



# Integrated pest and pollinator management — adding a new dimension to an accepted paradigm

David J Biddinger and Edwin G Rajotte

In this chapter we argue that while pesticides can be harmful to pollinators, when they are used in an integrated pest and pollinator management (IPPM) context, both pest management and pollinator protection may be achieved. Our growing knowledge of the impacts of pesticides on honey bees as well as bumble bees and solitary bees allows us to use the latitude we have in pest management including non-pesticidal pest management practices, changing pesticide types and incorporating other, less susceptible pollinator species into commercial practice. Pollinator health should be a central component of integrated pest management research, education and extension to produce viable IPPM approaches.

## Address

Department of Entomology, Center for Pollinator Research,  
Pennsylvania State University, 501 ASI Building, University Park, PA  
16801, United States

Corresponding author: Biddinger, David J ([djb134@psu.edu](mailto:djb134@psu.edu))

**Current Opinion in Insect Science** 2015, **10**:204–209

This review comes from a themed issue on **Social insects**

Edited by **Christina M Grozinger** and **Jay D Evans**

For a complete overview see the [Issue](#) and the [Editorial](#)

Available online 8th June 2015

<http://dx.doi.org/10.1016/j.cois.2015.05.012>

2214-5745/© 2015 Elsevier Inc. All rights reserved.

## Pesticides and the current pollinator crisis

Insecticides, by definition and design, kill insects including pollinators if sufficient dosage and exposure levels are met. Plant systemic neonicotinoid insecticides in particular may affect bee health and may contribute to the decline of some species [1<sup>\*\*</sup>]. In 2013, the European Commission imposed a two year moratorium on the use of some of these compounds [2] based on laboratory studies that demonstrated sublethal effects on honey bees or bumble bees [3<sup>\*\*</sup>]. Polemics for and against neonicotinoid bans concentrate on extremes, but the solution lies somewhere in between. Neonicotinoid types are not equally toxic [1<sup>\*\*</sup>,4<sup>\*</sup>], and not all bee species are equally susceptible [5<sup>\*\*</sup>]. Rather than banning neonicotinoids (or other pesticide types) as a class, we argue that we should modify pest management practices to include considerations for pollinator health.

Although laboratory-based studies can provide some information [6], appropriate field-realistic concentrations and formulations, as well as evaluating relevant short-term and long-term exposures and impacts are the best indicators of pollinator impacts [1<sup>\*\*</sup>,3<sup>\*\*</sup>,5<sup>\*\*</sup>]. Acute exposures of only a few days also conflict with growing evidence for more subtle, sublethal effects on growth, reproduction and behavior from long-term chronic exposure at low doses [7<sup>\*</sup>]. For example, the chitin inhibitor, novaluron, applied during bloom in almonds is not toxic to adult bees, but has sublethal effects on *Osmia* and honey bee reproduction [8]. The ‘field relevancy’ of some of the laboratory studies that led to the European Union ban of some neonicotinoids is hotly debated [3<sup>\*\*</sup>,9<sup>\*\*</sup>] and is difficult to gauge because most studies use a single dose rather than a range of doses to generate a response curve [9<sup>\*\*</sup>]. Other considerations should include synergy of insecticides with fungicides and other mixtures [5<sup>\*\*</sup>,10<sup>\*\*</sup>] and the impact of acaricides and antimicrobial drugs used against hive pests. It is these products which are the most frequently found contaminants in honey bee hives and have also been shown to also affect bee reproduction and health [11<sup>\*</sup>].

## Importance of neonicotinoids

Any pesticide has benefits and costs associated with it. Neonicotinoids were developed partly because of the Food Quality Protection Act (FQPA), which restricted organophosphate, organochlorine, and carbamate pesticides on public health grounds [12]. The generally vertebrate-safe neonicotinoids also contributed to pesticide resistance management by offering a different mode of action. But actions to ameliorate the perceived costs, such as the well-intentioned EU neonicotinoid ban, were based on the Substitution Principle (one set of compounds is replaced by newer, safer alternatives [13]), furthers the ‘pesticide treadmill’ [14], and could force growers to revert to the remaining older compounds, which have largely unknown pollinator impacts. Used judiciously, targeting pests at critical timings as in the following example in apple production, neonicotinoids can be effective while sparing pollinators as well as other beneficial organisms in conservation biological control programs [15].

## Integrated Pest Management and pollinators

Integrated Pest Management (IPM) is a long standing, science based, decision making process whose ecological roots lie in the use of multiple biological, cultural, physical, and chemical tactics to protect crops in a way that

minimizes economic, health, and environmental risks. IPM can address any pest complex (insect, disease, weed, vertebrate, among others) and can be adapted to any agricultural production goals including conventional, sustainable and organic. In addition, IPM can evolve to meet new production demands such as pesticide use reduction, incorporation of ecosystem services and food safety [16]. Likewise, IPM can be adjusted to protect pollinator health just as it is adjusted to protect other beneficial organisms such as predators and parasitoids. Indeed, the IPM paradigm, already understood by growers, will facilitate adoption of pollinator protection practices.

Although well understood, relatively easy to maintain, mobile in large numbers, and can rapidly communicate food source locations [17], honey bees are not the best pollinators for all crops [18,19]. Sole reliance on honey bees can be risky. North American beekeepers lost 1/3 of their colonies due to Colony Collapse Disorder (CCD) [20] and other factors [21] including a general 40% decline since 1947 [22]. Recent colony scarcity increased rental costs three-fold prompting consideration of alternative pollinators in Pennsylvania tree fruit [23]. So, the IPPM challenge is integration in two dimensions: Integrating alternative pollinators into crop production and integrating the welfare of all pollinators into the IPM crop protection programs, which often include pesticide use.

### The importance of pollinators in apple production

In southern Pennsylvania, apple farms are nestled in the rolling Appalachian Mountains among a patchwork of forest land and diverse agriculture. All cultivars require cross-pollination to ensure commercial, fresh market crops in which size and shape of the fruit is as important as yield, in contrast with other crops (e.g. almonds) where yield is maximized [24]. Unlike some apple production regions, mid-Atlantic U.S. apple pollination needs can be met by native bee species that occur in the landscape, and over half of Pennsylvania and New York apple growers do not rent honey bees [25,26\*].

Reliance on non-honey bee, wild pollinators requires multiple species to provide the biological insurance for sustainable pollination. However knowledge of species' distributions, pollination effectiveness, nutritional requirements, alternate food sources and nesting sites is needed in order to modify usually oversimplified agricultural landscapes. Of the 3500 bumble bee and solitary bee (or pollen bee) species in the US that are potential crop pollinators [27,28], the value of pollen bees alone is at least \$3 billion annually [27]. Wild and managed pollen bees can supplement or replace honey bees, with each wild pollinator species within a crop pollination guild having its own life history traits, flower preferences and pollination usefulness. The early bloom of tree fruits (e.g. plum, apple, among others) requires species that overwinter as adults.

For apples these include univoltine, solitary species (e.g. *Osmia*) and multivoltine species (e.g. *Bombus*) [26\*]. Of the 371 known bee species in Pennsylvania [29], over 180 occur in orchards during the growing season and 52 pollinate apple. Some such as *Osmia* can be 80 times more effective than honey bees [30].

### Roles of landscape and floristic diversity in support of apple pollinators

The reliability of wild pollinators depends on habitat suitability, both in the orchard and in the surrounding countryside [31\*]. In the Pennsylvania Appalachian mountains, orchards have steep slopes, well drained soils and a landscape matrix of approximately 8% orchards, 24% arable and pasture land, 9% developed area and 56% forests [32] and a continental climate [33]. The average two to four ha orchards are bordered by undeveloped scrub, forest, or fence rows where floristic diversity is correlated with pollinator communities. The forest edge/orchard border is the most species rich (169 out of 228 plant species recorded) and a significant predictor of bee species richness and abundance in the orchard [31\*,34–36]. This floristic diversity is also attractive to beneficial predators and parasitoids [37].

### IPM, pesticides and pollinators in apple

During the apple growing season, more than a dozen insect and mite pests [38,39], 8–10 fungal and bacterial diseases, and several vertebrate pests can attack the fruit and the trees [38]. Pennsylvania tree fruit IPM is an efficient and profitable combination of host plant resistance, biological control, sophisticated pest monitoring, and model-based pest predictions resulting in specifically-timed management practices [38]. Apple IPM has been modified to protect living IPM tools (biological control agents) [40–42,43\*,44], and can be further modified to protect pollinators giving rise to IPPM.

Pesticide applications may include multiple types of insecticides, fungicides, bactericides, herbicides, surfactants and others, each having a toxicity profile and impact on various insect species. Bee health is affected by field exposure to pesticides. Most studies consider only short-term acute contact exposure to adult bees in the laboratory using technical product in acetone [5\*\*,7\*]. Lab assays can be poor predictors of field performance [45,46,66\*\*]. Up to 100-fold toxicity differences were found comparing commercial formulations in water with technical products in acetone [5,4\*]. In addition, pesticide combinations sometimes add unexpected pollinator mortality [5\*\*,47–49,45].

Importantly, neonicotinoids control multiple sucking pests and are safer to biocontrol agents [38]. Not all neonicotinoids are equally toxic to bees [4\*]; specific active ingredients can be toxic to a particular pollinator species or not and may become more toxic when mixed

with fungicides [5\*\*]. Eliminating neonicotinoids would necessitate using less effective alternative pesticides, increase secondary pests and production costs and aggravate pest resistance problems. Neonicotinoid insecticides can be used to manage pests in apples, and through an IPPM approach, pollinators can be protected from them.

Since insecticides are not applied during the short apple bloom, direct contact of surface residues by bees is not likely. The mostly likely route of exposure is through the ingestion of contaminated pollen and nectar from systemic insecticides and fungicides applied before bloom. Ingestion bioassays are rare for bees other than the honeybee and some *Bombus* species, as are studies of exposure levels when bees encounter low doses in multiple flower visits over time [1\*\*,4\*]. The neonicotinoid, thiamethoxam, sprayed at the pink bud stage of apple at a typical 100 ppm field rate is reduced by translocation in the plant tissues; thus 5 days after a pre-bloom application, only 1–4 ppb is present in the nectar and pollen at 25% bloom [50]. Bee consumption rates of nectar and pollen are important in determining toxicity, but except for the honeybee, such consumption rates are largely unknown.

### Pesticide recommendations in apple IPM to protect pollinators

An important advantage of IPM is that the pest management practices can be adjusted to accommodate new factors such as pollinator protection. Information on pesticide effects on non-honeybees is for the most part lacking, but certain groups such as the megachilids (including *Megachile* and *Osmia*) appear less susceptible on average than honeybees [5\*\*,51]. This varies among species and pesticides even within the same pesticide class [5\*\*]. Using the honeybee as proxy for all pollinator species (as is presently done) is not an accurate predictor for other species like *Osmia* [5\*\*], leafcutter bees, or bumblebees, since susceptibility varies by bee species and pesticide [51]. For example, the Japanese orchard bee (*Osmia cornifrons*) was 26 times less susceptible to imidacloprid than the honeybee, but 12 times more susceptible to acetamiprid [5\*\*]. Present tree fruit IPM recommendations for pollinators are based on minimizing pesticide impact on honey bees rather than protecting wild pollinators. Pesticide recommendations for honeybees include no insecticide applications during bloom or when hives are present (except for insecticides that are non-toxic to honeybees (e.g. lepidopteran insect growth regulators [26°,45]), and apply bloom fungicides at night or early morning. Pesticide restrictions are lifted when hives are removed; sometimes well before the end of bloom and without regard to wild bees that may still be foraging.

Although systemic pesticides are regarded as biocontrol-friendly since the pesticides are absorbed into the plant tissues where they were accessible only to plant feeders

[52], the potential movement into the nectar and pollen from pre bloom sprays may make them toxic to bees. Although neonicotinoids have harmed bees in some agricultural systems [53,54], these pesticides may be integrated into agriculture to preserve their pest management aspects as long as precautions are taken to minimize their impacts on non-targets such as pollinators and other beneficial insects. For example, the rosy apple aphid (*Dysaphis plantaginea*), which is resistant to organophosphates, carbamates and pyrethroids, and for which no alternative control methods (including biological control) exists [55], is killed by a neonicotinoid application made just before bloom. Simply, adjusting the pesticide's application time to 10 days before bloom controls the aphids and drastically reduces pesticide residues in nectar and pollen (Biddinger, pers. comm.). Solutions like this should be investigated in all crops serviced by pollinators. A complete ban of this pesticide class would cause (a) a reversion to the older, more toxic compounds they were meant to replace, (b) exacerbation of pest resistance by removing a rotation partner, (c) a switch to broad spectrum pyrethroid sprays which would destroy existing IPM programs by eliminating most biological control agents, or (d) the complete loss of control of pests like the rosy apple aphid.

Even fungicides, long thought relatively harmless to pollinators and therefore safe to spray during bloom, are now indicted as potential pollinator threats [11°,56]. Bloom-sprayed fungicides break crop disease cycles early in the season reducing many sprays later in the season. Although most fungicides alone still appear safe, the simultaneous application of some fungicides (ergosterol biosynthesis inhibitors, DMI) may synergize neonicotinoid toxicity [5\*\*,10\*\*] and possibly that of other insecticides such as the pyrethroids [57]. A single lab study [10\*\*] using a technical neonicotinoid product dissolved in acetone, found synergism of 105–1141-fold to honeybees by contact with acetamiprid and thiacloprid when mixed with two different DMI fungicides. However, synergism of other neonicotinoid insecticides with DMI fungicides was not found. Formulated versions of acetamiprid and imidacloprid with field rates of a formulated DMI fungicide in water tested on both honeybees and *Osmia cornifrons* revealed synergism that was barely significant at a 5-fold level with acetamiprid, and insignificant for imidacloprid in the lab [5\*\*]. Field trials with formulated product of both the insecticide and fungicide showed similar results [58]. Rightly or wrongly, almost all fungicides, except the older contact fungicides, are considered bee-safe even in combinations [38,49,55,59]. These older fungicides have some insecticidal properties that can affect larval development through chronic exposure during nectar and pollen feeding [59,60]. Even fungicides acceptable in organic agriculture, sulfur and lime sulfur, are restricted during bloom because the odor is repellant to bees for up to 48 hours [61,62].

## IPM recommendations for conserving wild pollen bees for tree fruit pollination

Tree fruit IPM programs can be adjusted to provide both pest control and pollinator health protection in an IPPM framework if we can better understand the relative levels of susceptibility of various bees species to both acute and chronic exposures to pesticides and the sources and levels of exposure in the field over time. With this information, we can inform farmers on how to adjust their spray programs to choose pesticides that are less toxic to bees while still controlling pests, or how to adjust the timing of toxic pesticides to minimize exposure levels just as we have done for over 40 years in biological control programs to conserve predatory mites and other beneficial arthropods. Since neonicotinoid residues in plant tissue does not carry over the winter (Biddinger, pers. comm.), only prebloom applications have to be adjusted in tree fruit. In addition, while wild bees have great pollinator potential, they are also susceptible to pesticides and other factors such as lack of alternate forage and nesting sites. These other factors can also be part of the overall IPPM approach by expanding orchard management to include the surrounding landscape as well as siting nesting sites and hive placement in orchard interiors to accommodate species-specific foraging ranges [63]. This same approach can be applied to other crops.

The recognition of honeybee decline and a rising reliance on wild, pollen bees has started to be included in public policy, providing increased funding for research and education on this topic. The Food, Conservation, and Energy Act of 2008 (aka The Farm Bill) acknowledged the great importance of pollen bees for agriculture by providing funding for farmers to increase and protect pollinator habitat on farm land. Farmers are encouraged to seed strips of wildflowers along their property to encourage bee visitation to their crops, or to leave part of their property fallow to increase pollinator habitat [64,65]. USDA/NRCS provides conservation payments that underwrite pollinator-friendly farm practices.

Although some may say that we are in a pollinator crisis mainly based on honeybee declines, we assert that in addition to honey bee protection, we need to encourage and make use of the myriad other pollinator species and, by properly adjusting crop IPM practices to create IPPM that will protect all the pollinator species. Going forward we need to:

- Include pollinator protection in IPM education.
- Expand pesticide toxicity testing to include other pollinator species in addition to honey bees.
- Encourage federal and state agencies to fund research and extension programs that integrate pollinator health into IPM, yielding IPPM.
- Encourage USEPA and other regulatory bodies to include pollinator protection in pesticide use regulations.
- Encourage conservation bodies such as USDA/NRCS to incentivize farm practices that preserve pollinator health.
- Work with the private sector (commodity groups, agricultural input companies, food retailers, among others) to incorporate pollinator protection into their businesses.
- Provide public education so consumers can choose products produced with good pollinator protection standards.

## Acknowledgements

Funding was provided by a State Horticultural Association of Pennsylvania grant, an USDA-SCRI Research and Extension grant (PEN04398) on native pollinators, an USDA-NRCS Conservation Innovation grant with the Xerces Society for Invertebrate Conservation, and a current regional USDA-SCRI Coordinated Agricultural Project grant (M1CL05063) on integrated crop pollination.

## References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest
  - of outstanding interest
1. Blacquiere T, Smagghe G, van Gestel CAM, Mommaerts V: **Neonicotinoids in bees: a review on concentration, side effects and risk assessment.** *Ecotoxicology* 2012 <http://dx.doi.org/10.1007/s10646-012-0863-x>.
  - A key review of the recent literature of neonicotinoid insecticide lethal and sublethal effects on bees in agriculture, residue levels within plant tissues and evaluation of a risk assessment scheme for systemic pesticides.
  2. European Commission: **Commission implementing Regulation (EU) No 485/2013 of 24 May 2013 amending Implementing Regulation (EU) No 540/2011, as regards the condition of approval of the active substances clothianidin, thiamethoxam and imidacloprid, and prohibiting the use and sale of seeds treated with plant protection products containing those active substances.** *Official Journal of the European Union* 2013. L139/12 25.5.2013.
  3. Carreck NL, Ratnieks FLW: **The dose makes the poison: have “field realistic” rates of exposure of bees to neonicotinoid insecticides been overestimated in laboratory studies?** *J Apicu Res* 2014, **53**:607-614.
  - Review of what a ‘field-realistic dose of neonicotinoid insecticides is an how to relate laboratory studies with field evaluations.
  4. Hopwood JM, Vaughan M, Shepherd M, Biddinger D, Mader E: **Are neonicotinoids killing the bees?** *Xerces Soc Invertebr Conserv* 2012:32.
  - A general review of the literature surrounding neonicotinoids for the public that categorizes by crop and application type on various pollinator species.
  5. Biddinger DJ, Robertson J, Mullin C, Frazier J, Joshi NK, Vaughn M, Ashcraft S: **Comparative toxicities and synergism of orchard pesticides to *Apis mellifera* (L.) and *Osmia cornifrons* (Radoszkowski).** *PLoS One* 2013, **8**:e72587 <http://dx.doi.org/10.1371/journal.pone.0072587>.
  - Examines the acute contact toxicities of neonicotinoid other insecticides and fungicide mixtures as formulated product in water to better simulate field applications on both the honey bee and *Osmia cornifrons*.
  6. Medrzycki P, Giff H, Aupinel P, Belzunces LP, Chauzat M-P, Claben C, Colin ME, Dupont T, Girolamini V, Johnson R et al.: **In V. Dietermann; P Neumann (Eds) The COLOSS Beebook, Vol. 1: Standard methods for *Apis mellifera* research.** *J Apicu Res* 2013:52. <http://dx.doi.org/10.3896/IBRA.1.52.4.14>.
  7. Connolly C: **The risk of insecticides to pollinating insects.** *Commun Integr Biol* 2013, **6**:e25074 <http://dx.doi.org/10.4161/cib.25074>.



Discussion of the banning of some neonicotinoids in the European Union and the issue of pesticide replacement.

8. Hodgson EW, Pitts-Singer TL, Barbour JD: **Effects of the insect growth regulator, novaluron on immature alfalfa leafcutting bees, *Megachile rotundata***. *J Insect Sci* 2011, **11**:43.
9. van der Sluijs JP, Simon-Delso N, Goulson D, Maxim L,
  - Bonmatin J-M, Belzunces LP: **Neonicotinoids, bee disorders and the sustainability of pollinator services**. *Curr Opin Environ Sustain* 2013, **5**:293-305.

A review of the literature on the effects of neonicotinoid insecticides on pollinators in support of the European Union ban on several of these products.
10. Iwasa T, Motoyama N, Ambrose JT, Roe RM: **Mechanism for the differential toxicity of neonicotinoid insecticides in the honey bee, *Apis mellifera***. *Crop Protection* 2004, **23**:371-378.
 

One of the few studies examining differential contact toxicity of various neonicotinoid insecticides to the honey bee and demonstrating high levels of synergism with mixtures of fungicides.
11. Johnson RM, Dahlgren L, Siegfried BD, Ellis MD: **Acaricide, fungicide and drug interactions in honey bees (*Apis mellifera*)**. *PLoS ONE* 2013, **8**:e54092 <http://dx.doi.org/10.1371/journal.pone.0054092>.
 

Examines the effects of various pesticides and drugs used within the honey bee hive to control various pests.
12. Food Quality Protection Act of 1996. H.R. 1627 Public Law 104-170 104th Congress, United States of America.
13. Lofstedt R: **The substitution principle in chemical regulation: a constructive critique**. *J Risk Res* 2013. <http://dx.doi.org/10.1080/13669877.2013.841733>.
14. Cochrane WW: *The Development of American Agriculture: A Historical Analysis*. University of Minnesota Press; 1993.
15. Agnello A, Atanassov A, Bergh JC, Biddinger DJ, Gut LJ, Haas MJ, Harper JK, Hogmire HW, Hull LA, Kime LF *et al.*: **Reduced-risk pest management programs for eastern U.S. apple and peach orchards: a 4-year regional project**. *Am Entomol* 2009, **55**:184-197.
16. Rajotte EG: **From profitability to food safety and the environment: shifting the objectives of IPM**. *Plant Dis* 1993, **77**:296-299.
17. DeGrandi-Hoffman G, Tarpy DR, Schneider SS: **Patriline composition of worker populations in honeybee (*Apis mellifera*) colonies headed by queens inseminated with semen from African and European drones**. *Apidologie* 2003, **34**: 111-120.
18. Westerkamp C: **Honeybees are poor pollinators — why?** *Plant System Evol* 1991, **177**:71-75.
19. Batra SWT: **Bee introductions to pollinate our crops**. In *For Nonnative Crops, Whence Pollinators of the Future? Proceedings, Entomological Society of America*. Edited by Strickler K, Cane JH. *For Nonnative Crops, Whence Pollinators of the Future? Proceedings, Entomological Society of America* Thomas Say Publications in Entomology; 2003:85-98.
20. VanEngelsdorp D, Underwood R, Caron D, Hayes J Jr: **An estimate of managed colony losses in the winter of 2006–2007: a report commissioned by the apiary inspectors of America**. *Am Bee J* 2007, **147**:599-603.
21. Stubbs CS, Drummond FA (Eds): *Bees and Crop Pollination — Crisis, Crossroads, Conservation*. Entomological Society of America; 2001.
22. National Research Council's Committee on the Status of Pollinators in North America. 2007 (executive summary at: [http://www.nap.edu/catalog.php?record\\_id=11761](http://www.nap.edu/catalog.php?record_id=11761)).
23. Biddinger D, Rajotte E, Joshi NK, Ritz A: **Wild bees as alternative pollinators**. *Fruit Times* 2011, **30**:1-4 <http://extension.psu.edu/plants/tree-fruit/news/2011/wild-bees-as-alternative-pollinators>.
24. Westwood MN: *Temperate-zone Pomology*. Timber Press; 1993.
25. Joshi NK, Biddinger D, Rajotte EG: **A survey of apple pollination practices, knowledge and attitudes of fruit growers in Pennsylvania**. *10<sup>th</sup> International Pollination Symposium; Puebla, Mexico: 2011*.
26. Park M, Danforth B, Losey J, Biddinger D, Vaughn M, Dollar J, Rajotte E, Agnello A: *Wild Pollinators of Eastern Apple Orchards and How to Conserve Them*. Cornell University, Penn State University, and The Xerces Society for Invertebrate Conservation; 2012: 19p. <http://www.northeastipm.org/park2012>.
 

Identification guide to apple pollinators with notes on alternative forage and a ranking of pesticide toxicity.
27. Berenbaum M: **Committee on the status of pollinators in North America. Status of Pollinators in North America**. The National Academies Press; 2007.
28. Batra S: **Coaxing pollen bees to work for us**. In *Proceedings: Bees and Crop Pollination — Crisis, Crossroads, Conservation*. Edited by Stubbs CS, Drummond FA. *Proceedings: Bees and Crop Pollination — Crisis, Crossroads, Conservation* Thomas Say Publications in Entomology. Entomological Society of America; 2001:85-93.
29. Donovall LR, vanEngelsdorp D: **A checklist of the bees (Hymenoptera: Apoidea) of Pennsylvania**. *J Kansas Entomol Soc* 2010, **83**:7-24.
30. Greer L: **Alternative pollinators: native bees**. *ATTRA Horticultural Technical Note* 1999. <http://www.attra.org/attra-pub/PDF/nativebee.pdf>.
31. Kennedy CM, Lonsdorf E, Neel MC, Williams NM, Ricketts TH,
  - Winfree R, Bommarco R: **A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems**. *Ecol Lett* 2013, **16**:584-599.

Meta-analysis of many studies worldwide demonstrating a strong correlation of habitat diversity and pollinator diversity.
32. USDA-NASS: *Pennsylvania Agricultural Statistics 2011–2012*. 2012: Available at: [http://www.nass.usda.gov/Statistics\\_by\\_State/Pennsylvania/Publications/Annual\\_Statistical\\_Bulletin/2011\\_2012/pa\\_2012bulletin.pdf](http://www.nass.usda.gov/Statistics_by_State/Pennsylvania/Publications/Annual_Statistical_Bulletin/2011_2012/pa_2012bulletin.pdf).
33. The Pennsylvania State Climatologist. 2013. <http://climate.psu.edu/>.
34. Kammerer M, Biddinger DJ, Mortensen DA, Rajotte EG, Joshi NK, Leslie TW: **The role of local plant communities in supporting native bees in Pennsylvania apple orchards**. In *Proceedings, International Conference on Pollinator Biology, Health and Policy; Aug. 14–17, 2013, PA: 2013:121*.
35. Shackelford G, Steward PR, Benton TG, Kunin WE, Potts SG, Biesmeijer JC, Sait SM: **Comparison of pollinators and natural enemies: a meta-analysis of landscape and local effects on abundance and richness in crops**. *Biol Rev* 2013, **88**:1002-1021.
36. Ritz A, Biddinger DJ, Mortensen D, Vaughn M, Gillis J, Leslie T, Rajotte E, Joshi NK: **Developing floral provisioning plantings for enhancement of pollinators: a case study in Pennsylvania apple orchards**. In *Proceedings, International Conference on Pollinator Biology, Health and Policy; Aug. 14–17, 2013, PA: 2013:144*.
37. Biddinger D, Tooker J, Surcica A, Krawczyk G: **Survey of native biocontrol agents of the brown marmorated stink bug in Pennsylvania fruit orchards and adjacent habitat**. *Pennsylvania Fruit News* 2012, **92**:47-54.
38. Penn State Tree Fruit Production Guide 2014–2015. Penn State Cooperative Extension. AGRS-045. 357 p. <http://tfpg.cas.psu.edu/>.
39. Hull LA, Joshi NK, Zaman F: **Large plot reduced risk insecticide study for Lepidopteran pests infesting apples, 2008**. *Arthropod Manage Tests* 2009:1-6 <http://dx.doi.org/10.4182/amt.2009.A11>.
40. Biddinger D, Joshi NK, Rajotte E, Leslie T: **Towards biodiversity-based ecological IPM: case of US apple production**. In *Proceedings, 24th International Congress of Entomology; 19–25 Aug. 2012 Daegu, South Korea: 2012:pS901*.
41. Biddinger DJ, Hull LA, Joshi N, Ngugi H: **Impact of selected insecticides used for brown marmorated stink bug control and fungicides used for scab resistance on the predatory mite, *Typhlodromus pyri***. *Pennsylvania Fruit News* 2013, **93**:45-57.

42. Biddinger D, Leslie T, Joshi NK: **Reduced-risk pest management programs for Eastern USA peach orchards: Impacts on non-target arthropod parasitoids, predators and some select pests.** *J Econ Entomol* 2014, **107**:1084-1091.
43. Jones VP, Steffan SA, Hull LA, Brunner JF, Biddinger DJ: **Effects of the loss of organophosphate pesticides in the US: opportunities and needs to improve IPM programs.** *Outlooks Pest Manage* 2010, **21**:161-166.
- A review of integrated pest management in US tree fruit and the transition to reduced-risk pesticides that include the neonicotinoids.
44. Agnello AM, Atanassov A, Bergh JC, Biddinger DJ, Gut LJ, Haas MJ *et al.*: **Reduced-risk pest management programs for eastern US apple and peach orchards: a 4-year regional project.** *Am Entomol* 2009, **55**:184-197.
45. Cox DL, Knight AL, Biddinger DJ, Lasota JA, Pikounis B, Hull LA, Dybas RA: **Toxicity and field efficacy of avermectins against codling moth (Lepidoptera: Tortricidae) on apples.** *J Econ Entomol* 1995, **88**:708-715.
46. Biddinger DJ, Hull LA: **Effects of several types of insecticides on the mite predator, *Stethorus punctum* (Coleoptera: Coccinellidae), including insect growth regulators and abamectin.** *J Econ Entomol* 1995, **88**:358-366.
47. Biddinger D, Joshi NK, Robertson J, Rajotte E, Mullin C, Vaughan M, Frazier J: **Are neonicotinoid insecticides which partially replaced organophosphate and carbamate insecticides in USA tree fruit safer to native pollinators and biological control?** *Proceedings, 24th International Congress of Entomology*; 19–25 Aug. 2012. Daegu, South Korea: 2012:pO405.
48. Riedl H, Johansen L, Barbour J: *How to Reduce Bee Poisoning from Pesticides.* Oregon State University. PNW 591; 2006. <http://extension.oregonstate.edu/catalog/pdf/pnw/pnw591.pdf>.
49. Hooven LA, Sagili RR, Johansen E: *How to Reduce Bee Poisoning from Pesticides.* Oregon State University Extension Service. Oregon State University; 2013. PNW 591.
50. Biddinger DJ, Mullin C, Robertson JL, Rajotte E, Vaughn M, Frazier J, Joshi NK, Otieno M, Frazier M: **The impact of neonicotinoid insecticides on pollinators in tree fruit IPM programs.** In *Proceedings International Conference on Pollinator Biology, Health and Policy*; Aug. 14–17, 2013. University Park, PA: 2013:P69.
51. Arena M, Sgolastra F: **A meta-analysis comparing the sensitivity of bees to pesticides.** *Ecotoxicology* 2014, **2014**:1-11 <http://dx.doi.org/10.1007/s10646-014-1190-1>.
52. Jeschke P, Nauen R, Schindler M, Elbert A: **Overview of the status and global strategy for neonicotinoids.** *J Agric Food Chem* 2010, **59**:2897-2908.
53. Krupke CH, Hunt GJ, Eitzer BD, Andino G, Given K: **Multiple routes of pesticide exposure for honeybees living near agricultural fields.** *PLoS ONE* 2012, **7**:e29268 <http://dx.doi.org/10.1371/journal.pone.0029268>.
54. Henry M, Béguin M, Requier F, Rollin O, Odoux J *et al.*: **A common pesticide decreases foraging success and survival in honeybees.** *Science* 2012, **336**:348-350 <http://dx.doi.org/10.1126/science.1215039>.
55. Biddinger DJ, Demchak K, Rajotte EG, Baugher T, Joshi NK: **Pollinators and pesticide sprays during bloom in fruit plantings.** *Fruit Times* 2014. Available at <http://extension.psu.edu/plants/tree-fruit/news/2014/pollinators-and-pesticide-sprays-during-bloom-in-fruit-plantings>.
56. Pettis JS, Lichtenberg EM, Andree M, Stitzinger J, Rose R *et al.*: **Crop pollination exposes honeybees to pesticides which alters their susceptibility to the gut pathogen *Nosema ceranae*.** *PLoS ONE* 2013, **8**(7):e70182 <http://dx.doi.org/10.1371/journal.pone.0070182>.
57. Pilling ED, Jepson PC: **Synergism between EBI fungicides and a pyrethroid insecticide in the honeybee (*Apis mellifera* L.).** *Pesticide Sci* 1993, **39**:293-299.
58. Schmuck R, Stadler T, Schmidt HW: **Field relevance of a synergistic effect observed in the laboratory between an EBI fungicide and a chloronicotinyl insecticide in the honeybee (*Apis mellifera* L., Hymenoptera).** *Pest Manage Sci* 2003, **59**:279-286.
59. Ladurner E, Bosch J, Kemp WP, Maini S: **Foraging and nesting behavior of *Osmia lignaria* (Hymenoptera: Megachilidae) in the presence of fungicides: cage studies.** *J Econ Entomol* 2008, **101**:647-653.
60. Ladurner E, Bosch J, Kemp WP, Maini S: **Assessing delayed and acute toxicity of five formulated fungicides to *Osmia lignaria* Say and *Apis mellifera*.** *Apidologie* 2005, **36**:449-460.
61. Butler BC, Finney DJ, Schiele P: **Experiments on the poisoning of honeybees by insecticidal and fungicidal sprays used in orchards.** *Annals Appl Biol* 1943, **30**:143-150.
62. Mader E, Adamson NL: *Organic-approved Pesticides-Minimizing Risks to Pollinators. Invertebrate Conservation Fact Sheet.* The Xerces Society for Invertebrate Conservation; 2009. Available at: <http://www.xerces.org/wp-content/uploads/2009/12/xerces-organic-approved-pesticides-factsheet.pdf>.
63. Biddinger DJ, Joshi NK, Rajotte EG, Halbrendt NO, Pulig C, Naithani KJ, Vaughn M: **An immunomarking method to determine the foraging patterns of *Osmia cornifrons* and resulting fruit set in a cherry orchard.** *Apidologie* 2013, **44**:738-749.
64. Vaughn M, Mader E, Guisse J, Goldetz-Dollar J, Borders B, Biddinger D, Gillis J: *USDA-NRCS Conservation Cover (327) for Pollinators – Pennsylvania Installation Guide and Job Sheet.* 2012. <http://www.xerces.org/pollinator-conservation/agriculture/pollinator-habitat-installation-guides/>.
65. Vaughn M, Mader E, Guisse J, Goldetz-Dollar J, Borders B, Biddinger D, Gillis J: *USDA-NRCS Hedgerow Plantings (422) for Pollinators – Pennsylvania Installation Guide and Job Sheet.* 2012. <http://www.xerces.org/pollinator-conservation/agriculture/pollinator-habitat-installation-guides/>.
66. Robertson JL, Russel RM, Preisler HK, Savin NE: *Bioassays with Arthropods.* CRC Press; 2007. 199p. An easy to read manual for entomologist outlining the proper procedures for conducting, analyzing and interpreting pesticide bioassay data.