Crop Protection 103 (2018) 56–64

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Potential impacts of orchard pesticides on *Tetranychus urticae*: A predator-prey perspective

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ARTICLE INFO

Article history:
Received 24 July 2017
Received in revised form
10 September 2017
Accepted 15 September 2017

Keywords:
Non-target effect
Pesticide toxicity
Integrated control
Pesticide selectivity
Biological control

ABSTRACT

Tetranychus urticae Koch is a highly polyphagous pest that is notorious for developing resistance to pesticides. In many perennial cropping systems, integrated mite management relies on the conservation of natural enemies, especially phytoseiid mites, to prevent outbreaks. For successful conservation, it is important to understand non-target effects of pesticides on both spider mites and their key natural enemies, allowing producers to choose pesticides that do not selectively favor *T. urticae* over its natural enemies. Here, we examine lethal and sublethal non-target effects of common orchard insecticides and fungicides on *T. urticae* in laboratory assays and compare these effects to previous work with its most important predator in Washington orchards, *Galendromus occidentalis* (Nesbitt) (Phytoseiidae). In all cases, materials were either less harmful to *T. urticae* or were equally harmful to both species. Pesticides that were minimally harmful to *T. urticae,* but highly harmful to *G. occidentalis* included neonicotinoids (acetamiprid, thiacloprid, imidacloprid) and novaluron. The diamides (chlorantraniliprole, cyantraniliprole, flubendiamide) had minimal effect on both species. Some pesticides (lambda-cyhalothrin, spinetoram, spirotetramat) were highly toxic to both predator and prey. While the latter category may not cause immediate outbreaks, the ability of spider mites to develop resistance more quickly than their natural enemies indicates that these materials should be used with caution. This study emphasizes the importance of studying the non-target effects of pesticides on secondary pests and their biological control agents to provide a more detailed insight into conservation biological control.

1. Introduction

Spider mites are important pests in a variety of crops. In many cropping systems, like tree fruits, they are secondary pests; spider mites only become a management issue when pesticides are applied to control other pests. This is typically attributed to the non-target effects of many pesticides on spider mite natural enemies, especially phytoseiid mites, which result in disruption of biological control (Hoyt and Burts, 1974; Huffaker et al., 1970; McMurtry et al., 1970). However, some studies have reported that pesticides can also cause hormoligosis (reproductive stimulation at sublethal doses) in spider mites, resulting in an increase in the fecundity and therefore population growth of the pest (Dittrich et al., 1974; James and Price, 2002; Szczepaniec et al., 2011; Zeng and Wang, 2008).

It is therefore important to determine the effects of commonly used pesticides on both spider mites and their natural enemies. If a material is more harmful to the predatory mites than the pests, disruption of biological control is likely to occur. Even if spider mites are initially susceptible to a pesticide, they are likely to develop resistance more rapidly than phytoseiids. This is attributed to the haplodiploid reproduction (Croft and Van de Baan, 1988; Crozier, 1985), lower food resource limitation (Croft and Van de Baan, 1988), and high degree of polyphagy (Dermauw et al., 2012) of some species of spider mites (e.g. *Tetranychus urticae* Koch).

In Washington (USA), *T. urticae* is a common spider mite pest of apple (Beers and Hoyt, 1993). The most common phytoseiid in apple orchards is *Galendromus occidentalis* (Nesbitt) (Schmidt-Jeffris et al., 2015). It is a well-known predator of *T. urticae* and can successfully maintain the pest below economic thresholds when disruptive pesticides are avoided (Hoyt, 1969; Hoyt and Beers, 1993). In the 1960s, an integrated mite management program (IMM) was adopted that controlled the primary pest of apple, codling moth (*Cydia pomonella* (L.)), without harming spider mite

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https://doi.org/10.1016/j.cropro.2017.09.009
0261-2194/

biological control (Hoyt, 1969). This occurred because *G. occidentalis* had developed a degree of resistance to azinphos-methyl, an organophosphate that was commonly used for *C. pomonella* control (Croft, 1990a; Hoyt, 1969). However, a resurgence of spider mite outbreaks began to occur in the 1990s; this has been attributed to the shift from organophosphates and the adoption of neonicotinoids for the control of lepidopterans, aphids, and thrips (Beers et al., 2005). Neonicotinoids are now well-known for their non-target effects on predatory mites and ability to cause spider mite flare-ups in a variety of ecosystems (Beers et al., 2005; Beers and Schmidt, 2014; Duso et al., 2014; Poletti et al., 2007; Raupp et al., 2004; Sclar et al., 1998; Szczepaniec et al., 2011).

It is important to test the effects of newer pesticides on both the predator and pest, to determine if outbreaks are likely to occur, and to determine potential mechanisms of material selectivity. Although the non-target lethal and sublethal effects of common orchard pesticides are known for *Galendromus occidentalis* (Beers and Schmidt-Jeffris, 2015; Beers and Schmidt, 2014; Bostanian et al., 2009; Lefebvre et al., 2011; Schmidt-Jeffris and Beers, 2015), similar research has not been done for spider mites, especially for sublethal effects in general or lethal and sublethal effects of newer materials. The purpose of this study was to determine the effects of orchard pesticides used for a variety of direct and indirect pests, on *T. urticae* and compare these to previous results obtained for *G. occidentalis*. Comparison of how pesticides differentially affect the two species will allow for determination of materials likely to cause spider mite outbreaks.

2. Materials and methods

2.1. Colony maintenance

The colony of *T. urticae* was maintained on lima bean plants, *Phaseolus vulgaris* (L.) cv. 'Henderson Bush'. This colony was started from a field-collected population from a commercial pear orchard in the Wenatchee River Valley (Washington State, USA) in 2007. A separate culture of uninfested lima bean plants was used for the bioassay leaf disks (below).

2.2. Pesticide application

All materials tested are commonly used apple orchard pesticides (currently or in the recent past, i.e., azinphos-methyl) and represent a variety of modes of action (Table 1). Many materials are used for control of lepidopteran pests, primarily codling moth and obliquebanded leafroller (*Choristoneura rosaceana* (Harris)). Two fungicides (mancozeb + copper and sulfur) were also included because they have been shown in previous studies to affect both pest and predatory mite populations (Alston and Thomson, 2004; Ball, 1982; Beers et al., 2009; Hagley and Biggs, 1989).

Three concentrations of each pesticide were compared to a distilled water control in separate bioassays. The concentrations used were 2×, 1×, and 0.1 × the maximum labelled field rate applied at 935 L ha^{-1}. These doses were made by mixing the appropriate amount of formulated product in 1 L of distilled water to create the 2 × dose, then diluting for the other two doses. Pesticides were applied to individual disk arenas (below) using a laboratory sprayer (Potter spray tower, Burkard Mfg, Rickmansworth, England) set at 44.8 kPa using the intermediate nozzle. Each leaf disk was sprayed with 2 mL of the appropriate pesticide concentration or distilled water.

2.3. T. urticae bioassay

The bioassay arena consisted of a disk 2.2 cm in diameter cut from a bean leaf. The disk was placed with the abaxial surface facing up in a plastic cup (30 mL) filled with water-saturated cotton. The inner diameter of the portion cup was ca. 3.9 cm, allowing for space between the edge of the leaf disk and the container. Each pesticide concentration was represented by 50 disk arenas (replicates).

A single female *T. urticae* was transferred to each leaf disk using a fine brush. After transfer, all disks were sprayed with the appropriate treatment as described above. After treatment, females were allowed to feed and oviposit for 48 h, and then evaluated as either alive or dead and the number of eggs laid were counted. All females were then removed from the leaf disk. After the majority of the eggs in the untreated control had hatched, the number of hatched and unhatched eggs and live and dead *T. urticae* larvae were recorded. Arenas were held at 20 ± 2 °C and 16:8 L:D photoperiod during the experiment.

2.4. Data summary and analysis

This experiment was a completely randomized design (CRD) analyzed using a generalized linear model (PROC GENMOD, SAS

Table 1
Names, doses, and registrants of pesticides tested against *T. urticae*.

Common name	Mode of action[a]	Chemical class	Brand name	Formulation	Registrant[b]
Carbaryl	1A	carbamate	Sevin 4F	479 g L^{-1}	Bayer CropScience, Research Triangle Park, NC
Azinphos-methyl	1B	organophosphate	Guthion 50W	500 g kg^{-1}	Bayer CropScience, Research Triangle Park, NC
Lambda-cyhalothrin	3	pyrethroid	Warrior II 2.08CS	249 g L^{-1}	Syngenta Crop Protection, Inc., Greensboro, NC
Acetamiprid	4A	neonicotinyl	Assail 70WP	700 g kg^{-1}	Cerexagri-Nisso LLC, King of Prussia, PA
Thiacloprid	4A	neonicotinyl	Calypso 4F	479 g L^{-1}	Bayer CropScience, Research Triangle Park, NC
Imidacloprid	4A	neonicotinyl	Provado 1.6F	192 g L^{-1}	Bayer CropScience, Research Triangle Park, NC
Spinosad	5	spinosyn	Entrust 80W	800 g kg^{-1}	Dow Agrosciences LLC, Indianapolis, IN
Spinetoram	5	spinosyn	Delegate 25WG	250 g kg^{-1}	Dow Agrosciences LLC, Indianapolis, IN
Novaluron	15	IGR - benzoyl urea	Rimon 0.83EC	99 g L^{-1}	Chemtura Corporation, Middlebury, CT
Spirotetramat	23	tetramic acid	Ultor 1.25L	150 g L^{-1}	Bayer CropScience, Research Triangle Park, NC
Chlorantraniliprole	28	anthranilic diamide	Altacor 35WDG	350 g kg^{-1}	E.I DuPont de Nemours & Co., Wilmington, DE
Flubendiamide	28	anthranilic diamide	Belt 4SC	479 g L^{-1}	E.I DuPont de Nemours & Co., Wilmington, DE
Cyantraniliprole	28	anthranilic diamide	Exirel 100 g AI/liter	100 g L^{-1}	E.I DuPont de Nemours & Co., Wilmington, DE
Copper hydroxide	M1	inorganic	Kocide 3000	461 g kg^{-1}	E.I DuPont de Nemours & Co., Wilmington, DE
Sulfur	M2	inorganic	Kumulus 80W	800 g kg^{-1}	Arysta LifeScience North America, LLC, Cary, NC
Mancozeb	M3	dithiocarbamate	Manzate Pro-Stick	750 g kg^{-1}	E.I DuPont de Nemours & Co., Wilmington, DE

[a] Mode of action classification taken from Insecticide Resistance Action Committee (IRAC) v 7.2 (http://www.irac-online.org/content/uploads/MoA-classification.pdf) or the Fungicide Resistance Action Committee (FRAC) (FRAC Code List© 2013 http://www.frac.info/publication/anhang/FRAC%20Code%20List%202013-update%20April-2013.pdf.).
[b] The Registrant listed is from the time the experiments were begun.