Bees and other pollinators can be exposed to highly toxic pesticides by a variety of routes, some of which have only recently become apparent. Worryingly, several of these routes are not considered at all in the risk assessment process before a pesticide is approved. This factsheet summarises recent understanding of the different exposure routes for neonicotinoid and some other bee-toxic pesticides.

**Route A: Direct contact via crop spraying**

This is the most well-known and obvious route, when insecticides are sprayed onto crop foliage. Bees are at high risk when spraying takes place when crops are in flower and bees are foraging in the crop or close by. They can be directly covered in the spray, pick up traces when in contact with recently treated foliage or get hit by spray drift. Because of this high risk, many broad-spectrum insecticides (ones which are toxic to a broad range of insects) carry hazard warnings on the product label, recommending farmers to avoid spraying when crops or nearby weeds are in flower or when bees are foraging in the crop. Spraying early in the morning or in the evening or on cloudy days can also help to reduce the risk of harming honeybees, because they don’t tend to forage at these times. Bumblebees, however, forage at lower temperatures.
and earlier in the season and may be exposed. Farmers are required under UK regulations to notify local beekeepers before they spray so hives can be removed or closed, although this will not protect wild pollinators.

Despite label restrictions on use, unintentional bee kills can and do happen. In the UK there have been an increasing number of mass bee death incidents reported to the government ‘Wildlife Incident Investigation Scheme’ since 2008, with 27% of bee poisoning incidents associated with neonicotinoids in 2010 and 2011.

Table 1. Comparison of toxicity to honeybees of some neonicotinoid insecticides with other well-known pesticides

<table>
<thead>
<tr>
<th>Pesticide name</th>
<th>Pesticide group</th>
<th>Acute toxicity value by contact</th>
<th>Acute toxicity value by oral intake</th>
<th>Toxicity rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>chlorpyrifos</td>
<td>Organophosphate insecticide</td>
<td>0.059</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>clothianidin (S)</td>
<td>Neonicotinoid Insecticide</td>
<td>0.004</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>DDT</td>
<td>Organochlorine insecticide</td>
<td>5</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>endosulfan</td>
<td>Organochlorine insecticide</td>
<td>7.81</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>fipronil (S)</td>
<td>Phenylpyrazole insecticide</td>
<td>0.00417</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>glyphosate (S)</td>
<td>Phosphonoglycine herbicide</td>
<td>100</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>imidacloprid (S)</td>
<td>Neonicotinoid Insecticide</td>
<td>0.0037</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>mancozeb</td>
<td>Dithiocarbamate fungicide</td>
<td>140.6</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>thiacloprid (S)</td>
<td>Neonicotinoid Insecticide</td>
<td>17.32</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>thiamethoxam (S)</td>
<td>Neonicotinoid Insecticide</td>
<td>0.005</td>
<td></td>
<td>High</td>
</tr>
</tbody>
</table>

Toxicity values are given in microgrammes per bee for the pesticide dose at which 50% of honeybees tested are killed (the lethal dose, LD50 value). Toxicity rating is the interpretation provided by the FOOTPRINT database. Systemic pesticides indicated by (S).

While many insecticides are harmful to bees, their acute toxicity varies considerably. The UK Chemicals Regulation Directorate (formerly the Pesticide Safety Directorate) analysed 286 pesticides used in the EU and identified 40 as being toxic to bees. The neonicotinoid compounds clothianidin, imidacloprid and thiamethoxam are recognised as highly toxic to bees by US, UK and EU regulatory authorities. In terms of acute short term toxicity, these compounds are several hundred to a thousand times more toxic to bees than older insecticides such as endosulfan or DDT (Table 1). Furthermore, some of the neonicotinoid breakdown products are as toxic or more so than the original compound, posing risks as they degrade in the environment or within a hive’s food sources and once consumed. Bee larvae exposed to the longer lasting breakdown products inside the hive can be particularly vulnerable.

Neonicotinoid residues on sprayed crop foliage can remain toxic to bees for several days, enabling them to pick up harmful levels when visiting flowers or walking on leaves. For example, clothianidin residues remain toxic to honeybees for 5-21 days.

**Route B: Via pollen or nectar from crops seed-treated with neonicotinoids**

Neonicotinoids are systemic pesticides, which means they are taken up by the growing plant and transported in the sap to roots, stems, leaves and flowers. This property is one of their main commercial attractions because it provides season-long control of the sap-sucking and root-feeding pests targeted. However, it also means that the active (toxic) ingredients are present in nectar and pollen in flowers produced by crops to which these insecticides have been applied.

Treating seeds with neonicotinoids before or at planting stage is now commonplace for a range of cereal and other crops. When crops such as maize, oilseed rape and sunflower are in bloom, insects visiting the flowers are exposed to the very small amounts of neonicotinoids found in the pollen or nectar at levels of a few parts per billion. They may carry this back to the hive or nest, contaminating the colony’s food resources. Although the concentration levels are very low, these compounds are biologically active at extremely low doses and they are more toxic to bees via ingestion (food intake) than by external contact.

While foraging worker bees feed mainly on nectar, contamination of bee-collected pollen is of special concern for newly emerged nurse bees which feed on pollen in hive reserves. Bee larvae are also at risk because they are fed mixtures of pollen and honey processed by the hive bees. Generally, the levels of neonicotinoids that have been documented in pollen and nectar are not high enough to cause mortality to adult bees but the concern is
for bee larvae and for sublethal effects on adults, affecting behaviour, communication and reproduction (see factsheet 2).

Since the first indications in 1994 that contaminated pollen and nectar from seed-treated sunflower could be behind sudden bee poisonings reported in France, researchers have started to measure neonicotinoid levels in a range of seed-treated crops. For example, imidacloprid is regularly found in flowering treated maize in France at levels known from lab studies to induce a variety of effects. US researchers have highlighted the potential for widespread contamination of pollinator food sources because of the wide range of crops that use neonicotinoid seed treatments annually over huge acreages. In the UK, oil seed rape can provide a majority of all floral resources in lowland England when in flower. Pollinators will be exposed to 2-4 week pulses of neonicotinoids in floral resources from seed-treated crops. The impact on pollinators of contaminated pollen and nectar is likely to be high for honeybee hives surrounded by large areas of treated crops, as in much of today’s intensive farmland, and for wild bees which forage over short distances, and in early spring when there may not be many other readily available flowers.

Neonicotinoids are not just used by farmers - they are also widely used as seed treatments in garden centres in bedding plants and other ornamentals, sprayed in orchards and available as products for the amateur gardener. In the US, the products used by gardeners can be applied at higher doses than in agriculture, with fewer restrictions and the labels do not warn users of the hazards to pollinators. Very little research has been done on wild pollinator species other than bumblebees and on neonicotinoids other than imidacloprid so we have a very poor understanding of the possible consequences of this widespread exposure route.

**Route C: Direct contact during drilling of treated seed**

Major bee poisoning incidents occurred in parts of Germany in spring 2008, affecting several thousand hives, with 50-60% of bees killed. Tests on dead bees showed that almost all had a build-up of the neonicotinoid clothianidin and the origin was soon identified as maize seed treated with Bayer CropScience product Poncho. The seed company involved had failed to use the glue-like substance that sticks the pesticide to the seed, releasing the pesticide with dust from the drilling machines during maize planting. Wind carried the contaminated dust into neighbouring fields where bees were foraging. Germany temporarily suspended
neonicotinoid seed treatments on maize after this incident (see factsheet 4).

Losses of bees have been reported in several years in Italy at the time of sowing neonic- treated maize seed pneumatic drilling machines. It was first thought that exposure was via solid particles of seed falling on the vegetation surrounding the sown area and poisoning bees foraging on contaminated nectar and pollen but further investigation revealed high quantities of neonicotinoid insecticide residues in dead bees which had been in direct contact with airborne contaminated dust. Dust from abraded seed coatings was found to contain 20% neonicotinoid content, over 2,000 times the dosage in spray treatments. Bee mortality was very high in humid conditions, possibly because dust particles remained stuck to the bees’ hairs.

Similar, dramatic bee poisonings took place in parts of the US in 2010 and 2011 at maize planting, with neonicotinoids found on all affected bees. Here the problem was related to the talc that is used in the planter to keep the seeds flowing smoothly. Talc waste released from the machine exhaust was contaminated with neonicotinoids from the seed treatment at extremely high levels, reaching 700,000 times the lethal contact dose for an individual bee. At this concentration, even small amounts in dust killed some foraging bees and could be taken back to the hive by others. The researchers highlighted the huge contamination potential for a wide range of insects, especially as almost all US maize seed is treated with neonicotinoids. Routine cleaning of the equipment was unable to remove all the contaminated talc.

Improving the seed treatment process and modifying the drilling equipment to prevent release of contaminated seed dust or talc has been proposed as a way to reduce this exposure route. Nevertheless, beekeepers have reported further colony losses linked to maize sowing since 2009-2010 in Austria and Slovenia with coatings modified to be more resistant to abrasion while recent mechanical trials in Italy found that even modified equipment can still emit large amounts of very fine dust at acutely toxic concentrations. It seems there are no immediate solutions to these mechanical problems. Banning neonicotinoid seed treatments in maize, as has been done in Italy, (see factsheet 5) is an obvious alternative.

Route D: Other exposure routes

Neonicotinoid compounds are very persistent in soil and studies show that they can be taken up by untreated crops one or even two seasons after treated seeds are sown, possibly contaminating pollen and nectar. These researchers found neonicotinoids in soil samples from unplanted fields and in dandelions (a favoured pollen source) growing near treated fields, indicating contamination either from deposition of seed dust or talc exhaust or uptake from soil with residues from the seed treatment. Neonicotinoids readily dissolve in water, representing another route of
environmental contamination. With increasing use of these insecticides, there is the possibility of residues accumulating over time in the environment, perhaps at toxic levels$^{20}$. Yet another exposure route is via ‘guttation’ drops - the liquid exuded by growing plants overnight and in early morning. Bees and other insects sometimes collect these small droplets on the tips of leaves as water sources. Crops grown from treated seed have been shown to produce high concentrations of neonicotinoids in guttation drops, sometimes at levels approaching the dose of field applications$^{21,22}$. These droplets could present lethal doses for bees using them as drinking water, although this has not yet been demonstrated in the field. However, it remains a potential exposure route and researchers have recommended it should be included in the risk assessment process.

Neonicotinoids may also be applied as soil drenches, notably on pot plants and ornamentals, and sometimes injected directly into the trunk of trees and shrubs. Neonicotinoid residues in treated plants can persist for several years in woody species and may reach higher levels than in floral resources from seed-treated annual crops. US researchers are concerned about this exposure route as the products authorised on ornamentals contain higher doses than those for cereal crops and pollinators regularly visit flowering ornamentals$^{23}$. What is the impact of cumulative doses from multiple exposure routes?

Exposure to neonicotinoids will clearly vary from year to year and in different places, according to farming practices, the level of pesticide use, the type of planting machinery used, weather conditions, as well as the availability of natural habitats providing uncontaminated flowers and the foraging habits of different pollinator species. Knowledge gained from studies in the last few years has helped us understand how widely insects are exposed to these highly toxic insecticides and by many different routes. While a single dose at very low concentration may be insufficient to cause harm, the cumulative effect of many doses needs to be considered over the life cycle of individual pollinators and colonies.

“This results demonstrate that honey bees living and foraging near agricultural fields are exposed to neonicotinoids and other pesticides through multiple mechanisms throughout the spring and summer.”

Christian Krupke & colleagues, 2012
as a whole (see factsheet 2), especially for biological effects which may build up over time and those which are irreversible

More detailed information on exposure routes can be found in the useful summary reports by PAN North America (PANNA, 2012), the Xerces Society for Invertebrate Conservation in the US (Hopwood et al., 2012) and the very readable scientific paper by Christian Krupke and colleagues (2012) in the Dept. of Entomology at Purdue University, Indiana.

**Key points**

- Direct contact toxicity of some insecticides sprayed on crops can be high enough to kill individual bees and other non-target insects if adequate precautions are not taken.
- Neonicotinoid and other systemic insecticides are taken up in all the tissues of treated plants, including pollen and nectar in the flowers, exposing pollinators during flowering and later from food stored in the colony.
- Foraging on pollen and nectar from crops treated with neonicotinoids at seed stage exposes honeybees and other pollinators to low doses of residues across a range of flowering crops and ornamental plants.
- Particles of neonicotinoid-treated seed coatings, dust and talc released from seed drilling equipment forms another major and highly toxic exposure route. Guttation droplets in crop seedling leaves can contain very high levels and may pose a risk to insects collecting these for water.
- Neonicotinoid residues can persist in soil and water and are known to contaminate untreated crop plants and nearby flowering weeds, up to two years after the original crop treatment.

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**In this series**

If you would like to find out more about the relationship between pesticides and pollinator declines, all of these leaflets and other info are available via PAN UK’s bee webpages at: [http://bees.pan-uk.org](http://bees.pan-uk.org)

Bee Declines and the Link with Pesticides. Summary leaflet.

Fact sheets:

1. **Different routes of pesticide exposure**
2. Sub-lethal and chronic effects of neonicotinoids on bees and other pollinators
3. Serious shortcomings in assessing risks to pollinators
4. Different regulatory positions on neonicotinoids across Europe
5. Can restrictions on systemic insecticides help restore bee health?
6. What could farmers do to rely less on neonicotinoids?
7. Opportunities for improving and expanding pollinator habitats
8. Action on neonicotinoid and other bee-toxic pesticides
PAN UK’s vital work in the UK and in developing countries

Pesticide Action Network UK is a registered charity dedicated to:

- Eliminating the most hazardous pesticides,
- Reducing dependence on chemical pesticides,
- Promoting sustainable and equitable food systems and increasing the use of alternatives to chemical pest control in agriculture, urban areas, public health and homes and gardens.

In the UK, we campaign for tighter regulatory controls on pesticides and encourage retailers to tackle pesticide problems in their supply chains. We provide advice on alternative ways to control pests and work with local communities to reduce public exposure to pesticides. In the developing world, we raise awareness about pesticide hazards and train farmers in organic and low input agricultural techniques to help them make a decent living without putting their own health, their families or their environment at risk.

Populations of bees and other insect pollinators have fallen dramatically in recent years. The reasons for these declines are complex and wide ranging, but there is little doubt that pesticides are playing a key part.

PAN UK has prepared these fact sheets to cut through the confusion and provide an up-to-date and balanced explanation of the role of pesticides in pollinator declines. To find out more and what you can do, please visit http://bees.pan-uk.org

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