University of California, Santa Cruz
Center for Agroecology and Sustainable Food Systems
Farm Extension Program

A grower-managed biorational program for artichoke pests (BIORAPP) on the north central California coast

in cooperation with

Organic Farming Research Foundation
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ABSTRACT

A native egg parasite, *Trichogramma thalense,* was mass-reared in the laboratory and released a maximum of thirteen times against the eggs of the artichoke plume moth *(Platyptilia carduidactyla)* in three 5-acre biointensive artichoke production fields on the northern Santa Cruz/San Mateo County coast in 1998 and again in 1999-2000. A biorational grower-managed pest management program for these fields (BIORAPP) was used in 1998 and included Trichogramma releases, pheromone-based mating disruption, double-cut control, and intensive monitoring of artichoke plume moth (APM) presence and artichoke damage. This program was

monitored by a management team consisting of growers, an artichoke industry representative and a University researcher. Mass-released parasitoids were recovered from artichoke plume moth (APM) eggs collected post-release on only three dates, and in only one of the BIORAPP fields**,** in 1998; however, APM egg deposition was low in all other fields. Parasitoids were not recovered from any of the three adjacent, 5-acre, non-release conventional artichoke fields.

In the second year of the study we decided to focus on the potential of mass trapping of APM rather than parasitoid releases, due to poor results with releases and lack of facilities and personnel required for mass rearing of the *T. thalense.* The rearing of *T. thalense* was turned over to a commercial insectary (Rincon-Vitova in Ventura, California) so that the colony quality could be improved and to counteract potential deterioration due to the number of successive generations reared in our laboratory.

The impacts of BIORAPP management *(Trichogramma* release, pheromone-based mating disruption, double-cut cultural control, and intensive monitoring of APM abundance and artichoke damage) were also monitored in the fields. APM damage to buds, male artichoke plume moth flight, and larval density were measured from June (cutback) 1998 through May 2000. The BIORAPP combination of pheromone-based mating disruption, release of *T. thalense, and* intensive weekly monitoring resulted in an insecticide stress-free production season in 1998-1999 for the BIORAPP fields, with the exception of field B-2, which was treated with an insecticide in March 1999. Two of the BIORAPP fields and one control field exceeded the action threshold of 4% bud damage on individual dates; however, average seasonal bud damage for all fields was below 4% through May 2000. Buds were not sampled frequently enough in two fields (one BIORAPP and one control) to accurately assess percent damage. Two organic artichoke growers joined the BIORAPP management team in 1999. The fields (one of perennial and one of annual artichokes) enrolled by these growers had very low APM pressure throughout the season.

INTRODUCTION

Resistance to insecticides, increasing costs of substitute insecticides, interest in organic production and markets, and regulatory pressures limiting the use of presently registered or new materials for artichoke plume moth control have stimulated research interest in control alternatives. These alternatives have included pheromones (Klun et al. 198 1; Haynes and Birch, 1984; Haynes et al., 1981, 1983) microbial controls (Bari and Kaya, 1984), and native natural enemies (Lange, 1940, Bragg, 1971, 1974; Goh and Lange, 1980; 1989).

Goh and Lange (1980) reported that native natural enemies under insecticide stress-free conditions were economically ineffective and poorly synchronized in suppressing artichoke plume moth (APM) in a commercial fie]dd In insecticide-treated fields, they noted that egg loss due to abiotic factors and early instar predation are important mortality factors, but the contribution of these factors to overall generational mortality is insignificant in economic terms. They report they could detect no parasitism of egg stage APM in any artichoke fields studied, and in general, life tables for APM in commercially managed fields indicate that the native natural enemies play a small role in overall generational mortality, due to repeated insecticide applications. These conclusions have several implications for the current study, in which we were interested in enhancing biological control in artichokes. First, natural enemy augmentation could help overcome the poor searching ability of native natural enemy species. Also, insecticide use reduction could increase populations of native and augmented natural enemy species. Our research began with these methods, and later included the third method of using pheromones to mass trap adult male artichoke plume moths.

Egg parasitoids of APM were first collected by Dr. Mohammed Bafi (Artichoke Research Association, Salinas, CA) in 1986 from both Salinas and the Tomales Bay area. Two species were *collected: Trichogramma thalense* (Salinas) and a new species, *T. nr. pintoi* (Tomales Bay). Personnel of the University of California, Santa Cruz Center for Agroecology and Sustainable Food Systems (CASFS) subsequently collected both species in 1991 and began mass-rearing separate populations of both species in the laboratory at CASFS.

PROJECT INITIATION

In March, 1998, the CASFS farm extension program and the Organic Farming Research Foundation cooperated with two commercial artichoke growers to monitor a grower-managed farm-level comparison of *T. thalense* release into insecticide-free artichoke fields compared with matched insecticide-managed artichoke fields. In 1999, two additional (organic) growers joined the project. This cooperative effort, called BIORAPP (BIORational Artichoke Pest management Program), had the following objectives: (1) establish commercial, on-farm comparisons of these artichoke production systems; (2) release T *thalense,* mass-reared at the CASFS insectary into the BIORAPP-enrolled fields and evaluate the effects of this parasitoid on APM eggs; (3) incorporate pheromone-based mating disruption (I 998-1999) and mass trapping (I 999-2000) into the BIORAPP fields for APM suppression; and (4) compare APM activity and damage in both systems during the 1998-1999 and 1999-2000 production seasons.

The BIORAPP program was established by a management team composed of Dr. Sean L. Swezey (CASFS), Dr. Mohammed Bari (Artichoke Research Association), Steve Bontadelli (grower/PCA), and Tim Hudson (grower), with the addition of Jim Cochran (grower) and Mitchell Tories (grower) in 1999. Shortly after cutback in June of both years BIORAPP growers provided five-acre fields (B 1, B2, and B3 in 1998-1999; B 1, B3, B4, and B-5 in 1999-2000) for biointensive management (referred to as "BIORAPP fields" in the text) and conventional fields (C 1, C2, and C3 in 1998-1999; C I and C3 in 1999-2000) for comparison'. Conventional insecticide-based management practices were employed for these matched control fields. All of these fields were the traditional perennial (globe) artichokes except for B5, an annual (Imperial Star) artichoke field monitored in 1999.

To assess the performance of the BIORAPP fields, CASFS Farm Extension Program staff monitored artichoke plume moth infestation and adult moth trap capture; monitored T *thalense; and* collected damage data during harvest. Treatment and monitoring began in mid-June of each year, after all fields were double-cut back [2] at the start of the season to physically suppress initial APM infestation, and were monitored as weather permitted throughout the year. The annual artichokes were grown from mid-February through August 1999, and were monitored from mid-May through the end of August.

MATERIALS AND METHODS

Production Systems Management and Experimental Treatments

The experimental fields were located north (B1, B3, C I and C3) and south (B2, B-4 and C2) of Davenport on California State Highway 1, approximately 5-15 miles N of Santa Cruz, California, and

Fort Ord, near Marina, CA on Highway 68 (B5). A replicated complete block design with two management systems treatments (conventional and BIORAPP [Table I]) was established in 1998, with each treatment consisting of 5 acres. Because of the removal of some fields from production in 1999, a statistical comparison was not possible for the second field season. Production practices, with the exception of BIORAPP APM control methods, were the same for both treatments. The observed season lasted from cutback in June 1998 to cutback in May 2000, with the harvest season occurring from September to April.

APM control consisted of combined biological methods *[Trichogramma* release, mating disruption, pheromone ropes and mass trapping of APM adults in 1999-20001 in the BIORAPP treatment fields and two winter synthetic insecticide applications (Asana/Dimilin) in the conventional treatment fields. Insecticides were applied once to a BIORAPP field (B2), in March 1999. Nine (B3) to thirteen (B 1, B2) releases of *T. thalense* were made to BIORAPP fields in 1998. The Artichoke Plume Moth Degree Day Utility was run for each BIORAPP field to bracket APM generations, using the San Gregorio CIMIS weather station and the UC Statewide IPM pest forecasting routine (calculating 905-degree day units per generation). Biofix (first egg discovered) was set at June 19 in 1998 and June 10 in 1999. Degree day - based predictions were used to help *time Trichogramma* release dates in 1998.

Mass releases of T *thalense* adults from the CASFS laboratory culture were made in three central acres in each BIORAPP field. Parasitolds were released as pupae developing in host eggs glued to small, I in. sq. "release cards" taped into small, screened paper boxes (2 in.' of pupae per box), at a density of 12-16 boxes/acre throughout the three central acres. Each release card contained approximately 1,500 *T thalense* pupae programmed for emergence on the release day. Adults emerged from this laboratory-reared material into the box, exited the screened side, and then dispersed into the field. Releases were made at varying doses (thousands of pupae/acre) depending upon availability from the laboratory culture (see Figure 9 for doses). During 1998-1999, a mating disruption system was also used in the BIORAPP treatment fields in which APM pheromone lure ropes were placed in the artichoke plants by the growers at the rate of 480 per acre in July 1998. A mass trapping system was employed in the 1999-2000 season due to a shortage in the availability of pheromone ropes to the growers. This system involved the set-up and monitoring of pheromone/oil traps every 40 feet in the BIORAPP treatment fields. The traps consisted of a fourfoot piece of grape stake on which a metal bracket was attached to hold two plastic cups. One cup was inverted above the other and enclosed the APM pheromone lure rope, which was held in place with a paperclip inserted through a hole in the top of the cup. The other cup was filled threequarters full with water and a thin layer of oil.

Four meetings (March and December 1998; May and December 1999) of the BIORAPP management team were held to discuss project status and results, particularly degree-day accumulations, egg parasitism, and artichoke damage in the fields.

Data Collection

APM male flight was monitored in a pheromone-baited cup trap placed in each field. Males were collected weekly. APM larval incidence was monitored weekly by visual inspection of vegetative shoots and forming buds. Larvae were classified by early or late instar (first/second or third/fourth). APM egg incidence was monitored weekly by visual inspection of the undersides of 20 artichoke leaves per field. Bud damage was assessed weekly by inspection of 100 randomly selected buds **in** each field.

Bud damage levels were not assessed when fields contained fewer than 100 buds. Early bud damage is considered the best index of overall APM damage potential to the harvestable crop.

Fields B-2 and C-2 were taken out of artichoke production at the end of May 1999, so were not part of the second year of the study.
2Double cut back refers to a method used to control APM in which the crop is cut back, let grow for one month, and then cut back again.

To assess parasitism levels, naturally occurring APM eggs were collected from the release plot weekly, and laboratory-reared and observed for emergence of parasitoids. Percent parasitization was determined by dividing the number of emerged parasitoids by the total number of APM eggs collected on that sampling date.

RESULTS AND DISCUSSION

Note: Since APM infestation and damage levels differed greatly between fields, we present most of the results by field rather than as treatment averages.

APM flights

The degree day model predicted the development of four generations of APM during the 1998-1999 experimental period, representing four flight periods. Based on a biofix date of June 19, the flights were predicted to occur mid-August and late October, 1998, and early April, 1999. Fields B2 and C2 had the highest APM incidence, and APM trap captures match the predicted flight periods fairly closely (Figures I a and I b). Fields B I /C I and B3/C3 both had low flight captures during much of this period, and many captures occurred outside of predicted flight periods (Figures I c/ I d and I e/ I f:).

Biofix in the 1999-2000 season occurred on June 10, 1999. Based 'on this date, the degree day model weather predictions for San Mateo county indicated flights in n-tid-August, 1999, mid October, 1999, and early February, 2000. As in the 1998-1999 season, the adult APM capture data do not completely correspond to the degree day models in some of the fields monitored (Figures 2a/2b and 2c/2d). This is reflective of the effect of mass-trapping, which captures male moths and disrupts normal trap patterns. Biofix for the annual artichokes (field B5) occurred on February I 1, 1999, and subsequent generations were predicted in mid-June and mid-August 1999. Few APM were captured in this field (Figure 2f), evidence of the success of the annual system at escaping APM detection.

The perennial BIORAPP fields were cut back the end of May during the 4th flight to interrupt APM reproduction. APM trap captures were averaged over all BIORAPP and conventional control fields. Average seasonal APM trap captures were not significantly different between BIORAPP and control fields in 1998-1999 (paired t-test; $p = 0.443$). Statistical analyses were not done for the 1999-2000 season because we had only two control field replicates.

APM damage

Figure 3 illustrates the average frequency of bud damage by APM larvae in each field in the 1998-1999 season. Fields B3 and C3 had low yields, and were only sampled for APM damage 5 and I times, respectively, so the lack of damage found is not surprising. Bud damage generally was below 4%, an acceptable level, in all fields except B2. In B2, damage levels exceeded 4% on four dates, reaching about 10%, during the period between January and March 1999. With the exception of field B2 in March 1999, growers on the management team expressed satisfaction with these damage levels at both the December 1998 and May 1999 BIORAPP meetings.

Figure 4 shows that average bud damage over the 1999-2000 season was below 3% in all fields. The maximum bud damage on any one date was 8%, in the annual artichokes at the Fort Ord site (B5). Control fields during the 1999-2000 season showed low infestation of buds (0-2%). As in the 1998-1999 season, field C3 had low yields, and as a result was only sampled for bud damage 3 times.

Statistical analyses on damage were not done on data from either season, due to the highly variable number of sampling dates per field in 1998-1999 and the low number of control fields in 1999-2000.

APM in-field reproduction

There were no significant differences between BIORAPP and control fields in number of APM eggs found (Figure 5) (paired t-test of seasonal sums; $p = 0.099$), or APM larvae found (Figure 6) (paired t-test of seasonal sums; $p = 0.299$) during the 1998-1999 season. Most of the APM larvae found in 1998-1999 were found in field B2, which had consistently more larvae through the season than did C2. During the 1999-2000 season, APM eggs and larvae found in each field were averaged over each month, and the treatment averages are shown in Figures 7a and 8 (without field B5). Since B5 was an annual crop, the timing of planting and management differed from the other fields, so data from this field were not included in the graphs. There were few APM eggs in field B5 on all dates (Figure 7b), and only two APM larvae were found in B5, on a single date (March 4 1999). Again, statistical analyses were not performed on 1999-2000 data; however, based on the graphs there did not appear to be any strong differences between treatments in APM eggs and larvae found.

Parasitization of APM by *Trichogramma thalense*

Figure 9 shows the results of the *T. thalense* releases into the B2 field in 1998-1999. This was the only field with sufficient infestation from which to recover parasitoids. Detectable parasitization of APM eggs began on August 27, 1998 after four releases. One parasitized egg was found out of four APM eggs (25%) recovered from B-2 on that date. Parasitized APM eggs were also found in this field on two other dates in 1998; four parasitized of six viable APM eggs were recovered on September 3 (66%) and one parasitized egg (100%) was recovered on September 17. No other parasitized APM eggs were found in this study.

Generalist predator abundance

Brown lacewings (BLW) were by far the most common generalist predator found in all fields, and they were most commonly found in the egg stage. There was no significant difference between brown lacewing egg (BLWE) abundance in BIORAPP and control fields during the 19981999 season (Figure 10) (paired t-test of seasonal averages; $p = 0.428$). The seasonal BLWE abundance did not appear to depend on treatment in the 1999-2000 season, either (Figure 11). (Data from the 1999-2000 season are presented as seasonal averages rather than average values for each date because of differences in sample timing - due to the annual artichoke field - and differences in sampling dates between fields).

Costs

As a first step towards determining whether BIORAPP techniques could be part of an economically viable production system, we have estimated costs of rearing parasitoids and monitoring fields. In this study, total costs for field monitoring were $20 per week. If used in conjunction with degree-day predictions, annual monitoring costs would be about $800. Although monitoring was done on 5-acre plots, this level of monitoring could be applied to a field of up to about 40 acres with no additional costs, which would bring annual monitoring costs to $20 per acre. Total costs for rearing and releasing parasitoids were about $12,000 for the year, or about $4,000 per 5 acre field ($800 per acre). These rearing costs, prohibitively high for artichoke growers, reflect the small scale of our current rearing facilities. A larger and more efficient rearing operation could bring rearing costs down considerably, and we have given a small stock culture of T. *thalense* to a commercial insectary for development. In the future we may develop an agreement with this insectary (Rincon-Vitova) to collect parasitoids from known sites to augment their colonies.

CONCLUSIONS AND DIRECTIONS FOR FURTHER STUDY

The goals of this project were successfully accomplished. First, release of T. *thalense* parasitoids into BIORAPP fields during the 1998 production seasons added detectable mortality of APM eggs in the field with the highest APM infestation rates (field B2). Additionally, a six-month insecticide-free period was achieved in all BIORAPP fields in the first project season (June 1998 to March 1999-, field B2 was sprayed in March 1999), and in the second year BIORAPP fields did not receive any pesticide applications. Our results demonstrate that we can successfully rear a wild, adapted *Trichogramma* species in the laboratory, release it into a commercial production field (free of insecticide stress), and collect parasitized APM eggs in the release area. While costs of this program are currently prohibitively high, future improvements in efficiency could make the program economically feasible for growers.

Based on data from the field B5 in 1999, it appears that APM population sizes and damage levels in an annual artichoke production system are similar to those in the perennial system, and that the BIORAPP system was effective in the annual system. However, the annual site in this study was located in a different production area, with different levels of APM pressure, than the rest of the fields in the study. Unfortunately, an annual control site was not available to us in the current study.

There are several ways in which the BIORAPP approach could be further optimized. First, the degree-day model did not consistently result in accurate predictions of APM, perhaps because of low APM numbers, insecticide applications in the C fields, and/or use of long-ten-n temperature averages in the second project year. Second, the percent APM parasitism by laboratory-reared parasitoids reported here is lower and less consistent than those obtained in prior years of our research. Parasitization rates could possibly be increased by improving *Trichogramma colony* quality. Enhancing the efficiency of release organisms could improve control of APM larval hatch and damage to buds, and would help make mass release of *Trichogramma* an economically viable control option. *Trichogramma* effectiveness also needs to be assessed against APM in an annual (six month) artichoke production system; in such a system, the relationships between the timing of artichoke bud maturation, APM generations, and *Trichogramma* development differ from those of a perennial system, and *Trichogramma* control strategies may need to be rethought.

Additionally, artichoke yields were not measured in this project. While it is probable that any yield differences would be directly proportional to differences in bud damage between BIORAPP and control fields, a direct determination of yields would be a preferable measurement method.

The BIORAPP production systems project results suggest that biorational techniques (parasitoid release, pheromone ropes, mass trapping) can contribute to the suppression of APM damage at an acceptable level for North Coast artichoke -rowers interested in biorational and organically acceptable techniques and monitoring. Further studies are necessary for BIORAPP program optimization and to study the efficacy of this program in an annual artichoke production system.

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Table 1. BIORAPP Management Plan

MONTH / *APM Generation*	Activity
MAY - JUNE	Enroll BIORAPP fields and checks; management team planning meeting. Artichoke cutback(s). Set up pheromone traps; initiate degree-day forecasting; begin weekly APM egg, larva, bud damage surveys; begin weekly *T. thalense* release program (98-99); set up quality control and evaluation; (f) begin weekly fax or e-mail updates.
JULY - AUGUST *Summer Generation*	Pheromone rope application (98-99); Javelin (BT) - based larval suppression, combined with Dimilin or Asana if necessary, in close coordination with trichogramma release.
SEPTEMBER - NOVEMBER *Fall Generation*	Establish pick plots; harvest evaluation; pheromone rope application; Dimilin and Asana application if bud damage exceeds 4 - 6 %; continue *T. thalense* release in close coordination with applications (98-99). Mid-season report / meeting.
DECEMBER - MARCH *Winter Generation*	Dimilin / Asana applications if necessary; pick plot evaluations (not done); post-harvest interview; final yearly report; end-of-season report / meeting; next year planning.
APRIL - MAY *Spring (Foundation) Generation*	Enroll BIORAPP fields and checks; management team planning meeting

Figure 1a. Adult male APM captures
Field B 2, 1998-1999

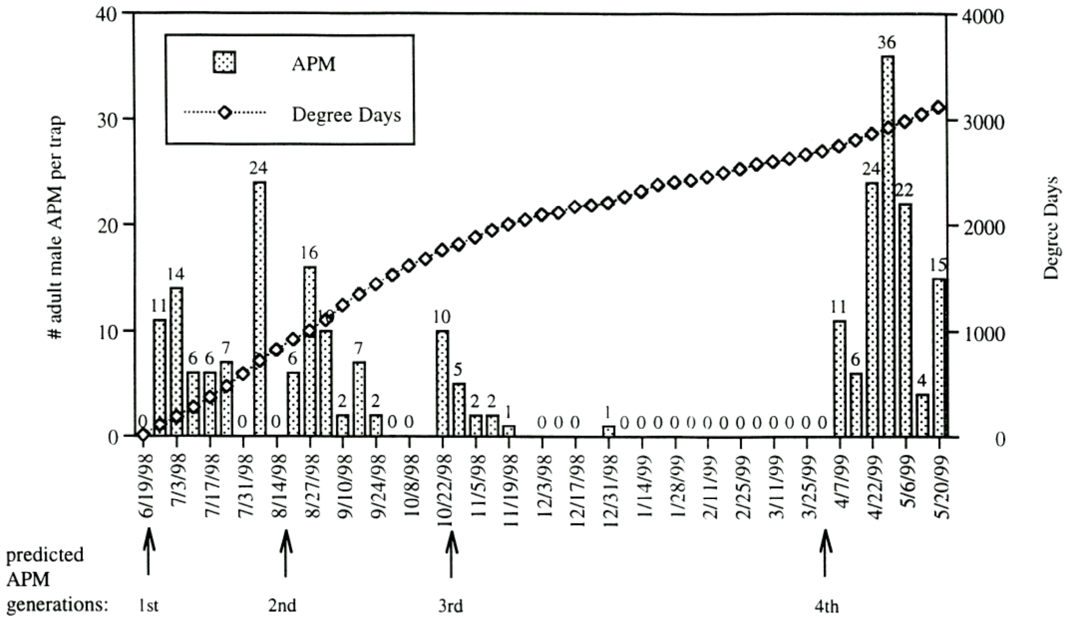


Figure 1b. Adult male APM captures
Field C 2, 1998-1999

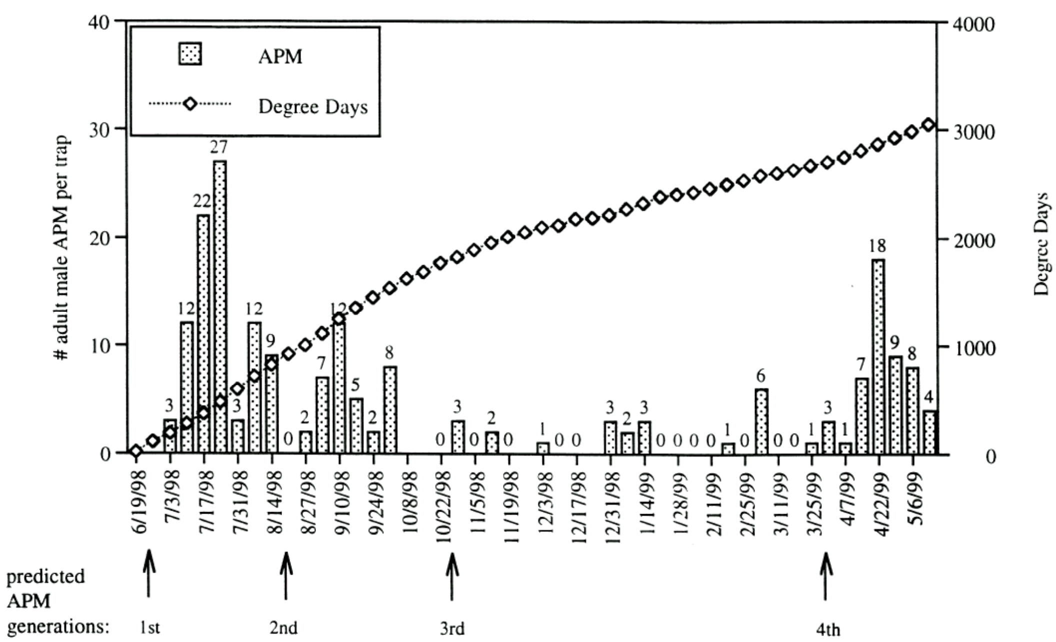


Figure 1c. Adult male APM captures
Field B 1, 1998-1999

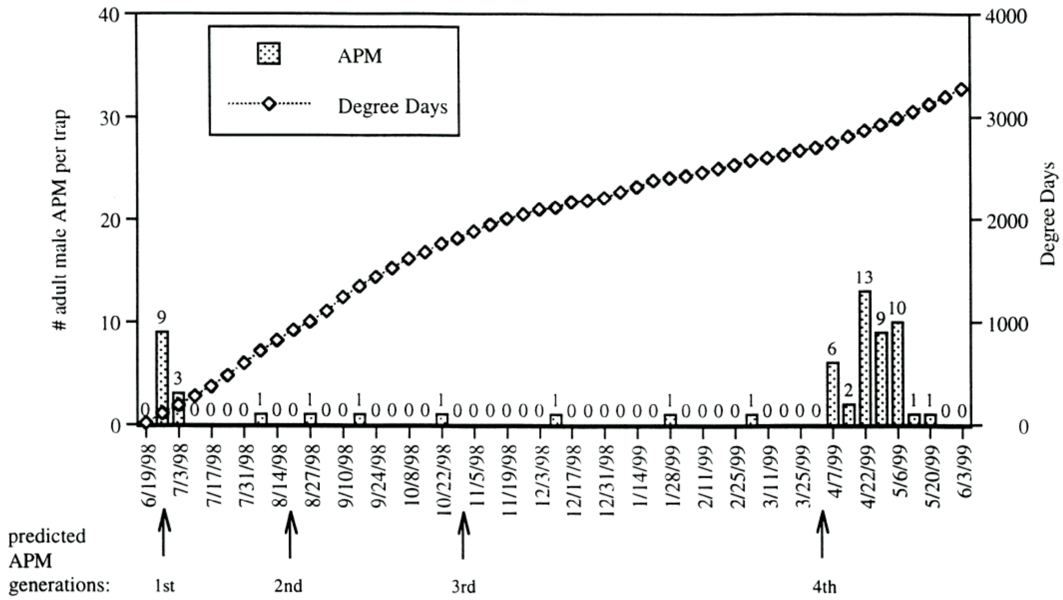


Figure 1d. Adult male APM captures
Field C 1, 1998-1999

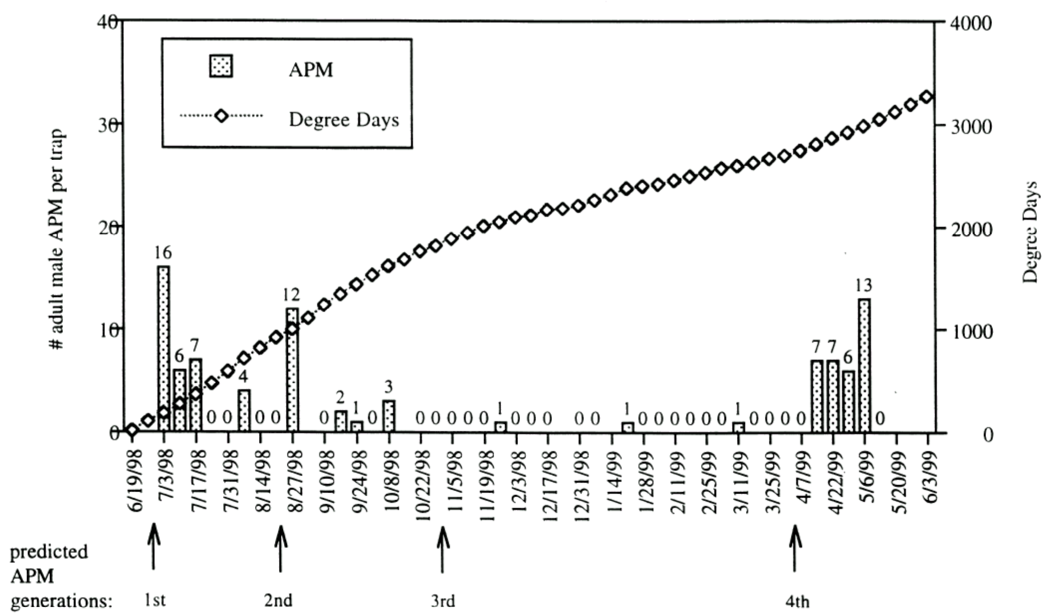


Figure 1e. Adult male APM captures
Field B 3, 1998-1999

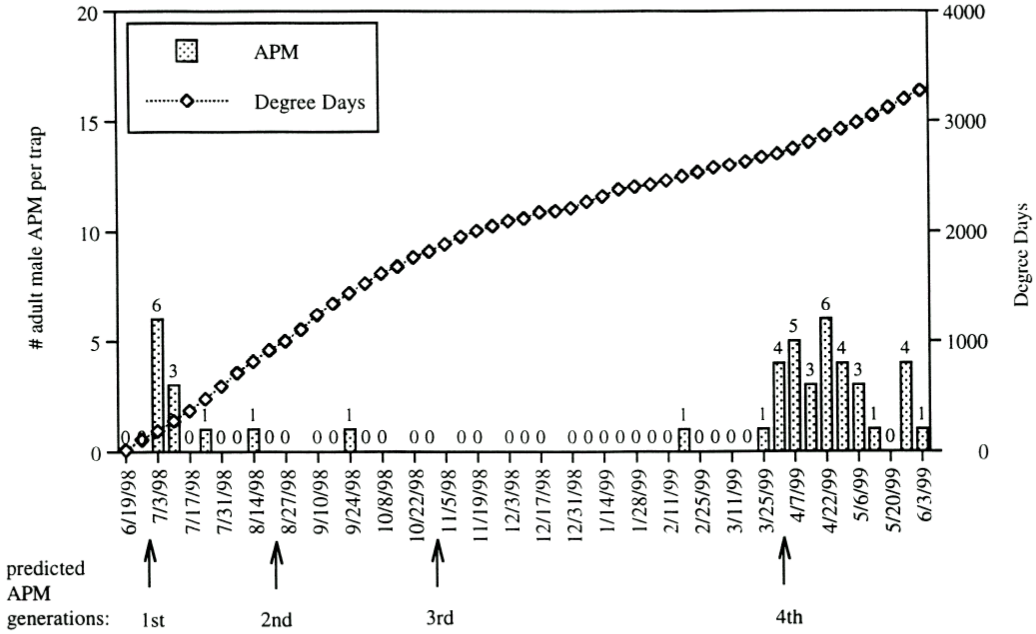


Figure 1f. Adult male APM captures
Field C 3, 1998-1999

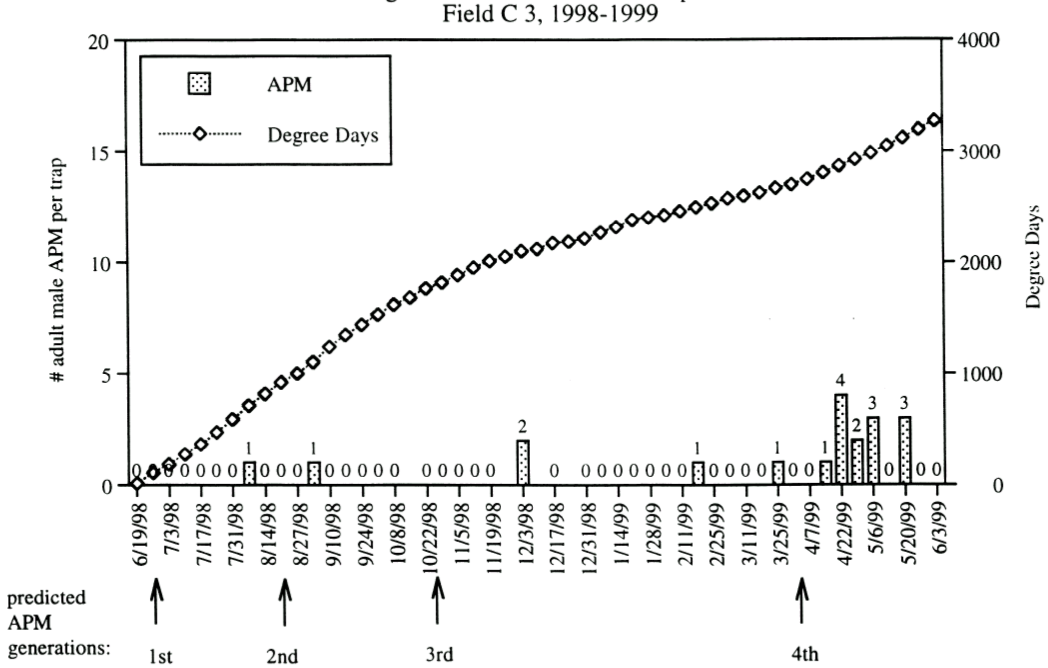


Figure 2a. Adult male APM captures
Field B 1, 1999-2000

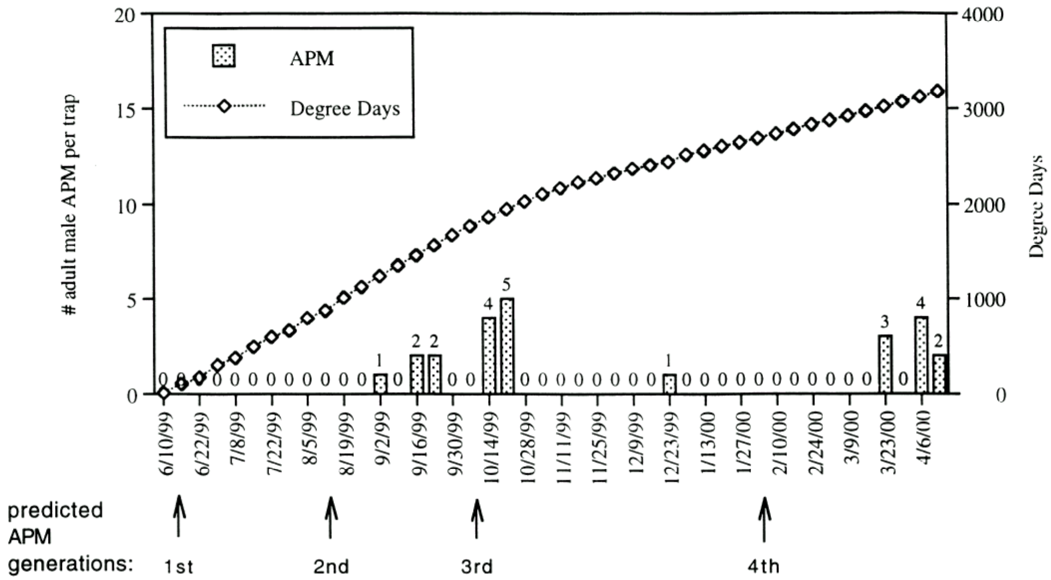


Figure 2b. Adult male APM captures
Field C 1, 1999-2000

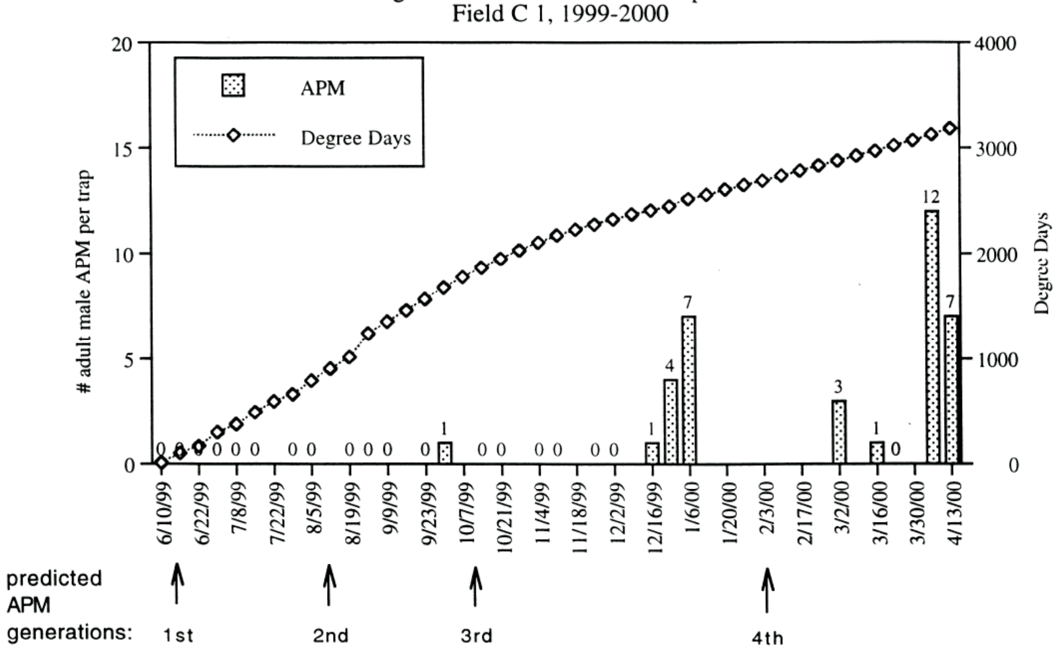


Figure 2c. Adult male APM captures
Field B 3, 1999-2000

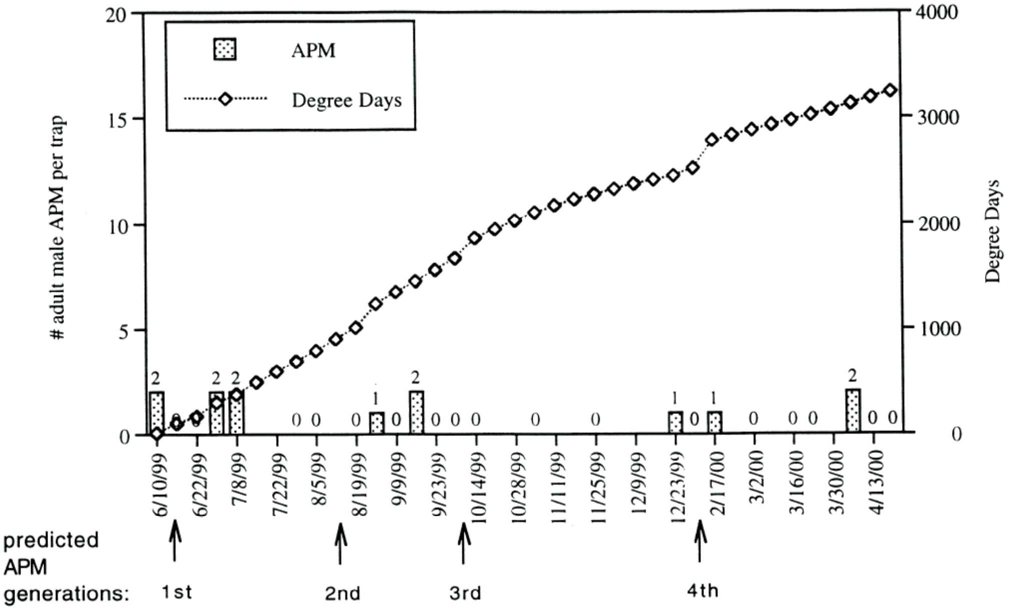


Figure 2d. Adult male APM captures
Field C 3, 1999-2000

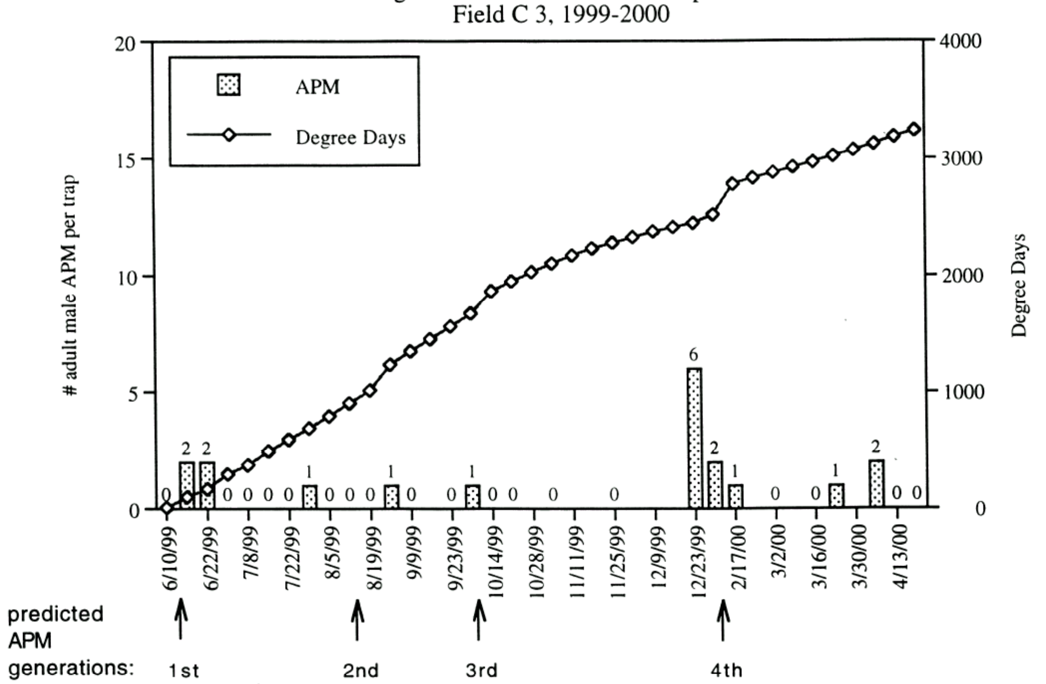


Figure 2e. Adult male APM captures
Field B 4, 1999-2000

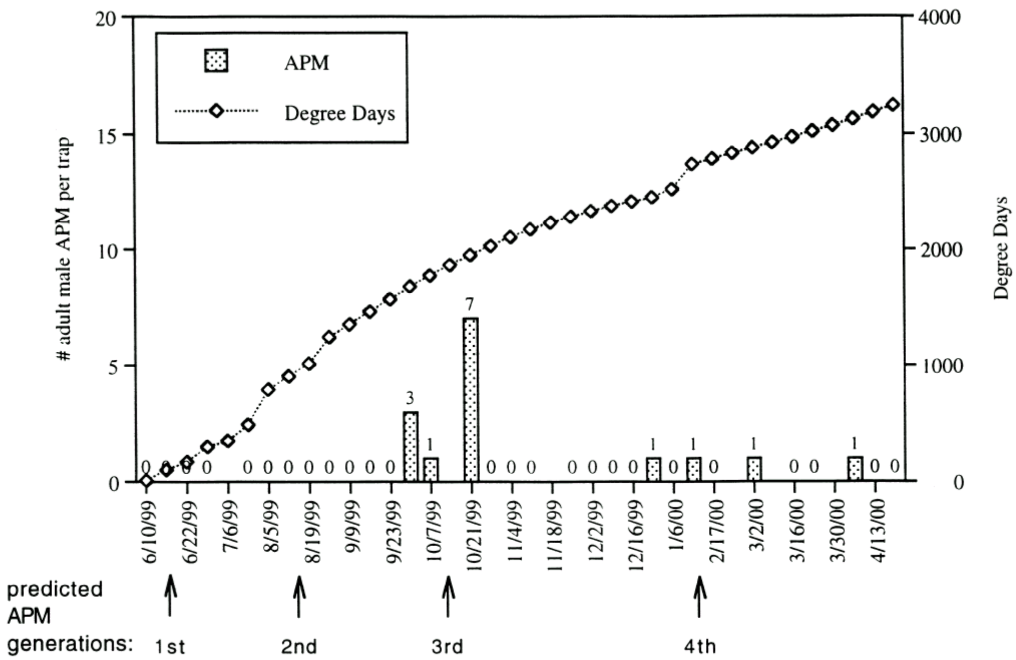


Figure 2f. Adult male APM captures
Field B 5, 1999

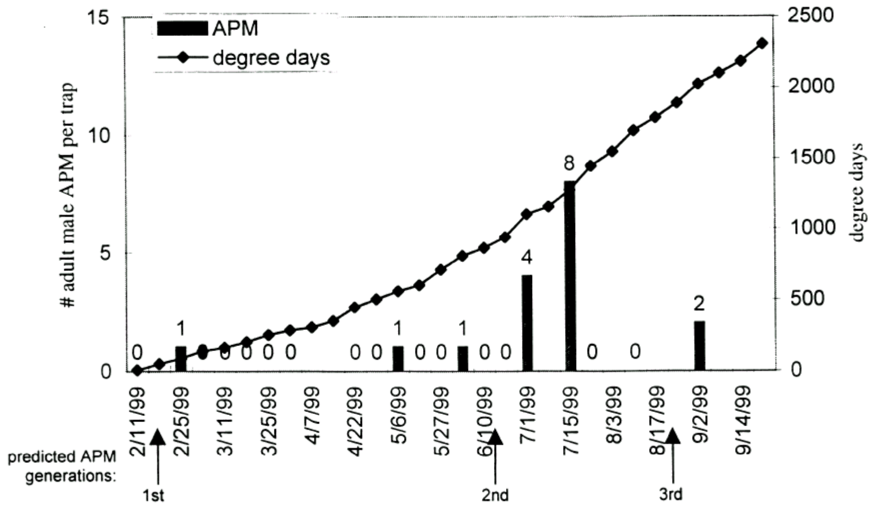


Figure 3. Average percent bud damage by APM larvae
1998-1999 season

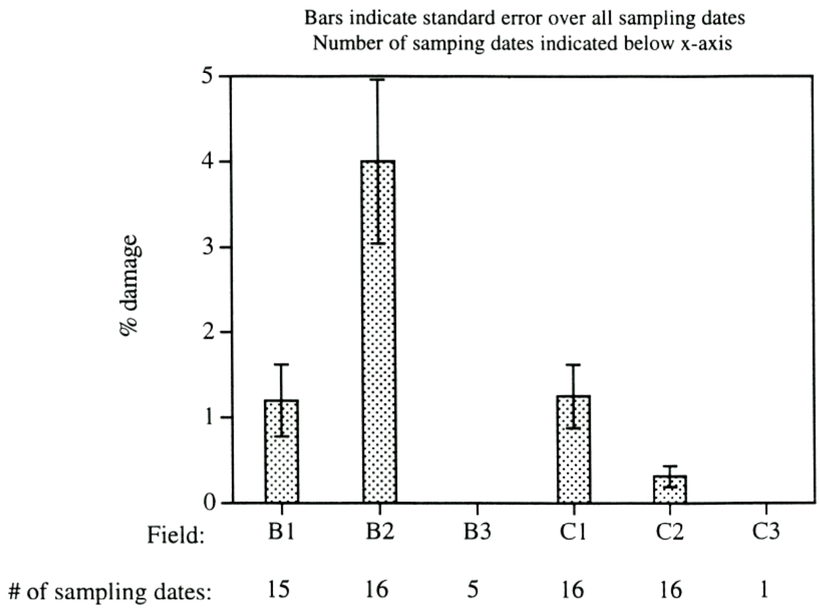


Figure 4. Average percent bud damage by APM larvae
1999-2000 season

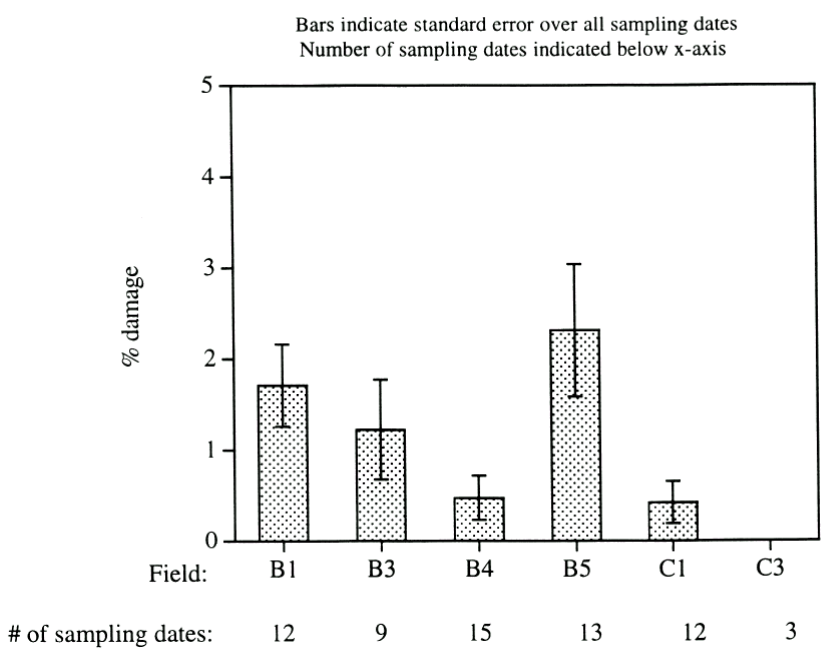


Figure 5. Artichoke Plume Moth (APM) Eggs in BIORAPP vs. control fields, 1998-1999 season

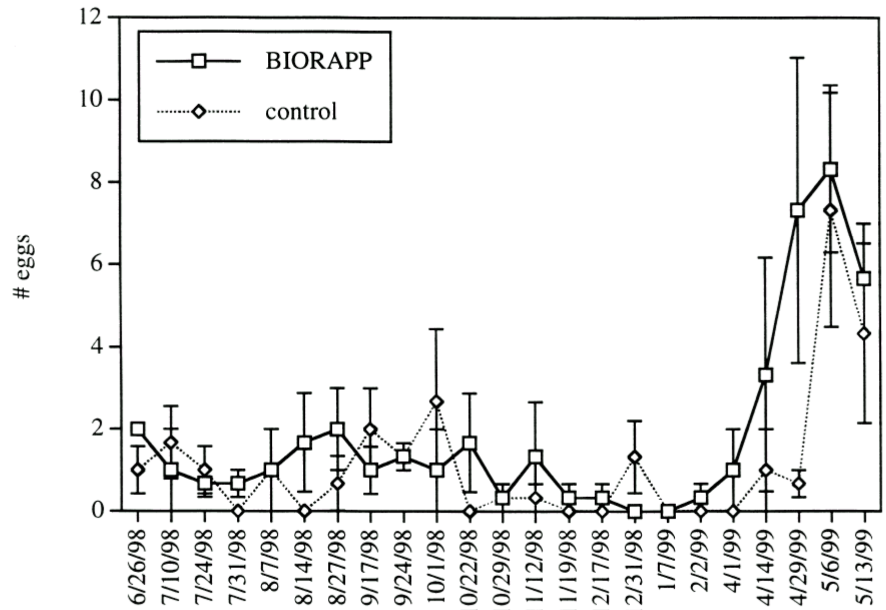


Figure 6. Artichoke Plume Moth (APM) Larvae in BIORAPP vs. control fields, 1998-1999 season

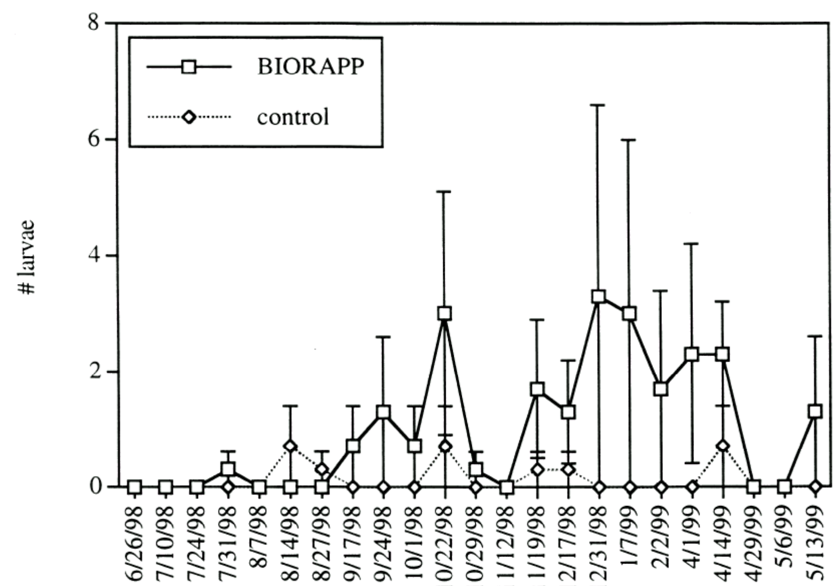


Figure 7a. APM eggs found per month in BIORAPP vs. control fields, 1999-2000 season

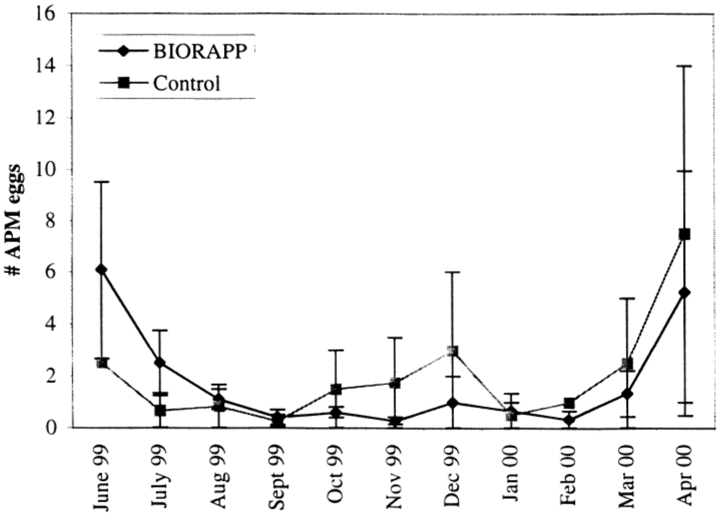


Figure 7b. APM eggs found per month in annual artichokes (field B5), 1999-2000 season

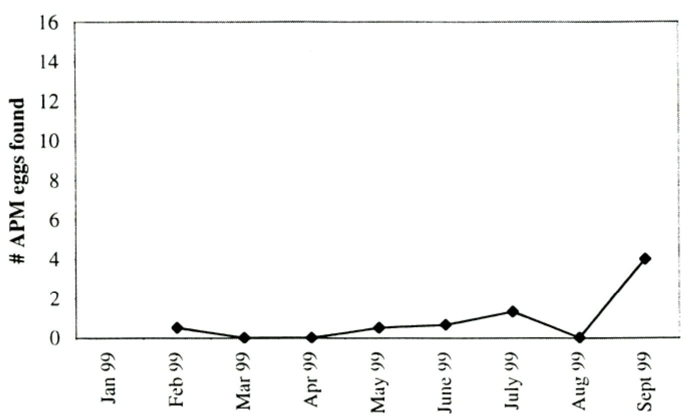
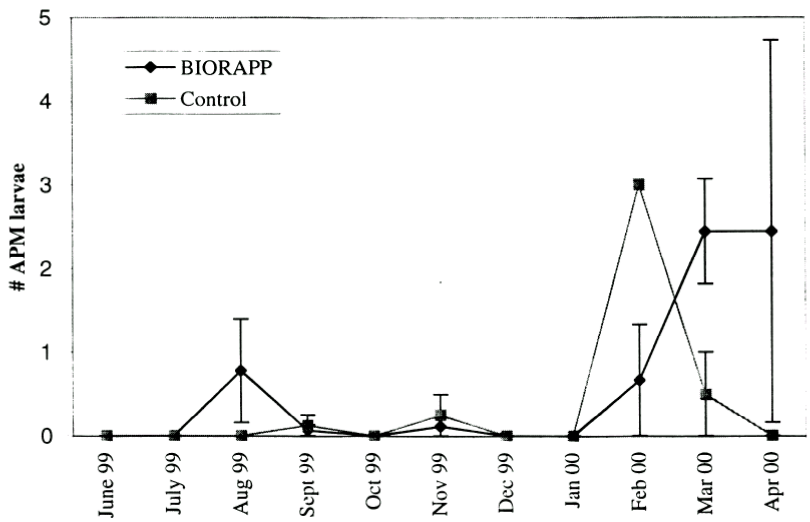
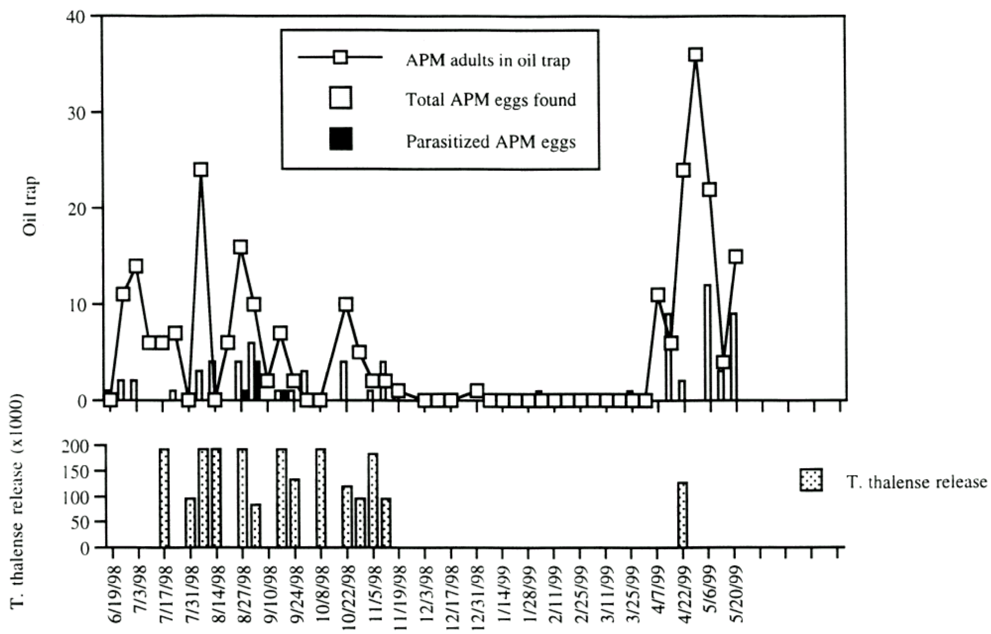


Figure 8. APM larvae found per month in BIORAPP vs. conventional fields, 1999-2000 season



Biointensive Field 2 (B2)



Control Field 2 (C2)

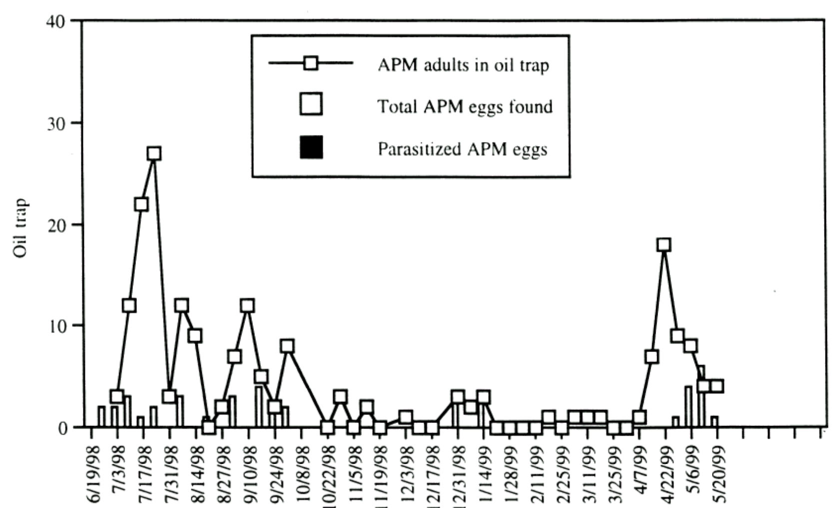


Figure 9. APM egg parasitism levels and*T. thalense* release rates, fields B2 and C2.

Figure 10. Brown lacewing eggs in BIORAPP vs. control fields, 1998-1999 season

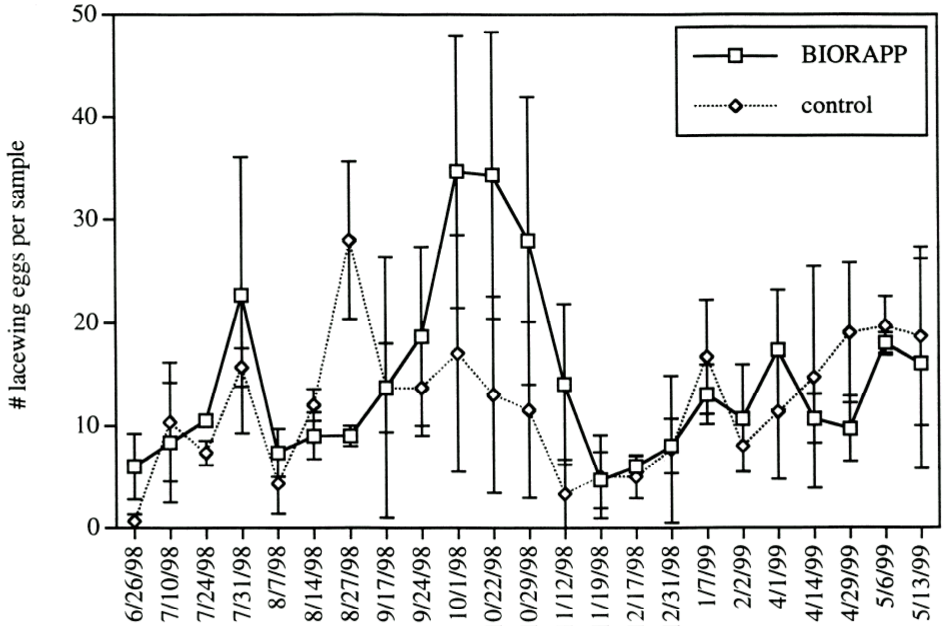


Figure 11. Brown lacewing eggs in BIORAPP vs. control fields, 1999-2000 season