More Than You Want to Know About Mites and Their Biological Control on Ornamentals

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INTRODUCTION

There are a minimum of 14 predatory mites sold commercially in North America by at least 58 different companies (Hunter 1994). Predatory mites are recommended as control agents for ants, flower thrips, fungus gnats and other mites. Because of the diversity of crops, organisms attacked, coverage in other chapters, very limited commercial grower utilization and the limits of our own expertise we have chosen to concentrate our discussion on the model system: *Tetranychus urticae* and its predator *Phytoseiulus persimilis*.

Mite pests cause serious economic losses in many agricultural systems each year including vegetable and ornamental crops in greenhouses. In greenhouses, a number of mite species are considered pests. The predominate mite pests are twospotted spider mite (*Tetranychus urticae* Koch), broad mite (*Polyphagotarsonemus latus* (Banks). Although a significant problem in some situations, cyclamen mite (*Steneotarsonemus pallidus* (Banks) has not received the attention that the other mite pests have in terms of research.

Chemical control is the primary method used for controlling these mites. Because of frequent applications of pesticides (1-2 times/week) to confined populations and few materials to use in rotation (1 or 2 in some crops), the potential for developing pesticide-resistant or tolerant strains is very high. Growers must also contend with phytotoxicity, labor costs associated with frequent pesticide applications, reentry periods into treated areas, arrival of new pests, and the occasional loss of an effective pesticide due to health hazards. Biological control of mites has been proposed as a solution to these problems. Biological control is a viable alternative to chemicals in several perennial crops, strawberries, and vegetable crops grown in greenhouses. There are many excellent reviews on the biology of phytoseiid mites and their use for biological control (Huffaker et al. 1969, McMurtry et al. 1970, Hussey & Huffaker 1976, Hoy 1982, McMurtry 1992, Tanigoshi, 1982). There are a couple excellent reviews on biological control in greenhouses (Hussey & Scopes 1985, van Lenteren & Woets 1988) but both focus predominantly on the situation in European greenhouses where vegetables are grown. Two papers on biological control in greehouses were used as the foundation for this paper ((Osborne et al. 1985, Osborne et al. 1994). In this paper, we have chosen to limit our discussion to the use of mass-reared natural enemies to control mites on plants grown under glass or in protected culture (slat sheds, interior landscapes, or greenhouses) in North America. The predominant species used is *P. persimilis* Athias-Henriot.

Biological control programs are currently available for the management of twospotted spider mite attacking greenhouse-grown vegetables, but these programs have not often been transferred successfully to ornamental plant production systems grown in protected culture. Secondly, many programs considered successful in the past have met with significant problems during the last few years (Steiner 1993). The possible reasons for these failures will be discussed in this paper.

THE TWOSPOTTED SPIDER MITE

The twospotted spider mite, *Tetranychus urticae* Koch, is the major spider mite pest of ornamental plants and vegetable crops grown in greenhouses. Furthermore, this ubiquitous spider mite is a serious pest of numerous ornamental plants in home landscapes, and is of considerable importance as a pest of food and fiber crops throughout the world. The literature on spider mites in general, and the twospotted spider mite in particular, is voluminous; however, much of the information (including references) has been summarized by Huffaker et al., 1969, 1970), McMurtry et al., (1970), van de Vrie et al,. (1972), Jeppson et al., (1975) and Hussey & Huffaker (1976).

The twospotted spider mite is a member of the family Tetranychidae which contains many harmful species of plant-feeding mites. There has been considerable confusion concerning the nomenclature (i.e. , scientific name) of the twospotted spider mite. In the past, acarologists and applied entomologists commonly referred to the spider mites in question as *Tetranychus bimaculatus* Harvey or *T. telarius* (Linnaeus). Boudreaux (1956) examined the so-called "twospotted spider mite complex" and demonstrated that more than one species was involved. In this case, the major species were the twospotted spider mite, *T. urticae* and the carmine spider mite, *T. cinnabarinus* (Boisduval) (Boudreaux 1956, Boudreaux & Dosse 1963, Jeppson et al. 1975). Common names such as red mite, red spider mite, glasshouse spider mite, twospotted spider mite, and common spinning mite generally referred to the species complex; the same is true for the approximately 60 synonyms (i.e., scientific names) in the literature, the most common ones being *T. telarius* (Linn.) and *T. bimaculatus* Harvey (Boudreaux & Dosse 1963, Jeppson et al. 1975).

In both male and female twospotted spider mites, development proceeds through the following stages: egg, larva, protonymph, deutonymph, and adult. The larval, protonymphal, and deutonymphal stages are further divided into feeding (active) and quiescent (resting) stages. The quiescent stages are referred to as nymphochrysalis (=protochrysalis), deutochrysalis, and teliochrysalis for larval, protonymphal, and deutonymphal stages, respectively. Thus, development of the twospotted spider mite can be summarized as follows: egg, larva (including nymphochrysalis), protonymph (including deutochrysalis), deutonymph (including teliochrysalis), and adult (Laing 1969, van de Vrie et al. 1972).

Developmental time of the twospotted spider mite will generally vary with conditions such as temperature, humidity, host plant, leaf age, etc. However, temperature is the most important factor that influences the rate at which mites develop. The lower threshold for development is about 12°C, whereas maximum upper limit to the development is about 40°C (Jeppson et al. 1975). Laing (1969) maintained the mites on strawberry leaflets at an average hourly temperature of 20.3°C and relative humidity fluctuating from 55% to 98%. Under these conditions, the mites developed from egg to adult in an average of 16.5 days. Shih et al. (1976) cultured the mites on lima beans at 27°C) and 90 (±)5% relative humidity. In this case, mites developed from egg to adult in an average of 7.6 days. Sabelis (1981) determined the developmental time required for an egg to develop to a female capable of laying eggs. In his studies, he reared the mites on detached rose leaves under two alternating day/night temperature regimes. The regimens studied were 25-35°C and 10-20°C for which he determined the developmental times to be 8.3 and 28.2 days, respectively. Additional aspects of developmental time are summarized in Table 1.

In a given colony of twospotted spider mites, both adult males and females can usually be found; however, females are normally about three times more abundant than males. Cagle (1949) provided an account of the characteristics of males and females. Generally, adult males can be found in close association with quiescent female deutonymphs. Evidence indicates that the quiescent female deutonymph releases a sex pheromone which attracts the male and keeps him in close proximity (Cone et al. 1971a, 1971b, Penman & Cone 1972, 1974). The male usually remains in the immediate vicinity of the quiescent deutonymph and mates with the emergent female. When more than one male attempts to "guard" a developing female, fighting among the males often occurs; usually, larger males win these encounters (Potter et al. 1976a, 1976b). Such fights involve pushing and grappling with the forelegs, jousting with the mouth parts and entangling the opponent with silk.

The life span of the adult female is divided into the preovipositional period and the ovipositional period, the former being the time between emergence from the teliochrysalis to the deposition of the first egg. Apparently, the preovipositional period (9% of the time required to develop from egg to egg) can last less than 0.5 day and as long as 3 days depending on temperature. The period during which eggs are deposited (ovipositional period) can last from 10 days at 35°C to 40 days at 15°C (Sabelis 1981). An individual female can deposit over 100 eggs in her lifetime (Shih et al. 1976, Carey & Bradley 1982). The total number of eggs laid/female and the eggs laid/female/day can, however, vary with age, temperature, species of host plant, relative humidity, nutrition of host plant, exposure to pesticides, etc. (Watson 1964, van de Vrie et al. 1972, Karban & Carey 1984). Temperature and age of the female are especially important determinants of egg production (fecundity). However, Sabelis (1981) determined that fecundity was affected very little at temperatures between 20-35°C. In his study, peak oviposition, (161 eggs/female) occurred at a temperature of 25°C, with the maximum rate (12 eggs/female/day at 25°C) occurring 2 days after the first eggs are laid. The effect of temperature is particularly evident in greenhouses, where spider mite populations often develop rapidly soon after the onset of summer temperatures.

Sex determination in twospotted spider mites (as in many other spider mites) is arrhenotokous. That is, females develop from fertilized eggs and have the normal two sets of chromosomes (diploid); on the other hand, males develop from unfertilized eggs and have only one set of chromosomes (haploid). Unmated females give rise only to males; mated females can produce either female or male progeny. According to Helle (1967), a single mating will suffice to provide a female with enough sperm to produce diploid eggs for her entire ovipositional period.

The phenomenon of arrhenotoky is of importance not only from an academic standpoint, but also from a practical one. Because the male has only one set of chromosomes, new genetic features (arising from mutations) will be immediately expressed. Through natural selection, these characteristics can be added quickly to the population (Helle & Overmeer, 1973). Therefore, the potential for development of genetic resistance to insecticides and miticides in the twospotted spider mite is greatly enhanced by this method of reproduction. Because of the high reproductive rate and fast generation time and the intense selection pressure brought on by chemical control of this pest in the greenhouse, resistance may develop in a comparatively short time.

The dispersal ability of *T. urticae* in greenhouses is an important factor to consider in the control of this pest. Hussey & Parr (1963) indicated that twospotted spider mites dispersed in the following ways: migration of newly emerged (presumably mated) females to oviposition sites; dispersal from infested plants, simply by dropping off; and movements over soil surface in accordance with the plane of polarized light. There is direct evidence that the mites are able to suspend themselves on silken threads and thus be carried along by air currents. Mites can also be dispersed on the clothing of greenhouse personnel or through the movement of infested plant material. Despite the dispersal ability of the mites, it is not uncommon to find infestations in one portion of the greenhouse throughout the season, and perhaps even from season to season. Patchy infestations in the greenhouse are characteristic of twospotted spider mites. In greenhouses where ornamental plants are grown, patches are often found at the ends of benches near the walls and away from center aisles. The cause of these patches may be associated with poor spray coverage in these hard to reach areas.

Under certain conditions, twospotted spider mites can overwinter as diapausing (mated) females. The diapause is presumably induced by photoperiod (i.e., shortened day length), low temperatures, and unfavorable food supply (see Parr & Hussey 1966, Jeppson et al. 1975). These diapausing females are yellowish-orange and hibernate in protected places (e.g., cracks, crevices) . They neither feed nor reproduce while in diapause. The diapause normally terminates in the spring when favorable environmental conditions return. In southern climates such as Florida, populations of twospotted spider mites cycle throughout the year, although sometimes at reduced rates of development during winter months. However, it is possible that a small portion of the population enters diapause during the winter months.

Twospotted spider mites feed on many species of plants and are a major pest of vegetables, ornamentals, fruit trees, hops, cotton, and strawberries (van de Vrie et al. 1972). At present, it is safe to assume that most of the major spider mite problems in greenhouses will involve twospotted spider mite.

The larva, protonymph, deutonymph, and adult feed mainly on the undersides of the leaves. When feeding, the body of the mite is tipped upward such that the 3rd and 4th pairs of legs are off the leaf surface and the mite is supported by the 1st and 2nd pairs of legs (Jeppson et al. 1975). Feeding is accomplished in the following manner: a pair of needle-like stylets penetrates the plants' parenchyma cells, the contents of which are then drawn into the body of the mite by a "pharyngeal pump". According to Laing (1969), protonymphs and deutonymphs spend about half their developmental times feeding and half in the resting or quiescent stage; the larvae spend slightly more time feeding than resting.

Damage to the plants is effected in several ways. First, feeding causes the destruction or disappearance of chloroplasts which then leads to basic physiological changes in the plant. Stomatal closure can be a primary host-plant response, and in such cases, uptake of CO_2 decreases resulting in a marked reduction in transpiration and photosynthesis (Sances et al. 1979a, 1979b) . These effects can occur at spider mite densities that are too low to cause visible damage. Reduction of photosynthetic area by spider mite feeding is permanent and can only be compensated for by production of new foliage. Methods have been developed to quantify the amount of feeding and therefore damage for both cucumber and tomato (Hussey & Parr 1963, French et al. 1976, Anonymous 1976a, Anonymous 1976b) . Both methods utilize a leaf damage index (LDI) using the following 0-5 scale: 0 = no damage; 1 = incipient damage with one or two 1-5 mm diameter feeding patches or 5% of the leaf area damaged; 2 = more and larger patches than 1 and with 15% of the area affected, 3 = denser speckling with 30% of the area damaged; 4 = about 60% of the leaf area damaged; and 5 = over 80% of the leaf area damaged with the leaf being chlorotic (French et al. 1976). When the mean LDI reaches 2.0 on tomato, 33% of the leaf area is damaged and loss in yield can be expected (Anonymous 1976b). Loss in yield for cucumbers occurs when the mean LDI reaches 1.9 which corresponds to 30% of the leaf area damaged (Hussey & Parr 1963). Secondly, it is likely (but not firmly established) that the mites actually inject phytotoxic substances into the plant when feeding (see Avery & Briggs 1968, Jeppson et al. 1975, Liesering 1960). Finally, the stippling or speckling of the upper leaf surface, plus the webbing produced by protonymphs, deutonymphs, and adults, leads to aesthetic injury, particularly in the case of ornamental plants. Hamlen (1978) evaluated the control of twospotted spider mite on *Dieffenbachia maculata* (Lodd.) G. Don and *Chamaedorea elegans* Mont. (parlor palms) by *P. macropilis*. He established damage indices to obtain a method by which aesthetic injury could be evaluated. The density of twospotted spider mite (stage of mite not indicated) needed to obtain the specified level of damage was determined experimentally for each host plant. Results indicated that *D. maculata* could tolerate more *T. urticae* before aesthetic injury resulted than could parlor palms. It is possible that certain ornamentals may not be good candidates for biological control programs because it is harder to obtain a suitable level of mite control, or they do not have the ability to recover quickly from or mask mite feeding damage. However, recent testimonials indicate that *P. persimilis* is working well for the control of twospotted spider mite on many species of palms grown in greenhouses (J. Brushwein, personal communication).

The factors which determine the abundance or density of spider mites have been discussed in considerable detail by Huffaker et al. (1969, 1970), McMurtry et al. (1970), and van de Vrie et al. (1972). With respect of outbreaks of spider mites, particularly since World War II, there are two central "hypotheses" or tentative explanations to account for these events. The first is that the upsurge of spider mites is due to improved cultural practices, such as pruning, fertilization, and pesticide use. For example, outbreaks of spider mites can be induced by certain fertilization practices or by certain pesticides, regardless of natural enemies. Apparently, these cultural practices increase the nutritive value of the plant and thus enable greater reproductive activity on the part of the spider mites. The second explanation is simply that widespread use of broad-spectrum insecticides destroy or greatly hamper natural enemies of spider mites and thereby allow pest outbreaks to occur. There is reason to believe that both mechanisms can act in concert in inducing spider mite outbreaks.

Most of the pertinent information in the literature concerns the influence of pesticides on outbreaks of spider mites under field conditions. According to van de Vrie et al. (1972), increases in abundance of twospotted spider mite ave been observed following use of certain agricultural chemicals in many different crops. Although the causes of such increases in greenhouses have not been determined, it would be a sound practice to minimize the use of insecticides and miticides in the greenhouse since outbreaks of twospotted spider mites in the field are often correlated with pesticide usage.

Probably the most common scenario for outbreaks of twospotted spider mites in greenhouses is as follows: The spider mites are accidentally introduced into the greenhouse without any of their effective natural enemies; if host plants and physical factors (e.g., temperature) are suitable, the population "explodes". Common sources of inoculum include infested plants carried into the greenhouse, spider mites (especially mated females) which cling to the clothing of greenhouse workers and weeds growing outside the greenhouse.

However, chemical controls used to control other pests (e.g., mealybugs or greenhouse whitefly) can destroy natural enemies which have been introduced into the greenhouses (see below) and thus, engender serious outbreaks of twospotted spider mites. Thus, insecticides, miticides, and fungicides should be used judiciously when natural enemies are present in order to minimize unnecessary problems with twospotted spider mites.

Biological control of twospotted spider mite, *T. urticae*, has been practiced in greenhouses throughout Europe for many years (Osborne et al. 1985). Because of the many problems and economic consequences associated with chemical control, research on biological control agents for twospotted spider mite has been conducted on ornamentals in Australia (Goodwin & Wellham 1992, Gough 1991), Canada (Burnett 1979), Europe (Gould & Light 1971, Sabelis 1981, Scopes 1985, Simmonds 1972, Stenseth 1976), and in the U.S.A. (Boys & Burbutis 1972, Field & Hoy 1984,1986, Hamlen 1978, 1980, Hamlen & Lindquist 1981, Hamlen & Poole 1980, Lindquist 1981, Osborne & Petitt 1985).

Many different natural enemies are associated with spider mites under field conditions. These enemies are either predators or pathogens; there are no known parasites (parasitoids) of spider mites (McMurtry et al. 1970). Many of the known predators belong to the predatory mite family Phytoseiidae for which an excellent bibliography as just been published which covers the Phytoseiidae as biological control agents for spider mites, other pest mites and insects (Kostiainen & Hoy 1996).

In greenhouses, there are two categories of predacious species that feed on twospotted spider mites: those which occur naturally and those which are artificially introduced. The predacious phytoseiid mite *P. persimilis*, is the major species used to control twospotted spider mites in greenhouses. However, *Galendromus* (=*Metaseiulus*, =*Typhlodromus*) *occidentalis* (Nesbitt), another predatory mite, has been evaluated for the control of mites on greenhouse grown roses with some success (Field & Hoy 1984, 1986). Pathogens occur naturally under certain field conditions and appear to be an important regulator of spider mite populations. *Hirsutella thompsonii* Fisher has been proposed as a possible microbial control for twospotted spider mites in greenhouses but has only been effective in the laboratory (Gardner et al. 1982). For this reason, *P. persimilis* will be the only natural enemy treated in this section.

The genus *Phytoseiulus* is contains 4 know species; *P. fragariae* Denmark & Schicha, *P. longipes* Evans, *P. macropilis* (Banks), and *P. persimilis* Athias-Henriot and is only known from tropical and subtropical areas (Takahashi & Chant 1993). These authors state that *P. persimilis* is known mainly from Mediterranean climates. However, this predacious mite was accidentally introduced into Germany from Chili in 1958 (Dosse 1958). From Germany, it was subsequently shipped to other parts of the world, including California (McMurtry et al. 1978) and Florida (Hamlen, 1980). *P. persimilis* has also become established in many regions including southern California (McMurtry et al. 1978). It has also been collected in the field in northern-California. According to Denmark & Schicha (1983), there are two synonyms for *P. persimilis*: *P. riegeli* Dosse and *P. tardi* (Lombardini).

During the early 1960's, research on this species was conducted in Great Britain, Holland, Canada, and the United States. Since these initial studies, the ability of this predator to control twospotted spider mites has been demonstrated on many plants, including cucumber (Gould 1970, 1971), tomato (French et al. 1976), ornamental ivy (Gould & Light 1971), rose (Simmonds 1972, Boys & Burbutis 1972), lima bean (Force 1967), dahlia (Harris 1971), strawberry (Laing and Huffaker 1969), and dieffenbachia and schefflera (Hamlen & Linquist 1981). Although these studies were conducted under greenhouse conditions (or in growth chambers), *P. persimilis* can be an effective natural enemy in commercial strawberry plantings (McMurtry et al. 1978, Decou 1994, Trumble & Morse 1993) and on ornamentals in commercial interior plantings (Lindquist 1981).

The developmental stage of *P. persimilis* is similar to that of the twospotted spider mite, ie., egg, larva, protonymph, deutonymph and adult, and has been studied in detail by many authors (Laing 1968, Sabelis 1981, Shaw 1982) . However, the three quiescent periods are absent. The oval eggs are laid in close proximity to a food source. They are light orange and translucent when first deposited, but with age, they darken. The eggs of the predator can be distinguished from those of the prey's by the color as well as the shape.

The hexapod larva apparently does not feed and remains inactive unless disturbed. The first feeding stage--the octapod protonymph--emerges from the larval exoskeleton and begins to search for food almost immediately. Feeding and searching continues, with intermittent periods of inactivity presumably due to satiation. The next developmental stage, the octapod deutonymph feeds throughout most of its development. Tho deutonymph later molts, giving rise to the adult; the adult is about the same size as the mature prey mite and is red. Feeding begins soon after molting.

Mating usually occurs within a few hours after molting. Multiple matings are common even though the sex ratio is approximately 4 females to 1 male (Laing 1968). A female that has mated once can lay eggs throughout her life span; whereas an unmated female will not reproduce (Amano & Chant 1978a, 1978b, Laing 1968, Schulten et al. 1978). The system of reproduction and sex determination is termed "parahaploidy" (Helle et al. 1978, Hoy 1982). In this system, both males and females arise from diploid eggs having 8 chromosomes. However, males retain only one complement of 4 chromosomes (haploid) because of the loss or heterochromatization of one half of the chromosomes.

Laing (1968) studied the life history and developed life tables for *P. persimilis* and *T. urticae*. His studies were conducted in growth chambers in which the temperature fluctuated between 18-35°C. The time spent in each developmental stage was recorded and various aspects of the reproductive biology were studied.

Under these experimental conditions, Laing (1968) determined that *P. persimilis* would develop from egg to adult in an average of 7.45 days; this is approximately half the time required for development of the twospotted spider mites under similar conditions. For a detailed comparison of its developmental times, at three different temperatures, for various life stages of *T. urticae* and *P. persimilis*, see Table 1. Furthermore, the mean generation time (T) was 17.32 days (compared to 24 for the prey), during which the predator population increased 44X (compared to 31X in the prey) (Table 2). Finally, the maximum rate of increase (r_{max}) for the predator was higher than that for the prey (Table 2). Given these statistics, it is not surprising that *P. persimilis* is one of the most effective natural enemies of twospotted spider mites known and as stated by Takahashi and Chant (1994) the genus Phytoseiulus and specifically *P. persimilis* represent an "extreme" case of r-strategists. In fact, at times, this species can be too effective--i.e., it can often eradicate the prey in the greenhouse (see later section).

Table 1. Developmental times (days) for *Tetranychus urticae* and its predator, *Phytoseiulus persimilis*.*

Temp. °C	Egg	Larva	Developmental stage**			Total
			PN	DN	PQ	
			T. urticae			
15	14.3	6.7	5.3	6.6	3.5	36.3
20	6.7	2.8	2.3	3.1	1.7	16.6
30	2.8	1.3	1.2	1.4	0.6	7.3
			P. persimilis			
15	8.6	3.0	3.9	4.1	5.6	25.2
20	3.1	1.1	1.4	1.6	1.9	9.1
30	1.7	0.6	0.8	0.8	1.1	5.0

*Data obtained on roses in growth chambers (Sabelis 1981).

[**]Key to symbols: PN = protonymph, DN = deutonymph, and PO = length of time before an adult female begins to oviposit.

The rate of oviposition does not depend on the age of the female, but on the number of eggs previously laid. Eggs will be laid at a rate dependent on conditions until the maximum number is reached or until the female dies from "old age" at about 50 days (Sabelis 1981). The most important conditions that influence the rate of oviposition are temperature, humidity, mating status and prey density.

Temperature has been shown to affect prey consumption, generation time, oviposition, and longevity of *P. persimilis* (Pruszynski 1976, Plotnikov & Sadkowskij 1972, Sabelis 1981, Shaw 1982, Laing 1968, McClanahan 1968, Takafuji & Chant 1976). The ultimate outcome of the predator-prey interaction is also influenced by temperature (Force 1967). The number of deutonymphs eaten by the most voracious stage (the young ovipositioning female) generally increases as the temperature increases. For example at a relative humidity of 75%, the average consumption of spider mite deutonymphs by a single female was 8.8 at 17°C compared to 13.5 at 26°C (Pruszynski 1976). Pruszynski also demonstrated that consumption of prey increased as the relative humidity decreased and the temperature increased. The author also cited a Russian study (Plotnikov & Sadkowskij 1972) in which spider mite eggs were offered as the prey item. The same trend seemed to occur, i.e., as temperature increased, so did the consumption of eggs. Pruszynski stated that *P. persimilis* is more sensitive than the prey to temperatures above 30°C and that the predator would stop feeding at about 35°C. The number of eggs and the rate at which they are consumed is also affected by the predator's ability to effectively search for food (see later section).

Table 2. Reproductive biology of *Tetranychus urticae* and its predator, *Phytoseiulus persimilis*.

	Average value at 20.3°C	
Parameter	*T. urticae*[*]	*P. persimilis*[**]
Preoviposition period (days)	2.1	3.0
Oviposition preiod (days)	15.7	22.3
Longevity (days)	17.8	29.6
Eggs laid per female	37.9	53.5
Eggs per female/day	2.4	2.4
Sex ratio	2.9:1	4.1:1
r_{max}[***]	0.143	0.219
R_o	30.93	44.36
T	24.00	17.32

[*]Data from Laing (1969).

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[***]Key to symbols: Rmax = Intrinsic rate of increase or the number of individuals produced per female per day. Ro = The number of daughters that replace an average female in. the course of one generation; and T = Mean generation time (days).

The rate at which *P. persimilis* develops is a function of temperature and is described by a straight line over the range of temperatures between 15-30°C (Sabelis 1981); as temperature increases, the time needed to develop decreases (Table 1). However, developmental times in the literature are quite variable and are possibly dependent on the strain studied.

Fecundity (number of eggs laid per female) is also influenced by temperature. The temperature at which the maximum reproduction (75 eggs) occurs is approximately 26°C; the optimum range for reproduction is 17-28°C (McClanahan 1968, Sabelis 1981). At constant temperatures outside this range, females lay fewer eggs. The rate of oviposition, as stated earlier, does not depend on the age of the female, but on the number of eggs previously laid until the maximum number is reached.

The effect of temperature on the overall predator-prey interaction was studied by Force (1967). He used constant temperatures of 15°C, 20°C, 25°C, and 30°C and obtained excellent control of twospotted spider mites at 20°C; however, at 30°C, *P. persimilis* was unable to affect control. At 15°C and 25°C, the prey was controlled, but not as dramatically as at 20°C. One problem with this study was the artificial condition of constant temperatures. However, the important points to note are that an optimum temperature apparently does exist and that extreme temperatures can have detrimental effects on the ability of the predator to control the pest population. Despite the temperature limitations, some effort has been made toward developing "heat tolerant" strains (Voroshilov 1979).

Developmental time can also be affected by relative humidity. A slight increase in the predator's developmental time was observed when the humidity was increased from 40% to 70% (Begljarow 1967, Ustchekow & Begljarow 1968, Stenseth 1979). Begljarow (1967) noted that development almost stopped at humidities of 25% to 35%. Pralavorio & Almaguel-Rojas (1980) reported that relative humidities below 70% resulted in a significant reduction in the ability of immature predators to molt from one stage to another.

Humidity also exerted an influence on survival of predator eggs at temperatures above 21°C. At 27°C and 40% relative humidity, only 7.5% of the eggs tested in one study hatched compared to 99.7% at the same temperature, but at 80% relative humidity. At 21°C, there was only a 10% reduction in hatching when eggs were held at the 40% RH compared to those held at 80% (Stenseth 1979). Begljarow (1967) showed that when eggs were held at a relative humidity of 50%, they appeared to shrivel at all temperatures between 13°C and 37°C; while at 60% RH, hatching was successful at temperatures below 30°C. Sabelis (1981) suggests that the critical relative humidity is 50% and therefore has little influence because the relative humidity in greenhouses rarely falls to levels where predators would be affected significantly.

The searching behavior and activity of *P. persimilis* can also vary in response to relative humidity. Mori and Chant (1966a, 1966b) investigated the influence of relative humidity on the behavior and activity of this mite and concluded that relative humidity was an important factor limiting the number of prey consumed per predator. In these studies, predator activity and the number of prey consumed per predator increased as relative humidity decreased (i.e., from 100% to 33%). This activity response due to humidity combined with recent evidence (see Sabelis and van der Baan 1983) that phytoseiid mites, including *P. persimilis*, are able to use odors (i.e., kairomones) associated with mite infested plants to locate their prey at a distance, further increases the predator's chances of finding and consuming twospotted spider mites.

One must be careful when extrapolating from relative humidity data obtained from studies where the humidity is artificially maintained at constant levels in very controlled situations. Gaede (1992) discussed the net water vapor exchange of *P. persimilis* and its ecological significance. He described how this species increasingly losses water by transpiration as the temperature increases. However, it also has the ability to absorb water vapor from an unsaturated environment. In his paper Gaede describes the diurnal water vapor profile around the leaf surface and determine that there are periods when *P. persimilis* can absorb water and restore a "previously-suffered" water deficit. Gaede also states that this species is positively hygrotactic when in a state of water deficit.

Because of commercial availability there has been at least two studies on cold storage of *P. persimilis*. Morewood (1992) determined that cold storage of this species in empty containers was unsatisfactory but they could be stored at 7.5 °C for 4 to 6 weeks in containers provisioned with food and moisture but no vermiculite of bran. These material should be added just prior to shipping because of their propensity to support mold growth.

All developmental stages of the twospotted spider mite are eaten by the adult female *P. persimilis*. The predator's larval stage does not feed, but the protonymph and deutonymph will feed on the egg, larva, and protonymph stages of spider mites (Takafuji & Chant 1976). The number of each stage eaten depends on the density of prey and predator, temperature, humidity, stage of predator feeding and which prey stages are available for it to feed upon (Shaw 1983).

P. persimilis depends almost entirely on animals as food (Ashihara et al. 1978, Chant 1961, Dosse 1958). Ashihara et al. (1978) reported that this predator fed, reproduced, and completed development only on mites in the subfamily Tetranychinae. However, Chant (1961) observed *P. persimilis* feeding on young thrips. *P. persimilis* is also cannibalistic when no other food (i.e., spider mites) is available (Dosse 1958, Laing 1968). Free-standing water (for the predator to drink) will, in the absence of food, increase survival by 23% (Mori & Chant 1966b, Ashihara, et al. 1978). Adult females, when fed on honey or a 10% sucrose solution, can survive at least four times longer compared to females being fed on water alone (Ashihara et al. 1978). However, neither sucrose nor free water

would promote reproduction. Ashihara et al. (1978) determined that females would not reproduce on a diet of honey, but if they were removed from the honey diet after 35 days and fed spider mite eggs they could achieve their normal reproductive potential.

When compared with five other predatory mites, *P. persimilis* was rated as having high dispersal powers, and its distribution and that of its prey were highly correlated (McMurtry 1982). The ability of *P. persimilis* to disperse and find new colonies of prey depends on the physical characteristics of the environment (Takafuji 1977), prey distribution and density (Nachman 1991, Zhang & Sanderson 1995), predator density (Zhang & Sanderson 1995), and the duration of infestation or the amount of the spider mite webbing present (Schmidt 1976, Sabelis 1981, Sabelis & Bakker 1992). *P. persimilis* has been shown to respond to volatiles (synomones) produced by leaves infested with *T. urticae* (Bruin et al. 1992, Dicke et al. 1993, Dicke & Dijkman 1992, Takabayashi & Dicke 1992). Sabelis and Afman (1994) demonstrated that females starved for 24 h at 25°C and 35% RH about 80% became airborne when exposed to wind velocities greater that 2 m/sec for 10 minutes. These authors also demonstrated that the volatiles emitted by leaves that had been previously infested by *T. urticae* would arrest this behavior.

One important environmental characteristic is the density of plants within the greenhouse. For example, when infested plants are dense enough for their leaves to touch, the predator can disperse readily. When the plants have little physical continuity, the predator's ability to disperse can be reduced by about 70% (Takafuji 1977).

The density of both predator and prey may play a part in the rate at which predators leave an infested plant in search of new sources of food. Young female predators increase the rate at which they depart from a colony as their density increases and that of the prey decreases (Sabelis 1981, Eveleigh and Chant 1982). When prey density is low relative to number of predators present, the adult predators begin to disperse in search of new food sources. On the other hand, nymphs of *P. persimilis* have a much lower capacity--and tendency--to disperse than do the adults and, as a result, they remain behind and feed on whatever food is left before they begin to disperse (Takafuji 1977). This behavioral characteristic can be a contributing factor to the extinction of prey. Also, the elimination or extinction of the prey in the greenhouse is made possible because *P. persimilis* has a much greater dispersal potential than its prey (Nachman 1981). In cases where little or no spider mite damage can be tolerated, such as on ornamental plants, this is a desirable situation. Because some damage can be tolerated in cucumber and tomato crops, it would be desirable to have a stable interaction between the predator and prey over an extended period of time.

The host plant can also influence the predators ability to manage mites. As just discussed continuity between plants is important (Jarosik 1990). Many ornamental crops are spaced so that they will receive optimum sunlight and develop symmetrical shapes. Therefore Nachman (1991) discussed how lowered dispersal rates increase the risk of local outbreaks of prey and may result in significant damage to the host plants. Tomato plant trichomes and the exudate they produce can entrap *P. persimilis* (Nihoul 1993, 1994).

The webbing produced by twospotted spider mites aids the searching predator in finding its prey. When webbing is contacted, the predator intensifies its search in the immediate area . The webbing appears to act as an arrestant for dispersing predators. In one study, females were able to find prey twice as fast when webbing was present compared to when webbing was absent (Schmidt 1976). Schmidt (1976) also reported that spider mite eggs had a similar effect, but to a lesser degree. Kairomones (chemical odors discussed earlier) may be responsible for this nonrandom searching behavior.

Release methods and guidelines have been developed for vegetables to increase the probability of successfully controlling *T. urticae* with predatory mites. One release method, termed

"Pest-in-First", requires the prey to be released in a uniform pattern before releasing the predator. A specific predator:prey ratio can therefore be established early in the season and the predator will become established uniformly throughout the greenhouse prior to the crop becoming infested naturally (Markkula & Tiittanen 1976). Other methods are designed to release predators when natural infestations of spider mites are found (French et al. 1976). Sufficient numbers of predators are released to create a desirable predator:prey ratio of 1:10 (Markkula & Tiittanen 1976) or 1:6-1:25 (Hamlen & Lindquist 1981). Where the pest mite population has reached high densities, the cost and logistics of releasing adequate numbers of predatory mites can be prohibitive. In greenhouses where ornamentals are grown, these tactics may not work well because the number of mites that can be tolerated is extremely low. In general, predators are used prophylactically. Predator releases are made once or twice a month even if no mites are present in the crop with the assumption that the crop is likely to become infested.

Because of problems with predatory mite shipments (see below) and price considerations, growers have requested that research be conducted to develop methods for optimizing the use of both naturally occurring and purchased predators. One method that is being evaluated is the use of alternate hosts for the predators to feed on. This concept isn't new. In Florida, a modified banker-plant system is being evaluated as a method for distributing parasitoids of whiteflies (Osborne et al. 1990). Similar systems are being developed for both aphids and mites. The mite system has potential in ornamental crops. The alternate host for the predatory mites is *Tetranychus evansi* Baker and Pritchard. The host range of *T. evansi* is somewhat restricted. Recorded hosts include tomato, eggplant, potato, peanut, rose, nightshade, Solanum, sweet potato, *Asystasia coromandeliana* Nees, red pepper, *Nicotiana glauca* Graham, *Phacelia* sp., lily of the valley vine, and *Salpichora rhomboidea* Mires (Jeppson et al. 1975). We are currently evaluating the use of this modified-banker plant system in commercial greenhouses. Eggplants infested with *T. evansi* have been placed uniformly throughout a crop of crotons (Codiaeum variegatum (L.) Blume) being used as stock plants. The eggplants are inoculated with both Neoseiulus (=*Amblyseius*) *californicus* (McGregor) and *P. macropilis*.

A different approach would be to use less specialized or "generalist" predators (McMurtry 1992, Karg et al. 1987) such as those the genera *Typhlodromus*, *Amblyseius* or some *Neoseiulus*. For example, releases of *Neoseiulus* (=*Amblyseius*) *barkeri* (Hughes) (=*Amblyseius mckenziei* Schuster & Pritchard) for spider mite control would be desirable because of their low cost and ability to prey on other pests such as the broad mite (*P. latus*), thrips or on pollen. Releases of these predators have not been evaluated for twospotted spider mite control except on single plants under very controlled situations. Unfortunately, few critical studies have been conducted in greenhouse situations using any of the commercially available predatory mites other than *P. persimilis*.

The most critical phase in the implementation of any biological control program is the release phase (French et al. 1976, Gould 1970, Markkula & Tiittanen 1976). Thus proper timing of predatory mite release is essential to achieve adequate control of the twospotted spider mite. Many of the past failures can be attributed to the detection of natural spider mite infestations too late to utilize biological control successfully (Stenseth 1980). In these cases, insufficient numbers of predatory mites were released to control an established and rapidly increasing mite population. Consequently, predators were unable to reduce mite numbers fast enough to prevent economic injury.

Release methods have been developed in order to increase the probability of successfully controlling *T. urticae* with *P. persimilis*. One release method, termed "Pest-in-First", requires the prey to be released in a uniform pattern before releasing the predator. At the appropriate time, the predator is subsequently released. A specific predator-prey ratio can therefore be established early in the season; the predator also becomes established throughout the greenhouse before mites naturally infest the crop (Markkula & Tiittanen 1976). A similar technique is the introduction of predator and prey at the same time. This is accomplished by purchasing a mixture of both species from a commercial insectary. In the Netherlands, predators are packed in plastic bottles which contain wheat bran and spider mites. These bottles are sealed with a screw cap equipped with a gauze covered hole for ventilation. This technique, like the "Pest-in-First" method, allows the establishment of specific predator to prey ratios. Thus, balanced control can be attained throughout the greenhouse (Ravensberg et al. 1983).

The rationale behind both of the above techniques is to establish the predator evenly throughout the greenhouse early in the season before the crop becomes naturally infested. This is important where a large portion of the spider mite population enters diapause. Experience has shown that spider mites leave the sites where they diapause and infest the crop as soon as environmental conditions become suitable. Because a large and unpredictable number of mites may enter a crop over a short period of time, severe damage can occur before the problem is noted. These techniques will allow growers the opportunity to establish predators early in the season which will provide a buffer against the immigrating mite population, and thus reduce the potential for damage.

In climates such as Florida, the mass influx of mites, as a result of diapause termination, is seldom seen. Mite infestations occur throughout the year and begin as small isolated patches. Many growers that use *P. persimilis* release them on a weekly or biweekly basis even if they have not detected the presence of mite infestations in their crops. This technique is similar to the approach they use with pesticide: applications being made based on what day of the week it is and not what is present in their crop. Release techniques designed to introduce predators when natural infestations are first found are desirable (French et al. 1976). Sufficient numbers of predators can be released to create a desirable predator-prey ratio, e.g., 1:10 on cucumbers (Markkula & Tiittanen 1976) or 1:6-1:25 on ornamental foliage plants (Hamlen and Lindquist 1981). When distinct patches of prey can be identified, predators should be released on every plant within the patch. Predators should also be released on plants around the outer edge of the infestation in order to establish a barrier that should slow or prevent the spread of the prey. If prey are found, but no distinct patches can be identified, *P. persimilis* should be released on every fifth plant (Anonymous 1976a). The number of predators to be released is dictated more by economics and their availability than any other factor. In situations where the mite population has reached high densities, the cost and logistics for releasing adequate numbers of predatory mites is usually prohibitive. In these cases, conventional chemical control should be employed to reduce the possibility of economic damage.

Many acaricides disrupt the predator-prey interaction even to the extent that acaricides must be applied during the remainder of the growing season. However, studies have shown that this problem can be avoided if a selective acaricide such as fenbutatin-oxide (Lindquist et al. 1980), abamectin (Zhang & Sanderson 1990) or insecticidal soap (Osborne & Petitt 1985). Selective pesticide use may also be achieved by applying the pesticides during a specific time when predators are not present or to a portion of the plant where the predators are not present (Sanderson & Zhang 1995). In the studies using fenbutatin-oxide or insecticidal soap, the authors demonstrated that a single application of the selective acaricide used in conjunction with an earlier release of predators gave better control than when either method was used alone.

Once the predators have been released in the greenhouse, some additional conditions should be taken into account. Insecticides, miticides and even certain fungicides residues can be detrimental to *P. persimilis* and should be used judiciously (Baker & Jacas 1995, Bluemel et al. 1993, Bluemel & Stolz 1993, Malezieux et al. 1992, Oomen et al. 1991). Whenever possible, selective chemicals should be used (see section on Common Problems). As stated earlier, the performance of the predator is conditioned by temperature and relative humidity and to consider this aspect could easily lead to failure of the control program. Sometimes the predator may simply exterminate (eradicate) the prey from the greenhouse; thus, careful monitoring of the mites is required in order to (1) detect such eradication and (2) determine when new introductions of twospotted spider mite occur so that another release of the predator can be made at the proper time.

THE BROAD MITE

The broad mite, *Polyphagotarsonemus* (previously) *Tarsonemus* or *Hemitarsonemus latus* (Banks) known by various names, e.g., yellow tea mite, broad mite, white mite, chili mite, citrus silver mite, has been reviewed by Beer (1954) and Lindquist (1986). *P. latus* (Banks) is an important pest of tropical and temperate crops (Jeppson et al. 1975) and, judging by the numerous reports (e.g., Anonymous, 1973, Mineo and Ragusa 1976, Dhoria and Bindra 1977, Cross 1979, Nakasuga 1978, Sombatsiri 1978, Hugon 1983), this potential for damage has become more evident during the last three decades.

Gerson (1992) gave a comprehensive list of 57 plant families used by *P. latus*, which range from the most primitive ones to the most evolved plant families. Also, the list of host plants has been detailed for different parts of the globe (Hill 1975), and includes annuals and perennials, monocots and dicots. The way in which *P. latus* attacks several plants has been described and illustrated by different authors (Nucifora 1961, Dhoria and Bindra 1977, Schoonhoven et al. 1978, Aubert et al. 1981). Attacks tend to be concentrated to young leaves. This mite sometimes causes damage to specific plant parts, e.g., stems, flowers, fruitlets or tips of shoots. Symptoms of broad mite attach are variable and depend, among other factors, on the characteristics of the plant species, their structures, i.e., the anatomical structure or chemical composition, the weather during or shortly after injury. Kabir (1979) reported that high temperature and low humidities favor *P. latus* development. Later, Brown & Jones (1983) gave one of the most detailed descriptions of *P. latus* development and concluded that, humid weather (75 -90% RH) is needed for *P. latus* development. The principal symptoms of injury on different plant parts consist of depigmentation, deformation, thickening, suberization and browning of leaves, suberization of floral buds and hypertrophy of the foliar hairs, short internodes in the shoots, drying of the flower stalk and suberization of fruits and pods (Lo and Chao 1972, Iacob 1978, Laffi 1982).

The variety of symptoms have also been linked to the plants responce to this pests feeding and putative toxins. These responces were originally confused with disease symptoms, herbicides or deficiency of micronutrients (Ammin 1979, Aubert et al. 1981, Higa and Namba 1970).

Ornamentals such as *Codiaeum variegatum*, vars. "Petra", "gold sun", "gold dust", *Schefflera* sp., *Impatiens* sp., *Gerbera* sp., *Dahlia* sp., *Celosia argentea* and *Spananthe paniculata* show symptoms varying from slight wrinkling to folding under towards the underside. The plants show generalized delayed growth. In some cases the leaves show partial loss of the foliar lamina, in other cases the loss is marked. In mature plants the undersides of the leaves show bronzing or red tones as a consequence of early attack. (Ochoa et al. 1994).

Erythrina spp., *Terminalia catappa* and *Cordia* sp. may exhibit slight to severe rolling. Occasionally, rolling may produce a pouch - like shape and in severe damage the main vein of the plant may be broken resembling a hairpin (Ochoa et al. 1994).

Damage produced by *P. latus* in many of its hosts can be used by other pests for protection, reproduction or feeding. Amongst those most commonly found and which also produce damage are thrips (Thysanoptera) , mealybugs (Pseudococcidae) (Ochoa et al. 1994) and other mite species (i.e., Tenuipalpidae)

A number of authors have reviewed the biology of *P. latus* (Jeppson et al. (1975), Nucifora (1940), Gadd (1946), Karl (1965), Kabir (1979) and (Ochoa et al. 1994)). Eggs are laid singly by the gravid female. The eggs are white, translucent, with ovals inside, arranged in a symmetrical form,and

large in comparison to the size of the adult (Jeppson et al. 1975). They hatch in about 2 days at 25°C and 90 -100% RH into a 6-legged larva that is opaque white, with 2 anterior pairs of legs situated as in the adult, but the posterior pair in the position of legs III of the adult (Jeppson et al. 1975). Larvae are fully characterized by the presence of a peculiar enlargement of the opisthosoma into a triangular platelike development that is most prominent in males. Male larvae are considerably smaller than female larvae. Larvae are not very active; they feed for ca. 1 day and molt (Gerson 1992). From this active stage mites of both sexes enter a quiescent pupal stage in which transformation to the adult takes its net reproductive rate (R_0) as being 17.58, and its intrinsec rate of increase (r_m) as 0.427 per day at 25°C. Interplant dispersion occurs through wind currents (Albert et al. 1981) or by phoresy on aphids and whiteflies (Smith 1935, Natarayan 1988, Fletchman et al. 1990).

Until recently, pesticides have been the only known method used (Brown & Jones 1983, Bassett 1985, Gerson 1992, Benuzzi & Nicoli 1993). Few studies have been conducted to investigate the suitability of broad mites as targets for biological control. The potential of phytoseiid mites as predators of the broad mite has been reported for different areas and crops (Anonymous 1977, Badii and McMurtry 1984, Moutia 1958). For a review of predacious mites see Gerson (1992). In Florida, six species of predacious mites (4 Phytoseiidae, 1 Bdellidae and 1 Ascidae) were observed in association with broad mites on lime fruits (Peña et al. 1989). The effectiveness of these mite predators for controlling broad mite populations was demonstrated by the latter authors. In an exclusion experiment, predators effectively controlled broad mites during the winter-spring season but failed to keep populations of this pest below economic injury levels during summer and fall. Several factors could be responsible for this. Since most of these mites are facultative predators, the presence of preferred prey or food substrates might influence the predator-prey interaction. Also, since broad mite has a short generation time and fruit injury is observed in 4-6 days, the ratio of predators to broad mites may need to be higher than the on observed during the summer and fall. Peña & Osborne (1996) have demonstrated that two biweekly releases of 200 N. californicus per lime tree effectively reduced broad mite densities below economic injury levels.

The potential for controlling broad mite biologically is just being realized. Since 1989, in greenhouses at "The Land" at Epcot, part of the Walt Disney World resort in Lake Buena Vista, FL, broad mite damage has been very effectively controlled by making augmentative releases of 10-30 *N. barkeri* per plant weekly in about 1.2 ml of bran. However, recent studies have shown that fewer predators may be sufficient and the interval between the releases can be longer (Fan & Petitt 1994a).

Control failures in pepper were observed during the winters of 1989-1991, causing reversion to treatments of elemental sulfur. The cause of the failures is unknown, but suspected to be due to reproductive diapause (Morewood & Gilkeson 1991). *N. barkeri* reared at The Land did not show any diapause, and broad mite has been controlled successfully since 1992 (F.L. Pettit personal communication).

LIMITING FACTORS AND RECOMMENDATIONS IN THE DEVELOPMENT OF BIOLOGICAL CONTROL PROGRAM

Despite good research results, biological control of mites has not been implemented in more than a few greenhouses on ornamental crops. The reasons are, in most cases, the same as those hindering development of biological control in greenhouses world wide (van Lenteren et al. 1980, Parrella 1990).

1. **Perception.** There are many factors limiting the implementation of biological control programs for pests of ornamental plants. One of the most important factors is the perception that we are currently marketing pest-free products and that the use of biological controls will result in plants that are infested, damaged and of inferior quality. However, complete reliance on chemical controls does not ensure quality plants because their use often results in unsightly residues and phytotoxicity. As noted by van Lenteren (van Lenteren et al. 1980), chemical controls are not always effective: "We have to be careful before completely dismissing biocontrol for such crops, because checking of heavily sprayed ornamental crops sometimes reveals still living pest insects, the number of pest insects being as high as or higher than crops treated with biocontrol". Another concern articulated by many growers is that they fear how regulatory personnel, buyers, and consumers will react to the presence of the beneficial organisms on the final product.

2. **Expectation.** Often, predators or parasitoids are perceived as biological pesticides. They are applied when pest density has reached economic (aesthetic) injury level which is established for chemical pesticides and an immediate control of the pest is expected like an effective pesticide. The use of predators and parasitoids requires more education and training of pest control managers and growers than the use of chemical pesticides. It must be realized that the impact of predators or parasitoids on pest population is slower, but often lasts longer than conventional pesticides. Maybe more important is the fact that these beneficials must be released before the pests reach the aesthetic level. Thus good scouting programs, including sampling and monitoring for both pests and beneficials, are needed.

3. **Technology development and transfer.** The use of parasitoids, predators, and microbial pesticides will require more education and training of the grower than has been provided for the use of conventional pesticides. The present demand for information is greater than is available. In addition to requiring different beneficial species for different situations and on different host plants, perhaps the most demanding techniques for development of biological and IPM programs are the development of scouting programs and step by step guidance (see Parrella et al. 1989) . Very little research has been conducted in these areas. Commercial growers are looking for specific recommendations. Without step-by-step guidance, many are reluctant to incorporate biological control into their pest management programs. Also important in the development of these techniques is a knowledge of how to contend with several pests on a crop. Many scientists researching biological control strategies are normally restricted to working with a single pest on a single crop, whereas a grower has to control several pests at the same time. Technology transfer from small scale research plots in university greenhouses to commercial nurseries has not occurred for most systems, except in a very limited way.

As to the mode of technology transfer, a lot can be learned from the biological control programs in Europe, where biological control is a common occurrence in greenhouses were vegetables are grown. The grower normally contracts with a producer of beneficial organisms for a complete product. This product can include the beneficial organism, monitoring or scouting services, consulting, release and follow-ups and labels which are attached to the produce to indicate that it was grown with the aid of biological controls. Recently, a commercial producer of *P. persimilis* from Europe established a program in Florida. Through a Florida broker, a program was established in which the predators are sold to the nurseries by a consultant. The consultant goes to many nurseries and evaluates the mite problem and determines if biological control has any potential under the specific conditions found in the nurseries. This program has been more successful than any tried by the University of Florida. The primary reason is that someone goes to the nursery and works with the grower.

4. **Limited commercial availability of effective beneficials.** This aspect covers many of the major impediments to implementing biological control programs. First, there are only a few companies that produce beneficial insects and mites. These companies are, with few exceptions, located in foreign countries or California. As a result, growers in the eastern United States who wish to purchase parasitoids or predators must obtain them through the mail. Unfortunately, little is known about what effect the stress of shipping might have on beneficials but it certainly reduces their utility. Because the greenhouse and ornamental industries are so widespread throughout the United States, insectaries that can supply regional needs or act as distributors of quality beneficials for larger producers may be a possible remedy. This arrangement also would address another critical need which is the lack of an advisory service that could help growers implement or use this more sophisticated technology: even this level of advisory input may not be adequate.

More than 1000 species of predatory phytoseiid mites exist with over 80 being found in Florida (Muma & Denmark 1970). We know very little about most of these species. This is probably one of the major reasons we have chosen to concentrate our efforts on just one species, i.e., *P. persimilis*. The original culture of this species, from which most of the existing cultures originated, began from the colonization of a few mites on orchids that entered Germany from Chile in 1958 (Dosse 1958). How much "new" genetic material has been introduced into these cultures since their original colonization is not known. At least 20 different species of predatory mites are listed by Hunter (1994) as being commercially available. However, most are either not available when requested or the numbers that one can obtain are only useful for small scale experiments or limited field trials. The predominant species being sold is *P. persimilis* but 3 other species are commonly advertised for controlling spider mites and include *Galendromus* (=*Metaseiulus*, =*Typhlodromus*) *occidentalis* (Nesbitt), *P. longipes* Evans, and *N. californicus*. Claims about one species being better suited to one "type" of environment while another is better suited to another have been made by producers.

Table 3. Biological attributes for 8 species of Phytoseiidae being used in ornamental greenhouses for mite control (Adapted from McMurtry 1982)

PHYTOSEIIDP REDATOR[1]	KNOWN FOOD SOURCES[2]	TEMP[3]	HUMD[4]	DISPERSAL ABILITY	DISTRIBUTION RELATIVE TO SPIDER MITE PREY	REPRODUCTION ON SPIDER MITES	VORACITY	DIAPAUSE	SURVIVAL WHEN PREY SCARCE
G. occidentalis	AB	low	low	high	high	med	low	yes	med
I. degenerans	ACD	?	?	low	low	low	high	NR[5]	high
M. longipes	A	low	low	high	high	high	high	NR	low
N. barkeri	ABCD	?	high	high	?	low	low	yes	med
N. californicus	ABCD	low	low	med	high	high	med	NR	med
N. cucumeris	ABCD	?	high	low	?	low	low	yes	high
P. macropilis	A	?	?	high	high	high	high	NR	low
P. persimilis	A	high	high	high	high	high	high	NR	low

[1]PREDATOR *Galendromus* (=*Metaseiulus*, =*Typhlodromus*) *occidentalis* (Nesbitt)
Iphiseius (=*Amblyseius*) *degenerans* (Berlese)
Mesoseiulus (=*Phytoseiulus*) *longipes* (Evans)
Neoseiulus (=*Amblyseius*) *barkeri* Hughes
Neoseiulus (=*Amblyseius*) *californicus* (McGregor)
Neoseiulus (=*Amblyseius*) *cucumeris* (Oudemans)
Phytoseiulus macropilis (Banks)
Phytoseiulus persimilis Athias-Henriot

[2]FOOD A=Tetranychidae
B=Tarsonemidae and other families of mites
C=Thripidae
D=pollen

[3]TEMP Reported sensitivity to high temperatures. A high sensitivity means that this species does not do well at high temperatures.
[4]HUMD Reported sensitivity to low relative humidities. A high sensitivity means that this species does not do well at low humidities.
[5]NR =Not Reported

compares the biological attributes for 8 predatory mites being evaluated for mite control in commercial greenhouses. This table was adapted from McMurtry 1982. McMurtry is an excellent discussion about the use of phytoseiids for biological control. In this paper he compared G. occidentalis and *P. persimilis* with 4 other species that are commonly found outside greenhouses.

The merits of using one species of predator over another have received limited critical evaluation on ornamentals in greenhouses. As stated earlier we have almost exclusively used *P. persimilis* for mite control in these situations. Field and Hoy (1986) evaluated the use of *G. occidentalis* for control of spider mites on roses in greenhouses. The authors concluded that the pesticide resistant and non-diapausing had significant potential and should be evaluated in large-scale commercial trials.

It seems unrealistic to expect one strain or one organism to be effective under the many diverse situations in which phytophagous mites cause damage. For example, *P. persimilis* (the strain most often sold) is sensitive to high temperatures, medium to low relative humidity, and pesticides (Osborne et al. 1985). When released under any of these conditions, the efficiency of this predator is reduced and in some cases it has failed to become established. Because of these environmental constraints on the effectiveness of *P. persimilis*, other predators of *T. urticae* are receiving some attention. M. longipes has been released for the control of mites in a few interior plantings where the low relative humidity is believed to prevent *P. persimilis* from reproducing. The initial results reported by plant maintenance personnel have been encouraging. Dinh et al. (1988) reported that the eggs of Neoseiulus (=Amblyseius) idaeus (Denmark & Muma), a *T. urticae* predator, have the highest tolerance to low humidity (as low as 30% RH at 25°C) reported to date. It must be emphasized that the influence of temperature and humidity on the biology of predatory mites can vary significantly with the strains of a given species. Perring & Lackey (1989) compared a strain of *P. persimilis* from Israel with one from California. Their studies suggest that neither strain was "resistant" to high temperatures. However, they do state that the Israel strain was "rather low humidity resistant at temperatures under the thermal maximum" which was 32°C. Baker et al. 1993 reported that the differences in saturation tolerance between 19 strains from 10 Phytoseiidae species were sometimes larger when comparing strains than when comparing species. Croft et al. 1993 reported that humidity tolerances for the mites they studied related to the geographic and host plant distributions from which the predators where collected.

Much research is needed in selecting a suitable species or combination of species for release in different situations. A number of papers have been published comparing multiple releases or interactions between various species of predatory mites. Yao and Chant (1989) found that in laboratory arenas, *Iphiseius (=Amblyseius) degenerans* displaced *P. persimilis* after 70 days. The results of these studies suggested that *A. degenerans* were feeding on *P. persimilis*. When dispersal to other arenas was allowed *P. persimilis* survived well but not *I. degenerans*. In this instance the authors that the decline in *I. degenerans* was due to its sedentary tendency and lack of alternate food sources in the system. In another study (Brodsguard & Hansen 1992), *N. barkeri* outcompete *N. cucumeris* when released on greenhouse cucumbers to control thrips. Ehler (1992) compared single (*P. persimilis*) versus multiple species (*P. persimilis*, *P. longipes*, *G. occidentalis* and *A. californicus*) releases for their impact on *T. urticae* infested beans in a small garden. Although the data suggested that the multiple release treatment was much more efficacious that the treatment with only *P. persimilis* the author suggests that the results are equivocal. It is obvious, as Ehler states, more research is needed.

One must be careful with mixing predators without a knowledge of how they might interact. As an example, Kabicek 1995, demonstrated that *N. barkeri* fed on larvae and eggs of *P. persimilis*. Cloutier & Johnson (1993) demonstrated that *Orius tristicolor*, a predator often used to manage thrips, would kill *P. persimilis* in significant numbers even when thrips where available. The impact of this feeding should be evaluated in the context within which they will be used. Multiple predators could

dampen the oscillations observed in some of the *P. persimilis-T. urticae* systems by switching prey once the preferred hosts begin to become scarce. This must be evaluated because it is simply conjecture at this point.

5. **Quality control.** A serious new problem has developed in the last few years. Many of the predatory mites available commercially and being sold have failed to perform. Poor establishment, lowered reproduction, and failure to manage the target pests have been observed in our laboratory and reported by growers. The problem was particularly severe in Alberta, Canada where growers have considerable experience using biological controls in greenhouses. In 1990, trials were conducted in Alberta to assess the health and performance of commercially available biological control agents (Steiner 1993). The parameters evaluated for *P. persimilis* were the percentage alive and with eggs on arrival, daily egg production of females, and survival over a seven day period. Mites were obtained from 1 Canadian and 2 European sources (total of 16 shipments). Mites from these shipments were also evaluated for microbial infections.

Calcium crystals were found using light microscopy and were found mostly within the Malpighian tubules and to a lesser degree in the digestive tract, cytoplasm, and legs. This condition is associated with a condition called "White Gut" which typifies cultures that perform poorly. *P. persimilis* from different suppliers as well as in different shipments from the same supplier contained differing amounts of contamination with microorganisms. Bacteria were only found in dead or moribund individuals leading the author to the conclusion that they were secondary invaders and not primary pathogens. Almost all mites were infested with coccoidal microorganisms but they were not definitively identified. Rickettsia were present particularly in eggs and early nymphal stages which coincide with reports of populations in Eastern Europe being infested with *Rickettsiella phytoseiuli* (Sutakova & Arutunyan 1990, Shutyakova et al. 1992, Sutakova 1994). Fungi and fungal spores were found only in small amounts and infections were rare. Microsporida spores from more than one species were found in samples from all suppliers. An "Israeli" strain of *P. persimilis* had the highest incidence of infection of both microsporida and rickettsia. The authors speculate that their addition to other cultures may have contributed to their contamination. No occluded virus was identified.

Quality control and pure cultures are critical to the implementation of reliable control programs. These issues are now being addressed by reputable firms engaged in the commercialization of biological controls.

Another significant problem with the use of predators is, in general, the difficulty experienced in mass-rearing them for release. However, some of them are easier to rear than others. For example, thrips have become more important in greenhouses during the last few years and phytoseiids in the genus *Neoseiulus* (=*Amblyseius*) have been evaluated in Europe for thrips control (Bonde 1989). One of the advantages to using these predators is they can be mass-reared easily on a flour mite which can be reared in substantial quantities on wheat bran (Hussey 1985).

6. **Multiple Cropping.** Growing more than one plant type in a greenhouse or even on the same bench is a common practice. Large monocultures, which are common in most of agriculture, are the exception in the ornamental industry. In Florida, some growers produce over a hundred different plant species and cultivars. This situation greatly complicates the development of pest control programs regardless of which tactics are used to manage the pest populations. Each species of plant has its own unique pest complex and its own sensitivities to environmental conditions, including phytotoxic reactions to pesticides. Mixed cropping can prevent the development of a single comprehensive control program that can be applied to an entire greenhouse: each crop must have its own unique program.

How do mixed cropping systems affect the utility of biological control? An example would be the production of croton and ivy in close proximity to each other. Crotons (*Codiaeum variegatum* (L.)

Blume) are predominantly attacked by spider mites when grown in commercial greenhouses whereas ivy is attacked by *Aphis gossypii* Glover and the silverleaf whitefly (SLWF) *Bemisia argentifolii* Bellows & Perring (= B. tabaci - Strain B). We have tools to manage whiteflies and mites on these crops but the limiting factor is the control of aphids. The chemicals commonly used to control the resistant strains *A. gossypii* (methomyl, diazinon or tank mixes of acephate and a pyrethroid) are extremely toxic to the predators of *T. urticae* and parasitoids of *B. argentifolii*. Therefore managing aphids on ivy results in chemical disruption on ivy and on nearby croton as the result of drift and/or vaporization of pesticides. What can be done to prevent this? The most obvious solution would be to physically separate the crops. The distance will depend on the spray equipment and pesticide used. Another method would be to use materials that are less disruptive to the biological control agents. We have preliminary information on certain compounds that could be used in an integrated fashion, but these have not been evaluated in large plot trials in commercial greenhouses to validate our small plot results.

7. **Sampling.** The development of efficient control programs for mites in any system will require the development of action thresholds and sampling programs. In such crops as cucumber Anonymous 1976a, Hussey & Parr 1963, foliage plants (Hamlen 1980), and tomato (Anonymous 1976b, French et al. 1976, Nihoul 1993; Nihoul & Hance 1993), and roses (Jesiotr 1978, Boys & Burbutis 1972, Sanderson & Zhang 1995) progress has been made toward these ends. Unfortunately, this will continue to be a significant and limiting factor considering the vast numbers of plant species grown in greenhouses and attacked by mites. Jones (1990) discussed the potential for developing generic sampling plans which would "speed technology transfer from larger, better-studied systems to minor crop systems. The results of his studies obtained from various plant species were similar to those obtained by Sanderson & Zhang (1995) for greenhouse grow roses that were either sprayed or not.

8. **New Pests.** The most disruptive factor for our development of IPM programs would be importation of new pests or elevation of secondary pests to a primary status as has occurred in recent years with the silverleaf whitefly (*B. argentifolii*), western flower thrips (*Frankliniella occidentalis* (Pergande)), melon thrips (*Thrips palmi* Karny), and banana moth (*Opogona sachari*). These perturbations occur in most growing regions of the world, but they become much more pronounced in southern climates. The lack of crop/host free periods in both the greenhouse and environs surrounding production facilities results in the continuous infestation/re-infestation by phytophagous insects and mites. The greenhouse can be characterized as an optimal environment for pest development which is constantly disrupted either chemically or through the movement of vast quantities of plant materials. Transient arthropods quickly become established once they enter the greenhouse because they are, in general, protected from their natural enemies and there are often large quantities of diverse plant materials which can be used as food.

9. **Attractiveness of short-term , quick fix methods.** Another problem facing all of agriculture is the attractiveness of short-term or quick fixes. An example is the control of *T. urticae* on greenhouse-grown foliage plants. Prior to the registration and wide spread use of abamectin, a major interest was expressed in the use of *P. persimilis* to control this severe mite pest by many growers throughout Florida. Chemical control was becoming more and more unreliable and the growers were reaching what might be called the "crisis phase" in the progression towards the development of biological control implementation. Abamectin was introduced and was so effective that many growers lost interest in alternative control tactics. In the past few years, mite control has become increasingly more difficult. Some chemicals have been removed from the market and many growers feel that *T. urticae* and *P. latus* are resistant to abamectin. We are again entering a crisis phase and growers have renewed their demand for biological means to control both *T. urticae* and *P. latus*.

It remains to be seen what will happen with *B. argentifolii* once a few of the new and very efficacious experimental compounds reach the market place as registered pesticides. We speculate that the interest/demand for biological control of *B. argentifolii* will significantly be reduced until such time as we begin to see resistance problems develop or until we can educate the agricultural community that biological control is the cornerstone of a pesticide resistance management program.

With respect to the current situation in many commercial greenhouses in Florida, there is a critical need for integrating biological control agents with existing cultural and chemical controls. Several forces create this need but it appears that the major one is value of preserving the current chemicals that are safe, effective and registered. These chemicals have to be considered a valuable resource and managed appropriately. Development of pesticide resistance to the materials is of utmost concern. The use of biological controls during specific phases in the production of ornamental plants will aid in our efforts to slow the onset of resistance in some of the target pests.

Although there are many obstacles, biological control programs for ornamentals are a viable technique that must receive additional funding and research so that they can be integrated with other methods for managing pests of ornamentals.

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