Tank Mixing Revisited

Recent quantitative research takes a close look at what pesticide mixtures growers are currently adopting. While popular for its potential to improve pest control, growers should approach tank mixing with caution.

By Raymond Cloyd

Growers mix a wide variety of pesticides in hopes of achieving success not found with separate applications. (Photos: Raymond Cloyd)

Pesticides — in this case, insecticides and miticides — are used primarily to control arthropod pests encountered in greenhouse production systems. These include greenhouse whitefly, sweet potato whitefly B biotype, green peach aphid, two-spotted spider mite, western flower thrips, American serpentine leafminer and citrus mealybug.

However, federal rules and regulations, such as the Food Quality Protection Act (FQPA), and manufacturers' voluntary withdrawal or cancellations have resulted in the continual loss or registration changes associated with "older" or conventional, broad-spectrum pesticides, particularly in the organophosphate and carbamate chemical classes. This has led to an increase in the development and availability of alternative pesticides that are more selective or control a narrower spectrum of arthropod pests compared to conventional pesticides.

Examples of alternative pesticide groupings include insect growth regulators; insecticidal soaps; horticultural oils; selective feeding inhibitors (blockers); microbial agents, such as beneficial bacteria and fungi; and related micro-organisms (e.g., spinosad). In addition to their selectivity, many of these alternative pesticides are less toxic to humans, leave minimal residues, are short-lived in the environment and have minimal impact on natural enemies, including parasitoids and predators. Although the availability of pesticides that demonstrate selectivity may be desirable, this presents a dilemma when dealing with multiple arthropod pest populations in greenhouses.

To regulate or control the myriad arthropod pests such as thrips, aphids, fungus gnats, leafminers, whiteflies, mealybugs and spider mites that feed on ornamental crops, greenhouse producers will mix together two or more pesticides, including conventional and alternative insecticides or miticides, into a single spray solution, which expands the activity of the application. As such, it may be necessary to tank mix two or more pesticides to obtain the same spectrum of control for multiple arthropod pests that a single broad-spectrum pesticide might provide. To further complicate matters, fungicides are sometimes added to tank mixtures to help manage plant diseases.

There is relatively minimal information currently available on the effect of pesticide mixtures in controlling arthropod pests typically encountered in greenhouses. There is no data or assessment pertaining to the types of pesticide mixtures (two- and three-way combinations) that greenhouse producers use to control arthropod pests. As such, we decided to survey greenhouse producers at two conferences in 2007 and one in 2008, during which the author gave presentations on the fundamentals of tank mixing, to determine the most widely used pesticide mixtures among the participants.

Survey Distribution and Completion

We distributed pesticide mixture evaluation forms during three sessions at two conferences in 2007: The OFA Short Course on July 14, 2007, in Columbus, Ohio; and the Greenhouse Experience Conference on Sept. 10, 2007, in Cleveland. The forms also went out at the Society of American Florists' Conference on Pest and Disease Management in Ornamentals on March 1, 2008, in Atlanta.

The evaluation forms were provided prior to the start of each session and asked for the respondents' four most common pesticide mixtures, and for what specific insect or mite pests. There were approximately 200 participants in attendance for all three sessions, and although not all the participants in the three sessions were affiliated with greenhouse production, a majority — greater than 80 percent — were greenhouse producers.

Partial results of the survey are summarized in Table 1 (opposite) and represent the first quantitative assessment to determine the pesticide mixtures conducted by greenhouse producers. (A full version of the table is available at www.gpnmag.com.)

A total of 45 fully completed evaluation forms were assessed; although 12 of the evaluation forms did not contain the arthropod pests targeted for the specific pesticide mixtures, they were still included in the results. The evaluation form specifically stipulated that only pesticide mixtures involving insecticides and miticides be

Top 25 Pesticide Mixtures from Survey Results

TRADE NAMES	COMMON NAMES	ARTHROPOD PEST(S)	COUNT
Two-Way Mixtures			
Avid + Talstar	Abamectin + Bifenthrin	Mites, whiteflies, mealybugs and aphids	8
Avid + Conserve	Abamectin + Spinosad	Thrips, aphids, and spider mites	6
Avid + Ornazin/Azatin	Abamectin + Azadirachtin	Thrips, spider mites, aphids and whiteflies	6
Orthene + Tame	Acephate + Fenpropathrin	Thrips, caterpillars, whiteflies and aphids	6
Conserve + Endeavor	Spinosad + Pymetrozine	Aphids, thrips, and caterpillars	5
Conserve + Pedestal	Spinosad + Novaluron	Thrips	4
Avid + Endeavor	Abamectin + Pymetrozine	Aphids and mites	3
Conserve + Floramite	Spinosad + Bifenazate	Thrips and mites	3
Avid + Flagship	Abamectin + Thiamethoxam	Aphids, mites and whiteflies	2
Avid + Floramite	Abamectin + Bifenazate	Thrips and mites	2
Avid + Marathon	Abamectin + Imidacloprid		2
Avid + Mavrik	Abamectin + Fluvalinate	Aphids and mites	2
Avid + TetraSan	Abamectin + Etoxazole	Spider mites	2
Avid + Ultra-Fine Oil	Abamectin + Paraffinic oil	Spider mites	2
Cleary's 3336 + Subdue	Thiophanate-methyl + Metalaxyl	Pythium and thrips	2
Conserve + Flagship	Spinosad + Thiamethoxam	Aphids, whiteflies and thrips	2
Conserve + Marathon II	Spinosad + Imidacloprid		2
Enstar II + Mavrik	Kinoprene + Fluvalinate	Mites, aphids and mites	2
Hexygon + Pylon	Hexythiazox + Chlorfenapyr	Spider mites	2
Ornazin/Azatin + Talstar	Azadirachtin + Bifenthrin	Fungus gnats, shore flies and whiteflies	2
Three-Way Mixtures			
Acephate + Azatin + Tame	Acephate + Azadirachtin + Fenpropathrin		1
Avid + Azatin + Pipron	Abamectin + Azadirachtin + Piperalin		1
Avid + Conserve + Decathlon	Abamectin + Spinosad + Cyfluthrin	Thrips, mites and aphids	1
Avid + Conserve + MilStop/Compass	Abamectin + Spinosad + Potassium bicarbonate/Trifloxystrobin		1
Avid + Daconil + Marathon II	Abamectin + Chlorothalonil + Imidacloprid		1

Common name = Active ingredient
Neem oil = Clarified hydrophobic extract of neem oil
Btk = Bacillus thuringiensis spp.. *kurstaki*
Lure = Attractant
Adjuvant (spray) with the active ingredient: blend of polyether-polymethylsiloxane-copolymer and nonionic surfactant

Table 1. *Results of pesticide mixture survey indicating two-, three- and four-way combinations used by the participants. Evaluation forms were distributed at two conferences in 2007 and one in 2008. Forty-five of the 200 distributed surveys were returned.*

included, but 13 participants included pesticide mixtures with fungicides. The return rate of the evaluation forms was 22.5 percent (45 out of 200), which may be considered a small sample size; however, the information gathered is useful in determining the extent of what pesticide mixtures are being used by greenhouse producers.

Survey Results

The two-way tank mixture cited most often on the evaluation forms — a total of eight times — was the combination of abamectin (Avid: Syngenta Professional Products) + bifenthrin (Talstar: FMC Corp.) for control of mites, whiteflies, mealybugs and aphids. The other two-way tank mixtures, cited six times by survey respondents, were abamectin + spinosad (Conserve: Dow AgroSciences); abamectin + azadirachtin (Azatin: OHP, Inc., and Ornazin: SePRO Corp.); and acephate (Orthene: Valent U.S.A. Corp.) + fenpropathrin (Tame: Valent U.S.A. Corp.). The two-way tank mixtures of spinosad + pymetrozine (Endeavor: Syngenta Professional Products); and spinosad + novaluron (Pedestal: OHP, Inc.) were cited five and four times, respectively. The chlorfenapyr (Pylon: OHP, Inc.) + acetamiprid (TriStar: Cleary Chemical Corp.) two-way mixture has been shown to provide 86 percent mortality of sweet potato whitefly B biotype nymphs 14 days after application.

All the commercially available miticides labeled for use in greenhouses and the two-spotted spider mite life stages (e.g., larva, nymph and adult) they are most active on are presented in Table 2 (page 24). A number of the miticide tank mixtures listed in Table 1 were legitimate based on the life stage activity of the active ingredients: abamectin + etoxazole (TetraSan: Valent U.S.A. Corp.), hexythiazox (Hexygon: Gowan Co.) + chlorfenapyr, and abamectin + clofentezine (Ovation: Scotts-Sierra Crop ➧

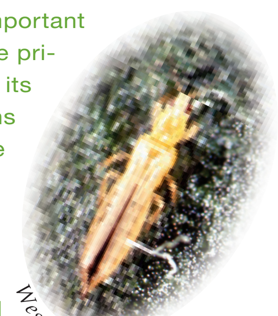
Popular Pesticides

Abamectin and spinosad were the pesticides most often included in two-way (abamectin was cited 15 times, and spinosad was mentioned 17 times) and three-way (nine mentions for abamectin and seven for spinosad) mixtures.

Both pesticides are labeled for control of Western flower thrips, one of the most important insect pests of greenhouses. In fact, after commercialization in 1998, spinosad is the primary pesticide used by greenhouse producers to control western flower thrips due to its effectiveness against this insect pest although there are now concerns regarding resistance. Abamectin, which has been available since 1980, is commonly used by greenhouse producers to control the two-spotted spider mite, a major arthropod pest of greenhouses.

Several of the two-way mixtures with spinosad including spinosad + abamectin, spinosad + bifenazate (Floramite: OHP, Inc.), and spinosad + imidacloprid (Marathon II: OHP, Inc.) did not affect control of western flower thrips.

Two-spotted spider mite



Western flower thrip

Protection Co.) in Table 2. However, the following miticide tank mixtures listed in Table 1 were questionable because of similar life-stage activity of the active ingredients: fenpyroximate (Akari: SePRO Corp.) + clofentezine, fenpyroximate + etoxazole, abamectin + chlorfenapyr, bifenazate + etoxazole, and hexythiazox + spiromesifen (Judo: OHP, Inc.) in Table 2.

One pesticide mixture that was difficult to interpret was the thiophanate-methyl (Cleary's 3336: Cleary Chemical Corp.) and metalaxyl (Subdue: Syngenta Professional Products) mixture for control of thrips, which received two counts. Both are fungicides with no insecticidal activity. The four-way pesticide mixture of abamectin + spinosad + bifenazate + myclobutanil (Eagle: Dow AgroSciences) was listed for control of mites, aphids, thrips and powdery mildew. However, spinosad is not active on aphids or mites,and abamectin is labeled only for aphid suppression. A pesticide specifically labeled for and with demonstrated efficacy on aphids should have been included in the mixture.

Studies have evaluated the effect of tank mixing pesticides on efficacy against western flower thrips, two-spotted spider mite and sweet potato whitefly B biotype. One study demonstrated that mixing the spinosad with other insecticides and miticides (imidacloprid, abamectin and bifenazate) in two-, three- and four-way mixtures did not negatively affect the ability of spinosad to control western flower thrips. Another study evaluated the effect of tank mixing the insecticides and miticides buprofezin (Talus: SePRO Corp.), acetamiprid, chlorfenapyr and bifenazate in two-, three- and four-way mixtures on the control of two-spotted spider mite and sweet potato whitefly B biotype. Overall, most of the tank mixtures did not affect control of either pest. However, the buprofezin + chlorfenapyr, and acetamiprid + ➧

Activity of Commercially Available Miticides

Active Ingredient	Trade Name	Activity Type*	Eggs	Larvae	Nymphs	Adults
Abamectin	Avid	T and C		X	X	X
Acequinocyl	Shuttle	C	X	X	X	X
Bifenazate	Floramite	C	X	X	X	X
Chlorfenapyr	Pylon	T and C		X	X	X
Clofentezine	Ovation	C	X	X	X	
Etoxazole	TetraSan	T and C	X	X	X	
Fenbutatin-Oxide	ProMite	C		X	X	X
Fenpyroximate	Akari	C	X	X	X	X
Hexythiazox	Hexygon	C	X	X	X	
Pyridaben	Sanmite	C	X	X	X	X
Spiromesifen	Judo	T and C	X	X	X	

**Activity Type Codes: C = Contact, T = Translaminar*

Table 2. *Activity of commercially available miticides for use in greenhouses and the life stages of two-spotted spider mite,* Tetranychus urticae, *on which they are most effective.*

chlorfenapyr + bifenazate tank mixtures resulted in lower sweet potato whitefly B biotype nymphal mortalities (less than 38 percent) than the other tank mixtures.

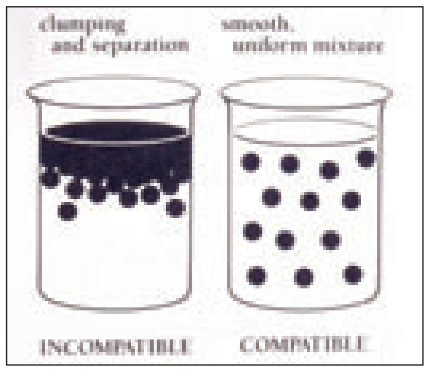
The survey results demonstrate that greenhouse producers mix together a diverse group of pesticides. However, it is not known where or how greenhouse producers get the idea to use specific products in pesticide mixtures. Tank mixing pesticides is popular because of the potential for improved pest control. But although there are benefits to tank mixing, there are several issues — discussed below in more detail — that growers should consider beforehand. It also is essential to consider *why* certain pesticides are being mixed together.

Greenhouse producers need to develop tank mixtures based on the developmental life stage of each pesticide's target pest. For example, tank mixing two products that have miticidal properties, such as abamectin + bifenazate, is not recommended because both are active on the adult stage of the two-spotted spider mite (Table 2). However, tank mixing abamectin with either clofentezine or etoxazole is appropriate because abamectin is primarily active on adults whereas clofentezine or etoxazole are active on the eggs, larvae and nymphs (Table 2). These tank mixtures target all life stages of the two-spotted spider mite.

Considerations for Tank Mixes

A concern when tank mixing pesticides is the potential to increase the concentration of surfactants. Many pesticides already contain an adjuvant or surfactant as a component of the formulation. However, at higher concentrations, surfactants may be harmful or phytotoxic to plants. As such, greenhouse producers need to be aware of the consequences of increasing the surfactant concentration when mixing pesticides.

Another consideration is the need to tank mix pesticides with different modes of action. For example, although pyridaben (Sanmite: Scotts-Sierra Crop Protection Co.) and fenpyroximate are in different chemical classes: pyridazinone and phenoxypyrazole, respectively. They have the same mode of action: mitochondria electron transport inhibitors (METIs), which disrupt the production of energy or adenosine triphosphate (ATP). As such, these two pesticides should



A "jar test" helps determine whether two pesticides are incompatible (evidenced by noticeable separation or layering) or compatible (evidenced by homogeneous appearance)

not be mixed together in a spray solution. Similarly, acephate and methiocarb (Mesurol: Gowan Co.), despite being in different chemical classes (organophosphates and carbamates), have identical modes of activity. The active ingredient blocks the action of acetylcholinesterase (AChE), an enzyme that deactivates acetylcholine (ACh), which is responsible for activating receptors that allow nerve signals to travel through the central nervous system. The active ingredients in both pesticides inhibit or block the action of AChE by attaching to the enzyme. So, tank mixing these pesticides should be avoided because this exposes the insect pest population to the same mode of action, which may result in the development of resistance. This is referred to as cross-resistance.

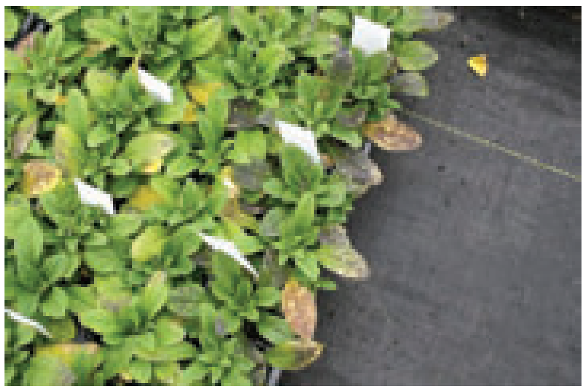
Benefits of Tank Mixes

Greenhouse producers often tank mix out of convenience — it is less time consuming, costly and labor intensive to mix together two or more pesticides into a single spray solution and then perform one application compared to two or more applications. Another reason for tank mixing is the potential for improved pest control or enhanced effectiveness. In fact, tank mixing two pesticides may result in greater mortality of arthropod pests than with separate applications.

Furthermore, tank mixtures may be more effective on certain developmental stages of arthropod pests. This type of activity is often referred to as synergism or potentiation. For example, tank mixing two different insecticides may result in higher mortality of insect pests, such as western flower thrips and certain whitefly species, than when the designated insecticides are applied separately.

In addition, insecticides containing the active ingredient ➧

azadirachtin and the insect-killing or beneficial fungus *Beauveria bassiana* (BotaniGard: BioWorks; and Naturalis: OHP, Inc.) appear to be more effective when tank mixed together compared to individual applications. It has been hypothesized that azadirachtin may actually "stress" insects, thus enhancing the efficacy of the beneficial fungus. For example, during the summer months, insect pests such as thrips and aphids molt or shed their skins (cuticles) so rapidly that beneficial fungi are unable to penetrate the insect. The insect sheds off the spore, forming conidia along with the old skin. However, tank mixing azadirachtin with *B. bassiana* may result in synergism or enhanced efficacy because azadirachtin, an insect growth regulator, may slow down the molting process, thus allowing the insect-killing fungus to penetrate the target insect pest and initiate an infection.



Tank mixing pesticides is a convenient option for many growers: It's less expensive and requires less labor than separate pesticide applications.

Concerns Related to Tank Mixes

Just as synergism improves the efficacy of two or more pesticides, the opposite — referred to as antagonism — may occur. Antagonism is when mixing two or more pesticides reduces effectiveness of the mixture compared to if applied separately. In other words, the mixture is less effective, based on percent mortality, than individual applications of each pesticide. It appears that azadirachtin may actually be toxic to certain beneficial fungi, thus resulting in antagonism. In addition to a reduction in effectiveness, there is also the potential for plant injury or phytotoxicity. Greenhouse producers need to read the label before tank mixing pesticides because labels, in general, state which products can and cannot be mixed together.

Another issue associated with tank mixing is incompatibility, a physical condition that prevents pesticides from mixing together properly in a spray solution. This may result in either a decrease in effectiveness or phytotoxicity. Incompatibility may be due to the chemical or physical nature of the pesticides, impurities in the water, water temperature or the types of formulations mixed together.

To determine compatibility between two (or more) pesticides, conduct a "jar test." This involves making a small sample of the spray solution and placing into an empty jar or other container, and allowing the solution to sit for approximately 15 minutes. If the pesticides are not compatible, there may be a noticeable separation or layering, or precipitates such as flakes or crystals may form. However, if the materials are compatible, the solution may appear homogeneous or resemble milk. It is important to understand that this procedure only determines compatibility, not synergism or antagonism.

A concern often affiliated with tank mixing pesticides is the prospect of resistance. Although this is still not well understood, there is speculation that applying two or more pesticides at different intervals has the same advantages as a pesticide mixture. However, this is not entirely true, as each individual arthropod pest in the population does not receive a lethal dose or ➧

concentration of each pesticide, and as a result resistance may evolve more rapidly than with a pesticide mixture. The mechanisms required to resist each material in the mixture may not be present in the arthropod pest population, and it may be more difficult for individuals in the population to develop resistance to several modes of action simultaneously. However, it should be noted that the ability of arthropod pest populations to evolve resistance depends on a number of factors; one of the most important is previous exposure to either similar or different modes of action.

In Conclusion

It is apparent from the survey

Though tank mixing can improve pest control, it can also lead to incompatibility or even phytotoxicity in a grower's crops.

results that many different pesticide mixtures are being used by greenhouse producers. However, tank mixing has both positive and negative attributes. Although greenhouse producers commonly mix pesticides to reduce labor costs associated with spray applications and potentially improve control of arthropod pests (synergism), they need to be cautious when tank mixing to avoid problems associated with antagonism, incompatibility and phytotoxicity.

Additionally, greenhouse producers may not be aware of which pesticide mixtures are compatible. Although pesticide labels often state whether certain pesticides can be mixed, not all combinations can be evaluated. Because tank mixing will likely continue to increase, further research is needed to assess pesticide mixtures, using the survey results, that are either synergistic or antagonistic so that greenhouse producers can speed up the process of deciding which pesticide mixtures to use and which to avoid.

Acknowledgements

The author is grateful to the OFA — an Association of Floriculture Professionals (Columbus, Ohio), Ball Publishing (Batavia, Ill.) and the Society of American Florists (Alexandria, Va.) for making it possible to conduct the survey during the designated sessions for each conference. GPN

Raymond A. Cloyd is associate professor and extension entomologist in Kansas State University's department of entomology in Manhattan, Kan. He can be reached at rcloyd@ksu.edu.

LearnMore
For more information related to this article, go to www.gpnmag.com/lm.cfm/gp0120802