Reprinted from
Proc. Fla. State Hort. Soc. 110:27-32. 1997.

POPULATION DYNAMICS AND CITRUS FRUIT DAMAGE BY TWO SPECIES OF LEAFROLLER, *ARGYROTAENIA AMATANA* AND *ARGYROTAENIA KIMBALLI* (LEPIDOPTERA: TORTRICIDAE)

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Additional index words. Hamlin orange, Ray Ruby grapefruit, caterpillar feeding, citrus fruit injury, citrus fruit damage, *Argyrotaenia amatana*, *Argyrotaenia kimballi*, *Bacillus thuringiensis*.

Abstract. **Larvae of *Argyrotaenia amatana* (Dyar) and *A. kimballi* Obraztsov (Lepidoptera: Tortricidae) were observed feeding on and were reared on citrus leaves and fruit in Fort Pierce, FL. A pheromone trapping program for adult males of both species was begun in 1989 using Pherocon® 1C traps to monitor flight periods. In 1991, 1995 and 1996, three field tests of the Dipel® 2× formulation of *Bacillus thuringiensis* were evaluated for efficacy against larval feeding on Hamlin oranges.**

At no time was larval feeding found to increase premature fruit drop at post bloom. In all three years, the percentage of fruit damaged by caterpillar feeding was significantly reduced (P ð 0.05) in plots sprayed with *B. thuringiensis*.

Adult male moth captures of *A. amatana* and *A. kimballi* from 1990 to 1996 indicated a peak of flight and mating activity each year in April, with continued activity throughout May and June. September and October were the months of least activity.

It has been well documented that moth larvae are destructive feeders on citrus in many growing regions of the world. In the late 1880's and early part of the 1900's, researchers in Florida and California reported the severity of feeding damage on citrus associated with a number of species of moth larvae.

Larvae of the orange tortrix (*Tortrix citrana* Fernald) feed on young, tender leaves and twigs, and occasionally puncture the rind of the fruit while beneath a protective leaf fastened to the fruit with webbing (Hubbard 1885; Quayle 1938).

Quayle (1938) reported that feeding of *Citripestis sagittiferella* Moore larvae in Malaya and the Dutch East Indies caused as much as a 100-percent loss in a grapefruit crop. In California, the orange tortrix was attributed with causing a 10-percent loss of the orange crop in the 1909-10 growing season, without accounting for its role in fruit drop from trees prior to harvest (Quayle 1938).

Argyrotaenia amatana (Dyar) and *Argyrotaenia kimballi* Obraztsov (Lepidoptera: Tortricidae) have not previously been identified as economic pests of Florida's multi-million dollar citrus industry, although Thompson (1938) cited a relative, *A. citrana* (Fernald) as unusually plentiful on young grapefruit during 1938. Barrows (1991) observed *A. amatana* larvae feeding on leaves of a variety of host plants. In previous reports, including Barrows, a wide variety of host plants have been reported as suitable for feeding by either or both species, but no mention is made of citrus as a potential host for either of these Tortricids (Kimball 1965).

In 1989, larvae of both *A. amatana* and *A. kimballi* were observed in Fort Pierce, FL feeding on citrus leaves and fruit (unpublished data). Further observations revealed that both species can complete their respective life cycles on the surface of the fruit.

There is a great deal of research quantifying the effectiveness of pheromone trapping techniques in monitoring for early detection of adult male tortricid moth activity (Jubb, et al., 1978; Broumas 1987). Supporting research has been conducted using pheromone traps to capture male Lepidoptera while testing the efficacy of various spray control programs (Reardon, et al. 1982; Reardon and Haissig 1983; Biever and Hostetter 1989).

Extensive work on blends, freshness and the effective field life and duration of types of pheromones have established thresholds and guidelines for pheromone longevity and use (Bailey, et al. 1988; DeLisle 1992; Faccioli, et al. 1993).

The use of various formulations of *Bacillus thuringiensis* (Bt) has been a very effective and environmentally friendly method of controlling a number of lepidopteran pests in a variety of crops (Reardon, et al. 1982; Reardon and Haissig 1983; Biever and Hostetter 1989). Work has also been completed to determine field persistence of *B. thuringiensis* Berliner var. *kurstaki* on a Balsam fir application from the previous year (Reardon and Haissig, 1983). Although lower populations of the targeted Tortricid were noted in the subsequent year, actual field persistence and pathogenicity of *B. thuringiensis* was undetectable.

The feeding of *A. amatana* and *A. kimballi* on oranges and grapefruit can be extensive enough to result in a cosmetic degradation of fresh fruit. In some cases, the ability of the larvae to penetrate the fruit peel results in a lesion, enabling the entry of organisms that initiate decay.

Similar to orange tortrix (Hubbard 1885; Thompson 1938; Quayle 1938), *A. amatana* and *A. kimballi* larvae frequently bind together three to four young terminal leaves of tender new flush with tubular webbing. Caterpillars of both species feed upon the fresh leaves of surrounding branches as well as the wilting leaves which have been bound together. Often, larvae will half-cut through small twigs and stems of tender growth, causing leaf-loss on seedlings in greenhouse plantings.

Both caterpillars have been observed feeding under the calyx or on the button of the fruit, circling the stem end of the fruit. Often, this type of feeding does not penetrate the rind, but scars it in the form of a ring around the calyx or a shallow crater, clearly seen at fruit maturity.

This study defines the larvae of *A. amatana* and *A. kimballi* as economic pests of citrus and describes the efficacy of one form of biological control for possible inclusion in an Integrated Pest Management (IPM) program. This research will report the peak periods of seasonal adult male moth flight activity for each species between 1990 and 1996 and it will indicate whether seasonal fruit drop correlates with an increase in feeding damage.

Materials and Methods

A 1-hectare block of Hamlin oranges (*Citrus sinensis* Osbeck) was inspected for signs of active feeding by Tortricid larvae during

Florida Agricultural Experiment Station Journal Series No. N-01424.

the early spring of 1988. Infested fruit were removed from the field, and larvae were reared to adults in the laboratory. Adult moths were sent to Division of Plant Industry, Gainesville, Florida for identification by Dr. J. B. Heppner.

A pheromone trapping program for adult male tortricid moths was begun at the Indian River Research and Education Center in Fort Pierce, FL in 1989. Three bait formulations, CACO, FTLR and OTR, manufactured by TRÉCÉ, Inc., Salinas, Ca. were evaluated in Pherocon® 1C traps to monitor adult male moth activity throughout the year. By 1991, CACO (TRÉCÉ product no. 3125) appeared to be the most successful bait in luring both *A. amatana* and *A. kimballi*. Use of the other two pheromones was then discontinued.

The CACO pheromone lure contains Z-11 Tetradecenyl acetate of greater than 99% chemical purity and about 96% isomeric purity (Rajapaksa, personal comm. 1997).

Traps were surveyed weekly for *A. amatana* and *A. kimballi*. New lures and sticky trap bottoms were replaced every two weeks. During alternate survey weeks when trap bottoms were not replaced, moths were removed to prevent being counted a second time the following week.

One trap was located between two trees within the tree line in the middle of a block of ruby red grapefruit on Cleopatra rootstock in the southeastern portion of the grove. The second trap was placed between two trees within the tree line in a block of Valencia oranges on rough lemon rootstock approximately 100 meters west of the first trap.

A third trap was added to the test on November 8, 1993 in a 1-hectare block of Hamlin orange trees on Volkameriana rootstock located in the northeastern portion of the IRREC grove. Throughout this report, these traps will be referred to by cardinal direction, East, West and North, respectively.

Three field tests of a *B. thuringiensis* (var. *kurstaki*) formulation at two rates against *A. amatana* and *A. kimballi* larval feeding activity were conducted in 1991, 1995 and 1996. In each case, Pherocon trap captures were used as indicators for timing of spray applications.

All three tests compared the same two rates of Dipel® 2X (Abbott Laboratories, wettable powder, 6.4% active ingredient) against an untreated condition: a high rate of 454 grams of material, and a low rate of 227 grams of material, both in 378 liters of water.

In 1991, each treatment was applied to 14 replications of single-tree plots in a randomized block design in one single-bedded 43-tree row of Hamlin oranges on Volkameriana rootstock. In 1995, treatments were applied to 14 replications of single-tree plots in a randomized-block design in the western half of two single-bedded 43-tree rows of the same Hamlin planting used in ‘91. In 1996, the plot layout from 1995’s test was repeated. Sprays were applied to “run-off” with a 756-liter hydraulic sprayer equipped with a KEN duplex handgun.

In 1991, two catch frames, each measuring 8519 sq cm in area, were placed under each tree to collect fruit which dropped from the trees. Catch frames were square in shape, with four wooden sides, 92 cm in length, 11.5 cm deep and 2 cm in thickness. Frame bottoms consisted of 1.27-cm mesh hardware cloth.

In 1995 and 1996, the frames were the same design, with frame sides 50 cm in length, with the same depth and thickness as above, and total area measured 2500 square cm in size. Four frames were placed under each tree.

Frames were surveyed weekly from the first week of May through mid-September. Fruit were removed from catch frames and examined for presence of caterpillar feeding damage. In 1995 and 1996, all harvested fruit were surveyed for damage at harvest time. Just prior to harvest in 1991, a sample of 100 fruit per tree were randomly examined for caterpillar damage.

Data were recorded for each trap, tree and catch frame, and were compared using analysis of variance, t-test and correlation. Means were separated using Duncan’s multiple range test (DMRT).

Results

Caterpillar feeding damage

For each of the three years, data were examined for statistical differences in several conditions. Data from 1991, when no complete yield was taken, compared total fruit dropped per treatment, percentage of caterpillar-damaged fruit from random 100-fruit survey at harvest, and percentage of damaged fruit found in catch frames.

For both 1995 and 1996, when complete yield was taken, a total of four conditions were examined for statistical significance. It should be noted that all references to “fruit drop” are based only on fruit collected in catch frames and does not take into account fruit which dropped and did not land inside a frame. Conditions examined for experiments in 1995 and 1996: total fruit harvested per tree; total number of damaged fruit harvested per tree; percentage of damaged fruit which was harvested; and percentage of damaged fruit dropped into catch frames.

In 1996, several trees in two plots were inadvertently harvested without record, so all data from replications 13 and 14 were ignored for that year and 1995 as well. For these two seasons, only data collected from the other 12 reps were examined.

Yield comparisons for 36 of the experiment’s 42 trees revealed significant differences with respect to the percentage of damaged fruit found during harvest (Fig. 1). In 1991, no full yield data was recorded, but the random sampling of 100 fruit/tree indicated noticeable differences. That trend was carried into the 1995 and 1996 growing seasons where plots treated with Bt had a smaller number of damaged fruit than did untreated conditions.

In the 1991 test, significantly more caterpillar-damaged fruit were present on untreated trees (Table 1 and Fig. 1). The untreated check averaged 6.0% caterpillar-damaged fruit, plots sprayed with Dipel 2X at the 227-gm rate had 1.5% damaged fruit and plots treated at the 454-gm rate showed 1.3% damaged fruit, significant at P ð 0.05.

In 1995, fruit shed from and fruit harvested from untreated trees showed significantly more feeding damage during the season (Table 1). Caterpillar feeding damage was found on 24.1% of the dropped fruit from the untreated check plots during the 1995 growing season. In plots treated with the 454-gm rate of Dipel 2X, 11.3% of the dropped fruit were damaged by caterpillar feeding, while in the 227-gm rate of Dipel 2X, 8.9% of the dropped fruit were damaged by caterpillar feeding. Damage in the untreated check was significantly greater (P ð 0.01) than in the two treated plots.

Total fruit harvested in each treatment in ‘95 was not significantly different. However, the total number and percentage of damaged fruit picked during harvest did reveal a significant reduction in feeding damage for Bt treatments (Table 1 and Fig. 1).

Also, no significant differences between treatments were found with regards to total fruit collected in catch frames nor with the percentage of all damaged fruit collected in catch frames, indicating that *A. amatana* and *A. kimballi* feeding damage does not directly cause an increase in seasonal fruit drop (Table 1).

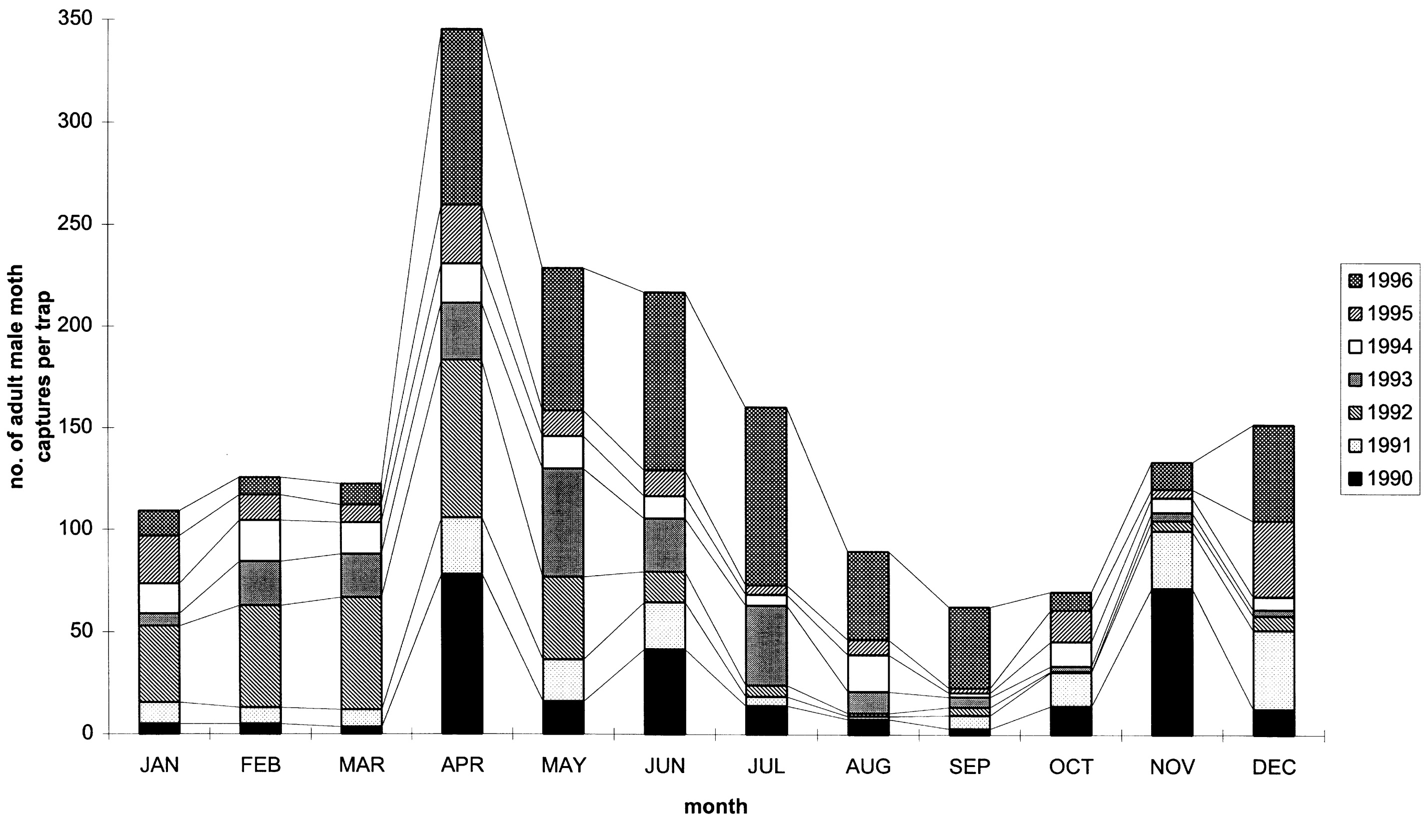

Figure 1. Cumulative average monthly adult moth captures 1990-1996 for *Argyrotaenia amatana* and *A. kimballi* combined.

Nor did caterpillar feeding contribute to a greater number of damaged fruit shed from trees during post bloom in the 1996 growing season. But at harvest in 1996, statistical differences could be measured between treatments with caterpillar-damaged fruit (Fig. 1). In the unsprayed check plots, 7.3% of all the fruit displayed typical caterpillar damage. At the 454-gm rate of Dipel 2X, 4.3% of the fruit were damaged, and in the 227-gm. rate, 3.5%, significant at P ð 0.05 (Table 1).

In total, much less fruit dropped during the 1996 growing season. Of all the fruit accounted for in 1995, 18.6% dropped and were collected in catch frames prior to harvest. But in 1996, only 8.7% of all counted fruit were collected in catch frames. Just 1.5% of all fruit (damaged and undamaged) from the check plots dropped, compared to 1.8% of all fruit in the 227-gm rate of Dipel 2X and 1.6% in the 454-gm rate.

Table 1. Feeding damage on Hamlin oranges by larvae of *Argyrotaenia amatana* and *A. kimballi* during three larvae control tests using the Dipel®2× formulation of *Bacillus thuringiensis*.

	Year and Treatment								
	1991			1995			1996		
	227[y]	454	0	227	454	0	227	454	0
Total fruit harvested	1400[x]	1400[x]	1400[x]	7377 ns[z]	7456 ns	7177 ns	6007 a*	4661 b*	4507 b*
No. of damaged fruit at harvest	21[x]	18[x]	84[x]	150 b**	180 b**	550 a**	211 b*	201 b*	331 a*
% Damaged fruit at harvest	1.5 b**	1.3 b**	6.0 a**	2.0 b**	2.4 b**	7.6 a**	3.5 b*	4.3 b*	7.3 a*
Total fruit dropped	3879 ns	3587 ns	3102 ns	474 ns	495 ns	427 ns	118 ns	75 ns	105 ns
No. of dropped fruit with damage	47 ns	29 ns	62 ns	42 b**	56 b**	103 a**	23 ns	16 ns	32 ns
% Dropped fruit with damage	1.2 ns	0.8 ns	2.0 ns	8.9 b**	11.3 b**	24.1 a**	19.4 ns	21.3 ns	30.5 ns

[x] = Data was based on 100 fruit/tree survey prior to harvest.
[y] = Grams of Dipel 2× in 378 liters of water.
[z] = Means separation within years by DMRT: significant at P ð 0.05 (*) or P ð 0.01 (**). Non-significant (ns).

In 1995, a total of 19,377 fruit were harvested from the experiment's trees while in 1996, the total was 14,563 fruit. In a direct comparison between each treatment during the two years, the 1995 yield was significantly greater than that of 1996 with Dipel 2X at 454 gms/378 *l* in '95 producing the most fruit (avg. 546.75 f/t). In 1995, Dipel 2X at 227 gms./378 *l* had the second highest average harvested amount of fruit per tree with 540.17 f/t.

A comparison of high fruit drop and diminished yield within each treatment did not correlate in the check plots in 1996. For 1996, total fruit dropped and counted in catch frames were 9.8 f/t (1.8% of countable crop) at the 227-gm. rate, 8.8 f/t (1.5%) in the untreated condition, and 6.3 f/t (1.6%) at the 454-gm. rate, and were not significantly different.

As for the total fruit harvested and collected in catch frames during the 1996 season, some trees sprayed with Dipel 2X showed a significantly greater average fruit/tree. Plots treated with the 227-gm rate yielded an average of 500.6 fruit/tree. Inexplicably, the 454-gm rate of Dipel 2X yielded just 388.4 f/t, not much higher than the 384.3 f/t recorded in the untreated check plots.

The total number of damaged fruit which dropped during the 1996 season was 2.7 f/t (8.8%) in the check; 1.9 f/t (9.7%) in the 227-gm rate; and 1.3 f/t (7.4%) in the 454-gm rate. The percentage of dropped fruit which was damaged by caterpillar feeding for each treatment was 30.5% in the check, 21.3% in the 454-gm rate, and 19.4% in the 227-gm rate. No significant differences were found either in total values, or in percentage comparisons between treatments.

Moth flight activity

Adult male moth captures tallied monthly from 1990 through 1996 indicate a peak of flight activity in late spring and early summer (Fig. 2 and Fig. 3). The month of April ranked as the most active of the year with an average of 120.9 moths per month (m/m) captured during the seven years of observation.

May (79.4 m/m) and June (77.9 m/m) had the second and third highest average capture amounts and July (59.7 m/m) was only slightly less. Trap captures tapered off consistently during the summer and into the fall with least activity in September (24.1 m/m) and October (25.1 m/m). Between November (42.3 m/m) and March (40.0 m/m), adult male moth activity remained steady with a low in January (38.4 m/m) and a high in December (56.9 m/m). February (41.9 m/m) and August (35.4 m/m) were the remaining two months. The average monthly moth captures were significantly different (P ð 0.01).

For the six-year period from 1990 through 1995, yearly captures of the two moth species combined were relatively consistent, ranging from a low of 136.3 moths per trap (m/t) in 1995 to a high of 299.0 m/t in 1992. Suddenly in 1996, 1,545 of the two species

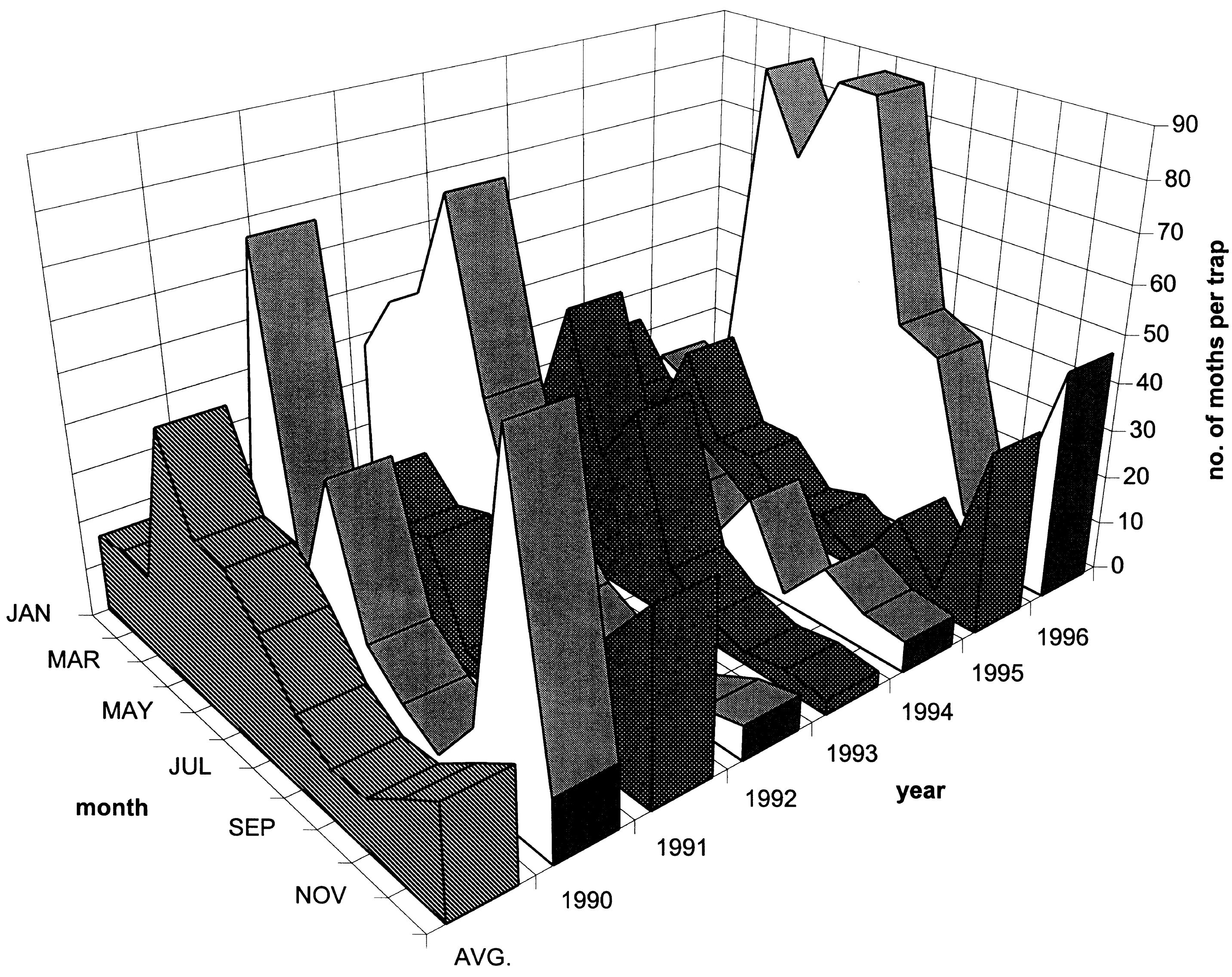

Figure 2. Average adult moth captures per trap 1990-1996 for combination of *Argyrotaenia amatana* and *A. kimballi*.

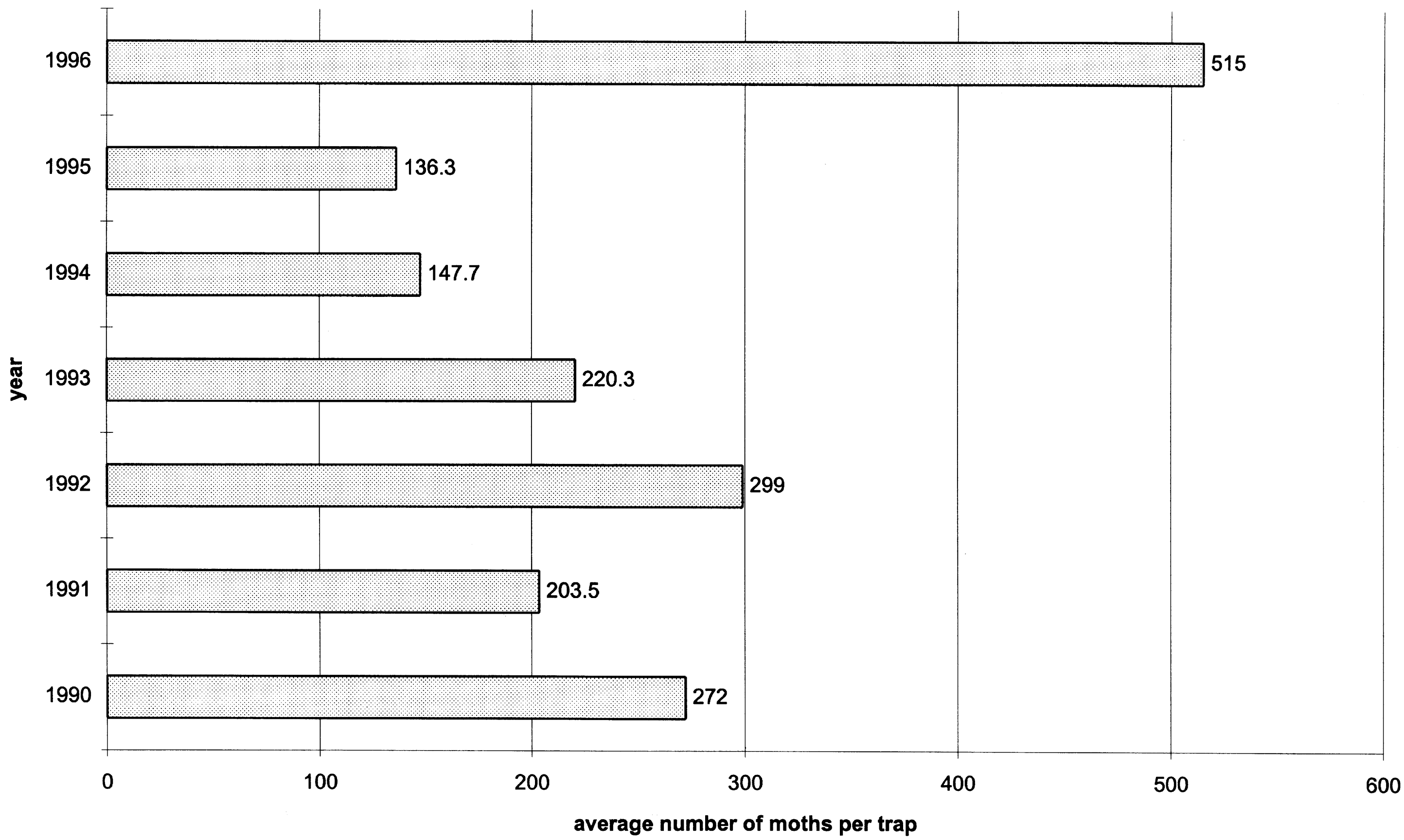

Figure 3. Average moth captures per trap for *Argyrotaenia amatana* and *A. kimballi* at IRREC, Fort Pierce 1990-1996.

were captured in the three pheromone traps for an average of 515.0 m/t.

Average moth captures per trap per year were as follows (note: beginning with 8 Nov. 1993, the test used three Pherocon 1C traps instead of only two): 1989 = (only eight months of data, May-December) 64 m/t; 1990 = 272 m/t; 1991 = 203.5 m/t; 1992 = 299.0 m/t; 1993 = (45 readings with two traps, 7 readings with three traps) 220.3 m/t; 1994 = 147.7 m/t; 1995 = 136.3 m/t; 1996 = 515.0 m/t (Fig. 4).

Monthly captures of *A. amatana* (Aa) and *A. kimballi* (Ak) from 1994-1996 in the pheromone trap located within the sprayed block reveal a steep increase in adult male Aa activity during 1996. In 1994, Aa captures totaled 4.5 per month, and 4.8 per month in 1995. But 1996 saw a dramatic increase with 36.25 Aa per month captured. Seven months had counts of or higher than 31 Aa with 100 captures in April being the most active month. May remained active with 65 Aa moths and followed in June by a slight dip in activity with 39 Aa moths. An unusual July recording of 81 Aa moths also contributed to 1996's high averages.

A. kimballi flight activity also increased notably during 1996. An average of 8.4 Ak per month were captured in 1994. But after dropping to 5.8 Ak per month in 1995, the average monthly Ak captures climbed to 15.75 in 1996.

For both species combined, the monthly average was 12.9 in 1994, 10.6 in '95 and 52.0 in '96. For the entire three years, an average of 15.2 Aa, 9.9 Ak and combined 25.2 moths were captured on a monthly basis.

Discussion

In all three tests, larval feeding on fruit did not correlate with premature fruit drop at post bloom. Fruit drop remains more a function of citrus tree physiology than it is a function associated with a certain increase in pest pressure.

Spraying *Bacillus thuringiensis* did provide a significant reduction in the percentage of fruit damaged by feeding of *A. amatana* and *A. kimballi* larvae.

With regards to the somewhat low yield found in the 454-gm rate of Dipel 2X in 1996, no plausible explanation can be suggested by the researchers. There was no apparent phytotoxicity nor measurable increase in fruit drop.

The sharp increase in moth captures in 1996 may have corresponded with environmental conditions favorable for an increase in activity. Climate conditions over the previous winter or throughout the spring may have resulted in an abundance of alternate host plants found among the grove's ground cover or ditch banks. Perhaps an interruption in grove care schedules augmented the available hosts for *A. amatana* and *A. kimballi* larvae, but this is only speculation.

The sharp increase in adult moth captures in 1996 corresponded with a lower number of caterpillar-damaged fruit during the same growing season. In 1995 and 1996, trapping within the experimental block was continued during the test period. Perhaps, removal of males from the population prior to sexual encounters with female moths was more successful this year than in years past and resulted in fewer caterpillars and less damage.

Acknowledgments

We thank Monty Myers, Michelle McGee, Christy Ferguson, Mike Burton and Danielle Giordano for their technical assistance.

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Reprinted from

Proc. Fla. State Hort. Soc. 110:32-36. 1997.

CORRECTION OF IRON DEFICIENCY IN ORANGE AND GRAPEFRUIT TREES IN HIGH pH SOILS

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Additional index words. Alkaline soil, *Citrus paradisi* Macf., *Citrus sinensis* (L.) Osb., iron chelate, iron chlorosis, optimal leaf iron concentration.

Abstract. **In some areas of flatwoods citrus production regions along the east coast and in south Florida, soils are highly calcareous and the trees exhibit iron (Fe) chlorosis symptoms. Currently, Fe-EDDHA (ethylenediiminobis-2-hydroxyphenyl acetic acid) chelate is the most effective source of Fe for high pH soils; however, it is an expensive source. Iron humate, a less expensive by-product of the drinking water decolorization process, was compared with Fe-EDDHA for Fe deficiency correction. Non-bearing 'Ambersweet' orange and 'Ruby Red' grapefruit (*Citrus paradisi* Macf.) and bearing 'Hamlin' orange (*Citrus sinensis* (L.) Osb.) and 'Flame' grapefruit trees, all on Swingle citrumelo rootstock, planted in high pH (> 7.6) soils, were used in this study. Iron humate was applied under the tree canopy in spring at rates from 0.07 to 7.0 oz Fe, for the non-bearing trees, or 0.75 to 12.0 oz Fe, for the bearing trees, per tree per year. Application of Fe humate at 0.75 oz Fe/tree/yr significantly increased the Fe concentration in the leaves as well as the fruit yield of both 'Hamlin' orange and 'Flame' grapefruit trees as compared to that of the trees in unamended soil. The fruit yield increase with application of Fe humate was generally very close to that with application of Fe-EDDHA at a similar Fe rate per tree. Modification of the Fe humate with addition of urea or ammonium nitrate did not increase Fe availability. Application of the Fe amendments regardless of rate or sources did not significantly affect the fruit quality. Application of Fe humate to non-bearing trees decreased twig dieback rating and increased flush growth, flush color rating, tree size, and leaf Fe concentration. This study demonstrated significant improvements in growth and Fe availability to non-bearing trees and Fe availability and fruit yield of bearing trees in high pH soils with application of Fe humate as compared to the unamended treatment.**

Iron (Fe) deficiency is a widespread problem in calcareous soils (Alva, 1992; Korcak, 1987). Soil application of organic Fe chelates is more effective than foliar application due to poor translocation of leaf-absorbed Fe (Anderson, 1982; Mortvedt, 1982). The effectiveness of Fe chelates depends strongly on the soil pH (Norvell, 1991). In highly calcareous soil with pH above 7, the only stable Fe chelate is EDDHA (as an example commercially available product is Sequestrene 138-Fe). The EDTA chelated Fe is stable only at pH < 6.5. Although the most effective source of Fe for high pH soils (pH > 6.5) is EDDHA chelated Fe, the high cost of this product is a major limitation for its use, particularly during the years of low net economic returns for a given production system. Therefore, it was necessary to explore an alternate low-cost Fe amendment which can be effective in high pH soils.

By-product materials from mining and industrial operations have been used to alleviate Fe chlorosis in various crop plants (Martens and Westermann, 1991; Parkpian and Anderson, 1986). Most agricultural industries are cautious about the use of industrial by-products as agricultural soil amendments. Therefore, it is important to conduct a thorough investigation on the by-product quality, crop response, and long-term effects on environmental quality. The by-product evaluated in this study came from a drinking water treat-

Florida Agricultural Experiment Station Journal Series No. N-01497.