Pesticide Action Network UK

Persistence of neonicotinoids and widespread contamination

Bee Declines & Pesticides factsheet 9

In 2012, Pesticide Action Network UK (PAN UK) produced a series of fact sheets looking at the impact that pesticides are having on bees and other pollinator species in the UK and globally. We have aimed to set out clearly for the general public and experts alike the facts on the issues based on the most up to date published scientific studies. The PAN UK factsheets look at key issues regarding pesticides and bee and pollinator species. They have covered topics such as the overuse of herbicides and the resulting loss of habitat for pollinators, alternatives to pesticides that farmers and others can use, contrasting policies in UK with other EU countries as well as the much debated issue of neonicotinoid insecticides and pollinator exposure via treated seed.


Credit: Graham White

In the four years since we published the first factsheets neonicotinoids and their use have been a particularly important issue, with much more evidence documented of their potential risks and harm. Many studies have linked the growth in the use of neonicotinoids and some other systemic insecticides with serious harm to honey bee populations, declines in wild bee populations and harmful effects on a range of other species including many pollinators and other invertebrates and bird species.

So concerned have the regulatory authorities in the EU been about the potential harmful effects of neonicotinoids that in 2013 they introduced a temporary, partial ban on certain uses whilst investigations into their harmful effects were undertaken. At the time of writing this factsheet (May 2016) the ban is still in effect and experts at the European Commission are reviewing the scientific evidence of the effects of neonicotinoids on bees.

This factsheet has been designed to complement the existing ones and continue PAN UK's contribution to a better public understanding of the debate and policy questions, based on the latest independent scientific findings.

Introduction

Not only are neonicotinoid insecticides extremely toxic to pollinators and many other non-target organisms, they can persist for long periods and readily enter water courses. The combination of these characteristics make them problematic environmental pollutants. In this factsheet we first summarise key information on the persistent nature of many neonicotinoids and recent data on contamination levels in soils and water. We then outline how such persistence can have impacts on pollinators and other non-target invertebrates long after the actual pesticide has been used on a particular crop.

Key Points

- Neonicotinoid residues from treated seeds can remain active for months or more in the soil, often persisting for more than one season.
- More studies prove that soil residues are taken up by wild flowers in field borders and may contaminate pollen and nectar, sometimes at high levels.
- Neonicotinoids readily move from application sites into waterways in and around fields, polluting puddles, ponds, wetlands, rivers, snowmelt, groundwater and wells.
- Recent studies in different countries show that neonicotinoids are frequently detected in many watercourses, not only around farmland but in urban areas too.
- Neonicotinoid levels in contaminated water often exceed water quality standards and pose risks to non-target aquatic life. Pollinators may be exposed when collecting water, in addition to exposure from treated crops or adjacent wildflowers.

Persistence on and in treated plants

When applied as a spray to crop or ornamental plant foliage, neonicotinoid residues can remain toxic to bees for several days, enabling them to pick up harmful levels by contact, e.g. clothianidin can remain toxic on leaves for 5-21 days[1].

Of more importance is neonicotinoid persistence in plant tissues due to the way the compounds are taken up and distributed throughout the target plant. Residues in the pollen and nectar from flowering annual crops grown from neonicotinoid-treated seed has been the focus of attention and is covered in our Factsheet 1 on routes of exposure. US studies show that when woody, perennial species, such as citrus and ornamental trees, are treated via soil drenches or trunk injections, neonicotinoids can persist for months or sometimes years and residues may reach higher concentrations in tree flowers and foliage than in seed-treated annual crops[2] .This also applies when perennial crops are treated via soil drenches, as often done, for example, in vines[3].

Persistence in soil

Unlike foliar sprays where around 50% of the active ingredient is usually absorbed by the plant, only somewhere between 1-20% of the active ingredient in neonicotinoid seed treatment gets absorbed into the crop tissues[4,5]. This means at least 80% ends up somewhere unintended. Apart from releases from seed dust at sowing (responsible for mass bee kills documented in maize), studies suggest most ends up in the soil.

How long these residues remain active in the soil is measured by their 'half-life', the time it takes for 50% of the insecticide to break down (termed the DT50 persistence value by scientists). Half-lives over 100 days are considered persistent and those over 365 days as very persistent. Table 1 shows half-life estimated averages for 5 neonicotinoids and 2 pyrethroid insecticides, for comparison, with the ranges from field data used by the EU regulators. Clothianidin and imidacloprid are especially persistent, with thiamethoxam less so, although it is important to understand that thiamethoxam itself breaks down into clothianidin. With at least two of the breakdown products of imidacloprid also

Table 1.

Insecticide/Group	Half-life (field) in days	Range (days)
Acetamiprid / neonic	3	0.5-5.5
Chlorpyrifos / organophosphate	21	2-65
Clothianidin / neonic	121	13-305
Deltamethrin / pyrethroid	21	7-28
Imidocloprid / neonic	174	104-228
Thiacloprid / neonic	18	9-27
Thiamethoxam / neonic	39	7-72

toxic to bees, assumptions based on half-life data for the parent compounds alone may underestimate how long toxic residues remain available.

More recent studies beyond those used for regulatory purposes show considerably wider ranges, with some values well into the 'very persistent' category. For example, clothianidin half-lives of 148 to 1,155 days, and in one extreme up to 19 years; imidacloprid up to 1,250 days; and thiamethoxam up to 301 days[6]. These data suggests that it could take over 5 years for imidacloprid and 15 years for clothianidin to fully degrade, offering long exposure time frames[7].

"These high levels of persistence are important factors that need to be considered when determining the ecotoxicological properties of the neonicotinoids"

European Academies Science Advisory Council, (EASAC), 2015

How long a particular neonicotinoid residue may remain biologically available in soil clearly varies hugely and will depend on many factors, including the soil type and its chemistry, the weather and other conditions affecting temperature and moisture, the amount of UV light, levels of organic matter and soil microbe activity, and the overlying vegetation. One large study of imidacloprid residues in French soils estimated an average 270 days[8]. In US, estimates ranged from 3-12 months. In the UK, one estimate gave 1,250 days for loamy soils[9].

Authors of the comprehensive Worldwide Integrated Assessment of Systemic Pesticides[10] conclude that neonicotinoid concentrations in soil can decline quite rapidly through breakdown processes, uptake by plants and leaching into water flow but under some soil conditions residues can persist for months, or years. Persistence tends to be highest under cool, dry conditions and in soils with high organic matter content. These conditions are typical of many agricultural fields in the northern temperate regions. Canadian studies report considerably longer half-lives than average for clothianidin and thiamethoxam in the Prairies, reflecting the cold soil temperatures, with 80% of initial clothianidin concentrations still present after 775 days[11]. Predicting persistence time is difficult under current limited understanding of concentration levels and degradation processes, while information on metabolite structure and reference materials is often owned by companies and not available for public research. These knowledge gaps generate major uncertainties in assessing exposure and risk from soil residues.

What has become clear is that soil residues can be frequently found in and around areas of treated crops and often persist into following seasons. One of the earliest independent studies found low level residues of imidacloprid in 91% of samples in 74 sites across France, even though only 15% of sites had been planted with treated seed the year before. Concentrations were higher at sites treated for 2 consecutive years, suggesting the ability to accumulate in soil[12]. Indeed,

one industry trial for imidacloprid treatment of winter wheat seed in the UK reported soil residues of 6-18 parts per billion (ppb) one year after sowing, which then rose to 18-60ppb after 6 years of repeated applications[13]. Sampling in UK arable fields in 2013 detected imidacloprid in 15 of the 18 fields, at levels up to 10.7ppb in the centre of fields, even though it had only been reported as used in two of these fields since 2010[14]. Similarly, clothianidin was detected in one field, and thiamethoxam detected in 7 fields, to which these chemicals had not been applied in the previous 3 years. Clothianidin residues up to 10 ppb were found in fields last treated 18 months earlier and at levels of 4.5ppb degrading from fields treated with thiamethoxam 30 months previously. This study confirms that detectable levels of neonicotinoids are present in soil for a considerable time after use in UK conditions.

"Persistence of neonicotinoids, especially in soil, and the fact that they can build up over time means an increased toxic burden for non-target organisms because of long duration exposure."

Worldwide Integrated Assessment of Systemic Pesticides, 2014

Table 2 summarises findings from recent studies on soil residues. Scientists disagree on whether neonicotinoid levels are building up and on what level of risk these may pose.

Table 2.

Country/crop	
Ontario, Canada / maize rotations[15]	**Levels detected**: average 4.36 ppb in parent soil and 59.86 ppb in surface soil dust before planting in fields with history of seed treatment
Ontario, Canada / maize[16]	**Levels detected**: total neonic residues 4.02 (range 0.07 to 20.30) ppb before planting, rising to 9.94 (range 0.53 to 38.98) ppb immediately after planting.
Ontario, Canada / maize[17]	**Levels detected**: Residues after 3-4 years of repeated annual use tend to level off at under 6 ppb Estimated half-lives: approx. 0.6 years (range 0.3-2.1)
Southern USA/ maize, cotton, soya[18]	**Levels detected**: Neonic residues before planting average 10 ppb. **Frequency detected**: over 80% of soil samples had some insecticide present
England / arable[19]	**Levels detected**: clothianidin range 0.02 to 13.6ppb; thiamethoxam range <0.02 to 1.50 ppb, imidacloprid range <0.09 to 10.7ppb **Estimated half-lives**: imidacloprid 200-500 days ; clothianidin 37-68 days; thiamethoxam 75-109 days
southern England/ oilseed rape[20]	**Frequency detected**: thiamethoxam and its clothianidin breakdown product in 100% soil samples under the crop. Imidacloprid in 100% and thiacloprid in 43% of samples even though not applied in previous three years.

Non-target area contamination: European regulators have been concerned about risks related to long persistence in soils, with potential to expose soil insects directly and pollinators via uptake of neonicotinoid residues by untreated vegetation. Since the first field findings that systemic insecticides can end up in wild flowers[21] more studies reveal that neonicotinoids are present in non-target areas. One of the Canadian studies detected clothianidin residues, albeit at levels under 0.15ppb in two soil samples from a conservation area near to arable fields[22]. Neonicotinoids were detected in 23% of wild flower samples around recently planted cotton, maize, soya fields in the US, with an average 10ppb[23]. The 2013 study in English arable farms[24] detected residues of all three neonicotinoids in samples from field edges, at lower levels than from field centres. New results from farms in Sussex[25] found that field margin soils were consistently contaminated with all of the commonly used neonicotinoids. Margins adjacent to oilseed rape all contained thiamethoxam and clothianidin, at levels significantly lower than those from cropland, and also imidacloprid in 93% of samples. In field margin soil from winter wheat fields, clothianidin from the same year's seed dressing was found in all soil samples, imidacloprid in 75%, thiamethoxam in 50% and thiacloprid in 25%. The same study found neonicotinoid residues in pollen and nectar from several wild flower species growing at field edges 1-2 metres from the crop, at levels up to 10 times higher than in crop pollen and nectar. The authors concluded that uptake from residues in the field margin soil was the most likely route for the contamination, indicating the extent to which these chemicals can move to untreated areas important for wildlife.

Persistence in water and contamination routes

Neonicotinoid residues in the soil don't just persist in treated fields but can move beyond, transported in water, dust and soil movements. These insecticides are very water soluble so significant transport may occur into groundwater or surface water. Leaching from the soil is one of the main mechanisms for contamination of surface and groundwater. The process is highly variable, depending on water temperature and pH and the physical state of pesticide applied. Leaching is more likely where soil organic matter levels are low and residues have little to bind to. Clothianidin has a very high leaching potential, as measured by the Groundwater Ubiquity Score, while imidacloprid and thiamethoxam have high potential[26]. Numerous US studies showing high mobility of imidacloprid in turf, greenhouse and irrigated soils and surfactants added to product formulations tend to increase leaching potential[27].

Other ways for neonicotinoids to end up in ground or surface water are:

- Accidental spillage
- Overspray or spray drift into ditches, streams
- Contaminated soil particles transported via sub-surface field drains
- Direct run-off after heavy rain, especially on steep slopes and from applications on hard surfaces or short turf
- Use as a soil drench

As for residues in soil, there is huge variability in neonicotinoid persistence in surface water but imidacloprid could persist in natural water bodies for several weeks at measurable concentrations under some circumstances. Clothianidin can be quite stable under environmentally realistic pH and temperatures. Breakdown products in water may also have toxicity concerns. Dutch researchers estimate imidacloprid probably averages a half life of 1-5 months in aerobic sediment and water[28].

Non-agricultural neonicotinoid application may contaminate water courses too – there has been some detection of neonicotinoids in wastewater plants from urban run-off, and a national survey of residues in US water courses recently discovered the presence of neonicotinoids occurred throughout the year in urban streams[29]. A study in Maryland, US, documented highest residue levels from water samples near golf courses and plant nurseries, highlighting the often overlooked contamination in run-off from turf grass and ornamentals applications in the US[30].

Water contamination levels

For many years, neonicotinoids were 'under the radar' for much official water monitoring, which focussed more on herbicides and on other insecticide groups. Survey work in different countries is now revealing the extent to which many water bodies and waterways are contaminated with neonicotinoids. Table 3 summarises a selection from North America, Europe and Australia. Contamination levels are often very low, around 1 part per billion or less, but can reach higher concentrations. In the Netherlands, concentrations up to 200ppb have been reported in groundwater, ditches and streams[31], with the worst

Table 3.

Country / Area	Contamination frequency	Concentrations found and/or Exceedance of permitted levels
Netherlands[35]	imidacloprid among top 3 pesticides exceeding national ecotox limits since 2004	Imidacloprid detected at a max. of 25,000 times the Dutch permitted level (13 parts per trillion)
USA: 3 farming regions of California[36]	imidacloprid detected in 89% of samples taken in in 2010-2011	US ecotox levels (1.05ppb) exceeded in 19% samples.
USA: Wisconsin groundwater in 2008-09[37]		Average concentrations in ppb: Imidacloprid 0.79; clothianidin 0.62; thiamethoxam 1.59. Thiamethoxam concentrations found at up to 9ppb Thiamethoxam exceeded US EPA values in several wells.
Canada: potato-growing areas in Quebec[38]	Imidacloprid found in 35% of wells	Residues detected up to 6.4 ppb
Canada: agricultural zones of the Prairie Pothole Region[39]	Thiamethoxam, clothianidin & imidacloprid present in 16–91% wetlands in fields seeded to canola, barley, wheat, oat & field pea	mean & max. concentrations of clothianidin & thiamethoxam frequently exceeded Canadian, US or EU guidance levels for imidacloprid. Clothianidin at up to 14 times the Canadian benchmark for imidacloprid of 230 ppt
Canada: Ontario maize fields[40]	Clothianidin found in 100% and thiamethoxam in 98% of samples	Clothianidin average of 2.2, max. 44ppb Thiamethoxam average of 1.1, max. 16.5ppb
Australia: rivers around Sydney[41]	5 neonics found in all river basins sampled, whether under residential or farming land use. Most samples contained more than 2 neonics.	Max concentrations for imidacloprid and thiacloprid were 4.6 and 1.4 ppb
Spain: Guadalquivir river basin[42]	imidacloprid in 58% of samples in 2010 and 17% in 2011	concentrations ranged from 2.34 to 19.20 ppt
Sweden: stream water around greenhouses[43]		Swedish guideline value (13ppt) exceeded 21 times in 2010 study, with max level of 1,154 times this value
Hungary: Danube and other rivers[44]	92% surface water contained neonics (at unquantifiable levels)	highest concentrations of thiamethoxam & clothianidin of 10–41ppb measured from temporary shallow water bodies after rain events in early summer.

cases exceeding national ecotox safety limits by three orders of magnitude[32]. Many routine water monitoring programmes may 'miss' neonicotinoid contamination if they do not sample for the breakdown products.

These studies are shedding more light on the fate of systemic insecticides in different environments and on the range of concentrations found, timings, transport routes and sources. A study in California found very frequent presence of imidacloprid in watercourses around fields, often at levels above toxicity guidelines developed in the US, Europe and Canada[33] .These researchers concluded that imidacloprid commonly moves offsite from irrigated agriculture conditions and contaminates surface waters at concentrations that could harm aquatic organisms. In the Canadian Prairies Pothole region, samples were taken from over 90 wetland areas near arable fields before sowing, during the growing season and after harvest, over two seasons[34]. Unsurprisingly, the researchers found the most frequent detections and the highest concentrations after spring planting but also frequent presence beforehand and hypothesised that this may result from carryover in the soil during winter and subsequent transport in snowmelt runoff. Results confirm that agricultural wetlands in colder climates are likely to be contaminated via snowmelt water and the soil particles in it, with temporary ponds at particular risk.

Toxic risk for invertebrates?

In 2014, the group of independent scientists who conducted the Worldwide

Integrated Assessment on Systemic Pesticides highlighted concerns about persistence of neonicotinoids and fipronil and how frequently these are ending up in water, exposing not only pollinators but a much broader range of non-target organisms. Since then, more studies have added to our understanding.

The first-ever analysis of residues in rainwater puddles, conducted in Canadian maize fields, revealed presence of at least one neonicotinoid in all field samples, along with a cocktail of other pesticides[45]. For some puddles with high concentrations, a high risk to honey bees from transporting and consuming this water was identified.

Researchers who recently found widespread occurrence of neonicotinoid insecticides in streams in intensive maize and soybean regions in the US Mid-West conclude that concentrations may frequently exceed chronic toxicity values for aquatic life during the growing season. They also noted that neonicotinoid presence is now far more frequent (averaging 50%) than the presence of organophosphate or carbamate residues were in the 1990s before the widespread use of systemic insecticides[46].

The US Geological Survey reported on the first national-scale investigation on neonicotinoid residues in water courses from agricultural and urban settings, conducted from 2011 to 2014 and spanning 24 states[47]. At least one of the five neonicotinoids currently used in the US was detected in more than half of the 48 streams sampled, with imidacloprid detected most frequently (37 %), followed by clothianidin (24 %) then thiamethoxam (21 %). Although levels did not exceed the US Environmental Protection Agency's aquatic life toxicity values, the team noted that the low levels in streams throughout the year warrant more research on the potential impacts not only on aquatic life but also the terrestrial animals that feed on these.

The Center for Food Safety's excellent 'Water Hazard' report[48] explores the recent North American findings on neonicotinoids in water and the implications for aquatic ecosystems. The report summarises conclusions from an international team of ecotoxicologists who have assessed 29 studies on water contamination levels in relation to risk to aquatic organisms. The team has found strong evidence that neonicotinoid exposures via water contamination are frequent, long-term and at levels which commonly exceed several existing water quality guidelines. They also propose stricter residue limits in order to avoid lasting effects on these ecosystems.

These aspects are covered in more detail in PAN UK's forthcoming Factsheet 10 on exposure of non-target organisms to neonicotinoids.

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**

Bee Declines and the Link with Pesticides. Summary leaflet.

Fact sheets (2012):

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

Fact sheets (2016):

9. **Persistence of neonicotinoids and widespread contamination**

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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 to 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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