

ECOLOGY

Tasteless pesticides affect bees in the field

Two studies provide evidence that bees cannot taste or avoid neonicotinoid pesticides, and that exposure to treated crops affects reproduction in solitary bees as well as bumblebee colony growth and reproduction.

NIGEL E. RAINE & RICHARD J. GILL

Insects such as bees are crucial for the pollination of agricultural crops and wild plants^{1,2}, helping to ensure food security and maintain biodiversity. Yet a range of environmental stressors are threatening bee populations around the world^{3–6}. The impact of pesticide exposure, particularly from neonicotinoid insecticides, has received substantial recent research attention^{7,8} and has become a topic of public debate. Studies that have reported adverse effects of neonicotinoids on bees have been criticized for several reasons: that exposure tests are carried out under laboratory or semi-field settings rather than in the field and use pesticide-treated foods containing unrealistically high dosages; and that bees can detect chemical residues on treated crops and avoid foraging on them. Further weight has been added to such criticisms because the few field studies that have investigated potential impacts on honeybees and bumblebees from exposure to neonicotinoid-treated crops have been interpreted to show little or no effect^{9–13}, although limitations to these studies have been highlighted^{7,14}. Two studies published on *Nature's* website today strike at the heart of these evidence gaps and improve our understanding of pesticide exposure risks to bees.

In their paper, Kessler *et al.*¹⁵ present a carefully controlled laboratory study testing the ability of both honeybees (*Apis mellifera*) and bumblebees (*Bombus terrestris*) to taste the three most commonly used neonicotinoids — clothianidin, imidacloprid and thiamethoxam. When hungry worker bees could choose to collect from feeders containing either a solution of neonicotinoid-treated sugar water or an untreated solution, neither species avoided the treated food, which contained neonicotinoid concentrations comparable to those found in the nectar and pollen of treated crops. Surprisingly, the bees in fact preferred the treated solution in the imidacloprid and thiamethoxam tests, which the authors suggest arises from the pharmacological action of these insecticides

on receptors in the bees' brains. The authors corroborated their behavioural results with neurophysiological measurements showing that bees are unable to taste neonicotinoids in sugar water.

Scaling up from the laboratory, Rundlöf *et al.*¹⁶ undertook an ambitious study to assess the impacts of neonicotinoid exposure on bees placed near fields of treated oilseed rape

(also known as canola). The experiment — the largest of its kind so far — involved 16 fields across southern Sweden: 8 fields were planted with seeds treated with the systemic insecticide clothianidin, the pyrethroid insecticide β -cyfluthrin and the fungicide thiram, and 8 control fields were treated solely with thiram. Like Kessler *et al.*, these researchers studied both honeybees and bumblebees, but followed entire colonies rather than individuals. Furthermore, they monitored nests of a species of solitary bee (*Osmia bicornis*), as well as surveying wild bees in field margins.

In treated fields, Rundlöf and colleagues found fewer wild bees and observed reduced growth rate and reproduction of bumblebee colonies (which produced fewer males and fewer new queens — consistent with previous semi-field and field studies^{14,17,18}) compared to control fields. They also found that none of the solitary bees that emerged from nests placed next to treated fields came back to their natal nest to build new brood cells, whereas

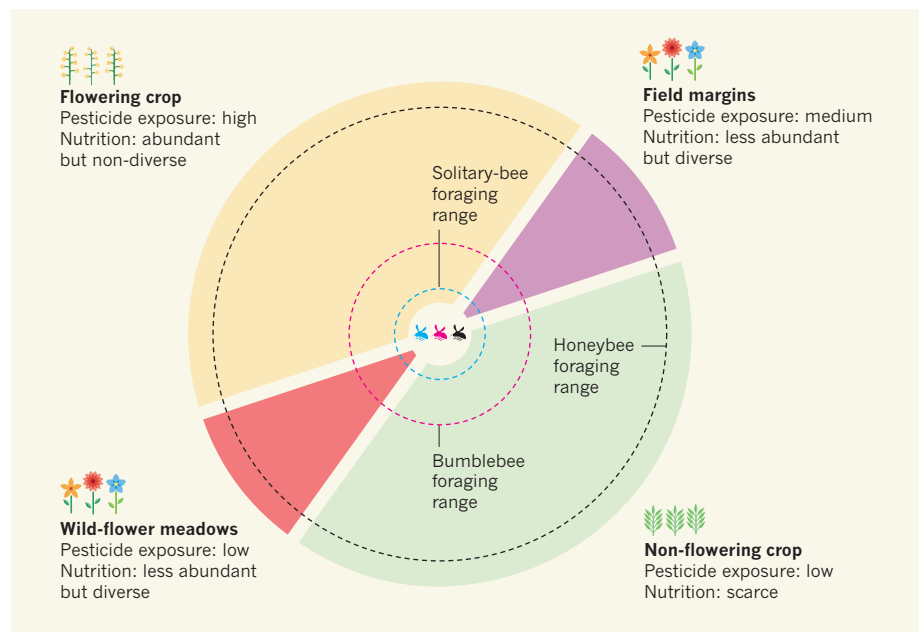


Figure 1 | Bee foraging options and pesticide exposure. Non-flowering crops and pasture cover large areas of rural land, but typically provide limited food resources for bee populations. Flowering crops can provide plentiful (although non-diverse) bee food, but are often treated with pesticides, a direct route for exposure. Flower-rich meadows provide a diverse bee diet, but these are becoming increasingly scarce, and small areas may support only low bee numbers. Furthermore, wild flowers in field margins may contain pesticide residues. Rundlöf *et al.*¹⁶ show that the growth rates and reproduction of bumblebee colonies are lower in neonicotinoid-treated fields than in control fields, and that reproduction of solitary bees can also be affected. However, the authors found no effect on honeybee colonies. These differences may result from different ecologies: honeybees can forage many kilometres from their hive, whereas bumblebees roam over smaller areas, and solitary bees fly less far from their nest. Honeybees also use the waggle dance to communicate the location of rewarding flower patches to nest-mates. Thus, honeybees may have reduced pesticide exposure from visiting a greater mixture of foraging sources or through a greater chance of avoiding treated crops. However, Kessler *et al.*¹⁵ show that neither honeybees nor bumblebees can taste neonicotinoids, suggesting that such avoidance behaviour is unlikely. (Nest sites, foraging ranges and the relative proportion of habitat types vary across landscapes — those depicted are representative only.)

emergent females successfully produced brood cells in six of eight untreated fields. By contrast, there was no significant difference in honeybee colony growth between treated and control fields. However, the authors' power analysis indicated that they would only have been able to detect a minimum effect size of about 19% for honeybees.

These studies provide timely data to address calls for further evidence about the environmental risks of neonicotinoids. The insecticides tested by the authors are currently subject to a European Union moratorium for use as seed treatments on crops attractive to bees, but this usage restriction will be reviewed before December 2015. It is hard to say whether the preferences observed by Kessler and colleagues for nectar containing imidacloprid and thiamethoxam residues would occur in a more complex field setting, where many variables could interfere with foraging decisions. However, their study does imply that foraging bees are unlikely to avoid seed-treated crops in the field, and supports previous reports of honeybees and bumblebees bringing back nectar and pollen from treated fields^{9–12,16}. If the preference for treated food does apply in the field, these findings suggest that we could be underestimating the exposure risk to bees from treated crops.

Both studies also highlight the fact that different bee species vary in their responses to exposure. Current pesticide registrations rely on ecotoxicological testing of just one species, the honeybee, when assessing risks for all insect pollinators. Yet Rundlöf and colleagues found negative effects of neonicotinoids on solitary bees and bumblebees in the field, but not on honeybees, suggesting that a single species might not represent the responses of other pollinators. Potential explanations for these apparent differences could include a variable affinity of neuronal receptors for binding neonicotinoids; differences in detoxification capacities; and divergent foraging behaviours, which influence levels of exposure (Fig. 1). Differences could also result from variation in social organization and life-history strategies. Even the smallest perennial honeybee colonies contain a queen and several thousand workers that overwinter as a group, whereas annual

bumblebee colonies rarely contain more than a queen and a few hundred workers. Each solitary bee is responsible for its own foraging and reproduction during its few weeks of adult life. The sheer number of workers in the honeybee colony may better enable buffering of stress over long periods, whereas the more severe pinch points that bumblebees and solitary bees experience could render them more susceptible to environmental pressures^{19,20}.

If field experiments to assess exposure are deemed so important, why have so few been carried out? Limiting factors include the scale of such studies, the levels of replication required to achieve appropriate statistical power, and human and budgetary resources. Even with 16 fields, Rundlöf and colleagues' study had relatively low statistical power and, as with other field studies, many environmental factors probably varied among their sites and could not be standardized. Such studies can provide only correlational evidence of impacts, whereas controlled-exposure studies, such as that of Kessler *et al.*¹⁵, are better suited to determining causative relationships through manipulative experimentation. The complementarity of these two approaches needs to be considered by policy-makers and for future research planning.

Although the two latest studies contribute to our understanding of the risk neonicotinoids pose to bees, knowledge gaps remain. For example, we need further evidence about how neonicotinoid exposure might affect social bee colonies over multiple seasons, how soil residues might affect ground-nesting bees and how neonicotinoid exposure interacts with other environmental stressors. We also need a greater understanding of how neonicotinoids affect other pollinators and natural enemies of crop pests, and of the persistence of these chemicals in soil and their take-up by untreated plants growing in or next to treated fields.

Fundamentally, we must move towards finding the right balance between the risks of neonicotinoid exposure for insect pollinators and the value these pesticides provide to ensure crop yield and quality. Selective use of neonicotinoid seed treatments, on the basis of a demonstrable need for systemic pest

protection, might help to reduce non-target exposure and slow the onset of pest resistance. We also need to consider and evaluate alternative options for pest control. It would be unfortunate if the recent focus on the risks from neonicotinoids led unintentionally to broader use of alternative pesticides that prove to be even more harmful to insect pollinators and the essential ecosystem services that they provide. ■

Nigel E. Raine is in the School of Environmental Sciences, University of Guelph, Guelph, Ontario N1G 2W1, Canada.

Richard J. Gill is in the Department of Life Sciences, Silwood Park, Imperial College London, Ascot SL5 7PY, UK.

e-mails: nraine@uoguelph.ca; r.gill@imperial.ac.uk

1. Garibaldi, L. A. *et al.* *Science* **339**, 1608–1611 (2013).
2. Ollerton, J., Winfree, R. & Tarrant, S. *Oikos* **120**, 321–326 (2011).
3. Vanbergen, A. J. *et al.* *Front. Ecol. Environ.* **11**, 251–259 (2013).
4. Nieto, A. *et al.* *European Red List of Bees* (European Commission, 2014); available at go.nature.com/c4g8lm
5. Burkle, L. A., Marlin, J. C. & Knight, T. M. *Science* **339**, 1611–1615 (2013).
6. Ollerton, J., Erenler, H., Edwards, M. & Crockett, R. *Science* **346**, 1360–1362 (2014).
7. Godfray, H. C. J. *et al.* *Proc. R. Soc. B* **281**, 20140558 (2014).
8. Pisa, L. W. *et al.* *Environ. Sci. Pollut. Res.* **22**, 68–102 (2015).
9. Cutler, G. C. & Scott-Dupree, C. D. *J. Econ. Entomol.* **100**, 765–772 (2007).
10. Pilling, E., Campbell, P., Coulson, M., Ruddle, N. & Tornier, I. *PLoS ONE* **8**, e77193 (2013).
11. Cutler, G. C., Scott-Dupree, C. D., Sultan, M., McFarlane, A. D. & Brewer, L. *PeerJ* **2**, e652 (2014).
12. FERA. *Effects of Neonicotinoid Seed Treatments on Bumble Bee Colonies Under Field Conditions* (FERA, 2013); available at go.nature.com/w9jiti
13. Cutler, G. C. & Scott-Dupree, C. D. *Ecotoxicology* **23**, 1755–1763 (2014).
14. Goulson, D. *PeerJ* **3**, e854 (2015).
15. Kessler, S. C. *et al.* *Nature* <http://dx.doi.org/10.1038/nature14414> (2015).
16. Rundlöf, M. *et al.* *Nature* <http://dx.doi.org/10.1038/nature14420> (2015).
17. Gill, R. J., Ramos-Rodriguez, O. & Raine, N. E. *Nature* **491**, 105–108 (2012).
18. Whitehorn, P. R., O'Connor, S., Wackers, F. L. & Goulson, D. *Science* **336**, 351–352 (2012).
19. Bryden, J., Gill, R. J., Mitton, R. A. A., Raine, N. E. & Jansen, V. A. A. *Ecol. Lett.* **16**, 1463–1469 (2013).
20. Gill, R. J. & Raine, N. E. *Funct. Ecol.* **28**, 1459–1471 (2014).