SANTOS, G. L., D. KAGELER, D. E. GARDNER, L. W. CUDDIHY, AND C. P. STONE. 1992. Herbicidal control of selected alien plant species in Hawaii Volcanoes National Park, p. 341-375 *in* Stone, C. P., C. W. Smith, and J. T. Tunison [eds.]. Alien plant invasions in native ecosystems of Hawai'i: management and research. University of Hawaii Press, Honolulu.

THOMAS, P. A., AND P. M. ROOM. 1986. Taxonomy and control of *Salvinia molesta*. Nature, Lond. 320: 581-584.

THOMPSON, D. Q., R. L. STUCKEY, AND E. B. THOMPSON. 1987. Spread, impact, and control of purple loosestrife (*Lythrum salicaria*) in North American wetlands. Fish and Wildlife Res. 2, U.S. Fish and Wildlife Serv., Washington.

VAN RIPER III, C., S. G. VAN RIPER, M. L. GOFF, AND M. LAIRD. 1986. The epizootiology and ecological significance of malaria in Hawaiian birds. Ecol. Monogr. 56: 327-344.

VERSFELD, D. B., AND B. W. VAN WILGEN. 1986. Impact of woody aliens on ecosystem properties, p. 239-246 *in* Macdonald, I. A. W., F. J. Kruger and A. A. Ferrar [eds.]. The ecology and management of biological invasions in southern Africa. Proceedings of the National Synthesis Symposium on the Ecology of Biological Invasions. Oxford University Press, Cape Town, South Africa.

VITOUSEK, P. M. 1986. Biological invasions and ecosystem properties: can species make a difference? p. 163-176 *in* Mooney, H. A. and J. A. Drake [eds.]. Ecology of biological invasions of north America and Hawaii. Springer-Verlag, New York.

VIVRETTE, N. J., AND C. H. MULLER. 1977. Mechanism of invasion and dominance of coastal grassland by *Mesembryanthemum crystallinum*. Ecol. Monogr. 47: 301-318.

WAAGE, J. K., J. T. SMILEY, AND L. E. GILBERT. 1981. The *Passiflora* problem in Hawaii; prospects and problems of controlling the forest weed *P. mollissima* (Passifloraceae) with heliconiine butterflies. Entomophaga 26: 275-284.

BIOLOGICAL CONTROL OF THE TWO-SPOTTED SPIDER MITE (ACARINA: TETRANYCHIDAE) ON COMMERCIAL STRAWBERRIES IN FLORIDA WITH *PHYTOSEIULUS PERSIMILIS* (ACARINA: PHYTOSEIIDAE)

GORDON C. DECOU
Agri-Tech Services, 9911 Oak Run Drive, Bradenton, FL 34202

ABSTRACT

Biological control of *Tetranychus urticae* Koch in Florida's commercial strawberry fields is possible by use of the predacious mite *Phytoseiulus persimilis* Athias-Henriot. A low and stable population of both species is maintained after about 2 months. Immigration of local parasitoids and predators contributes stability. The cost is likely to be lower than that of chemical control, and strawberry yields are not reduced.

Key Words: Biocontrol, *Tetranychus urticae*, predacious mites.

RESUMEN

Control biológico de *Tetranychus urticae* Koch en campos comerciales de fresas en la Florida se logra con el uso del ácaro predador, *Phytoseiulus persimilis* Athias-Henriot.

Una población baja y estable de ambas especies se mantiene despues de 2 meses. La inmigración de parasitoides y predadores locales contribuye a la estabilidad. Usualmente, el costo es más bajo que el de control quimico y no se reduce el rendimiento de fresas.

Two-spotted spider mites, *Tetranychus urticae* Koch (Acarina: Tetranychidae), are the most economically important arthropod pests in commercial strawberry production in Florida (Jepson et al. 1975, Hochmuth 1988). Spider mites often infest strawberry plants from the nursery, and their control by chemicals can be difficult due to plant density and resistance of the spider mites to acaricides (Smith & Fulton 1951, Helle 1965, Cranham & Helle 1985). Spider mite populations can be controlled by seasonal inoculative release of *Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseiidae), a predacious mite, with proper release strategies and techniques. Once control has been achieved, the predator and prey populations remain stable.

Commercial Strawberry Production

Traditional strawberry production methods in central Florida include control of spider mites by application of various acaricides. These chemical applications often are made prophylactically and tend to be overused. The cost of controlling spider mites chemically totals $100-400 per acre (Prevatt 1991, author's experience), depending upon perceived levels of damage caused by spider mites and/or on perceived need for treatment.

To minimize chemical treatments, and to avoid induction of resistance to chemicals, Agri-Tech developed procedures to monitor spider mite populations and to predict onset of economic thresholds. They also developed integrated pest management for spider mites in strawberries in Florida, using biological control whenever feasible. This method of integrated pest management is effective in controlling spider mite populations, and in reducing use of chemicals. It also provides a substantial cost saving to growers and a reduction in development of resistance to chemicals in spider mite populations during each growing season.

An integrated management approach to pest control in strawberries has operated for 10 years or more in central Florida, but it still accounts for only several hundred of the total of 5,000 acres planted. Our experiments with the predacious mite *Phytoseiulus persimilis* to improve management of spider mites were in collaboration with the University of Florida's Gulf Coast Research & Education Center. We were successful in developing a system which controls *T. urticae* in commercial strawberry fields, and this system was implemented during the 1992-1993 growing season on >200 acres of strawberries.

Management

Ensuring that mite-free strawberry plants arrive from the nursery is the first step in controlling *T. urticae* infestations. This allows plants time to develop enough foliage to ensure successful establishment of *P. persimilis* during releases without risking extremely high spider mite populations that may otherwise have to be controlled by use of acaricides.

Proper weekly scouting procedures for spider mites in the field, and thresholds for release of *P. persimilis*, are essential for success. The system developed for the 1992-1993 season involved inspection of ≥50 mature strawberry leaflets per block of 7-10 acres. Mature leaflets were chosen because *T. urticae* tend to establish there first. Leaflets

were inspected using a 14× hand lens, noting presence of all stages of spider mites. The percentage of spider-mite-infested leaflets was recorded, and 10% infested leaflets was considered to exceed this threshold. Much higher levels of infestation by spider mites were too high to be overcome by release of *P. persimilis* without risking considerable damage to the crop.

When it was determined that the threshold had been reached, *P. persimilis* was introduced, by hand, at one per plant or approximately 20,000 per acre. Cost of the mites, for one release, was about $100 per acre plus application costs. In most fields one release was sufficient, although occasionally a few extra predacious mites accelerated control in critical situations. A second release of *P. persimilis* was required about 25% of the time to ensure that control was obtained before noticeable damage had occurred to the plants. Situations requiring the second release were always due to infested nursery stock plants arriving for transplant.

Release Techniques and Strategies

Fields must be prepared for introduction of *P. persimilis* before the threshold of spider mites is reached. The use of predacious mites requires complete commitment from the grower in two ways. First, any spray program must use only compatible chemicals. Second, growers must have patience to allow the predators to stabilize the spider mite population more slowly than with chemicals. Without this commitment, mite control will fail.

Any spray program must be adjusted in several ways; even the use of fungicides is important. A spray program that proved successful was a twice-weekly fungicide application of captan 80WP (liquid captan proved to be harmful to *P. persimilis*) with a weekly *Bacillus thuringiensis* Berliner application. Use of most other chemicals is discouraged, although research on compatible pesticides continues. The acaricides Vendex (fenbutatin-oxide) and Agri-mek (abamectin) at half of the standard dosages were safe to *P. persimilis*; this allows use of these chemicals when control by predacious mites is delayed. Our preference for biological control, with use of chemicals only when strictly needed, will help reduce the use of acaricides and avoid resistance.

The predacious mites are shipped from a producer/vendor at 2,000 mites per plastic bottle in a vermiculite medium with a limited food supply. There is a screened air vent in the cap of the bottle which we replace with a ¼ in washer. During application, we rotate the bottles gently to ensure a uniform distribution of mites throughout the bottle because they tend to climb up toward the cap. Occasional inversion of the bottle reduces the chance of releasing too many mites at once. To release the mites, the bottle is held directly over each strawberry plant while the foliage is opened to allow the vermiculite to penetrate the crown of the plant as deeply as possible. One shake of the bottle over every plant releases the *P. persimilis* at approximately 1 per plant. It is necessary to monitor workers closely as they exhaust bottles, and to recalibrate from time to time as necessary. It is important to remember that this process is performed only once per season and that it must receive the close attention it deserves to ensure its success.

Purchasing *P. persimilis* mites is not without complication. When dealing with distant insectaries, it helps to allow for possible shipping delays or lack of availability. Usually the predacious mites are available without any delay, but it is worthwhile giving advance notice when in need of a large order. Most shipping can be done overnight. We found that preparing for an order when 5% of the leaflets are infested with spider mites usually allows sufficient time for release when thresholds are reached.

Once releases are complete, it is critical that the population of both species of mites continue to be monitored weekly, even twice a week if needed, during the crucial initial 4 weeks after release. The most important aspect of determining whether *P. persimilis*

is thriving is discovering the presence of eggs, larvae and nymphs. These other life stages are recorded and included in the weekly leaf counts, allowing the progress of the population to be monitored.

The predator-prey relationship of this system is typical of many in nature. Although the prey population is high initially, the predator mite quickly establishes itself and reproduces so rapidly that it overtakes the prey. At this point, both populations collapse and nearly disappear, only to remain at very low, oscillating densities. At this time the classic predator-prey relationship has been achieved, and biological control is established for the remainder of the growing season. The stability of this system is further enhanced by migration into the fields of locally-occurring predators and parasitoids. In all fields we found invasion by lacewings, *Aphidius*, ladybird beetles, and some local species of predacious mites. This contributes toward the control of aphids, thrips, caterpillars and mites and may reduce the need for chemicals.

Results

To demonstrate the effect of biological control using *P. persimilis*, data from several farms that experienced varying circumstances will be reviewed. The first example illustrates events on a farm with very high spider mite populations during the initial scouting visit (Fig. 1). Although the spider mite population was well over threshold from the start, releases of *P. persimilis* were made on 19 November, and followed by a second release on 16 December when it appeared that the predacious mites were taking too long to achieve control. The second release seemed to be an immediate success. I am

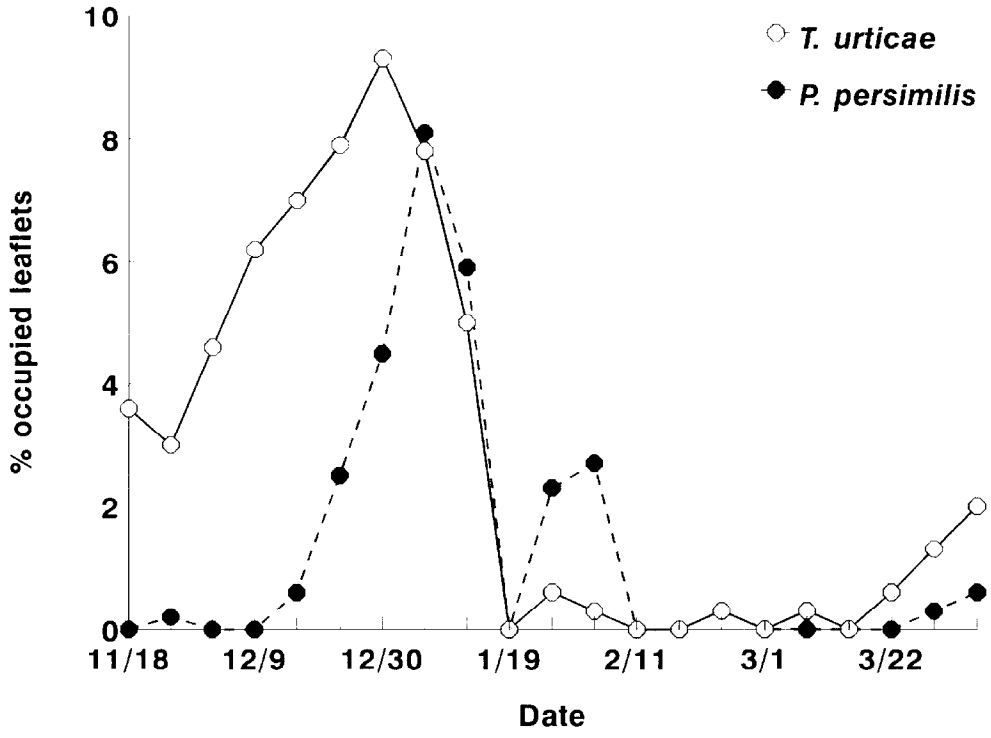

Fig. 1. Percent of strawberry leaflets inhabited by one or more *P. persimilis* or spider mites from November 1992 to March 1993 in field 1. Two releases of predacious mites were made, each at 20,000 per acre.

not sure whether this nearly instant response was due to the additional release of predators or was just a coincidence as progeny of mites from the original release became abundant. Ultimately, control of spider mites was achieved on this farm as both populations rose, then peaked, only to fall as the classic predator-prey relationship endured through the remainder of the growing season.

One of the difficult periods in achieving control by *P. persimilis* follows within the first 10-14 days after release. Experience has shown that it can be difficult to find many predacious mites soon after release using standard scouting techniques. To calm fears of possible failure, dig deeply into the strawberry plants to find evidence of the predacious mites. Usually there is just enough evidence of the predators to be encouraged. The predacious mites appear to move downward, deeply into the plant at first, even when spider mites are readily available near the top of the plant, then slowly disperse toward the top of the plant. This dispersal characteristic, along with others, is a subject for further research.

Another example of biological control, along with one application of an acaricide, is shown in Figs. 2-3. The initial spider mite population was over threshold, but an attempt was made to control the population with predacious mites. A release of *P. persimilis* was made in both fields on 11 November, but within the next two weeks it became apparent that damage to the strawberry plants would occur if an acaricide were not employed. Since the predators were reproducing steadily, but not quickly enough due to the spider mites' early high density, Vendex was applied at half of the standard treatment dose to both fields on 26 November or 3 December. Following the Vendex application, a temporary decrease in spider mite numbers was observed in field 2, but

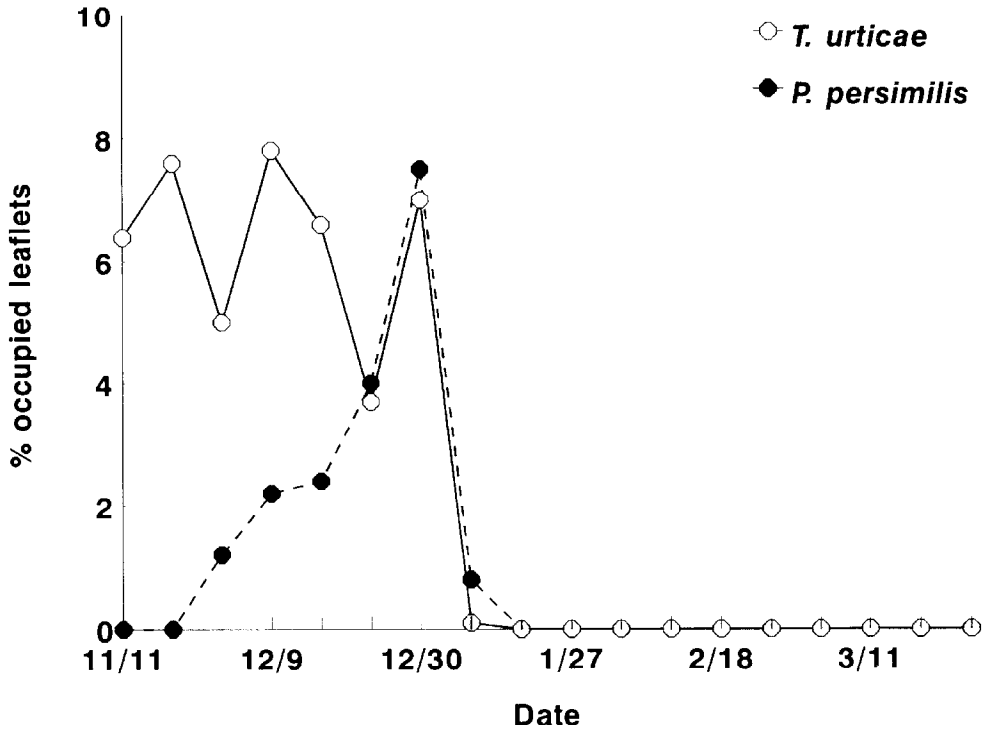

Fig. 2. Percent of strawberry leaflets inhabited by one or more *P. persimilis* or spider mites from November 1992 to February 1993 in field 2. Predacious mites were released at 20,000 per acre, and one acaricide treatment was applied.

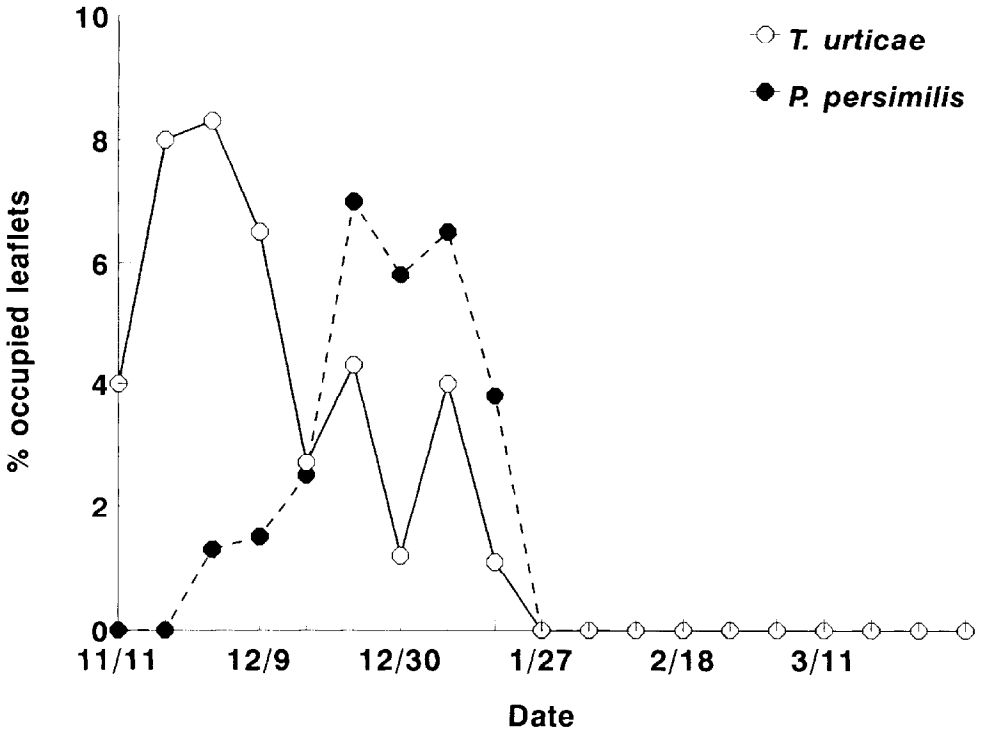

Fig. 3. Percent of strawberry leaflets inhabited by one or more *P. persimilis* or spider mites from November 1992 to February 1993 in a field 3. Predacious mites were released at 20,000 per acre, and one acaricide treatment was applied.

this break afforded just enough control over the next 2 weeks. The population of spider mites in field 3 continued to decline as *P. persimilis* quickly increased in numbers two weeks after the acaricide application. Again, control of *T. urticae* was attained. The two fields exhibited a stable predator-prey relationship between the two mite populations for the remainder of the growing season, as few of either species could be detected.

Two important features of the system were demonstrated on these farms. One is that use of some acaricides, in emergency situations, at low levels, will not jeopardize the control afforded by *P. persimilis*. This is important to commercial growers who can not afford to wait for delayed biological control and to risk loss of yield. The other is that populations of spider mites shown in Fig. 1-3 were too high for reasonable, prompt control in commercial fields using *P. persimilis*, without risking damage. Hence, the threshold of 10% of the leaflets infested is realistic.

Releases of *P. persimilis* were also tried at a reduced level of 10,000 mites per acre (Fig. 4). Control was achieved, although the system took longer to reach stability. A release was made when 12% of the leaflets were infested, but *P. persimilis* had already entered the field from a neighboring field, occupying 2% of the strawberry leaflets by the time a deliberate release was made. The presence of *P. persimilis*, even in such low densities before the release, may have assisted its success. Both populations increased slowly until they reached the same high density observed in the other examples before finally collapsing and achieving stability.

Importantly, the plants had matured fully by the time of this late-season release. The increased amount of foliage provided much more of a chance for *P. persimilis* to move from the vermiculite medium to the leaves, during release, before being disturbed by wind. The outcome of releases on plants with little foliage (i.e., early in the growing

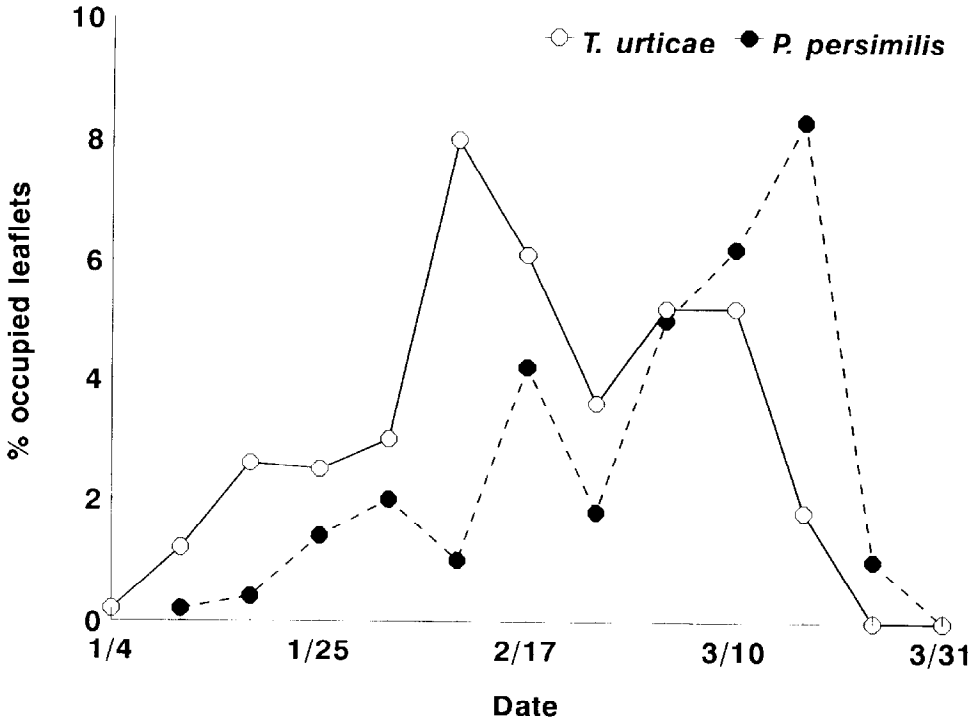

Fig. 4. Percent of strawberry leaflets inhabited by one or more *P. persimilis* or spider mites from January to March 1993 in field 4. Predacious mites were released at 10,000 per acre.

season) can be uncertain. It is preferable to wait for the development of 4-5 fully-expanded leaves.

In the fields under biological control by *P. persimilis*, I have observed stronger plant growth and healthier, denser foliage, possibly due to the absence of chemical treatments (see also Trumble et al. 1988). The growers observed larger fruit size, and reported equal, or larger, yields under biological control compared to chemical control. The cost of chemical control in strawberry fields usually rises through the growing season as mites become more difficult to control. In contrast, an early expenditure on predacious mites stabilizes spider mite densities throughout the season. Every grower realized a cost saving compared to chemical control of mites, and more so when savings of additional, unnecessary, chemical treatments are included in the balance.

Costs for acaricides in two of the fields the previous year were $375 (Fig. 5) and $300 (Fig. 6) per acre. These totals do not include labor, fuel, depreciation, etc. This is much higher than the average cost of $100-150 per acre for *P. persimilis*.

For comparison, we plotted the spider mite populations from two of the farms from the previous year (1991-2) under chemical control (Fig. 5-6). Although actual counts of spider mites were made per complete trifoliate leaf at the time, we divided the counts by 3 in an attempt to bring the value closer to the rating method we now employ while using biological control methods. This allows a rough comparison of spider mite population movements under both systems. The threshold for treatment under chemical control was 5 mites per trifoliate leaf or 1.7 per leaflet. The farm data shown in Fig. 5 shows mite populations over threshold nearly the entire season and demonstrated poor response to repeated applications of various acaricides.

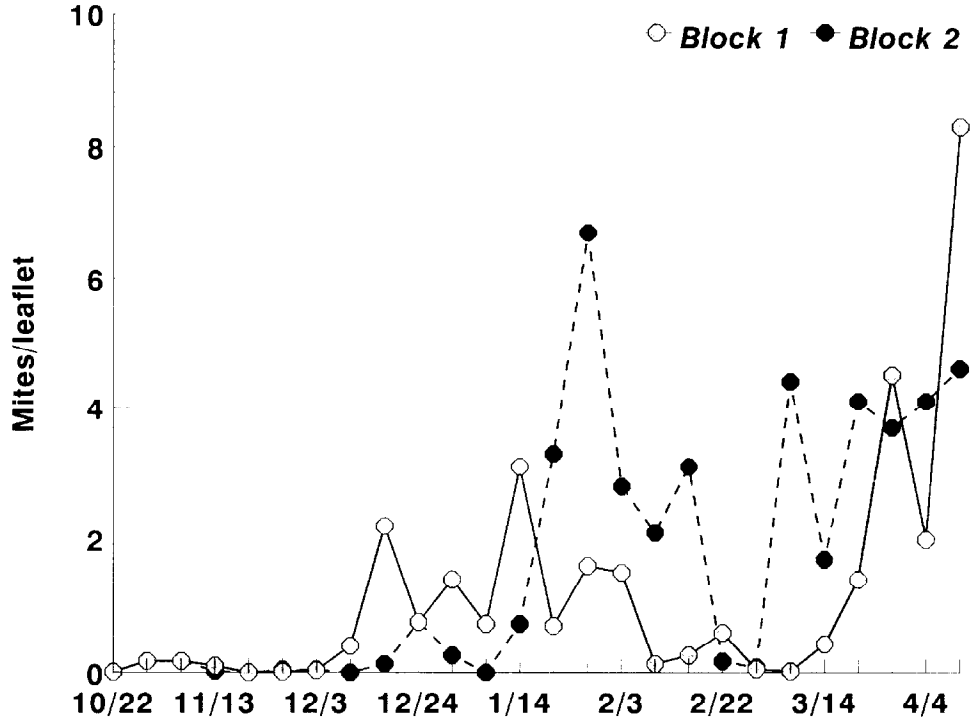

Fig. 5. Number of two-spotted spider mites per strawberry leaflet from October 1991 to April 1992 in field 5. The spider mites were treated with chemicals.

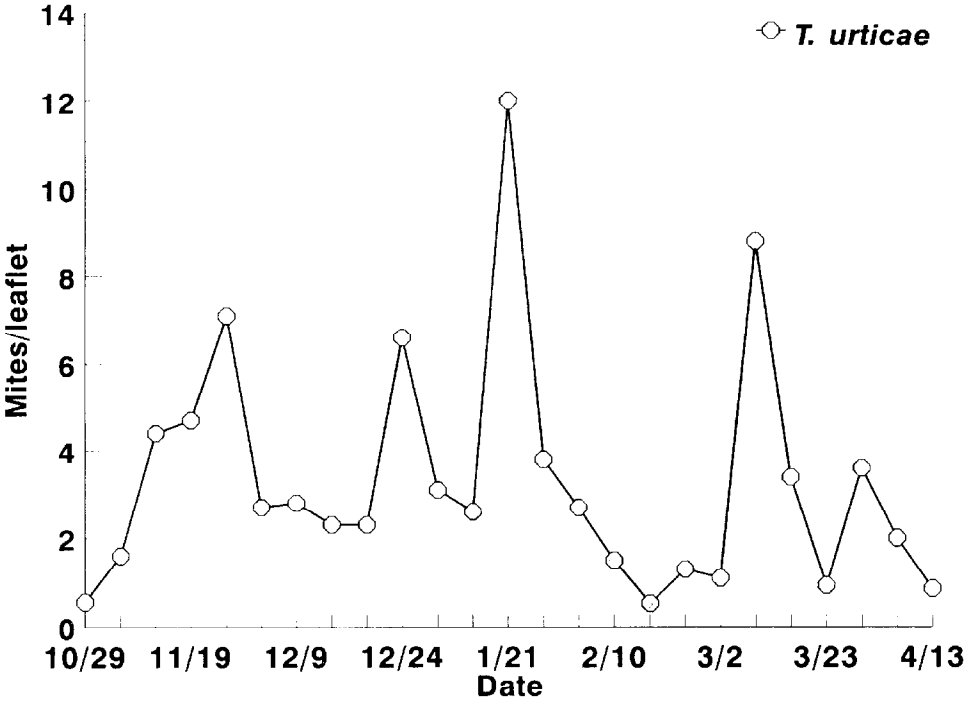

Fig. 6. Number of two-spotted spider mites per strawberry leaflet from October 1991 to April 1992 in field 6. The spider mites were treated with chemicals.

The farm data shown in Fig. 6 provide a more typical view of spider mite response under chemical control. The population remained low initially as the colder weather and early success in spraying provided an effective combination. As temperatures rose in the spring, and reproduction by spider mites increased accordingly, chemical control became increasingly ineffective. This disadvantage was accelerated by the effect of resistance to chemical acaricides. After several weeks of chemical applications, resistance became an increasing problem until the end of the season when all control was finally lost. The opposite is true under biological control: the stability of the predator/prey system provides a field which can be harvested until the market determines otherwise, not because spider mite control fails. Biological control by predacious mites allows commercial growers to take advantage of a late-season market that would be impossible under chemical control.

Conclusion

Research on the following subjects would be helpful. Can spider mites be controlled by predacious mites on strawberry plants at the nursery? What would be the effect of travel from the nursery to the farm on the predator/prey relationship? What is the feasibility of using "banker" plants, held as stock at the farm during the fallow season? Can effects of various chemical pesticides on the predator/prey relationship be characterized more adequately? Why do the predacious mites (*P. persimilis*) move downward into leaf axils of strawberry plants when they are released, what can be done to counterbalance this, and what are the other effects of migration by the predacious mites?

Acknowledgments

I thank M. van de Vrie, University of Florida Gulf Coast Research & Education Center, Bradenton, for his advice, and J.F. Price of the same Center for graphing data. I thank the owners of the following farms for their cooperation: Artesian, Williford Packers, and Foy.

References Cited

Cranham, J. E., and W. Helle. 1985. Pesticide resistance in Tetranychidae, p. 405-421 *in* Helle, W. and M. W. Sabelis [eds.]. Spider mites: their biology, natural enemies, and control. Elsevier; New York, Vol. 1B.

Helle, W. 1965. Resistance in Acarina: mites. Adv. Acarol. 2: 75-93.

Hochmuth, G. J. 1988. Strawberry production guide for Florida. Florida Coop. Ext. Serv., Circular 142C.

Jepson, L. R., H. H. Keifer, and E. W. Baker. 1975. Mites injurious to economic plants. Univ. California Press; Berkeley.

Prevatt, J. W. 1991. Florida strawberry production costs and returns. Bradenton GCREC Res. Rept. BRA1991-8, Food and Resource Econ. Dept., Inst. Food Agric. Sci., Univ. Florida.

Smith, F. F., and R. A. Fulton. 1951. Two-spotted spider mite resistance to aerosols. J. Econ. Entomol. 44: 229-233.

Trumble, J. T., W. Carson, H. Nakakihara, and V. Voth. 1988. Impact of pesticides for tomato fruitworm (Lepidoptera: Noctuidae) suppression on photosynthesis, yield, and nontarget arthropods in strawberries. J. Econ. Entomol. 81: 608-614.