Neonicotinoids and bees: What's all the buzz?

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What's all the buzz?

Neonicotinoid insecticides kill bees. Or do they? The European Union has approved a moratorium – though manufacturers say there is no evidence to implicate their product. But they demand experiments that cannot be performed, says **Dave Goulson**, subject their own data to no statistical analysis, and spuriously reject good evidence that does exist. So how strong is the link between these chemicals and the decline of our bees?

In the last few months there has been a blizzard of media coverage of claims that neonicotinoid insecticides are killing bees. There have been political inquiries in Westminster, petitions with millions of signatures calling for bans, beekeepers protesting outside the UK Parliament. Even the satirical UK television news quiz, *Have I Got News for You*, picked up on it. In late April 2013 the EU passed a motion to place a moratorium on the use of some of these chemicals. The moratorium is only on their use on flowering crops, and lasts for just two years. Yet the UK government voted against the moratorium, saying that the evidence was inconclusive, and the agrochemical industry maintains that there is no evidence linking these pesticides to the declines in honeybees and bumblebees. In the meantime new scientific studies are being published at a prodigious rate, adding to the mountain of (sometimes conflicting) evidence. It is exceedingly difficult for any interested member of the public to discern the truth.

What are neonicotinoids?

Let us first look at these chemicals in a little detail. 'Neonics' were developed in the 1980s, and the first commercially available compound, imidacloprid, has been in use since the early 1990s. Clothianidin is a similar product made by Bayer. They are "nicotinic acetylcholine receptor agonists", meaning they bind to and block open nerve receptors in the insect brain, causing paralysis and death. Most neonics are toxic to insects in minute quantities; for example, the LD_{50} (the dose that kills 50% of individuals) for ingestion of imidacloprid and clothianidin in honeybees is 5 and 4 nanograms per insect, respectively, which for comparison is approximately one ten-thousandth of the LD_{50} for DDT. To put it another way, 1 gram of clothianidin, not much more than the content of a salt sachet, is enough to deliver an LD_{50} to 250 million honeybees.

Neonics are soluble in water, and are readily absorbed by plants via either their roots or leaves and then are transported throughout the tissues of the plant. This provides many advantages in pest control, for they protect all parts of the plant, even bits that cannot be sprayed. In developed countries, neonics are predominantly used as seed dressings for a broad variety of crops such as oilseed rape, sunflower, cereals, beets and potatoes, though some are sprayed onto fruit crops; they are sold for garden use as a spray on flowers and vegetables, and they are also widely used against fleas on dogs and cats. One attraction of seed dressings

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is that they require no action from the farmer: they prophylactically protect all parts of the crop for several months following sowing. Neonics are now the most widely used class of insecticides globally, with imidacloprid the second most widely used agrochemical in the world (after glyphosate, the active ingredient in Roundup). In the UK, use of neonics rose from 3 tonnes in 1994 to nearly 80 tonnes in 2011.

Do neonics harm bees?

Neonics are routinely used to dress seeds of oilseed rape, sunflower and maize, and these crops are major sources of food for both honeybees and wild pollinators. Being systemic, small concentrations of neonics are found in both pollen and nectar of seed-treated crops, usually between < 1 and 8 parts per billion (ppb) in nectar and between <1 and 50 ppb in pollen. Much higher concentrations occur when neonics are sprayed onto plants. To ingest a lethal dose from a seed-treated crop, a bee would need to consume several millilitres of nectar or a gram or so of pollen, which is unlikely in the short term for a honeybee which weighs around 0.1 g, but could easily be accumulated over a number of days or weeks. A recent meta-analysis by James Cresswell at Exeter University[1] , based on 13 studies of the impacts of imidacloprid on honeybees, found that field-realistic doses (for seed-treated crops) under laboratory and semi-field conditions had no significant lethal effects. Overall, the balance of evidence at present suggests that field-realistic exposure of bees to neonicotinoids in nectar and pollen of seed-treated crops is unlikely to cause substantial direct mortality.

The key word here is "direct". Although there is little convincing evidence for direct mortality in bees, there is strong evidence for important sub-lethal effects. Exposure to sub-lethal doses of neonicotinoids is known to reduce learning ability, foraging ability and homing ability in both honeybees and bumblebees[2]. A bee that gets lost or cannot collect food is as good as dead to its parent colony. Such effects will not be revealed in standard safety-testing protocols which typically involve lab or cage trials with food *ad lib*; but they would be much more marked under natural conditions when colonies rely on their workers to locate patches of flowers across the landscape. However, very few studies have been carried out in which bees that have been exposed to pesticides have to navigate across realistic distances. In one such recent study, Richard Gill *et al.*[3] at Royal Holloway, London, found that bumblebee workers from colonies exposed to field-realistic concentrations of imidacloprid in nectar suffered from impaired foraging ability when gathering food in a natural setting, particularly when collecting pollen. As a result, treated colonies grew more slowly. This corroborates work by Penelope Whitehorn[4] in my own research group which attempted to simulate what happens when a bumblebee colony is near a field of treated oilseed rape. She fed colonies in a lab for two weeks with nectar and pollen to which realistic concentrations of

imidacloprid had been added, and then placed the colonies out on the University of Stirling campus to see how they fared when left to their own devices. The treated nests grew more slowly and ultimately produced 85% fewer queens than the controls. James Cresswell's group have since found that just 1ppb of imidacloprid in their diet is enough to reduce egg-laying in bumblebees by 30%. Overall, there is clear evidence that exposure of bees to field-realistic levels of neonicotinoids has significant sub-lethal impacts, and that in the case of bumblebees this has been demonstrated to have major impacts on colony success.

The industry response to these and other studies has been to argue that all were performed at least partly in a laboratory, or using a means of exposing bees to pesticides that would not occur in the wild. They have argued that the only convincing way to demonstrate that these effects harm bees in the real world is to conduct an experiment entirely outdoors, with free-flying bees at all stages. The flaw in this argument was neatly demonstrated by a study conducted by the Food and Environment Research Agency in 2012. They attempted to repeat Penelope Whitehorn's experiment, but exposing the bumblebee nests to pesticides in a more "natural" way, by placing the nests next to treated oilseed crops. They managed to find one untreated oilseed rape field which was meant to act as a control, while they placed other nests adjacent to a field treated with clothianidin or one treated with imidacloprid (hence having no true replication since there were many confounding differences between sites). Unfortunately for their experiment, bees can fly, and they forage over an area of several square kilometres. Bees from their control nests flew to feed on treated fields, and so were exposed to a cocktail of neonicotinoids (as were the "treated" bees). In other words, they had no controls, no true replicates, and no power to detect any effect. It is essentially impossible to conduct a controlled experiment with free-flying bees, for there is nowhere in the UK where one could put the control nests. Industry is calling for an experiment that cannot be performed.

There are two further points to be made here. Firstly, shouldn't the onus have been on industry to conduct a convincing field test of the safety of their compounds before they were ever allowed to sell them? And secondly, since when were controlled lab experiments meaningless? Almost all of the great discoveries in biology were made in labs. We cannot possibly hope to understand the complex interactions between organisms and their environment without doing controlled experiments. Universities invest millions in building controlled environment facilities in which to conduct ecological experiments. Is this all a waste of money?

Other environmental risks

While bees have been receiving the bulk of the attention, some other environmental concerns have arisen. It has emerged that the large majority (between 80% and 98%) of the active ingredient applied to seeds is not adsorbed by the growing crop, but remains in the soil and soil water. It has also very recently become apparent that neonics persist in soils for far longer than had been appreciated. When asked by the UK Environmental Audit Committee in November 2012 how long imidacloprid lasts in soil, manufacturer Bayer's representative said that it had a half-life of 16–200 days. However, Bayer themselves conducted a field study of the persistence of imidacloprid in soils in East Anglia in the early 1990s, showing quite clearly that it persists much longer than this, and that it rapidly accumulates with annual applications[5] (Figure 1). They sowed fields with dressed winter wheat for six years in a row, and measured soil concentrations the day before the next sowing. After one year, soil concentrations varied between 5 and 20 ppb, depending on application rate. After 6 years, they had risen to up to 50 ppb, with little sign of a plateau being reached. These data were submitted to the EU regulatory authority in 2006, which concluded that "Long-term field dissipation trials … have confirmed that the compound has no potential for accumulation in soil". No statistical analyses were performed on the data. By my own rough calculations based on the mean values given, the data suggest a half-life exceeding 1000 days, and to my mind this is unequivocal evidence for accumulation in soil. Quite how the EU regulators came to their conclusions remains unexplained.

So, increasing quantities of long-lived, water-soluble, highly toxic (to arthropods) compounds have been applied to soils across the globe for 20 years. It seems likely that this might be having negative effects on soil organisms, and perhaps on aquatic organisms through leaching into streams and ponds. Studies of rivers, creeks and drains in California found imidacloprid in 89% of samples, with 19% of samples exceeding the US Environmental Protection Agency (EPA) guideline of 1.05 ppb. In the Netherlands, concentrations of up to 200 ppb in groundwater, streams and ditches have been reported. To put these values in context, the LC_{50} (the concentration that kills 50% of test subjects over 96 hours) for

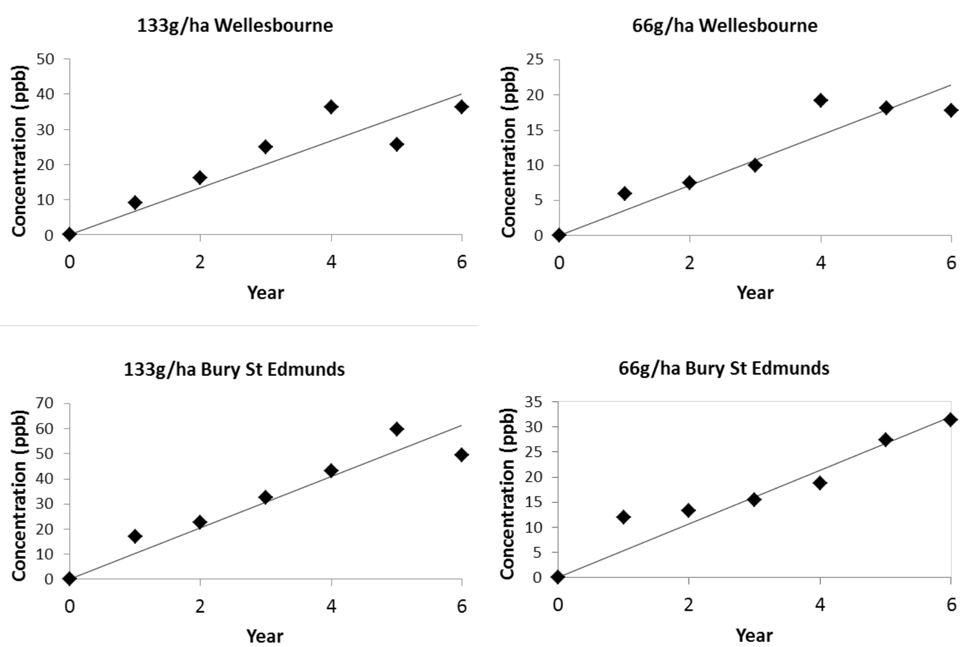

Figure 1. Levels of imidacloprid detected in soil into which treated winter wheat seeds were sown each autumn (1991–1996). Study sites are both in the east of England. Treatment rates were 66 or 133 g a.i. ha^{-1} except in the first year, when they were 56 and 112 g, respectively. Data from F. J. Placke[5]

the mayfly *Epeorus longimanus* is just 0.65 ppb. Mayflies have been in rapid decline in much of Europe. Notably, no neonicotinoids feature in the EU Water Framework Directive's list of priority substances for aquatic pollution monitoring, so they are not specifically targeted and screening methods may not be well suited to their detection.

It is widely established that neonics are, weight for weight, much less toxic to vertebrates than they are to arthropods, which perhaps might lead one to conclude that they pose few risks to birds or mammals. However, even here there is cause for concern. If seed-eating birds or rodents consume dressed seed spilled during sowing they will rapidly exceed their LD_{50}. For example, maize seeds are typically treated with about 1 mg of active ingredient per seed, beet seeds with 0.9 mg, and the much smaller oilseed rape seeds with 0.17 mg. A grey partridge, weighing approximately 390 g, needs to eat about 5 maize seeds, 6 beet seeds or 32 oilseed rape seeds to receive an LD_{50}. A grey partridge typically consumes around 25 g of seeds a day, equivalent to some 600 maize seeds, so clearly there is the potential for birds to swiftly consume a lethal dose. By a similar calculation, 3 maize seeds treated with imidacloprid would deliver more than the LD_{50} to a mouse. The EPA estimates that 0.5–1% of drilled seeds remain accessible to granivorous vertebrates (i.e. they are not buried during drilling), and this does not include spillages which may occur, for example when transporting grain or loading hoppers. With typical sowing rates of 50 000 seeds per hectare for maize and 800 000 seeds per hectare for oilseed rape, we might expect sufficient seed to be available on the soil surface to deliver an LD_{50} to 100 partridge or 167 mice for every hectare sown. However, we do not know whether vertebrates actually consume these seeds; if they are repelled by the colour or taste then there may be no issue.

But don't we need pesticides?

All pesticides kill non-target organisms, but they are probably a necessary evil if we are to feed the world. The trick is finding ones that protect crops well while doing as little damage as possible. How do neonics stack up in this respect? In the build-up to the EU vote on a moratorium, the agrochemical industry commissioned a glossy report by the Humboldt Forum which claimed that the moratorium would cost the EU €17 billion and result in the loss of 50 000 jobs in the agricultural sector. Are neonics really so important to farming? Interestingly, there is an acute shortage of evidence on this point. The Humboldt document appears to base its calculations primarily on asking an undisclosed number of farmers how much they thought their yield would drop if neonics were not available. The biggest figures were then extrapolated across Europe. Quite how farmers could know these figures is unclear, since they do not conduct their own agronomic trials.

The published scientific literature is also not very illuminating. Given their widespread use, it is surprising that so few studies have attempted to compare the effectiveness of neonicotinoids with alternative means of pest control. Several studies in North America[6–8] have compared yields in soybean and winter wheat with and without neonic seed dressings, and found either no difference or a yield increase which was not sufficient to pay for the seed dressing, yet neonic seed dressings are still used by most farmers. Similar studies from Europe are lacking, and are urgently needed to help us to make an informed decision about the costs and benefits associated with neonics.

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It has been suggested that the European moratorium will lead to farmers reverting to old generations of pesticides which are much worse. This seems unlikely, not least since most if not all such chemicals have been withdrawn. At present UK oilseed rape is almost all dressed with neonics, and then is typically sprayed twice in summer with a pyrethroid. One agronomist I spoke to said that he would be recommending an additional, earlier pyrethroid spray when the moratorium comes into place. Although pyrethroids are toxic to bees, this is unlikely to have a substantial impact since the extra spray would be applied long before the crop flowered, and pyrethroids do not persist for long in the environment or get transferred to the nectar and pollen. However, given the soybean studies from the US, one might question whether the neonic seed dressing was ever needed in the first place.

Whatever happened to integrated pest management?

When I was at University in the 1980s, I read Rachel Carson's *Silent Spring*[9], and was taught about the terrible mistakes made in agriculture in the 1950s and 1960s when indiscriminate use of persistent, broad-spectrum insecticides, and the abandonment of traditional cropping practices such as rotations, led to huge pest outbreaks. The pest insects had all become resistant, while their natural enemies had largely been eradicated. As a result, an approach called integrated pest management (IPM) had been developed, and we were taught that this was the future of pest control. IPM is predicated on minimising pesticide use: farmers monitor their crop pests, and only take action when necessary; they encourage natural enemies as far as possible, use crop rotations and other cultural controls to suppress pests, and only use the insecticides as a last resort. Even then, they avoid those that persist in the environment. Whatever happened to this philosophy? Why are we now applying pesticides prophylactically to more or less all crops? Did we learn nothing from our past mistakes?

Has the moratorium solved the bees' problems?

I am afraid the answer to this is an emphatic "no". Bees have been declining for many decades, and much of their decline has been due to loss of flower-rich habitat, which has been exacerbated by the arrival of non-native diseases (especially the *Varroa* mite for honeybees), and by widespread use of pesticides. We have taken a step to reduce (but not remove) their exposure to some brands of one type of pesticide, for two years. Neonics will still be widely used, for example on winter wheat, and there are likely to be high levels in soils for years to come, so bees will still be exposed to them. There seems to be no clear plan to monitor the outcome of the moratorium, and it is unclear what will happen once it expires, for we may not be much wiser than we are now. The moratorium can be seen as a short-term political move to delay addressing the issue properly.

At the Convention on Biological Diversity in 2002, world leaders committed to achieving a significant reduction in the rate of loss of biodiversity. By almost all indices, we have failed to reach this target. In the UK, the recent *State of Nature* report (http://www.rspb.org.uk/Images/stateofnature_tcm9-345839.pdf) highlighted that the majority of UK species continue to decline, and many are at perilously low levels. The reasons for these declines remain unclear and are the subject of ongoing debate, but it seems likely that the annually increasing use of neonics may be playing a role in driving these declines. If we want to ensure healthy populations of honeybees, bumblebees, and other wild pollinating insects upon which we depend for our crop production, and more generally if we wish to support the healthy, diverse ecosystems upon which our future health and well-being depend, then we need to find ways to produce food in a sustainable way which incorporates the needs of biodiversity. At present we are failing to do this.

References

1. Cresswell, J. E. (2011) A meta-analysis of experiments testing the effects of a neonicotinoid insecticide (imidacloprid) on honey bees. *Ecotoxicology*, **20**, 149–157.
2. Henry, M., Beguin, M., Requier, F., Rollin, O., Odoux, J.-F., Aupinel, P., Aptel, J., Tchamitchian, S. and Decourtye, A. (2012) A common pesticide decreases foraging success and survival in honeybees. *Science*, **336**, 350–351.
3. Gill, R. J., Ramos-Rodriguez, O., Raine, N. E. (2012) Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Nature* doi:10.1038/nature11585
4. Whitehorn, P., O'Connor, S., Wackers, F. and Goulson, D. (2012) Neonicotinoid pesticide reduced bumble bee colony growth and queen production. *Science*, **336**, 351–352.
5. Anon (2006) *Draft Assessment Report (DAR) – public version – Initial risk assessment provided by the rapporteur Member State Germany for the existing active substance imidacloprid.* Volume 3, Annex B.8: Environmental fate and behaviour. http://dar.efsa.europa.eu/dar-web/provision
6. McCornack, B. P. and Ragsdale, D. W. (2006) Efficacy of thiamethoxam to suppress soybean aphid populations in Minnesota soybean [Online]. *Crop Management*. doi: 10.1094/CM-2006-0915-01-RS.
7. Ohnesorg, W. J., Johnson, K. D. and O'Neal, M. E. (2009) Impact of reduced-risk insecticides on soybean aphid and associated natural enemies. *Journal of Economic Entomology*, **102**, 1816–1826.
8. Bueno, A. D., Batistela, M. J., Bueno, R. C. O. D., Franca-Neto, J. D., Nishikawa, M. A. N. and Liberio, A. (2011) Effects of integrated pest management, biological control and prophylactic use of insecticides on the management and sustainability of soybeans. *Crop Protection*, **30**, 937–945.
9. Carson, R. (1962) *Silent Spring*. Boston: Houghton Mifflin.

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