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Systemic Insecticides 101

By Raymond A. Cloyd

They're critical tools for growers, and understanding how this class of insecticides works will help you perform more effective and efficient pest control.

Systemic insecticides are substances that, when applied to a plant, are absorbed and translocated into other plant parts through the sap stream, thus rendering treated areas insecticidal or toxic to certain insects. The problems associated with obtaining sufficient plant coverage for control or suppression of particular insect pest populations with conventional or alternative insecticides may be simplified by the use of systemic insecticides (SI). It is possible, with SI, to control or suppress many insect pest populations, which spend some or all of their life cycles in inaccessible areas on plants—a situation that has always presented a challenge when using conventional or alternative insecticides.

This article is intended to provide the information producers need to understand how systemic insecticides work. In addition, we'll cover the following:

- the types of SI and processes associated with activity;
- the benefits of using SI;
- what influences efficacy of SI;
- insect and mite pests susceptible to SI; and
- commercially available SI classes and groupings.

This information should allow growers to make more informed decisions regarding the application of systemic insecticides to control or suppress insect (and mite) pest populations on both greenhouse and nursery-grown crops.

How systemic insecticides work

Table 1 (opposite) lists systemic insecticides that are commercially available for use in greenhouse and/or nursery production. These products may be applied to the plant as a foliar spray where the active ingredient directly penetrates plant tissues (such as leaves and stems), or to the growing medium as a drench or granular application. For drench or granular applications, the active ingredient is absorbed by plant roots, and then transported (translocated) to areas throughout the plant, such as growing points where certain insect pests feed.

Systemic insecticides (and some miticides) typically move within the vascular tissues either through the water-conducting tissues (xylem) or food-conducting tissues (phloem), or both, depending on specific characteristics such as physical properties of the active ingredient. Once inside the plant, the active ingredient may move back and forth from the water-conducting tissues to the food-conducting tissues or vice versa (a process known as lateral diffusion). The xylem and phloem have different pH values of 5 and 8, respectively. Furthermore, weak acids or those compounds with p*Ka* values (discussed below) between 5.0 and 5.5, and compounds that are highly lipophilic (also discussed later in the article) can cross membranes easily. Some SI (such as imidacloprid) are not affected by pH differences and, as such, can move freely between the xylem and phloem due to a process called "biomembrane permeability" or "passive diffusion."

In general, movement of materials in the xylem is easier than in the phloem. However, this is contingent on the physical and molecular properties associated with the active ingredient of the systemic insecticide. Furthermore, the rate of passive transport in the transpiration stream of the xylem will depend on the rate of water movement through the plant. Factors that may influence the rate of passive transport are light intensity, ambient air temperature, relative humidity, and water availability in the soil or growing medium.

What they are and how they work

Previous researchers indicated that systemic insecticides can be divided into two types: endolytic and endometatoxic. Endolytic SI are those that remain in plants in the original form and have systemic activity until decomposed (or broken down) by the plant. Endometatoxic SI are eventually converted in the plant into metabolites that are more toxic to insect pests than the original active ingredient. For example, acephate (Orthene/Precise) is converted into methamidaphos, and imidacloprid (Marathon/ Merit) is converted into several metabolites, including olefine and 4, 5-dihydroxy. These metabolites are typically more water-soluble and toxic to phloem-feeding insect pests than the original active ingredient.

Systemic insecticides may be absorbed by roots and leaves. The key processes associated with activity and efficacy of SI when applied to the growing medium as a drench or granules are *absorption, translocation* and *distribution.*

- Absorption refers to uptake of the active ingredient from the soil or growing medium by the root system, or by plant leaves after a foliar application.
- Translocation is the movement of the active ingredient throughout the plant, primarily by means of the transpiration stream.
- Distribution involves movement of the active ingredient into the plant parts where insects are feeding.

Factors that may impact absorption, translocation and distribution and, thus, the efficiency of systemic insecticides are:

- plant age;
- plant growth rate;
- plant growth stage (for example, vegetative vs. flowering);

Table 1. Pest control materials (insecticides and miticides) registered for use in commercial greenhouses and/or nurseries that have systemic activity.

Common name (active ingredient)	Trade Name	Application Type	Target Pests*
Acephate	Orthene/Precise	Foliar, Drench, Granule	Aphids, whiteflies and mealybugs
Acetamiprid	TriStar	Foliar	Aphids, whiteflies and mealybugs
Dinotefuran	Safari	Foliar, Drench, Granule	Aphids, whiteflies and mealybugs
Flonicamid	Aria	Foliar	Aphids, whiteflies and mealybugs
Imidacloprid	Marathon/Merit	Foliar, Drench, Granule	Aphids, whiteflies and mealybugs
Pymetrozine	Endeavor	Foliar	Aphids and whiteflies
Spirotetramat	Kontos	Foliar, Drench	Aphids, whiteflies and spider mites
Thiamethoxam	Flagship	Foliar, Drench	Aphids, whiteflies and mealybugs

* Consult the manufacturers' labels for additional insect pests controlled or suppressed by each pest control material.

- environmental conditions (such as temperature, relative humidity and light intensity);
- soil/growing medium type;
- soil/growing medium condition (for example, dry vs. moist); and
- physiological variations of plants.

Newly expanded leaves tend to absorb systemic insecticides more efficiently than very young or mature leaves, and movement from older to younger leaves occurs more frequently. Compounds that move readily in the xylem are more appropriate for soil/growing medium applications as long as they are not strongly adsorbed (bound-up) by soil or growing medium particles.

Previous researchers noted that systemic insecticides, when absorbed by plant roots, are translocated to "all" plant parts. Well, this is not necessarily the case; what is more important is that a lethal concentration of the active ingredient may not be present in areas of the plant where insect pests are feeding. For foliar applications of systemic insecticides, the plant surface must be sprayed thoroughly, because translocation from a treated to an untreated area of a plant is generally inadequate for effective control or suppression of insect pests.

There are a number of factors that may influence the efficiency and efficacy of foliar applications, including evaporation, absorption of leaves, and environmental degradation; for example, by sunlight and rainfall. Absorption into plant leaves may be impacted by a leaf's age; its surface (trichomes or waxiness), its type, such as broad vs. narrow; and leaf temperature. Furthermore, the material may not always penetrate through the leaf tissues. In fact, the active ingredient may get entrapped in the cuticular layers and not actually permeate into plant cells.

Benefits

The benefits of systemic insecticides are, in general:

- plants may be continuously protected throughout the growing season (depending on plant type) without the need for repeat applications;
- systemic insecticides—when applied as a drench or granule to the soil/growing medium—are less susceptible to ultraviolet light degradation or rainfast (or "wash off");

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Oleander aphid (*Aphis nerii*)
All three insect pests shown are phloem-feeders and susceptible to systemic insecticides applied to the growing medium.

Citrus mealybugs (*Planococcus citri*)

Sweet potato whitefly B-biotype (*Bemisia tabaci*) nymphs

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• there are no unsightly residues on plant leaves or stems when applied to the soil/growing medium; and

• plants treated with systemic insecticides as a soil/growing medium drench or granule may be less harmful to natural enemies, workers and customers compared to plants having received spray applications of conventional insecticides. Furthermore, the restricted entry interval (REI) is reduced—equal to or less than 12 hours—for greenhouse/nursery drench and granular applications.

What influences efficacy?

Systemic insecticides may be applied directly to the growing medium as a drench or granule, or they are sprayed onto plant leaves and stems. When applied to the growing medium as a drench or granule, SI are absorbed by plant roots, translocated and distributed throughout the plant, providing up to eight weeks of consistent residual activity against phloem-feeding insects. However, they may take longer to be distributed throughout the plant. In contrast, SI applied to plant leaves will rapidly kill target insect pests and may provide up to four weeks of residual activity. Regardless of the application method, systemic insecticides provide long-term protection from insect pest injury.

In general, SI are water-soluble, which allows the active ingredient to dissociate in water and then be absorbed by plant roots when applied as a drench or granule to soil/growing medium. Water solubility, which may be expressed as grams per liter (g/L) or parts per million (ppm), determines how rapidly the active ingredient is absorbed by roots, and then translocated and distributed throughout plant parts such as leaves and stems.

A highly water-soluble SI may kill insect pests quickly but may not provide long-term or sufficient residual activity compared to a less water-soluble systemic insecticide. Also, those SI that are highly water-soluble are more prone to leaching. However, this will be influenced by watering techniques and growing medium type, which is associated with binding to the active ingredient thus reducing the leaching potential, but may prohibit plant absorption.

For example, growing media containing more than 30 percent bark and/or peat moss tend to bind to the active ingredient of certain systemic insecticides. This reduces the amount of active ingredient absorbed by plant roots and may result in inadequate control or suppression of target insect pests. The rate of uptake and leaching may be influenced by root system development and absorption rate of water by the plant.

Drench or granular applications of SI must be performed when plants are actively growing and have an extensive, well-established root system in order to enhance the uptake of the active ingredient through the vascular plant tissues. Applications made during warm, sunny days will also lead to increased movement of the active ingredient through the transpiration stream. In contrast, absorption is inhibited when plants do not have well-established root systems. Additionally, conditions of high humidity and low light may lead to less or slower absorption of systemic insecticide active ingredients by plant roots. A delay in the uptake of the active ingredient may result in taking longer to substantially impact insect pest populations. SI are also more active and effective in killing phloem-feeding insect pests when plants are herbaceous rather than woody, particularly when dealing with stem-feeding insects such as aphids and mealybugs.

When applied to the growing medium as a drench or granule, SI need to be utilized preventively in order to control or suppress populations of aphids, mealybugs and whiteflies. If, however, they are applied after insect pest populations are already established on plants or plants have developed woody tissue, this may delay control or suppression—resulting in insect pest populations causing damage before ingesting enough active ingredient to kill a substantial number of individuals. In the meantime, these insect pests are producing additional generations. The reproductive capacity of aphids, for example, warrants that systemic insecticides be applied prior to an infestation because once aphids are established and reproducing, then there may be no way to prevent plant damage.

Who is susceptible?

Most systemic insecticides are translocated through the plant via the transpiration stream, and are primarily active on phloem-feeding insect pests with piercing-sucking mouthparts such as aphids, whiteflies, mealybugs and soft scales; these insect pests feed exclusively within the phloem sieve tubes. As an insect feeds, it withdraws a lethal concentration of the SI active ingredient.

Consider, for example, the aphid: The piercing-sucking mouthpart or proboscis of an aphid is inserted into plant tissues, reaching the conductive cells or sieve tubes through which water and food are transported. The aphid then imbibes the active ingredient of the SI as it withdraws plant fluids. Spider mites, however, including the twospotted spider mite (*Tetranychus urticae*), broad mite (*Polyphagotarsonemus latus*) and cyclamen mite (*Phytonemus pallidus*), and eriophyid mites do not feed within the xylem or phloem. Twospotted spider

Table 2. Water solubility (ppm and g/L), acid dissociation constant (p*Ka*), and octanol-water partition coefficient (log P_{oct}) of the neonicotinoid insecticides available for use in greenhouses and nurseries that may be applied either to the foliage or the growing medium as a drench or granule.

Common Name (active ingredient)	Trade Name	Application Type	Water Solubility (ppm)	Water Solubility (g/L)	p*Ka*	log P_{oct}
Acetamiprid	TriStar	Foliar	2950 ppm	2.9 g/L	0.7	0.8
Dinotefuran	Safari	Foliar and Drench	39,830 ppm	39.8 g/L	12.6	-0.64
Imidacloprid	Marathon/Merit	Foliar and Drench	500 ppm	0.51 g/L	0.57	
Thiamethoxam	Flagship	Foliar and Drench	4100 ppm	4.1 g/L	N/A	-0.13

Aria is one of several effective systemic insecticides on the market.

mite feeds within leaf cells, damaging the spongy mesophyll, palisade parenchyma and chloroplasts with their stylet-like mouthparts, which reduces chlorophyll content and the plants' ability to photosynthesize.

Because spider mites do not feed in the vascular tissues, they are typically not susceptible to systemic insecticides; this has changed, however, with the active ingredient spirotetramat, which is sold as Kontos (OHP Inc., Mainland, PA). This active ingredient, which moves both up and down the plant, actually has systemic activity against the twospotted spider mite when applied as a drench to the soil/growing medium or as a foliar spray.

Western flower thrips (*Frankliniella occidentalis*) also have piercing-sucking mouthparts; however, they do not feed exclusively in the phloem sieve tubes. They instead feed within the mesophyll and epidermal cells of leaf tissues. Because of this, systemic insecticides applied as a drench or granule to the soil/growing medium are less effective against western flower thrips. Furthermore, SI typically do not translocate or accumulate in flower parts, such as petals and sepals, where western flower thrips adults normally feed.

In general, chewing insects such as beetles, caterpillars and leafminers are not controlled or suppressed by systemic insecticides that are applied as a drench or granule to the soil/growing medium, although this may depend on the rate applied. Some SI are effective via contact and ingestion. For example, the neonicotinoid insecticides will control or suppress populations of certain leaf-feeding beetles and leafminers.

What can you use?

The primary systemic insecticides commercially available for use in greenhouses and nurseries are in two chemical classes or groupings: neonicotinoid and selective feeding blocker. The neonicotinoid SI include imidacloprid (Marathon and Merit), acetamiprid (TriStar), thiamethoxam (Flagship) and dinotefuran (Safari).

All neonicotinoid insecticides have a similar chemical structure and mode of action. The common characteristics associated with neonicotinoid SI include:

- bind to the post-synaptic nicotinergic acetylcholine receptors (mode of action);
- primarily used against phloem-feeding insects such as aphids, whiteflies, mealybugs, soft scales and certain leaf-chewing beetles;
- have minimal, if any, direct effect on mites;
- may be applied, depending on the particular formulation, as a foliar spray, drench or as a granule to the soil/growing medium;
- have both systemic and translaminar properties, in which material penetrates leaf tissue and forms a reservoir of active ingredient within the leaf, providing residual activity even after leaf residues dissipate;
- have 12-hour or less REI.

Dinotefuran (Safari) can be applied to trees as a basal trunk spray, which simulates or acts like a soil/growing medium treatment.

As a chemical class, the neonicotinoid systemic insecticides have similar chemical structures; however, they vary greatly in certain characteristics that may influence movement into plants, including water solubility and two physical estimated properties: p*Ka* and log P_{oct}. The p*Ka* is the acid dissociation constant and indicates the strength of an acid. The larger the p*Ka* value the weaker the acid, which influences the ability of the active ingredient to cross membranes. The log P_{oct} refers to the octanol-water partition coefficient and is associated with the lipophilicity of compounds. Lipophilicity refers to the ability of compounds to dissolve in fats, oils and lipids. Compounds that are lipophilic (log P_{oct}>4) are generally not systemic, whereas compounds that are considered to be either moderate or intermediate in lipophilicity have a log P_{oct} between 0.5 and 3.5. These compounds move through the xylem to plant shoots. Root absorption is greater when compounds are more lipophilic. Table 2 presents the water solubility, p*Ka*, and log P_{oct} of the neonicotionid systemic insecticides.

The other class of systemic insecticides is the selective feeding blockers, which includes flonicamid (Aria) and pymetrozine (Endeavor). These SI are active on aphids and whiteflies by inhibiting feeding via interfering with neural regulation of fluid intake in the mouthparts, thus resulting in starvation. This is a physical mode of action and, as such, it would take a long time for an insect population to develop resistance.

Wrapping it up.

It is important to understand how systemic insecticides work, the processes involved in maximizing the effectiveness and benefits of SI, and those insect and mite pests that are susceptible to SI. When used appropriately, SI may provide long-term protection from certain insect pests without having to rely on routine spray applications, which may reduce labor costs. However, it is important to maximize proper insecticide stewardship in order to reduce the risk to natural enemies and avoid the prospect of insect pest populations developing resistance to commercially available systemic insecticides.

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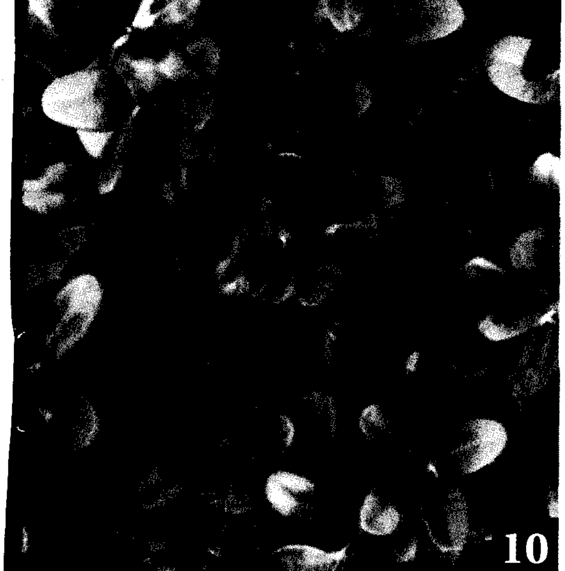

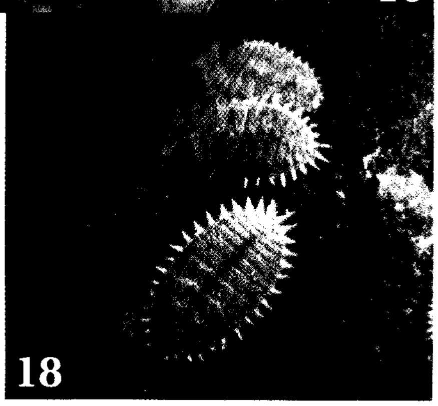

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On the cover:

Used for centuries as a reliable foundation plant, boxwood is enjoying a recent renewal of interest.

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