COMPATIBILITY CONFLICT: IS THE USE OF BIOLOGICAL CONTROL AGENTS WITH PESITICIDES A VIABLE MANAGEMENT STRATEGY?

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ABSTRACT

Biological control or the use of natural enemies is an alternative pest management strategy for dealing with arthropods. However, natural enemies may not always provide adequate control of plant-feeding insects and mites in greenhouses. As a result, research has assessed the concept of using natural enemies in conjunction with pesticides and the potential compatibility when both pest management strategies are implemented together. There are a variety of factors that influence the ability of using natural enemies with pesticides, these include whether the natural enemy is a parasitoid or predator, natural enemy species, life stage sensitivity, rate of application, timing of application, and mode of action of a particular insecticide or miticide. Pesticides may impact natural enemies by affecting longevity (survival), host acceptance, sex ratio, reproduction (fecundity), foraging behavior, percent emergence, and development time. In our studies, we have found a number of pesticides to be compatible with the natural enemies of the citrus mealybug, *Planococcus citri* and fungus gnats, *Bradysia* spp. For example, we have demonstrated that foliar and drench applications of the insecticides novaluron and pyriproxyfen, and the fungicides fosetyl-Al and mefenoxam to be compatible with the predatory mite, *Stratiolaelaps scimitus*. We have also shown that the insecticides azadirachtin and pyriproxyfen are compatible with the citrus mealybug parasitoid, *Leptomastix dactylopii*. Additionally, the insecticides buprofezin, pyriproxyfen, and flonicamid were not harmful to the adult stage of the mealybug destroyer, *Cryptolaemus montrouzieri*. Despite the emphasis on evaluating the compatibility of natural enemies with pesticides, it is important to assess if this is a viable and acceptable pest management strategy in greenhouses.

INTRODUCTION

Biological control or the use of natural enemies such as parasitoids, predatory mites, predatory bugs, and/or beneficial bacteria, fungi, and nematodes is an alternative strategy to manage greenhouse pests (Van Driesche and Heinz 2004). However, the sole use of biological control may not always be sufficient to control plant-feeding insect or mite populations in greenhouses (Medina *et al.* 2003). As a result, research within the last 5 to 10 years has investigated the possibility of using so-called "biorational" or "reduced risk" insecticides or miticides in conjunction with biological control agents (=natural enemies) to determine if there is compatibility when both management strategies are implemented together. Those insecticides and miticides that are classified as biorational or reduced risk include insect growth regulators, insecticidal soaps and horticultural oils, and microbials including beneficial bacteria and fungi, and related compounds.

If a given insecticide or miticide kills a particular target pest or pests, why would it not kill a natural enemy? It is equally important to define what is meant by "compatibility?" Biorational insecticides and miticides are considered to be more selective to natural enemies and potentially more compatible than most conventional insecticides and miticides because they are active on a broad range of target sites or systems (Croft 1990). In fact, several commercially available biorational insecticides/miticides state that their products are not disruptive to beneficial insects and mites. However, research conducted worldwide has shown that biorational insecticides/miticides may in fact be harmful to certain natural enemies. Although biorational insecticides/miticides may not be directly toxic to a particular natural enemy there may be indirect effects such as delayed development of the host and natural enemy inside, delayed adult emergence, and/or decreased natural enemy survivorship (Croft 1990). In general, the harmful effects of biorational insecticides and miticides may be due to direct contact, host elimination, residual activity, or sublethal effects (Parrella *et al.* 1999):

Direct contact: directed sprays of biorational insecticides/miticides may kill natural enemies or in the case of parasitoids they are killed while in developing hosts.

Host elimination: biorational insecticides/miticides may kill hosts, which may lead to natural enemies dying or leaving because they are unable to locate additional hosts.

Residual activity: although spray applications of biorational insecticides/miticides may not directly kill natural enemies, any residues may have repellent activity thus influencing the ability of parasitoids or predators to locate a food source.

Sub-lethal effects: biorational insecticides/miticides may not directly kill a natural enemy, but may affect reproduction such as sterilizing females, reducing the ability of females to lay eggs or impact the sex ratio (number of females vs. males). Additionally, foraging behavior may be modified thus influencing the ability of a parasitoid or predator to find a host (Elzen 1989). Also, those parasitoids that host feed such as the greenhouse whitefly parasitoid, *Encarsia formosa* may inadvertently consume residues on hosts after a spray application. Residues on a potential host may make them unacceptable to a parasitoid or predator.

Differences in natural enemy susceptibility to biorational insecticides/miticides may be due to a number of factors including 1) whether the natural enemy is a parasitoid or predator, 2) species of natural enemy, 3) life stage (i.e., egg, larva, pupa, and adult) sensitivity, 4) developmental stage of host, 5) rate of application, 6) timing of application, and 7) type or mode of action of biorational insecticide or miticide used. All these differences are complex primarily due to the interactions that may occur among the factors mentioned above and the variability in natural enemy sensitivity. Further complicating the "picture," the harmful effects from biorational insecticides/miticides may not be associated with the active ingredient but due to inert ingredients such as carriers or solvents (Cowles *et al.* 2000).

Biorational insecticides/miticides are generally more specific in pest activity and more physiologically sensitive to natural enemies than conventional insecticides/miticides (Croft 1990). A number of biorational insecticides/miticides used in greenhouses have been evaluated for both their direct and indirect effects on natural enemies. Below are descriptive examples, based on studies, on the compatibility of biorational insecticides and miticides with various natural enemies.

EFFECTS OF PESTICIDES ON NATURAL ENEMIES

INSECT GROWTH REGULATORS

The insect growth regulators that have been evaluated for both their direct and indirect effects on natural enemies include the juvenile hormone mimics pyriproxyfen, and kinoprene; the chitin synthesis inhibitors diflubenzuron and buprofezin; and the ecdysone antagonists tebufenozide and azadirachtin.

Pyriproxyfen. Pyriproxyfen, in laboratory studies, is non-toxic or harmless to the larval and adult stages of the green lacewing, *Chrysoperla carnea* (Medina *et al.* 2003) and predatory bugs, *Orius* spp. with no harmful effects on adult female oviposition and egg viability (Nagai 1990). Pyriproxyfen is also non-toxic to the predatory bug, *Orius laevigatus* via ingestion and residual contact (Delbeke *et al.* 1997). Although harmless to certain predatory insects, pyriproxyfen is toxic to immature parasitoids developing inside the silverleaf whitefly, *Bemisia argentifolii* nymphs (Hoddle *et al.* 2001). Natural enemy species may influence compatibility as demonstrated with pyriproxyfen, which appears to be harmless to *Eretmocerus eremicus* (Hoddle *et al.* 2001) and *Encarsia pergandiella*, but is highly toxic to *Encarsia formosa* (Liu and Stansly 1997).

Kinoprene. This insect growth regulator is consistently harmful to certain natural enemies, especially parasitoids. As mentioned above, the rate used may influence natural enemy susceptibility. For example, kinoprene reduces adult emergence of the leafminer parasitoid, *Opius dimidiatus* (Lemma and Poe 1978) and the aphid parasitoid, *Aphidius nigripes* (McNeil 1975) at all rates tested. Applications of kinoprene may inhibit adult emergence when applied to hosts containing the larval and pupal stages of certain parasitoids (McNeil 1975). It has been shown that kinoprene is extremely toxic to the aphid parasitoid, *Aphidius colemanii* when exposed to directed sprays and one-day old residues (Olson and Oetting 1996). Furthermore, kinoprene-treated poinsettia (*Euphorbia pulcherrima*) leaves are harmful to the silverleaf whitefly parasitoid, *Eretmocerus eremicus* six and 96 hours after treatment (Hoddle *et al.* 2001). Although harmful to parasitoids, kinoprene is less toxic to certain predators and different life stages. For example, applications of kinoprene did not negatively affect ladybird beetle eggs (Kismali and Erkin 1984).

Diflubenzuron. Diflubenzuron has minimal impact on natural enemies when applied either directly or indirectly under laboratory conditions. However, the life stage (egg, larvae, pupae, and adult) treated influences the effects of this chitin synthesis inhibitor. For example, diflubenzuron is harmful to the early larval stages of green lacewing (*Chrysoperla carnea*) whereas later larval stages are not affected (Medina *et al.* 2003; Niemczyk *et al.* 1985). It has been demonstrated that the young larvae of the mealybug destroyer, *Cryptolaemus montrouzieri* when treated with diflubenzuron fail to develop into adults whereas diflubenzuron has minimal impact on the citrus mealybug parasitoid, *Leptomastix dactylopii* (Mazzone and Viggiani 1980).

Buprofezin. Buprofezin is toxic to the larval stage of predatory ladybird beetles whereas it is less toxic to adult ladybird beetles (Smith and Papacek 1990), although it may have a sterilizing effect on some species (Hattingh and Tate 1995). Buprofezin is less harmful to other predators as demonstrated in a laboratory study where applications of buprofezin did not negatively effect the development (nymph to adult) of the predatory bug, *Orius tristicolor* (James 2004). In general, buprofezin is less toxic to parasitoids (Jones *et al.* 1998). For example, buprofezin does not effect oviposition of the two whitefly parasitoids, *Eretmocerus* sp., and *Encarsia luteola* when the young or adults are exposed to spray residues. Additionally, buprofezin has no effect on the foraging behavior of adult *Eretmocerus* sp. (Gerling and Sinai 1994).

Tebufenozide. In laboratory studies, tebufenazide is harmless to the green lacewing, *Chrysoperla carnea* (Medina *et al.* 2003). This insect growth regulator, which is primarily used against caterpillar larvae, does not affect adult green lacewing female reproduction (Medina *et al.* 2003).

Azadirachtin. Azadirachtin applications have been shown to negatively affect green lacewing, *Chrysoperla carnea* females by inhibiting oviposition (Medina et al. 2003). However, in a large-scale laboratory study, applications of azadirachtin were not toxic to the egg and adult stages of the predatory mites *Phytoseiulus persimilis* and *Amblyseius cucumeris* when exposed to treated bean leaves (Spollen and Isman 1996). Studies have also shown that the number of eggs laid by the aphid predator, *Aphidoletes aphidimyza* are not negatively affected by azadirachtin (Spollen and Isman 1996).

INSECTICIDAL SOAP AND HORTICULTURAL OIL

Direct spray applications (wet sprays) and short-term residues of insecticidal soap and horticultural oil are toxic to most natural enemies, especially parasitoids. However, once the residues have dissipated they are less harmful. Studies with the western flower thrips predatory mite, *Neoseiulus* (=*Amblyseius*) *cucumeris* have indicated that this mite is more sensitive to horticultural oil than insecticidal soap (Oetting and Latimer 1995). Direct applications of horticultural oil are harmful to the predatory mite, however, 1 to 2% concentrations have been shown to be less toxic. Although insecticidal soap appears to be minimally harmful to the predatory mite, sprays of a 4% insecticidal soap have been shown to be very toxic (90% mortality after 48 hours) (Oetting and Latimer 1995). Direct spray applications of insecticidal soap are extremely toxic to the twospotted spider mite predatory mite, *Phytoseiulus persimilis* (100% mortality), whereas there are no harmful effects 3 days after release (Osborne and Petitt 1985).

BACTERIA

In general, sprays of *Bacillus thuringiensis* (*Bt*) are safe to most predators including ladybird beetles, green lacewing, and certain predatory bugs. However, initial sprays may delay the development of certain natural enemies. The effects of *Bt* on the different life stages of natural enemies have been shown to be highly variable (Croft 1990). Additionally, the effects of *Bt* may take longer to impact natural enemies compared to other biorational insecticides. It appears that the larval stage of certain natural enemies such as green lacewing (*Chrysoperla* sp.) and ladybird beetles are more susceptible to *Bt* sprays than adults (Kiselek 1975). It is important to note that any lethal or sub-lethal effects may not be directly caused by the bacteria, but indirectly by altering the available food source or killing hosts before they complete development (Marchal-Segault 1975).

FUNGI

Entomopathogenic fungi vary in how they impact natural enemies depending on whether natural enemies consume spores or they are directly affected by sprays. Natural enemies may ingest fungal spores when either grooming (cleaning themselves) or when feeding on a contaminated host or food source. The fungi *Metarhizium anisopliae* and *Beauveria bassiana* can infect and harm ladybird beetles, depending on the concentration. Direct sprays of *M. anisopliae* and *B. bassiana* results in 97% and 95% mortality, respectively of adult ladybird beetles. However, the severity of the effect is very much dependent on the concentration of spores applied (James and Lighthart 1994). Applications of entomopathgenic fungi may indirectly affect predators that feed on hosts that have been sprayed. For example, 50% of mealybug destroyer (*Cryptolaemus montrouzieri*) larvae died when they consumed mealybugs that were sprayed with a *B. bassiana* product. However, the product was harmless to the adult (Kiselek 1975). Direct applications of the fungus, *Cephalosporium lecanii* had no impact on the longevity of the leafminer parasitoid, *Diglyphus begini* (Bethke and Parrella 1989). In contrast, direct sprays of this same fungus were shown to be harmful to the aphid parasitoid, *Aphidius matricariae* (Scopes 1970) and the greenhouse whitefly parasitoid, *E. formosa* (Ekbom 1979).

SPINOSAD

The impact of spinosad on natural enemies has been extensively studied since its introduction. It has been demonstrated that direct applications (wet sprays) of spinosad are extremely harmful to parasitoids including *Aphidius colemani* and *E. formosa*, however, any toxic effects generally decrease as the spray residues age (Miles *et al.* unpublished). Spinosad applications have been shown to be toxic to the eggs of *Trichogramma* spp. parasitoids and the larval stage (Consoli *et al.* 2001). Applications of spinosad have exhibited toxic effects to *E. formosa* and *Orius laevigatus* shortly after treatment—but populations of both were not seriously affected after 2 to 3 weeks. Spinosad has been shown to not harm the larval stage of the aphid predatory midge, *Aphidoletes aphidimyza* (Miles *et al.* unpublished).

Spinosad appears to be very compatible with many predatory insects and mites. Studies have demonstrated that spinosad has no direct or indirect negative affects to green lacewing (*Chrysoperla carnea*) (Medina *et al.* 2001), ladybird beetle (*Hippodamia convergens*), minute pirate bug (*Orius laevigatus*), big-eyed bug (*Geocoris punctipes*), and damsel bug (*Nabis* sp.) (Thompson *et al.* 2000). Spinosad has also been shown to not directly harm predatory mites including *Amblyseius californicus, P. persimilis, A. cucumeris*, and *Hypoaspis miles* at the rates tested (Miles *et al.* unpublished).

UNIVERSITY OF ILLINOIS RESEARCH

A major part of our research effort at the University of Illinois is to assess the compatibility of commercially available insecticides and miticides with natural enemies. For example, we have conducted several studies to test the direct and indirect effects of insect growth regulators on the natural enemies of fungus gnats and mealybugs. In our research, we found that foliar and drench applications of the insect growth regulators novaluron and pyriproxyfen were not directly or indirectly harmful to the soil-predatory mite, *Stratiolaelaps scimitus* (Cabrera *et al.* 2004; Cabrera *et al.* 2005). We have also demonstrated that azadirachtin is safe to use with the citrus mealybug parasitoid, *Leptomastix dactylopii*. Pyriproxyfen was found to be slightly toxic whereas both direct and indirect applications of kinoprene were extremely toxic to this parasitoid (Rothwangl *et al.* 2004). We have also demonstrated that applications of the insecticides buprofezin, pyriproxyfen, and flonicamid are not harmful to the adult stage of the mealybug destroyer, *C. montrouzieri* (Cloyd and Dickinson, unpublished data)

CONCLUSIONS

It is important to note that many studies are conducted under laboratory conditions, which represents a “worse-case scenario” and that if there are no harmful effects under these conditions then it is likely that the biorational insecticide or miticide will not be harmful when used in the greenhouse. In addition, the concentration or rate also influence whether biorational insecticide/miticide will negatively impact natural enemies. In order to avoid any harmful effects to natural enemies it is recommended to make releases several days after an application although applying biorational insecticides or miticides may still decrease host quality thus increasing parasitoid or predator mortality. For example, parasitoid females may not lay eggs in un-suitable hosts and predators may not consume hosts that are an inadequate food source (=poor quality). Applications of biorational insecticides/miticides may also kill a majority of the hosts thus reducing the amount available for natural enemies. Finally, the fact that many biorational insecticides and miticides may need to be applied frequently (depending on the pest population) in order to obtain sufficient control of insect or mite pests increases the likelihood that natural enemies will be exposed to sprays or spray residues, which may have a deleterious effect on foraging behavior or reproduction.

It is apparent that there is variability in the compatibility of natural enemies to biorational insecticides/miticides based on the type of biorational insecticide or miticide, whether the natural enemy is a parasitoid or predator, and stage of development. Biorational insecticides/miticides are effective for controlling many different types of greenhouse pests and are generally less harmful to natural enemies than conventional insecticides/miticides, which suggest that they are more likely to be compatible with natural enemies. However, it is important to know which biorational insecticide/miticide is compatible or not compatible with natural enemies in order to avoid disrupting successful biological control programs.

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