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Management of Plant-Feeding Mites in Interior Plantscapes

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ABSTRACT

Plants grown in greenhouses, conservatories, and interiorscapes are susceptible to many different types of plant-feeding mites. Although there are a diversity of mite species that may feed on ornamental plants grown or used in interior plantscapes this paper focuses on three major species: twospotted spider mite (*Tetranychus urticae*), broad mite (*Polyphagotarsonemus latus*), and cyclamen mite (*Steneotarsonemus pallidus*). These mites are polyphagous and cause damage by withdrawing plant cell contents with their stylet-like mouthparts inducing stippling, bronzing, or leaf distortion, depending on the mite type. Cultural control of mites includes irrigation, fertility, and host plant resistance. The use of biological control has been successful in cut flower greenhouses such as roses (*Rosa* spp.) using the predatory mites *Phytoseiulus persimilis*, *Neoseiulus californicus*, and *Amblyseius fallacis*. However, the primary method of managing mites, especially in greenhouses, involves applications of miticides. Currently, there are many miticides available for control of twospotted spider mite with variable modes of action, whereas fewer miticides are available for control of broad and cyclamen mite. Due to their biology, genetics, and reproductive capacity, twospotted spider mite can develop resistance to miticides within a short period of time, which means that proper rotation programs, based on mode of action, must be implemented in order to sustain effective miticides. The availability and extensive use of neonicotinoid-based insecticides, in particular imidacloprid, that provide control of phloem-feeding insects such as whiteflies, aphids, and mealybugs may be responsible for the increase in twospotted spider, broad and cyclamen mite populations on many ornamental crops. Although plant-feeding mites have been and continue to be a problem in interior plantscapes, there are several pest management strategies that may be implemented in order to alleviate problems with these mite types.

Keywords: Greenhouse, conservatory, interiorscape, pest management, miticides, biological control, twospotted spider mite, broad mite, cyclamen mite

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INTRODUCTION

Plant-feeding mites are problematic arthropod pests in interior plantscapes such as greenhouses, conservatories, and interiorscapes (van de Vrie *et al*. 1972). If left unchecked, populations can reach excessive levels within a short period of time (Helle and Sabelis 1985; Zhang 2003). There are a number of different mite species that attack ornamental plants; however, mites that are a major concern in interior plantscapes include the twospotted spider mite (*Tetranychus urticae* Koch), broad mite (*Polyphagotarsonemus latus* Banks), and cyclamen mite (*Steneotarsonemus pallidus* Banks). All three have a very broad host range including herbaceous annuals, perennials, and woody ornamentals.

BIOLOGY, FEEDING AND DAMAGE

Twospotted spider mite

Twospotted spider mite feeds on over 300 plant species grown in greenhouses, and occurs in conservatories and interiorscapes (Jeppson *et al.* 1975). They are small (1.6 mm in length) and adult females possess distinct black spots located on both sides of the body. Although the twospotted spider mite is, in general, yellow-green in color, color may vary depending on the host plant fed upon. Adult females lay spherical-shaped, translucent to pale colored eggs in clusters on the underside of leaves. Eggs hatch into yellow-green six-legged larvae, which quickly mature into eight-legged nymphs (deutonymphs and protonymphs). They turn a red-orange color prior to overwintering (Jeppson *et al.* 1975). Development from egg to adult is temperature dependent. Twospotted spider mite prefers hot, dry environmental conditions for development and reproduction. For example, twospotted spider mite can complete a life cycle in

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Invited Mini-Review

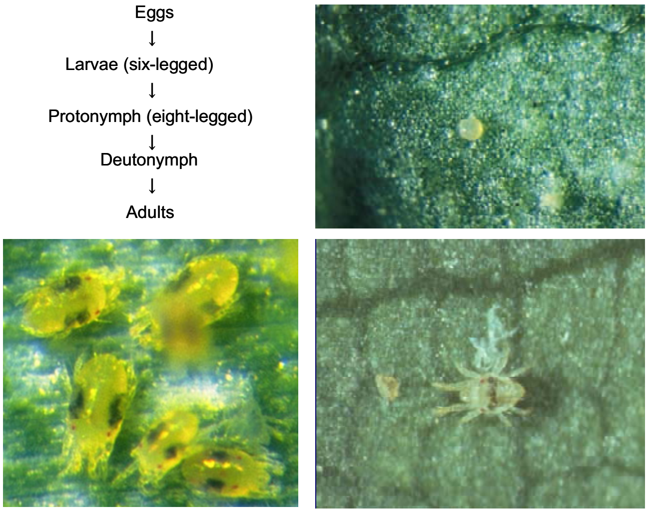

Fig. 1 Twospotted spider mite life stage.

less than a week at 30 to 32ºC. Females lay eggs several days after reaching the adult stage, laying >10 eggs per day, producing >100 eggs within a two-week period. The sex ratio is typically female-biased (3:1) (Laing 1969; Shih *et al.* 1976; Carey and Bradley 1982; **Fig. 1**).

Twospotted spider mite feeds within plant cells damaging the spongy mesophyll, palisade parenchyma, and chloroplasts thus reducing chlorophyll content and the plant's ability to photosynthesize. They prefer, but are not limited to, feeding on leaf undersides with their stylet-like mouthparts causing characteristic symptoms such as leaf bleaching, yellow stippling and bronzing of leaves (Lal and Mukharji 1979; Sances *et al.* 1979, 1982; Tomczyk and van de Vrie 1982). Twospotted spider mite may inject toxins into plants during feeding, resulting in an increase in phosphates translocated to the meristematic region (Storms 1971). Injury caused by twospotted spider mite feeding may lead to excessive water loss via transpiration (Atanasov 1973) due to disruption of the stomates (Sances *et al.* 1979). Twospotted spider mite may cause plant stomates to close, particularly on young leaves, decreasing CO_2 uptake, and reducing transpiration and photosynthesis (Sances *et al.* 1979; de Angelis *et al.* 1983a). Also, feeding by twospotted spider mite may result in an increase and/or decrease in the production of certain secondary plant constituents due to an acceleration of enzymatic reactions. This is likely due to the metabolic conversion of pulegone to menthal isomers resulting in an increase in the availability of soluble carbohydrates such as glucose-6-phosphate (de Angelis *et al.* 1983b). Twospotted spider mite feeding, in addition to affecting plant foliage, may result in the production of fewer and smaller flowers on ornamental plants such as roses (*Rosa* spp.) (Jesiotr 1978).

Heavy populations of twospotted spider mite will result in the production of webbing on the underside of leaves or on plant stems (Zhang 2003). Twospotted spider mite typically spread throughout a crop or among plants by crawling (McEnroe and Dronka 1971), although they may disperse by 'roping' or fall onto plants using webs they have created (Brandenburg and Kennedy 1982). This allows them to find host plants of higher nutritional quality. This scenario typically occurs with hanging baskets grown in greenhouses. Plants are located such that the ambient air temperature is warmer than the rest of the greenhouse. As twospotted spider mite populations increase, and plant quality declines, they fall onto plants located below the hanging baskets. Aerial dispersal of twospotted spider mite is not well understood although it appears that adult females may be dispersed via air currents (Smitley and Kennedy 1985). However, their dispersal response is dependent on density and plant nutritional quality (Suski and Naegele 1966; Bernstein 1984; Li and Margolies 1993). For example, on lima bean (*Phaseolus lunatus*) plants, dispersal was more prevalent at high twospotted spider mite female densities (8 females/cm^2) compared to low densities (3.5 females/cm^2), and dispersal increased two-fold when twospotted spider mite larvae had fed on poor quality leaves (Li and Margolies 1993). Twospotted spider mite tends to respond positively to increased fertility levels, particularly nitrogen (Henneberry 1962, 1963), since amino acids are essential for development and reproduction (Tulisalo 1971). Rodriguez (1964) and Watson (1964), for example, indicated that twospotted spider mite responds favorably, in terms of reproduction and population growth, to nitrogen and phosphorus concentrations; however, these responses occur at low to moderate concentrations whereas higher concentrations of nitrogen and phosphorus reduce population growth. Water-stressed plants undergo changes in the concentration of soluble sugars and amino acids thus increasing their nutritional value to twospotted spider mite (Tomczyk and Kropczynska 1985; Colijn and Lindquist 1986; Wermelinger *et al.* 1990).

Broad mite and cyclamen mite

Broad and cyclamen mite feed on a wide-variety of ornamental plants including begonia, cyclamen, fuchsia, Transvaal daisy (*Gerbera jamesonii*), and impatiens (Jeppson *et al.* 1975; Gerson 1992). They are major arthropod pests of *G. jamesonii* grown in greenhouses (Smith 1939). Broad and cyclamen mite require very different environmental conditions than twospotted spider mite. These mites tend to be a problem under cooler temperatures (around 15ºC) and higher relative humidities (70 to 80%), which are conducive for their development and reproduction (Jeppson *et al.* 1975). Both mites have similar developmental and reproductive potential; however, cyclamen mite females tend to lay fewer eggs (up to 16 eggs) than broad mite females (approximately 25 eggs). Broad and cyclamen mite feed on young foliage and floral parts such as flower buds retarding growth and preventing flowers from fully-developing (Smith 1939). Typical symptoms of feeding by broad and cyclamen mite include bronzing and distortion of plant leaves. Broad mite, in general, may cause more extensive damage to the entire plant than cyclamen mite. Excessive populations often lead to these mites feeding on both the upper and lower portions of the entire leaf surface. The presence of either broad or cyclamen mite is typically after plant injury is noticeable as opposed to actually finding the mites themselves (Smith 1939).

Broad mite adults are approximately 0.25 mm long, amber to dark-green in color, and oval in shape with a white strip extending down the back. Eggs are oval-shaped and covered with protrusions. Broad mite tends to feed on the underside of young leaves. Development from egg to adult takes less than one week, and females can lay up to 25 eggs (Jeppson *et al.* 1975; Cho *et al.* 1996; Gui *et al.* 1998). Broad mites may disperse within a greenhouse by attaching themselves to whiteflies, including the greenhouse (*Trialeurodes vaporariorum*), sweet potato (*Bemisia tabaci*), and silverleaf whitefly (*Bemisia argentifolii*), which is now synonymous with the sweet potato whitefly, *Bemisia tabaci* B-biotype (Parker and Gerson 1994; Fan and Petit 1998; Wu *et al.* 2000).

Cyclamen mite is also 0.25 mm long; however, the eggs are oval and smooth with no protrusions. Females are yellow-brown in color. The life cycle, from egg to adult, may be completed in 1 to 3 weeks depending on temperature. Cyclamen mite females can lay 1 to 3 eggs per day; potentially laying up to 16 eggs during the oviposition period. The sex ratio is female biased (2-5:1) (Jeppson *et al.* 1975; Zhang 2003). Similar to broad mite, cyclamen mite may be dispersed throughout a greenhouse by attaching to whiteflies. This may be the primary method by which cyclamen mite is distributed within a greenhouse. Symptoms of cyclamen mite feeding on *G. jamesonii* include bronzing and curling of leaves. Heavy-infestations may cause leaves to appear brittle, which turn brown to silver. In addition, distorted or twisted leaves are reduced in size (Smith 1939; Jeppson *et al.* 1975).

SAMPLING

Sampling is an important procedure that will determine the presence of particular twospotted spider mite life stages, which may assist in appropriately timing miticide applications. The best way to determine the extent of a twospotted spider mite infestation is to place a white sheet of paper (21.6 x 27.9 cm) underneath the leaves of infested plants and "lightly" brush or tap the branches of the plants. Twospotted spider mites will drop onto the white sheet of paper. A 10x hand-lens can then be used to assess the numbers of twospotted spider mites present (Dreistadt 2001). Sampling plans have been developed to assess density estimates of twospotted spider mite populations (Sanderson and Zhang 1995). For example, a binomial presence-absence sampling plan, which is used to assess twospotted spider mite population levels by counting twospotted spider mites on leaves as opposed to counting the total number of twospotted spider mites, was developed for ivy geranium (*Pelargonium peltatum*) in order to determine the population dynamics of twospotted spider mite and assist greenhouse growers in establishing thresholds (Karlik *et al.* 1995; Opit *et al.* 2003). However, sampling plans may vary especially because twospotted spider mite may be distributed differently based on plant species. On impatiens (*Impatiens walleriana*), a consistently higher percent of twospotted spider mites were detected in the intermediate leaf zone compared to the inner or other zones (Alatawi *et al.* 2005). Action thresholds, which are the number of insect or mite pests observed visually that warrant the implementation of a control strategy, are based on information obtained from sampling. Although minimal quantitative data is available, action thresholds have been determined for twospotted spider mite. For example, Jesiotr (1978) suggested an action or economic threshold of 0.5 twospotted spider mites per rose leaflet (=0.06 twospotted spider mites/cm^2), and an action threshold of 5 twospotted spider mites/leaf/week has been proposed for cut roses (Casey and Parrella 2002).

CONTROL

Twospotted spider mite

The foremost way to minimize problems with twospotted spider mite in interior plantscapes is the implementation of cultural control strategies, which includes removal of weeds and heavily-infested plants, and irrigation practices. Lindquist *et al*. (1987) showed that overhead misting, which increases relative humidity, decreased twospotted spider mite movement among the crop. The researchers hypothesized that misting increased the relative humidity creating an environment that is not favorable for twospotted spider mite. This may alleviate problems with twospotted spider mite in either greenhouses or conservatories. Overhead irrigation has been shown to be effective in reducing twospotted spider mite populations and thus feeding damage on impatiens, *I. wallerana* (Opit *et al.* 2006). However, non-overhead irrigation practices associated with a reduction in weight from container capacity had no effect on twospotted spider mite feeding on ivy geraniums, *P. peltatum* (Opit *et al.* 2001). Plants that are stressed due to lack of moisture tend to be more susceptible to twospotted spider mite than plants that receive routine irrigation. For example, schefflera (*Brassaia actinophylla*) plants that are moisture-stressed retain higher populations of twospotted spider mite than plants that are irrigated regularly (Colijn and Lindquist 1986). This response may be associated with the fact that when a plant is moisture-stressed, the cooling effects of transpiration are reduced resulting in an increase in leaf temperature (Chadhuri *et al.* 1986; Wermelinger *et al.* 1990; Stiefel *et al.* 1992).

Commercially-available miticides are typically used to control twospotted spider mite in interior plantscapes, particularly in greenhouses. The miticide, abamectin, which has been available since the 1980's and is widely-used by greenhouse producers, has provided effective control of twospotted spider mite (Sanderson and Zhang 1995; Zhang 2003). However, due to the frequency of use for >20 years, especially in California and Florida, twospotted spider mite populations are now less susceptible to abamectin (Zhang 2003). Continual reliance on miticides increases the probability of twospotted spider mite populations developing resistance to miticides (Dittrich 1975; Carbonaro *et al.* 1986). In fact, twospotted spider mite populations have developed resistance to a number of miticides including fenbutatin-oxide, tebufenpyrad, cyhexatin, clofentezine, hexythiazox, chlorfenapyr, etoxazole, pyridaben, and fenpyroximate (Carbonaro *et al.* 1986; Herron *et al.* 1993; Jacobson *et al.* 1999; Devine *et al.* 2001; Gorman *et al.* 2001; Uesugi *et al.* 2002). Additionally, certain insecticides may actually stimulate reproduction of twospotted spider mite. James and Price (2002) demonstrated that twospotted spider mite females laid up to 26% more eggs compared to the water control when exposed to plants treated (foliar and drench) with imidacloprid, which is a neonicotinoid-based systemic insecticide (Tomizawa and Casida 2003).

Many newer or currently introduced insecticides and miticides have a narrow spectrum of arthropod pest activity (Casey and Parrella 2002; Grafton-Cardwell *et al.* 2005), and a considerable number of these newer miticides are effective in controlling twospotted spider mite (Cloyd 2003, 2005). In addition, most of the miticides currently available have translaminar properties, which mean that the material penetrates the leaf cuticle and the active ingredient resides within the leaf tissue including the spongy mesophyll and palisade parenchyma cells, providing a reservoir of active ingredient. Twospotted spider mites that feed on the leaves, even after spray residues have dried, may still ingest enough active ingredient to kill them. The miticides currently available also have very distinct modes of action, which allows greenhouse producers, conservatory curators, and interiorscapers to develop sustained rotation programs that minimize the potential for twospotted spider mite populations developing resistance.

Essential oils or oils derived from plants have been evaluated to determine their efficacy against twospotted spider mite. For example, certain monoterpenes are toxic to twospotted spider mite (Lee *et al.* 1997), and peppermint phenolics have been shown to affect the fecundity and development of twospotted spider mite (Larson and Berry 1984). Research conducted under laboratory conditions demonstrated that extracts of *Kochia scoparia* were toxic to twospotted spider mite (Shi *et al.* 2006). Further studies have demonstrated that twospotted spider mite is susceptible to oil extracts of sweet basil (*Ocimum basilicum*) and French lavender (*Lavandula officinalis*) (Refaat *et al.* 2002); mint (*Mentha virdis*) and peppermint (*Mentha piperita*) (Momen *et al.* 2001); spearmint (*Mentha spicata*), lemon eucalyptus (*Eucalyptus citriodora*), and pennyroyal (*Mentha pulegium*) (Choi *et al.* 2004); lambsquarters (*Chenopodium ambrosioides*) (Chiasson *et al.* 2004); and sage (*Salvia officinalis*) (Kawka and Tomczyk 2002).

In addition to essential oils, several other plant-derived insecticides have been evaluated for controlling twospotted spider mite. Azadirachtin, which is derived from the seeds of the Indian tree (*Azadirachta indica*) (Schmutterer 1990), at high concentrations (>64 ppm), negatively affected fecundity and survival (based on adult longevity) but failed to impact fertility and offspring development (Martinez-Villar *et al.* 2005). Extracts derived from garlic (*Allium oleraceum*) have been shown to be inadequate repellents against twospotted spider mite (Boyd and Alverson 2000).

Insecticidal soaps that are registered for use in greenhouses and typically derived from potassium salts of fatty acids oftentimes are recommended for control of twospotted spider mite in non-refereed publications such as extension fact sheets, trade journal articles, and reference books (Olkowski *et al*. 1991) despite the fact that minimal quantitative data exist regarding efficacy. However, Osborne (1984) demonstrated that insecticidal soap was comparable with a standard miticide in controlling twospotted spider mite. Even inert ingredients, either carriers or surfactants, which are used during the formulation process of certain insecticides or miticides may kill mites. For example, certain organosilicone-based surfactants have been shown to have miticidal properties (Cowles *et al.* 2000).

An alternative management approach for dealing with twospotted spider mite is the use of predatory mites in the family Phytoseiidae. The primary predatory mite utilized in interior plantscapes is *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) (Simmonds 1972; Hamlen and Lindquist 1981; Zhi-Quiang and Sanderson 1995; Workman and Martin 2000). However, there are a number of alternative predatory mite species that may be used including *Neoseiulus californicus* McGregor (Acari: Phytoseiidae), *Amblyseius* (=*Neoseiulus*) *fallacis* Garmen (Acari: Phytoseiidae), and *Galendromus occidentalis* Nesbitt (Acari: Phytoseiidae) (McMurtry 1982; McMurtry and Croft 1997). Since conservatories and interiorscapes are environments with constant public traffic, they tend to rely more on the use of predatory mites for controlling twospotted spider mite, which avoids exposing the public to miticide residues or odors. Release rates of predatory mites may vary depending on the twospotted spider mite density and crop species. Opit *et al.* (2005) recommended a release rate of 1:4 (predator:prey) for *P. persimilis* on ivy geranium (*P. peltatum*) and Simmonds (1972) indicated that releases of 2, 5, or 10 *P. persimilis* per rose (*Rosa* spp.) bush were sufficient enough to reduce populations of twospotted spider mite.

Predatory mites, by themselves, however, may not be able to maintain twospotted spider mite populations below damaging levels (Burnett 1979; Helle and Sabelis 1985), which is the reason why there is an emphasis to integrate miticides with predatory mites. Research has shown that certain miticides are non-toxic to different predatory mite species. For example, Cloyd *et al.* (2006) demonstrated that the miticides chlorfenapyr, spiromesifen, and bifenazate were not harmful to *N. californicus*; however, these same miticides were toxic to *P. persimilis*. Cote *et al*. (2002) found that even 14 day-old residues of chlorfenapyr were harmful to *P. persimilis*. This indicates that the potential toxic effects of miticides are dependent on the predatory mite species. Studies have demonstrated that certain insecticides/miticides such as hexythiazox (Blumel and Gross 2001), azadirachtin (Spollen and Isman 1996), and abamectin (Zhi-Qiang and Sanderson 1990) are not harmful to *P. persimilis* under laboratory conditions.

Host plant resistance or using plants or plant cultivars that are naturally tolerant of twospotted spider mite is not being implemented as much as it should be in interior plantscapes. Breeding programs, in general, focus on the horticultural characteristics of plants such as flower color, floral scents, and leaf-variegation with minimal emphasis on twospotted spider mite resistance, which in the long-term may lead to a reduction in the use of miticides. Host plant resistance has been evaluated in zonal geranium (Chang *et al.* 1972; Gerhold *et al.* 1984) and impatiens (Al-Abbasi and Weigle 1982). Studies designed to assess the potential of host plant resistance for managing twospotted spider mite have demonstrated that certain geraniums (*Pelargonium* spp.) are less susceptible to twospotted spider mite feeding (Snetsinger *et al.* 1965 Potter and Anderson 1982). In their study, Opit *et al.* (2001) showed that the ivy geranium cultivar 'Amethyst 96' was more susceptible to twospotted spider mite feeding than 'Sybil Holmes.' The variations observed between the two cultivars may be correlated with differential phosphorus concentrations. It has been demonstrated that zonal geraniums, *Pelargonium hortorum* possess hair-like appendages or trichomes on leaves and stems that exude a sticky substance containing unsaturated anacardic acids, which trap twospotted spider mite (and other insects) inhibiting movement and female reproduction. However, only certain geraniums secrete these unsaturated anacardic acids whereas other species exude a saturated form that is dry, which has no effect on twospotted spider mites (Snetsinger *et al.* 1965; Chang *et al.* 1972; Gerhold *et al.* 1984).

Broad mite and cyclamen mite

The predatory mite, *Neoseiulus barkeri* Hughes (Acari: Phytoseiidae) has been used successfully in controlling broad mite populations (Fan and Petitt 1994; Pena and Osborne 1996). Miticides with translaminar properties such as abamectin and chlorfenapyr are typically recommended for control of broad mites since they are normally protected from contact miticides. Preventative applications are required, particularly on those crops that are susceptible; because once damage is evident it may be too late to control broad mite. Removing plants that are exhibiting symptoms, and those surrounding symptomatic plants, is always recommended to prevent the spread of broad mite within a crop.

Cyclamen mite control is similar to broad mite in that miticides with translaminar activity are preferred over contact miticides. The predatory mites, *Neoseiulus* (=*Amblyseius*) *cucumeris* Oudemans (Acarina: Phytoseiidae) and *N. californicus* have been used to control cyclamen mite in greenhouses. It has been demonstrated that immersing plants in hot water (15ºC for 7 minutes) kills cyclamen mites residing on plants; however, this treatment may injure certain plant species (Croft *et al.* 1998; Easterbrook *et al.* 2001; Petrova *et al.* 2002).

There has, in general, been an increase in twospotted spider, broad, and cyclamen mite populations on a variety of ornamental plants, even those that were not initially considered susceptible. A possible explanation for the increase in these mite species may be due to the extensive use or reliance on neonicotinoid-based insecticides, including imidacloprid, that are used to control phloem-feeding insects such as aphids, whiteflies, and mealybugs (Tomizawa and Casida 2003). Although these insecticides, which have systemic activity and are typically applied to the growing medium as drenches, are effective against phloem-feeding insects they do not control mites (James and Price 2002). Prior to the introduction of the neonicotinoid-based insecticides, greenhouse producers typically applied broad-spectrum insecticides/miticides including aldicarb and oxamyl to control the diversity of arthropod pests encountered in greenhouses. In addition to providing control of the target pest(s) these insecticide/miticide applications in all likelyhood indirectly maintained twospotted spider, broad, and cyclamen mite populations below damaging levels. As such, the absence of applying these broad-spectrum insecticides/miticides and relying more on neonicotinoid-based insecticides may have allowed twospotted spider, broad, and cyclamen mite populations to escape selection pressure and build-up to damaging levels.

Twospotted spider mite, broad mite, and cyclamen mite will continue to be a problem in interior plantscapes although populations may fluctuate depending on the plant species, plant age, plant quality, and environmental conditions. Currently, there are a number of highly effective miticides for twospotted spider mite whereas there are fewer miticides available for broad and cyclamen mite although more miticides are including both these mite pests on the label; however, efficacy data is minimal or lacking. In addition, globalization or the movement of plants from offshore growing facilities in other regions of the world such as South America will contribute to the potential of introducing these mite pests into interior plantscapes.

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