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Comparative analysis of pesticide effects on natural enemies in western orchards: A synthesis of laboratory bioassay data

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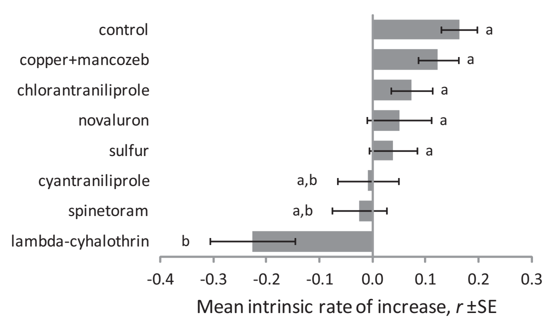
HIGHLIGHTS

- We report acute and sublethal effects of pesticides on natural enemies.
- Acute mortalities were greater for adult than juvenile life stages for spinetoram.
- Sublethal effects on daily fecundity, fertility and sex ratio are documented.
- Population models are used to estimate the effects of pesticide exposure.

GRAPHICAL ABSTRACT



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ABSTRACT

Pesticides are commonly used for pest management in apple, pear and walnut orchards in the western U.S. and may disrupt biological control of secondary pests in these crops. A comparative analysis was made of results obtained from a series of laboratory bioassays of acute mortality and life table response experiments to estimate lethal and sublethal effects of eight pesticides on seven natural enemy species through use of stage-structured population models. Even though a number of the pesticides tested were reduced-risk products, all of them with the exception of copper plus mancozeb and chlorantraniliprole, caused more than 80% acute mortality of at least one life stage of at least one of the natural enemy species at a full field-rate concentration and could thus be considered moderately harmful according to the International Organization for Biological Control classification for laboratory bioassays. Important sublethal effects included reductions in daily fecundity and egg fertility. From integration of the lethal and sublethal effects in matrix models, the mean of the estimated intrinsic rates of increase for natural enemy species was negative for exposure to cyantraniliprole, lambda-cyhalothrin and spinetoram, but positive and not significantly different from the control for exposure to chlorantraniliprole, copper plus mancozeb, novaluron, and sulfur. For comparisons among pesticides, there appears to be considerable variation in response among natural enemy species that can only be represented effectively from a full life table response experiment and a population-level endpoint, whereas among natural enemy species, their population-level response to the range of pesticides tested could frequently be represented by acute adult mortality alone.

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1. Introduction

The conservation of natural enemy activity in agricultural crops is one of three key approaches to the biological control of arthropod pests (Mills, 2014). While conservation biological control includes a number of different strategies for manipulating environmental conditions to enhance the abundance and activity of natural enemies (Jonsson et al., 2008), one of the most important is the judicious use of pesticides to avoid disrupting the biological control services provided by natural enemies. Ever since Stern et al. (1959) highlighted the need for a more holistic and integrated approach to pest management, and Carson (1962) popularized the issue of disruptive impacts of insecticides on natural ecosystems, the compatibility of pesticides and natural enemies has been a major concern for conservation biological control.

While the selectivity of pesticides with respect to natural enemies can be tested both in the laboratory and in the field, the majority of studies have been conducted in the laboratory due to the uncertainty of uncontrollable biotic and abiotic influences on field studies (Galvan et al., 2006; Beers et al., 2016). The early classes of synthetic insecticides, such as organochlorines, organophosphates and carbamates, were acutely toxic to a broad range of arthropod natural enemies (Croft, 1990; Sterk et al., 1999) and the focus of laboratory bioassays was on measures of mortality, such as LC50s, as toxicological endpoints (Stark et al., 2007a). However, with the emergence of newer classes of pesticides, such as insect growth regulators, spinosyns, diamides, and strobilurins, effects on natural enemies are less likely to be lethal, but may include sublethal effects on their life history performance and behavior (Stark and Banks, 2003; Desneux et al., 2007). For these newer classes of pesticides it has also been important to use multiple routes of exposure (oral, topical and residual) in laboratory bioassays (Banken and Stark, 1998; Stark and Banks, 2003; Galvan et al., 2006), in contrast to the standardized methodology of exposing natural enemies to fresh dry residues that had been developed earlier for the older classes of pesticides (Hassan, 1986, 1992; Croft, 1990).

One of the most important challenges in using laboratory bioassays to test for effects of pesticides on different aspects of the life history performance of a natural enemy has been to effectively extrapolate from the multiple life history parameters (development time, sex ratio, fecundity, etc.) obtained from measurement of individuals in the bioassays (individual-level endpoints) to a single index of the response of the natural enemy population to pesticide exposure (population-level endpoint). Two different approaches for integrating combinations of lethal and sublethal effects into single response indices include the total effects or reduction coefficient approach (Overmeer and van Zon, 1982; Urbaneja et al., 2008; Biondi et al., 2012) and the demographic approach (Forbes and Calow, 1999; Stark et al., 2007b; Forbes et al., 2008, 2011; Hanson and Stark, 2011a). The total reduction coefficient is simply the product of the proportional reductions for each individual-level measurement, after correction relative to the control, expressed as an overall percentage reduction. The demographic approach is more complex, but also more inclusive, in that it is based on data from life table response experiments that were specifically designed to estimate population-level responses to environmental factors that are measured as individual-level effects (Caswell, 1989). Life table response experiments have proven to be an effective way to estimate the individual-level effects of exposure to toxicants for organisms with short generation times, such as arthropods (Stark and Banks, 2003; Stark et al., 2007a).

The literature on laboratory bioassays of pesticide effects on natural enemies is extensive and such studies are an integral part of the registration process for pesticides in Europe (Desneux et al., 2007). The majority of studies have been designed to test the effects of a range of different pesticides on one or two species of natural enemy (e.g., Biondi et al., 2012; Liu et al., 2012; Amarasekare and Shearer, 2013; Wang et al., 2013; Beers and Schmidt, 2014). The main objective of these studies is the ability to rank or to classify the pesticides with respect to their selectivity for the natural enemy species in question. For example, the International Organization for Biological Control (IOBC) uses a standardized classification for the impact of pesticides on natural enemies that consists of four categories: harmless (<30% effect), slightly harmful (30–80% effect), moderately harmful (80–99% effect), and harmful (>99% effect) (Sterk et al., 1999). This is intuitively appealing as it provides an opportunity to consider the use of more or less selective materials with respect to preserving or enhancing the biological control services in cropping systems. However, the predictive ability of such a ranking of pesticide effects will depend on how representative the natural enemy species selected for testing is in terms of its functional role in contributing to the biological control services in different crops and locations. In contrast, other laboratory studies of pesticide effects on natural enemies have tested the effects of a single pesticide on a range of different natural enemy species (e.g., Jansen et al., 2011; Rodrigues et al., 2013). In this case, the objective is to determine how variable the impacts are among individual species within the natural enemy community of a particular crop or within a particular taxonomic group of natural enemies. While this provides valuable data on the variation in selectivity of a particular pesticide, it can seldom be used to guide the choices that are often sought by pest management practitioners in seeking materials that are compatible with biological control. Although a number of laboratory studies fall within the continuum between these two extremes of experimental designs, it is surprisingly difficult to compare different studies due to the wide variation in pesticide concentrations, natural enemy life stages, routes of exposure, and experimental methods and arenas used, and perhaps as a consequence, we know of no meta-analyses of pesticide effects on natural enemies.

Here we focus on a set of laboratory studies designed to determine the selectivity of eight different pesticides (two used only as a mixture) employed for orchard pest management in the western United States with respect to eight different natural enemy species that are well represented in these tree crops. Each of these studies focused on a single natural enemy species, but all were coordinated to use similar pesticide concentrations, natural enemy life stages, routes of exposure, and experimental methods. This allows us to examine variation in effects of pesticides among natural enemy species and to build a more comparative evaluation of the consequences of pesticide choice on natural enemy communities in western orchards. The objective of this comparative analysis is to address the question of the extent to which laboratory observations from individual species can be generalized to other members of a natural enemy community, and to help guide future laboratory studies of pesticide effects on natural enemies.

2. Natural enemies, pesticides and experimental design

Codling moth, *Cydia pomonella* (L.), (Lep., Tortricidae) is a key pest in apple, pear and walnut orchards throughout the western United States. One of the main objectives of this collaborative study was to assess the risk of pesticides that are used for the management of codling moth, and fungal or bacterial diseases in these crops, to the natural enemies associated with the secondary arthropod pests that occur in these orchards. A set of eight natural enemy species were selected for the laboratory bioassays. Two of