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Mitigating the effects of insecticides on arthropod biological control at field and landscape scales

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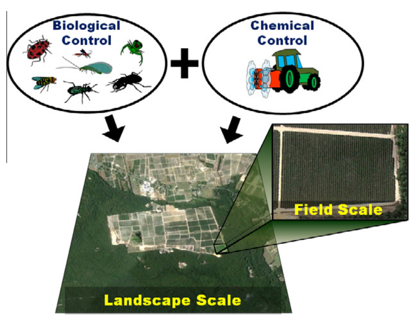
HIGHLIGHTS

- Global changes in agriculture affect pesticide use and biological control.
- Insecticides can have lethal and sub-lethal effects on natural enemies.
- Disruption of biological control can be mitigated using a variety of methods.
- Impacts can be managed at the landscape scale to enhance area-wide IPM.

GRAPHICAL ABSTRACT



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ABSTRACT

Integrated pest management (IPM) programs emphasize the combination of tactics, such as chemical and biological control, to maintain pest populations below economic thresholds. Although combining tactics may provide better long-term sustainable pest suppression than one tactic alone, in many cases, insecticides and natural enemies are incompatible. Insecticides can disrupt natural enemies through lethal and sub-lethal means causing pest resurgence or secondary pest outbreaks. Legislative actions such as the Food Quality Protection Act (US) and the Directive on Sustainable Use of Pesticides (EU) have placed greater restrictions on insecticides used in agriculture, potentially enhancing biological control. Here we focus on the effects of insecticides on biological control, and potential mitigation measures that can operate at different scales. At the farm scale, natural enemies can be conserved through the use of selective insecticides, low doses, special formulations, creation of refugia, special application methods, and targeted applications (temporal or spatial). At the landscape scale, habitat quality and composition affect the magnitude of biological control services, and the degree of mitigation against the effects of pesticides on natural enemies. Current research is teasing apart the relative importance of local and landscape effects of pesticides on natural enemies and the ecosystem services they provide, and the further development of this area will ultimately inform the decisions of policy makers and land managers in terms of how to mitigate pesticide effects through habitat manipulation.

1. Introduction

Over the past century, agriculture has experienced rapid intensification across much of the planet, particularly in the regions where food and fiber production are possible (Millennium Ecosystem Assessment, 2005). This intensification has increased

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net primary production from farmland for the human population, but this has had negative effects on biodiversity including birds (Donald et al., 2001), butterflies (Flick et al., 2012), bees (Kremen et al., 2002), and insect biological control agents (Thies and Tscharntke, 1999). While this latter group of insects provide valuable pest regulation, this ecosystem service can be compromised in agricultural systems where their survival is reduced through exposure to pesticides. Sustainable agricultural systems must be based on balancing the needs for production with support of the biodiversity upon which agricultural systems depend (Bianchi et al., 2006; Crowder and Jabbour, 2014), and managing pesticide risks to beneficial insects is an essential aspect of this.

With the needs for biodiversity protection in agriculture to support ecosystem services and their contributions to crop production in mind, is it possible to integrate chemical and biological pest control? This was the original objective of the integrated control concept, the precursor to integrated pest management (IPM) (Stern et al., 1959; van den Bosch and Stern, 1962). Advances in synthetic organic chemistry prior to and during World War II resulted in the proliferation and use of many inexpensive and efficacious pesticides (National Research Council, 2000), often without full consideration of how they might impact the environment or non-target organisms. Increasing awareness of the risks of reliance on pesticides led to the development of alternative control strategies and a return to integrated methods of pest management (Perkins and Patterson, 1997). Most recent legislation such as the Food Quality Protection Act (FQPA 1996) and the Directive on Sustainable Use of Pesticides (EU 128/2009/EC) put greater restrictions on pesticide use and specifically products with broad-spectrum activity. This has provided additional impetus to adopt insecticide chemistries with a more benign environmental profile and to find approaches that can integrate chemical and biological control. In fact, the Directive calls for European Union member states to develop national action plans for sustainable pesticide use by 2014, and has essentially two goals: encourage adoption of IPM and decrease pesticide use (Hillocks, 2012). While this mandate is broad, in this review we focus on insecticides, rather than fungicides and herbicides, because of their greater impact on arthropod natural enemies. However, we recognize that side effects on natural enemies by these other classes are relevant to the potential delivery of biological control (Theiling and Croft, 1988; Yardim and Edwards, 1998).

Biological control constitutes an essential component of many pest management programs in multiple ecosystems (e.g. Hoy, 1994; Bale et al., 2008). Gentz et al. (2010) argued that in the context of an IPM program, selective chemical compounds used in tandem with biological control agents may provide more comprehensive management than either approach alone. It may not be broadly applicable in all agricultural situations, but with new technology such as geographic information systems (GIS) and genetically modified (GM) crops, and with further research into development of sustainable agriculture, the compatibility between chemical and biological control can be enhanced. If insecticides and biological control are to be compatible (or as close to compatible as possible), three key factors in insecticide use will need to be addressed: chemistry, timing, and location (Hassan and Van de Veire, 2004). Chemistry, the inherent toxic properties of the insecticide, relates to physiological selectivity which is based on differences in physiologies between a particular pest and its predators and parasitoids (Ripper et al., 1951). Application timing can be adjusted so insecticides do not interfere with natural enemy release or applications are made when natural enemies are in less susceptible life stages (Hassan and Van de Veire, 2004). Spatially-targeted pest management can reduce the amount of active ingredient used by applying insecticides only to areas where pest density is high or plant damage tolerance is near zero (National Research Council, 2000). If a pest's spatial distribution is not uniform, insecticides may not need to be applied to the entire field to achieve effective control. Areas of low pest density that remain untreated can enhance biological control by providing a steady host source for natural enemies in addition to leaving a portion of the natural enemy population unexposed (Van Driesche and Heinz, 2004).

2. Biological control in a changing world

Global trade is increasingly bringing insect pests into new regions of the world, causing disruption to well-established and stable IPM programs (Pimentel, 2007). In many cases these IPM programs have provided reduced levels of pesticide use and have supported transition away from broad-spectrum insecticides, either through market incentives such as better prices for organically-produced food and fiber, or in response to policies. These include the EU Directive on Sustainable Use of Pesticides and the FQPA that were mentioned above. While these widespread changes in the intensity of pesticide use have been expected to increase the levels of biological control, such progress is in jeopardy in many systems due to the arrival and establishment of invasive pests.

Rapid adaptation of IPM approaches to respond to the new challenges of invasive pests is essential for continued profitability of crops facing this type of challenge. For example, the tomato leafminer, *Tuta absoluta* (Meyrick), recently moved from South America to Europe and the Mediterranean Basin, and caused significant increase in the use of insecticides to prevent crop damage. Rapid screening of insecticides for their safety against the complex of natural enemies that can affect *T. absoluta* in this new geographic range allowed informed decisions to be made about which chemical tools should be used for its management (Desneux et al., 2010; Urbaneja et al., 2012). This was particularly critical in protected culture where many tomatoes are produced. A similar situation faced the cotton and vegetable farmers of Arizona when the whitefly, *Bemisia tabaci* (Gennadius) Biotype B, developed large populations causing millions of dollars of lost revenue (Ellsworth and Jones, 2001). The response to this pest is a classic example of how the original integrated control concept (Stern et al., 1959) remains relevant 50 years after its introduction. Through a series of coordinated research projects and statewide implementation partnerships, this invasive pest was brought under control by a combination of natural enemy conservation and well-timed use of selective growth regulator insecticides, with widespread use of thresholds for spray decision-making so that money was not wasted, and so that biological control agents could be conserved. For instance, when this species first invaded there was widespread use of broad-spectrum insecticides, which killed its natural enemies and promoted rapid evolution of resistance. It wasnot until farmers moved towards growth regulators that the problem improved (Naranjo and Ellsworth, 2009a,b).

High levels of insecticide use are common in response to a new invasive pest but with appropriate support for research and education programs, there can be longer-term transition to selective and more biologically based controls that can be integrated into ongoing IPM programs (Naranjo and Ellsworth, 2009a). When this happens, biological control has a chance for establishment and providing significant contributions to pest suppression. In some cases, the effectiveness of selective insecticides may not be sufficient to meet demanding pest management targets, making biological control very challenging. This is the current situation for the recent invasion of the fruit pest *Drosophila suzukii* Matsumura into North America and Northern Europe (Cini et al., 2012), though research is currently underway to develop conservation and classical biological control for this pest.