Effects of Neonicotinoids on Pollinators

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Pollination

• 90% of all flowering wild plants depend on insect pollination

• At least $\frac{1}{3}$ of the global crop production is from crops that to some extent depend on insect pollination

Both *bee* and *non-bee* pollinators

Rader et al. (2016) PNAS
Both honey bees and wild bees contribute to crop pollination and rather complement than replace each other.

Garibaldi et al. (2013) Science
Review

Neonicotinoids – from zero to hero in insecticide chemistry

Peter Jeschke\textsuperscript{1,*} and Ralf Nauen\textsuperscript{2}

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\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{neonicotinoids.png}
\caption{Development of insecticidal classes in crop protection, 1990–2005, expressed as percentage of total.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{neonicotinoids.png}
\caption{Development of insecticidal classes in seed treatment, 1990–2005, expressed as percentage of total.}
\end{figure}
Neonicotinoids

• Imidacloprid (Bayer Crop Science) was the first (1991)
• Acetamiprid, nitenpyram, thiamethoxam, thiacloprid, clothianidin, dinofuran (1995-2002)

• Effective against many insect pests
• Systemic
• Water soluble
• Slow degradation (long half-life)
• High selectivity against insects over mammals

Increasing knowledge on neonics and bees

Lundin et al. (2015) PLoS ONE
## Most known about seed treatment in corn

Table 1. Total number of studies on neonicotinoids and bees in different crops, study examples for each crop, and number of studies for each method of application in each crop (‘Seed’ = seed treatment application, ‘Foliar’ = foliar spray application, ‘Soil’ = furrow, drench or drip irrigation application, Granulate = granulate application).

<table>
<thead>
<tr>
<th>Crop Linnean name</th>
<th>Common name</th>
<th># studies</th>
<th>Study example</th>
<th>Application method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zea mays</td>
<td>Maize</td>
<td>28</td>
<td>[28]</td>
<td>Seed: 28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Soil: 3</td>
</tr>
<tr>
<td>Brassica napus</td>
<td>Oilseed rape</td>
<td>7</td>
<td>[29]</td>
<td>Seed: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Soil: 2</td>
</tr>
<tr>
<td>Helianthus annuus</td>
<td>Sunflower</td>
<td>7</td>
<td>[30]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Turfgrass</td>
<td>4</td>
<td>[31]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 1</td>
</tr>
<tr>
<td>Cucumis melo</td>
<td>Cantaloupe</td>
<td>3</td>
<td>[32]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 2</td>
</tr>
<tr>
<td>Gossypium spp.</td>
<td>Cotton</td>
<td>3</td>
<td>[33]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 2</td>
</tr>
<tr>
<td>Solanum lycopersicum</td>
<td>Tomato</td>
<td>3</td>
<td>[34]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 2</td>
</tr>
<tr>
<td>Citrus spp.</td>
<td>Citrus fruits</td>
<td>2</td>
<td>[35]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 1</td>
</tr>
<tr>
<td>Cucurbita pepo</td>
<td>Pumpkin, squash</td>
<td>2</td>
<td>[36]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 1</td>
</tr>
<tr>
<td>Malus domestica</td>
<td>Apple</td>
<td>2</td>
<td>[37]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 2</td>
</tr>
<tr>
<td>Brassica juncea</td>
<td>Mustard</td>
<td>2</td>
<td>[38]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foliar: 1</td>
</tr>
<tr>
<td>Actinidia spp.</td>
<td>Kiwifruit</td>
<td>1</td>
<td>[39]</td>
<td></td>
</tr>
<tr>
<td>Brassica rapa</td>
<td>Turnip rape</td>
<td>1</td>
<td>[40]</td>
<td></td>
</tr>
<tr>
<td>Glycine max</td>
<td>Soybean</td>
<td>1</td>
<td>[33]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
</tr>
<tr>
<td>Medicago sativa</td>
<td>Alfalfa</td>
<td>1</td>
<td>[10]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
</tr>
<tr>
<td>Triticum spp.</td>
<td>Wheat</td>
<td>1</td>
<td>[41]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Seed: 1</td>
</tr>
</tbody>
</table>

Lundin et al. (2015) PLoS ONE
Most knowledge about honey bees

<table>
<thead>
<tr>
<th>Species</th>
<th>N studies</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Apis mellifera</em>, <em>Apis cerana</em></td>
<td>168</td>
</tr>
<tr>
<td><em>Bombus terrestris</em>, <em>Bombus impatiens</em>, <em>Bombus</em> spp.</td>
<td>42</td>
</tr>
<tr>
<td><em>Megachile rotundata</em>, <em>Apoidea</em> spp., <em>Melipona quadrifasciata</em>, <em>Osmia bicornis</em>, <em>Osmia lignaria</em>, <em>Nannotrigona perilampoides</em>, <em>Nomia melanderi</em>, <em>Osmia cornifrons</em>, <em>Scaptotrigona postica</em></td>
<td>17</td>
</tr>
</tbody>
</table>

Lundin et al. (2015) PLoS ONE
Most knowledge from lab studies

...and field studies estimating exposure in honey bee collected pollen or nectar/honey (but very few on effects)

Photo: Hollis Woodard lab

Lundin et al. (2015) PLoS ONE
24 h exposure of bumble bees in cage trial

Baines et al. (2017) Scientific Reports

NOAEL

- thiamethoxam: 0.93 ng/bee
- imidacloprid: 0.93 ng/bee
- clothianidin: 1.9 ng/bee
- acetamiprid: 37.5 ng/bee
Lethal and sublethal effects

Individual level effect

Sublethal effects?

or

LD50

Colony level effect?

?
Three alarming studies in 2012

**LETTER**

Combined pesticide exposure severely aff individual- and colony-level traits in bee

Dr. David L. Kent, Optical Sciences Institute, and Ways P. Pizza

Three alarming studies in 2012 have demonstrated the severe effects of combined pesticide exposure on individual and colony-level traits in bees. These studies highlight the importance of understanding the complex interactions between pesticides and their impacts on bee health and productivity.

A Common Pesticide Decreases Foraging Success and Survival in Honey Bees

Mickaili Honig, Maxima Ragan, Faline Rager, Orama Ral, Jean-François Brient, Jean Apte, Sylvie Schmichl, Akiel Decourt

Non-lethal exposure of honey bees to thiamethoxam (neonicotinoid pesticide) causes high mortality due to hiving failure at levels colony at risk of collapse. Simulated exposure events on free-labeled with an RFID tag suggest that foraging is impaired by intoxication. Theses experiments offer new insights into the common neonicotinoid pesticides used worldwide.

Colony collapse disorder (CCD) is a recent, pervasive syndrome affecting honey bee (Apis mellifera) colonies in the Northern hemis which is characterized by a sudden disappearance of honey bees from the hive (1). Multiple causes of CCD have been proposed, such cutes, pathogens, parasites, and natural habitat degradation (2). The relative contribution of these stressors in CCD is not clear. Some scientists and beekeepers suspect perils local to cultural practices (1), practices that need to be improved to prevent CCD. In this study, we evaluated the potential impact of pesticide use on colony collapse disorder by assessing the effects of combining pesticides with commonly used in beekeeping.

Table 1. Main characteristics of the experimental colonies (average ± standard deviation).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
<th>Treatment 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (days)</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Number of worker bees</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Colony size (m²)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Pesticide application</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 1. Honey bee forager honey bee fitted with a sensor equipped with an RFID tag for marked foragers.

ScienceExpress: [http://www.sciencexpress.org](http://www.sciencexpress.org)
Semi-field study on bumble bee colonies

Whitehorn et al. (2012) Science
Semi-field study on honey bee foraging

Landscape-scale experiment in 2013

- 8 pairs of spring-sown canola fields and surrounding landscapes
- random assignment to treatment (clothianidin seed dressing) and control
- treatment blinded during field work
Verifying exposure – oilseed rape pollen use and clothianidin residues

Photo: Albin Andersson

Photo: Albin Andersson
Table 1 | Clothianidin concentrations in bee-collected pollen (ng g\(^{-1}\)) and nectar (ng ml\(^{-1}\)), and field border differences between treatments (control or insecticide-coated seeds)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Insecticide seed coating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean ± s.e.m.</td>
</tr>
<tr>
<td>Honeybee pollen</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Honeybee nectar</td>
<td>0–0.61</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Bumblebee nectar</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Field border plants (≤2 days after sowing)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Field border plants (2 weeks after sowing)</td>
<td>No material collected</td>
<td>0–6.5</td>
</tr>
</tbody>
</table>

The neonic treatment had no significant influence on *Apis mellifera* colony strength

![Graph showing colony strength comparison between control and seed coating treatments. The graph indicates no significant difference (NS) between the two treatments.](image)

The neonic treatment was negatively related to *Bombus terrestris* colony growth

...and *Bombus terrestris* reproduction

Queens: -85%

Relation between the neonic treatment and reduced nesting of *Osmia bicornis*

Reduced wild bee density in oilseed rape fields treated with the neonic

Wild bees are in Sweden bumble bees and solitary bees

But that’s just one crop/year/region...

Autumn sown canola in three countries

• Clothianidin treated canola expressed higher clothianidin residues than the control crop, but residues very low (LOD-2.21 ppb)

• No systematic differences in neonicotinoid (clothianidin + thiamethoxam + imidacloprid) residues between treated and control sites

• No systematic differences in (most) bee measures between treated and control sites

Woodcock et al. (2017) Science
Autumn sown canola in three countries

Woodcock et al. (2017) Science
Correlative study links bee decline to neonics

Neonicotinoids:
-- canola foraging bees
- other bees

Canola cover:
+ canola foraging bees
other bees

Foliar applied insecticides:
canola foraging bees
other bees

Figure 2 | Posterior distributions for the effect sizes describing wild bee population persistence in England.
Effects on pollination

Figure 1 | Effects of pesticide treatment on colony-level behaviour.

Stanley et al. (2015) Nature
Figure 1 | The environmental fate of neonicotinoids. When neonicotinoids are applied as a seed...
Dust
Neonicotinoids can be released as dust from coated seeds during mechanized planting. This dust can move off-site exposing bees or contaminating non-target sites.

Spray Drift
When applied as a spray, neonicotinoids can drift off-site directly exposing bees or contaminating non-target sites.

Uptake
Plants take up neonicotinoids, allowing the chemical to spread through the plant's tissues potentially exposing insects that eat pollen, nectar, or other plant tissue.

Persistence
Most neonicotinoids are long-lived. As such they can persist in the environment for months to years after an application.

Leaching
Neonicotinoids can leach into subsurface water where they can enter ground water or be taken up by neighboring plants.

Watershed Contamination
Neonicotinoids are water-soluble by design. This means they can move with shallow subsurface flow or with surface runoff into local waterbodies.

Movement Into Habitat of Ground Nesting Insects
70% of native bees are ground nesting. Ground nesting insects could become contaminated, especially when neonicotinoids are applied as a soil drench.

Wind Erosion
Neonicotinoids have been found in soil and soil dust. Contaminated soil can be dispersed by wind.
Non-crop habitats emerge as exposure routes

Neonicotinoids in “bee-friendly” ornamental plants

Lentola et al. (2017) Environmental Pollution
All but one of these garden insecticides contain neonicotinoids, and none of the labels indicate that they are poisonous to bees and adult butterflies. Photograph by Matthew Shepherd.

Hopwood & Shepherd (2012) Neonicotinoids in Your Garden. Xerces Society
Visit for more information: http://xerces.org/neonicotinoids-and-bees/
Drivers of bee decline

Interacting multiple factors!

- Habitat loss & degradation
- Pathogens
- Pesticides
- Invasive species
- Nutrition
- Climate change
Questions?

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