check had greatly increased, and plots treated with Knack only slightly increased, and aphids in the Furadan-treated plots were beginning to recover. At this time Furadan still had significantly fewer aphids than the check, but did not differ from Knack. Knack did not show a significant reduction in the aphid population relative to the check until 15 DAT at which time it did not differ from Furadan. Against whiteflies in cotton, Knack generally require ca. 14 days to exhibit a significant population reduction (Palumbo and Hannan 1997).

With cotton aphids, 14 days is approximately the time required to induce mortality (Table 7). Thus, much of the activity observed in this field trial may have been due to Knack's insecticidal qualities rather than its activity as a sterilent. However, at 13 DAT, the population structure differed between the Knack and check treatments (Table 10). Most of this difference appears to be due to a larger percentage of adults in the Knack treatments relative to check, suggesting a decrease in reproduction, though this relationship was not obvious at 15 DAT. (Tables 10 and 11). It is possible that the sterilizing action may have been more obvious if a 21 DAT observation were recorded, however the aphid population had crashed by this time.

Knack may have other beneficial attributes involving aphid management not addressed in this report. Satoh and Plapp (1993) reported that juvenoid insecticides not only act as aphid population growth regulators but also increase the susceptibility of insecticide resistant aphids to insecticide.

## Summary

Insecticides have been implicated in inducing outbreaks of cotton aphids in cotton. There has been much research and speculation into the reasons why insecticides cause aphid outbreaks in cotton including the destruction of natural enemies and the stimulation of aphid reproduction. The insecticides Capture and Orthene have both been implicated in stimulating aphid reproduction. We could not detect any increase in the intrinsic rate of increase of cotton aphids treated with sublethal dosages of Capture, Furadan or Orthene. Based on simple linear regression models, Capture and Furadan tended to cause a decrease in reproductive potential with increasing sublethal dosages, while no trend was noted for Orthene. These data suggest that stimulation of reproduction by these insecticides may not play a major role in cotton aphid outbreaks or resurgence.

The insecticide Knack demonstrated significant activity towards cotton aphid. Knack caused sterility in most aphids exposed to dosage exceeding 1 ppm, and reduced aphid longevity by about 50%. Modifying aphid population structure and growth through the use of juvenoid insecticides such as Knack, may prove to be an effective proactive approach to pest control without adversely impacting beneficial organisms and minimizing pest resurgence.

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Table 1. Age-specific life table statistics for cotton aphid reared on cotton dipped in concentrations of Capture.

| Dose (ppm) | Statistic[a] | | | | |
|---|---|---|---|---|---|
| | *n* | *G* | $R_O$ | $r_m$ | *L* |
| 0 | 6 | 6.00 ± 0.26 a | 59.83 ± 5.50 ab | 0.68 ± 0.03 a | 35.17 ± 4.39 ab |
| 0.03 | 5 | 6.40 ± 0.24 a | 49.60 ± 7.47 ab | 0.61 ± 0.04 a | 23.60 ± 3.23 b |
| 0.045 | 4 | 6.50 ± 0.29 a | 63.00 ± 10.09 ab | 0.63 ± 0.03 a | 27.75 ± 4.39 ab |
| 0.06 | 3 | 6.00 ± 0.58 a | 52.67 ± 8.57 ab | 0.66 ± 0.04 a | 32.00 ± 4.93 ab |
| 0.075 | 5 | 6.60 ± 0.40 a | 69.00 ± 4.79 a | 0.65 ± 0.04 a | 29.40 ± 4.18 ab |
| 0.09 | 6 | 7.17 ± 0.40 a | 59.50 ± 5.16 ab | 0.58 ± 0.03 a | 42.00 ± 3.01 a |
| 0.105 | 5 | 6.40 ± 0.24 a | 57.80 ± 7.46 ab | 0.63 ± 0.03 a | 31.40 ± 3.83 ab |
| 0.135 | 5 | 7.80 ± 1.46 a | 40.00 ± 4.32 ab | 0.54 ± 0.10 a | 36.60 ± 2.11 ab |
| 0.165 | 5 | 10.20 ± 2.24 a | 33.60 ± 11.44 b | 0.41 ± 0.12 a | 29.60 ± 3.11 ab |

Mean ± SEMs in a column followed by the same letter are not significantly different based on an Ryan-Einot-Gabriel-Welsch multiple F test ($P < 0.05$) (SAS Institute Inc. 1989).

[a]*n*, number of observations; *G*, generation time or number of days to reproductive maturity; $R_O$, net reproductive rate; $r_m$, intrinsic rate of increase; *L*, longevity in days.

Table 2. Age-specific life table statistics for cotton aphid reared on cotton dipped in concentrations of Furadan.

| Dose (ppm) | Statistic[a] | | | | |
|---|---|---|---|---|---|
| | *n* | *G* | $R_O$ | $r_m$ | *L* |
| 0 | 6 | 5.67 ± 0.33 a | 62.17 ± 4.08 a | 0.74 ± 0.05 a | 39.50 ± 3.08 a |
| 0.125 | 5 | 5.80 ± 0.37 a | 72.20 ± 5.55 a | 0.75 ± 0.04 a | 43.60 ± 3.83 a |
| 0.25 | 4 | 6.00 ± 0.71 a | 56.50 ± 9.95 a | 0.69 ± 0.07 a | 42.25 ± 9.49 a |
| 0.375 | 3 | 6.00 ± 0.58 a | 55.00 ± 8.39 a | 0.68 ± 0.08 a | 36.67 ± 1.86 a |
| 0.5 | 5 | 6.80 ± 0.73 a | 54.00 ± 12.62 a | 0.59 ± 0.12 a | 38.60 ± 6.02 a |
| 0.625 | 4 | 6.00 ± 0.41 a | 46.75 ± 7.76 ab | 0.64 ± 0.02 a | 41.00 ± 5.49 a |
| 0.75 | 6 | 6.33 ± 0.21 a | 53.17 ± 5.69 ab | 0.63 ± 0.03 a | 41.33 ± 5.14 a |
| 0.875 | 6 | 6.50 ± 0.22 a | 60.33 ± 6.84 ab | 0.63 ± 0.03 a | 34.33 ± 5.53 a |

Mean ± SEMs in a column followed by the same letter are not significantly different based on an Ryan-Einot-Gabriel-Welsch multiple F test ($P < 0.05$) (SAS Institute Inc. 1989).
[a]*n*, number of observations; *G*, generation time or number of days to reproductive maturity; $R_O$, net reproductive rate; $r_m$, intrinsic rate of increase; *L*, longevity in days.

Table 3. Age-specific life table statistics for cotton aphid reared on cotton dipped in concentrations of Orthene.

| Dose (ppm) | Statistic[a] $n$ | $G$ | $R_O$ | $r_m$ | $L$ |
|---|---|---|---|---|---|
| 0 | 7 | 6.29 ± 0.36 a | 80.14 ± 4.61 a | 0.71 ± 0.05 a | __[b] |
| 50 | 6 | 7.00 ± 0.45 a | 80.00 ± 6.61 a | 0.64 ± 0.04 a | __[b] |
| 80 | 6 | 7.33 ± 0.56 a | 77.83 ± 11.95 a | 0.61 ± 0.06 a | __[b] |
| 100 | 8 | 6.75 ± 0.31 a | 66.00 ± 5.51 a | 0.63 ± 0.03 a | __[b] |
| 200 | 7 | 7.29 ± 0.36 a | 66.57 ± 6.59 a | 0.58 ± 0.04 a | __[b] |
| 500 | 7 | 7.29 ± 0.47 a | 78.57 ± 7.11 a | 0.61 ± 0.05 a | __[b] |
| 800 | 7 | 7.57 ± 0.48 a | 77.00 ± 9.18 a | 0.58 ± 0.05 a | __[b] |
| 1000 | 7 | 6.57 ± 0.30 a | 73.29 ± 8.70 a | 0.66 ± 0.05 a | __[b] |

Mean ± SEMs in a column followed by the same letter are not significantly different based on an Ryan-Einot-Gabriel-Welsch multiple F test ($P$ < 0.05) (SAS Institute Inc. 1989).

[a]$n$, number of observations; $G$, generation time or number of days to reproductive maturity; $R_O$, net reproductive rate; $r_m$, intrinsic rate of increase; $L$, longevity in days.

[b]Although reproduction had ceased, several aphids had not died when this report was written, so $L$ is not reported.

Table 4. Simple linear regression formulas of age-specific life table statistics for cotton aphid reared on cotton dipped in concentrations of Capture.

| Life table statistic | Regression formula $Y = \alpha + \beta X$ | $r^2$ | $P$ |
|---|---|---|---|
| $G$ | Y = 5.35 + 21.04X | 0.68 | 0.006 |
| $R_O$ | Y = 64.69 - 137.93X | 0.40 | 0.067 |
| $r_m$ | Y = 0.70 - 1.32X | 0.68 | 0.006 |
| $L$ | Y = 30.27 + 21.46X | 0.04 | 0.594 |

[a]$G$, generation time or number of days to reproductive maturity; $R_O$, net reproductive rate; $r_m$, intrinsic rate of increase; $L$, longevity in days.

Table 5. Simple linear regression formulas of age-specific life table statistics for cotton aphid reared on cotton dipped in concentrations of Furadan.

| Life table statistic | Regression formula $Y = \alpha + \beta X$ | $r^2$ | $P$ |
|---|---|---|---|
| $G$ | Y = 5.75 + 0.88X | 0.51 | 0.046 |
| $R_O$ | Y = 63.28 - 13.17X | 0.53 | 0.173 |
| $r_m$ | Y = 0.74 - 0.153X | 0.69 | 0.01 |
| $L$ | Y = 41.38 - 4.23X | 0.20 | 0.265 |

[a]$G$, generation time or number of days to reproductive maturity; $R_O$, net reproductive rate; $r_m$, intrinsic rate of increase; $L$, longevity in days.

Table 6. Simple linear regression formulas of age-specific life table statistics for cotton aphid reared on cotton dipped in concentrations of Orthene.

| Life table statistic | Regression formula $Y = \alpha + \beta X$ | $r^2$ | $P$ |
|---|---|---|---|
| $G$ | Y = 6.94 + 0.0002X | 0.03 | 0.687 |
| $R_O$ | Y = 75.00 - 0.0002X | 0.0002 | 0.972 |
| $r_m$ | Y = 0.64 - 0.00002X | 0.04 | 0.618 |

[a]$G$, generation time or number of days to reproductive maturity; $R_O$, net reproductive rate; $r_m$, intrinsic rate of increase.

Table 7. Age-specific life table statistics for cotton aphid reared on cotton dipped in concentrations of Knack.

| Dose (ppm) | Statistic[a] $n$[b] | $G$ | $R_O$ | $r_m$ | $L$ |
|---|---|---|---|---|---|
| 0 | 8 | 6.13 ± 0.44 a | 80.50 ± 7.23 a | 0.74 ± 0.06 a | 38.38 ± 3.22 a |
| 0.1 | 8 | 6.38 ± 0.32 a | 63.13 ± 6.95 ab | 0.65 ± 0.04 a | 27.38 ± 2.96 ab |
| 0.5 | 8 | 5.80 ± 0.58 a | 28.50 ± 10.77 cd | 0.36 ± 0.13 b | 19.63 ± 3.58 cd |
| 1 | 8 | 6.57 ± 0.48 a | 48.50 ± 9.96 bc | 0.53 ± 0.08 ab | 24.00 ± 2.42 bc |
| 2 | 8 | 8.00[c] | 7.25 ± 7.25 d | 0.06 ± 0.06 c | 13.38 ± 3.22 bc |
| 3 | 8 | 6.00[c] | 5.00 ± 5.00 d | 0.08 ± 0.08 c | 17.00 ± 3.42 bc |
| 5 | 8 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 12.00 ± 1.68 bc |
| 8 | 6 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 12.17 ± 1.33 bc |
| 15 | 6 | 7.00[c] | 5.00 ± 5.00 d | 0.08 ± 0.08 c | 14.83 ± 2.76 bc |
| 25 | 6 | 7.00[c] | 0.17 ± 0.17 d | 0.00 ± 0.00 c | 14.83 ± 2.75 bc |
| 30 | 6 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 12.00 ± 0.77 bc |
| 80 | 6 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 11.17 ± 1.42 c |
| 150 | 6 | 5.00[c] | 2.00 ± 2.00 d | 0.08 ± 0.08 c | 14.33 ± 3.80 bc |
| 250 | 6 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 13.17 ± 2.43 bc |
| 300 | 5 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 15.40 ± 5.48 bc |
| 400 | 6 | 5.00[c] | 2.67 ± 2.67 d | 0.09 ± 0.09 c | 19.67 ± 3.48 bc |
| 450 | 6 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 14.67 ± 2.30 bc |
| 600 | 6 | __[c] | 0.00 ± 0.00 d | 0.00 ± 0.00 c | 16.17 ± 2.90 bc |

Mean ± SEMs in a column followed by the same letter are not significantly different based on an Ryan-Einot-Gabriel-Welsch multiple F test ($P$ < 0.05) (SAS Institute Inc. 1989).

[a]$n$, number of observations (may be fewer for $G$); $G$, generation time or number of days to reproductive maturity; $R_O$, net reproductive rate; $r_m$, intrinsic rate of increase; $L$, longevity in days.

[b]$n$ for $G$ differed for some doses because $G$ was not always calculable. The $n$ for doses 0.5 = 5, 1 = 1, 2 = 1, 3 = 1, 5 = 0, 8 = 0, 15 = 1, 25 = 1, 30 = 0, 80 = 0, 150 = 1, 250 = 0, 300 = 0, 400 = 1 450 = 0 and 600 = 0.

[c]G was incalculable or statistically analysis was not possible because there was no reproduction, or fewer than three data points.

Table 8. Percentage of cotton aphids sterilized when reared on cotton treated with various concentrations of Knack

| Dose (ppm) | *n* | Percentage sterilized |
|---|---|---|
| 0 | 8 | 0.0 |
| 0.1 | 8 | 0.0 |
| 0.5 | 8 | 25.0 |
| 1 | 8 | 12.5 |
| 2 | 8 | 87.5 |
| 3 | 8 | 87.5 |
| 5 | 8 | 100 |
| 8 | 6 | 100 |
| 15 | 6 | 83.3 |
| 25 | 6 | 83.3 |
| 30 | 6 | 100 |
| 80 | 6 | 100 |
| 150 | 6 | 83.3 |
| 250 | 6 | 100 |
| 300 | 5 | 100 |
| 400 | 6 | 83.3 |
| 450 | 6 | 100 |
| 600 | 6 | 100 |

Table 9. Mean number of cotton aphids per leaf treated with a single application of Furadan or Knack relative to an untreated check.

| Treatment | DAT[a] | Upper Canopy | Middle Canopy | Total Aphids |
|---|---|---|---|---|
| Check | 2 | 9.68 a | 17.78 a | 27.45 a |
| Knack | 2 | 6.65 a | 14.88 a | 21.53 a |
| Furadan | 2 | 0.18 b | 0.53 b | 0.70 b |
| Check | 4 | 25.05 a | 31.78 a | 56.83 a |
| Knack | 4 | 16.13 a | 26.03 a | 42.15 a |
| Furadan | 4 | 0.50 b | 0.13 b | 0.63 b |
| Check | 7 | 38.70 a | 90.05 a | 128.75 a |
| Knack | 7 | 26.60 a | 27.80 ab | 54.40 ab |
| Furadan | 7 | 65.50 b | 2.28 b | 8.83 b |
| Check | 11 | 72.30 a | 152.35 a | 224.65 a |
| Knack | 11 | 41.30 a | 72.20 ab | 113.50 ab |
| Furadan | 11 | 15.95 a | 16.35 b | 32.30 b |
| Check | 15 | --[b] | 111.11 a | 111.11 a |
| Knack | 15 | --[b] | 36.60 b | 36.60 b |
| Furadan | 15 | --[b] | 16.90 b | 16.90 b |
| Check | across DATs | 36.43 a | 80.61 a | 109.76 a |
| Knack | | 22.67 b | 35.50 b | 53.64 b |
| Furadan | | 5.79 c | 7.24 c | 11.87 c |

Means in a column within a DAT followed by the same letter are not significantly different based on an F-protected Duncan's Multiple Range Test (P < 0.05) (SAS Institute Inc. 1989).
[a]DAT, days after treatment.
[b]Upper canopy not sampled at 15 DAT.

Table 10. Frequency of population structure stages of cotton aphids from Knack-treated or untreated cotton.

| | | Percentage within each stage[a] | | | | |
|---|---|---|---|---|---|---|
| Treat. | DAT | Sm Nym | Med Nym | Lg Nym | Adult | $X^2$, df, *P* |
| Knack | 13 | 72.4 | 11.6 | 5.5 | 10.6 | 20.98, 3, < 0.001 |
| Check | 13 | 86.8 | 4.7 | 4.4 | 4.2 | |
| Knack | 15 | 53.4 | 16.2 | 13.7 | 16.7 | 2.00, 3, NS |
| Check | 15 | 48.9 | 19.9 | 15.9 | 15.3 | |
| Knack | across DATs | 62.8 | 13.9 | 9.7 | 13.6 | 7.50, 3, < 0.025 |
| Check | | 69.5 | 11.6 | 9.6 | 9.2 | |

Analysis based on multivariant $X^2$ contingency table comparisons (SAS Institute Inc. 1989).
[a]Sm Nym, small nymphs (1st and 2nd instar); Med Nym, medium nymphs (3rd instar); Lg Nym, large nymphs (4th and 5th instars).

Table 11. Frequency of nymphs to adult stages of cotton aphids from Knack-treated or untreated cotton.

| | | Percentage within each stage | | |
|---|---|---|---|---|
| Treatment | DAT | Nymphs | Adults | $X^2$, df, *P* |
| Knack | 13 | 89.4 | 10.6 | 9.05, 1, < 0.005 |
| Check | 13 | 95.8 | 4.2 | |
| Knack | 15 | 83.3 | 16.7 | 0.18, 1, NS |
| Check | 15 | 84.7 | 15.3 | |
| Knack | across DATs | 86.4 | 13.6 | 5.24, 1, < 0.025 |
| Check | | 90.8 | 9.2 | |

Analysis based on multivariant $X^2$ contingency table (SAS Institute Inc. 1989).