Pesticide Risk Tool (PRT)
Acute Pollinator Risk Index
White paper
October 2014

NOTE TO READERS:

The Acute Pollinator Risk Index was developed for the Integrated Pest Management Institute in Madison, Wisconsin. At the time, it inserted itself into a suite of indicators named PRiME – for the '**P**esticide **Ri**sk **M**itigation **E**ngine'.

PRiME has now been renamed PRT (**P**esticide **R**isk **T**ool) and this technical white paper has been modified to reflect this change of nomenclature. Otherwise, it is still the same indicator and no further changes have been made. This documentation as well as the full suite of indicators in the PRT can be found at https://pesticiderisk.org/

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SUMMARY AND PURPOSE

The purpose of the pollinator risk index in the PRT (Pesticide Risk Tool) is to provide a credible 'snap shot' of the relative risk of different pesticide products – particularly to wild pollinators but also to managed bees. The index represents the number of lethal doses accumulated by an adult 'composite' bee that combines activity and consumption patterns of a forager and hive honeybee. The index is able to account for the degree of systemic activity of different pesticides, as well as exposure through contaminated spray or dust, exposure from nectar or pollen contamination as well as contaminated sources of water. The index allows for an objective comparison of the acute risk from different pesticide active ingredients and/or different formulations of the same pesticides.

1. INTRODUCTION

Field tests that consider the impact of pesticides on honey bees or wild pollinators are seldom carried out as a condition of pesticide registration. Instead, results from laboratory tests are used to trigger product label warnings; *viz.* "*to reduce injury to bees, restrict application to the period after dark when bees are inside the hives or in the early morning before the bees are foraging*". While these label recommendations may help reduce the immediate impact of the application to managed crop pollinators, it is highly unlikely that they are sufficient to completely protect them, let alone native pollinators in the surrounding habitat. For example, non *Apis* bees (e.g., bumble bees) are known to have seasonal and daily foraging cycles that differ markedly from those of honey bees (Thompson and Hunt, 1999; Thompson, 2001), and mortality in those species usually goes unnoticed. Of course, different pollinator species may also differ markedly in their sensitivity to different pesticides (Tasei, 2002; Biddinger et al. 2013).

The 'traditional' approach to risk assessment for pollinators has been to derive a simple risk index made up of either contact or oral toxicity in the honey bee (generally the former) and potential exposure, typically the amount of spray falling within a given surface area. For example, a simple contact toxicity index can be obtained by dividing an exposure rate in g a.i./ha by the LD_{50} contact toxicity (µg/bee) to obtain a number of lethal doses per area regardless of foliage density or other complicating variables (EPPO 2010). In a recent analysis (Mineau et al., 2008b) it was shown that such simplistic risk indices, along with pesticide use information, were reasonable predictors of bee poisoning incidents compiled over a 21 year period in the United Kingdom although there were specific products and situations where the fit was not as good. Mineau et al. (2008) argued that, when applied to honey bee losses in flowering field crops (e.g. oilseed rape or canola), index values higher than 50 were indicative of potential die-offs, and that values higher than 400 were associated with frequent kills as reported by beekeepers. Based on industry field tests, the

European Food Safety Authority (EFSA) in its 2013 guidance, proposed a similar trigger of 42 for 'downward' spray applications (field crops) and 85 for sideways or upward applications (typically orchards, vineyards, hops). A trigger of 50 was proposed in the recently published Pellston workshop proceeding on pollinator risk assessment (Fisher and Moriarty 2014; appendix 6).

However, this simplistic approach is no longer adequate following the massive proliferation of systemic pesticides (primarily insecticides, and fungicides) in agriculture and home gardening products which often are not sprayed but applied as seed coatings or soil drenches. Even when they are sprayed, systemic pesticides are translocated to different parts of the plant and can give rise to delayed toxicity from a number of exposure routes. With concerns over these systemic pesticides and the neonicotinoid group of active ingredients in particular, there has been an explosion of research, discussion, meetings and proposals of new risk assessment approaches.

This index attempts to make use of the considerable amount of recent work in the area of assessment of risk to pollinators, principally the efforts of EFSA (2013), USEPA/PMRA/CDPR (2012, 2014) in attempting to chart a regulatory course of action but also a plethora of researchers (e.g. Rortais et al. 2005; Halm et al. 2006; Alix et al. 2009; Mommaerts et al. 2010; Blacquiere et al. 2012, Stoner and Eitzer 2013; Fisher and Moriarty 2014; Sanchez-Bayo and Goka 2014) who have all argued for radical changes to the risk assessment process to better account for the risk from systemic pesticides. We will borrow concepts and information from the above including, where possible, the principal regulatory sources (EFSA and North American regulators) even though the nature and purpose of an index is clearly different from that of a regulatory approval process.

2. THE CURRENT STATE OF SCIENCE

In recent years, a consensus has gradually emerged on the following:

- It is insufficient to consider acute lethal toxicity to individual honey bees as the sole basis for a risk assessment. Several concerns have been raised over the integrity of the hive as a result of behavioral, immune function, larval growth and development effects, queen production, and queen fecundity in response to chronic low level pesticide ingestion. Whereas the loss of some worker bees has been deemed acceptable[1] there is some uncertainty about the level of loss of specific bee castes that can be sustained before the integrity of the hive is affected.

[1] Based on a published model, the European Food Safety Authority (EFSA 2013) is proposing a trigger of 7% reduction in colony size or a mortality rate increase of 1.5X for a six-day period, 2X for a three-day period or 3X for a two-day period. There are no criteria proposed for the loss of nurse bees. Khoury and colleagues (2011) have proposed that an important stress on a colony is the early recruitment of nurse bees and other

- It is insufficient to only consider toxicity to the honey bee when so many different species of key pollinator species, including bumble bees and solitary bees are exposed also.
- Honeybees and other pollinators are typically exposed to a wide range of active and “inert” ingredients simultaneously, many of which exhibit acute or sub-acute toxicity to pollinators. Although we lack field data, current literature has shown additive and even synergistic effects when bees are exposed to certain insecticides (e.g. pyrethroids and neonicotinoids) and fungicides concurrently (Pilling et al. 1995; Iwasa et al. 2004; Biddinger et al. 2013). Recently, Bayer has announced (Andersch et al. 2010) that different neonicotinoid insecticides could act in a synergistic fashion, increasing concerns over multiple residues in environmental matrices or even honey. The use of tank mixes and insecticide-fungicide seed treatments in agriculture contributes to this multi-component exposure also.
- Exposure can take many forms and is not restricted to spray applications, especially in the case of systemic products. Notable ‘new’[2] routes of exposure include ingestion of contaminated nectar and pollen, contact with and ingestion of insecticidal dust following the planting of coated seeds, drinking from guttation fluids and honeydew on plants, puddles in field and other surface waters, and contact with residues in honeycomb wax.
- The persistence of the newer systemic insecticides and fungicides in perennial plants, soils, and waterways—with half-lives measured in months or even years in some cases—poses an ongoing exposure source over time, in some geographic areas leaving no window for pollinators to obtain pesticide-free forage.

In its recent guidance[3], the European Food Safety Authority (EFSA 2013) recommended that considerations such as those listed above be part of the first tier of a redesigned risk assessment scheme. They propose that the additional test data required for first tier assessment of pesticides should include:

- Oral chronic toxicity to adults over a 10 day period (LD_{50} in ug/bee/day)
- Assessment of the effects of oral chronic exposure on the hypopharyngeal glands of nurse bees (NOEL in ug/bee/day)
- Oral toxicity to larvae expressed as ug/larva over the development period (NOEL)
- A consideration of the potential for cumulative effects

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hive bees into the foraging guild as forager losses increase. None of these complex scenarios are currently considered in the risk assessment process.

[2] Some of these sources of exposure have in fact been considered by several authors previously. However, it is only with the increasing popularity of the neonicotinoid insecticides that they have gained wider attention and given rise to regulatory concerns.

[3] It is unclear at this stage whether the guidance documents and, more importantly the new testing requirements, have force of law in the EU.

- A consideration of the potential for population-level effects

In addition, the acute oral and contact tests are to be carried out on formulations as well as on the active ingredient if the latter's toxicity cannot adequately be predicted from tests on the active ingredients alone; the same would apply to the larval and adult chronic tests depending on the relative toxicity of the formulated product. Metabolites need to be tested under some circumstances also (see EFSA 2013 for details). For the first time, guidance on risk assessment includes solid formulations such as granules or seed treatments. If concerns are raised with respect to the systemic activity of either solid formulation, risk assessors are advised to consider not only the risk to pollinators foraging on the treated crop, but foraging also on weed species in the treated fields, field margins, adjacent crops as well as succeeding crops.

Unfortunately, notwithstanding their validity, we cannot design a risk index that addresses all of these points without the requisite data. Indeed, we expect that it will be some time before the newly required data become routinely available for pesticides and before comprehensive risk assessments become possible. Data will likely never be generated for older products currently registered, making comparisons with newer products difficult. Given the difficulty of imposing a broader (and much more costly) testing strategy on pollinators at large, EFSA proposed a series of uncertainty factors that could be applied to the tier 1 risk quotients:

- Uncertainty factor of 5 for honey bee larval toxicity to account for intraspecific (strain) differences in toxicity and extrapolation from lab to field.
- Uncertainty factor of 3 to extrapolate from spray drift to dust drift, the latter having been shown to be much worse (e.g. Girolami et al. 2013).
- Uncertainty factor of 5 for bumble bees and 10 for solitary bees to account for the more serious consequences of losing foraging bees.
- Uncertainty factor of 10 to account for interspecies toxicity differences.

Notwithstanding the pesticide industry's objection to these recent proposals (ECPA 2013), such a large number of safety factors and the resultant high level of uncertainty make the development of a risk indicator difficult. Although realistic, they indicate the obvious: Most insecticide treatments, with the exception of pest-specific biological agents (e.g. baculoviruses) are very likely to cause harm to many wild and managed pollinator species. It is no coincidence that pollinators are not faring well in our current intensive agricultural systems. It is likely that all insecticides and a significant number of fungicides would 'fail' such a first tier of assessment and require semi-field or field testing or at least label statements and other forms of mitigation which, as argued above may not be effective to protect wild pollinators and, in many cases, managed pollinators as well. A further contradictory aspect of the tier progression envisioned by EFSA is that field testing at higher tiers of risk assessment will probably be restricted to honey bees because of the commercial imperative[4]; given the safety factors proposed, risk is likely to be identified more often for bumble bees or solitary bees.

3. TOWARDS A WORKABLE INDEX OF POLLINATOR RISK

The purpose of the pollinator risk index in PRT is to provide a credible 'snap shot' of the relative risk of different pesticide products – particularly to wild pollinators but also to managed bees. As such, the exact parameters with which exposure is calculated for this indicator are not so important. As long as they are reasonable and representative of probable field conditions, the correct relative risk ranking of different pesticide applications will be maintained.

Label statements intended to protect managed hive bees, although commendable, are clearly insufficient to negate a high risk carried by any given pesticide. The new labeling proposed by EPA (EPA 2013) allows for exceptions that will put bees at significant risk, *viz.*:

''*Do not apply this product while bees are foraging. Do not apply this product until flowering is complete and all petals have fallen unless one of the following conditions is met:*

- *The application is made due to an imminent threat of significant crop loss, and a documented determination consistent with an IPM plan or predetermined economic threshold is met. Every effort should be made to notify beekeepers no less than 48-hours prior to the time of the planned application so that the bees can be removed, covered or otherwise protected prior to spraying.*''

Also, in cases where the crop is likely to prove attractive to pollinators long after application of a systemic product, a full accounting of risk has to include the crop itself, regardless of any attempts by the grower to reduce the immediate risk through application or other management practices.

We therefore propose a two part index: 1) An on-crop index leaving some possibility of risk reduction through management practices, and 2) An off-crop index based primarily on field margins that receive spray drift or dust following a pesticide application. Recent evidence has highlighted the role of contaminated water, either from surface runoff (e.g. Main et al. 2014) or guttation water (e.g. Girolami 2009) as a possible source of exposure for some bees. We will assume that bees are always able to obtain water from the cultivated field edge of a cropped field even if foraging in the field margin.

[4] However, Blacquiere and colleagues (2012) argue that it would be easier to conduct higher tier tests (that include whole colony integrity and survival criteria) on micro-colonies of bumble bees with a few individuals only.

However, for reasons outlined below, **the risk to bees from contaminated water sources will be assessed separately, at least initially**.

The first iteration of the PRT pollinator index will, as noted above, represent a snapshot in time and will, by necessity, be an acute pollinator index. Ideally, a pollinator index should also consider the duration and reversibility of toxic injury. Wild pollinator species are typically staggered in their emergence and peak activity in the course of a growing season – as are arable weeds in field borders. The persistence of toxic residues increases the probability that a larger number of pollinator species will be affected during any given time period, thus reducing any potential for redundancy in pollination services. We propose that the persistent lethal toxicity of pesticides as well as their sub-lethal effects following chronic exposure be part of <u>future improvements</u> to this index. Limited data on the toxicity of treated foliage over time does exist ('extended residual activity' or ERT currently being a conditional requirement of the US EPA) but is currently inadequate to build an index. Similarly, we are just starting to obtain data on the persistence of systemic residues and the possibility of carry-over across several flowering seasons. Unfortunately, larval feeding tests and chronic adult toxicity tests as recently proposed (EFSA 2013) will not be available for some time.

A growing body of information is being developed on the toxicity of insecticides to pollinators other than honey bees, notably bumble bees (*Bombus* species) or several solitary bee species. However, to date, data are only available for a small proportion of active ingredients, and tests have not been standardized. As Table 1 from UK DEFRA (2008) indicates, a safety factor of 10 (as proposed by EFSA 2013) is certainly reasonable (although still under-protective) in light of the toxicity data available to date on the alfalfa leafcutter bee (*Megaliche rotundata*) alone. A more recent analysis of paired toxicity data from the same sources (Arena and Sgolastra 2014) found that a safety factor of 10 applied to the honeybee toxicity endpoints was sufficiently protective in 95% of cases and that the honeybee tended (as shown by a median value of ratios) to be slightly more sensitive than the paired test species. However, the full range of sensitivity ratios between the honeybee and one of the other 19 bee species with which it was paired ranged over 6 orders of magnitude! The differential weight of test bee species is part of the reason for this vast difference but it is much more complicated (Arena and Sgolastra 2014). Sanchez-Bayo and Goka (2014) regressed *Bombus* LD50 values against *Apis* LD50 values. They concluded that the susceptibility of both genera was similar when exposed by the oral route but that the honeybee was more sensitive than bumblebees by the contact route even after correcting for weight. However, the inclusion of limit values (e.g. >100) in their log-log plots may have affected these conclusions.

Table 1. Contact toxicity of insecticides to honeybee and solitary bee species (24 h unless stated) (Updated from a DEFRA 2008 compilation based on Tasei et al, 1988, Mayer et al 1993,1998,1999, Helson et al, 1994, Stark et al, 1995). Cases where honey bee data would clearly under-protect other species are highlighted in red.

Chemical Type	**Name**	***Nomia melanderi*** **LD_{50} (µg/ bee)**	***Apis mellifera*** **LD_{50} (µg/ bee)**	***Megachile rotundata*** **LD_{50} (µg/ bee)**
Carbamate	Aminocarb	*	0.121	0.068
	Carbaryl	*	0.385	0.592
	Mexacarbamate	*	0.061	0.071
Neonicotinoid	Imidacloprid	0.04	0.04	0.04
Organophosphate	Diazinon	0.45	0.23	0.12
	Fenitrothion	*	0.171	0.039
	Trichlorfon	*	5.137	10.3
Pyrethroid	Bifenthrin	0.14	0.05	0.006
	Cyhalothrin	0.036	0.022	0.002
	Deltamethrin	*	0.024**	0.005
	Permethrin	*	0.024	0.018
Phenyl pyrazole	Fipronil	1.130	0.013	0.004

* No Data

** Added to the existing compilation

PRT environmental indices have typically shied away from the use of extrapolation or safety factors in favor of using species sensitivity distributions (SSDs) coupled with a calibration of toxic endpoints against actual field data. However, conducting SSDs on bee data will not be possible for some time. **In the PRT pollinator index, we will therefore use acute honey bee toxicity (both contact and oral) to which a provisional safety factor of 10 will be applied in order to cover other bee species.**

On the exposure side, **we will design a 'composite' honey bee from two temporal castes** by combining the exposure potential of both nurse bees (pollen ingestion) and foragers (nectar consumption). In other species (e.g. bumble bees), individual bees do not exhibit the same degree of specialization as the honey bee and consume both pollen and nectar in great quantity. Nurse bees and nectar foragers are two of the three adult bee 'categories' thought to be most at risk by Halm et al. (2006), the other category being wintering bees.

It should be clear by now that there will be a **wide gap between the ideal index, as discussed in the previous section, and what can be calculated currently for the vast majority of in-use pesticides**. As information on the role sub-lethal toxicity may play in defining colony survival becomes more commonplace, we expect that this index will change to reflect these regulatory developments. In the meantime, the PRT index will, by necessity, be based on lethal toxicity following a combination of acute exposures. Of course, the idea that it is insufficient to look at acute lethal toxicity in order to assess pesticide risk is not unique to pollinators. Most of the indices in the PRT system have a similar limitation. Yet, we keep coming back to acute toxicity and lethal endpoints because these are often the only data available for the majority of products. An (implicit) assumption that is made (but largely untested) is that any sub-lethal effects will happen at a fixed proportion of lethal effects, and that acute effects will provide an indication of sub-acute or even chronic effects, thus preserving the relative risk ranking of different pesticides. We know that this is unlikely to be true for some groups of insecticides, for example insect growth regulators, which have a mode of action that is specific to a life stage not currently being tested. Until better larval test data become available, PRT will only be able to flag these products and warn the user that risk to pollinators is likely to be seriously underestimated.

4. DATA SOURCES

Data from two acute toxicity tests are typically available for honey bees – acute oral and contact toxicity. Both the contact and oral toxicity tests report calculated toxicity values as ug/bee. The oral toxicity test was not hitherto a requirement of North American registration. It is now proposed that this test be carried out for any pesticide with a contact toxicity of less than 11 ug/bee (USEPA/PMRA/CDPR 2014). Unfortunately, the relationship between oral and contact toxicity is not always very good. **A regression approach (under development) will be used to derive one from the other.** It is hoped, however that for compounds of high bee toxicity (i.e. where it is important to generate a good indicator value), it will be possible to find both oral and contact toxicity data.

Toxicity data were assembled from a variety of sources including principally Atkins et al. (1981), the EPA Pesticide Ecotoxicity Database (download available from http://www.ipmcenters.org/Ecotox/index.cfm), the French AGRITOX database (http://www.dive.afssa.fr/agritox/index.php), INCHEM (http://www.inchem.org/) the Footprint database (http://sitem.herts.ac.uk/aeru/footprint/) and the Pesticide Manual (British Crop Protection Council – Several Editions).

A number of explicit rules were created in order to deal with limit values, multiple or missing values and other data issues. These are listed below; they are used independently for both contact and oral toxicity values.

1. Values generated for the technical active ingredient are used preferentially, although data obtained with formulations can be used if technical a.i. values are not available.
2. If there is a single LD_{50} value, this value will be used as the LD_{50} estimate, whether it is exact or approximate (i.e. is a limit value with a ">" qualifier or an approximate value usually denoted by c.). Limit values with a "<" qualifier cannot be used.
3. If there are multiple exact values, the LD_{50} estimate is calculated from the geometric mean of these values.

4. If there are multiple limit values, all with a “>” prefix, the highest value will be used as the LD$_{50}$ estimate.
5. If there are multiple limit values, all with a “<” prefix, no LD$_{50}$ estimate will be determined.
6. If there are multiple values, some of which are exact values and others limit values with a “>” prefix, the limit values will be discarded if their values are less than the smallest exact LD50 value. Limit values with a “>” prefix that are higher than the smallest exact value will be used as if they were exact values along with the exact LD50 values to calculate a geometric mean as in rule 2.
7. If there are multiple values, some of which are exact values and others limit values with a “<” prefix, the limit values will be discarded if their values are greater than the smallest exact LD50 value. Limit values with a “<” prefix which are lower than the smallest exact value will be used as if they were exact values along with the exact LD50 values to calculate a geometric mean as in rule 2.

Needed information on pesticide mode of action and physico-chemical characteristics are assembled from a number of existing sources as outlined in other documentation of the PRT system. (e.g. See white Papers at https://pesticiderisk.org/about/materials)

5. INDEX STRUCTURE

In order to account for all possible exposure routes, both the on-crop and off-crop PRT pollinator indices will consist of a summation of several sub-indices reflecting different exposure routes for the index’s composite[5] bee. **The indices will be expressed as the number of lethal doses (as measured by the appropriate average lethal dose or LD$_{50}$[6]) cumulated by a foraging bee in the course of a day.** Sub-indices will need to be calculated for both contact and oral routes where appropriate; i.e. depending on the application type and the extent to which the pesticide can be translocated, whether it is labelled as a systemic product or not. (See section 6. below on ‘Defining systemic activity’)

Knowing which sub-indices are applicable to different pesticide use scenarios will require the construction of tables that will reflect which sub-components of the risk indices need to be toggled on or off under specific use conditions, whether the treated crops produce attractive pollen or nectar etc…. Some of this information has already been assembled; e.g.

[5] As indicated earlier, this imaginary bee will have some of the pollen-eating characteristics of nurse bees in order to better reflect species with less division of labour.

[6] Our preference would be to use a probabilistic approach where each bee’s probability of survival is assessed based on the extent of its exposure. However, to do this next step properly, the slope of the probit values used to determine the LD50 is needed. This is seldom available for the data publically reported from bee tests.

see table in Appendix 3 copied from EFSA (2013) for attractiveness of crop species in Europe.

Initially, the PRT pollinator index will compute an acute risk based on expected peak exposures[7] for each of the individual exposure routes. In future refinements, it is expected that, as suggested above, indices be cumulated over the life-span of a bee (or perhaps even a full year in the life of a hive) in order to account for the persistence and or gradual buildup of residues in different matrices. Other PRT indices of chronic injury are computed by using the foliar degradation rate of pesticides in wildlife foodstuffs. The same approach cannot be followed here because considerable uncertainty remains with respect to both the uptake and subsequent degradation rates of residues in pollen, or nectar.

6. DEFINING SYSTEMIC ACTIVITY

A key part of the pollinator index is to account for the systemic activity of pesticides. We could, as first suggested by Alix and Vergnet (2007) for the French regulatory system, calculate pollen and nectar concentrations only for those compounds clearly defined and marketed as systemics. Indeed, most of the discussion to date (e.g. Fisher and Moriarty 2014) has given rise to different risk conceptual frameworks for systemic and non-systemic pesticides. However, this assumes that translocation of pesticides into plant tissue is an 'all or nothing' phenomenon – which is clearly not the case given descriptions from reference material of pesticides that are 'partially systemic' or having 'some systemic activity'. Whether or not a compound is noted as being systemic depends primarily on the uses it is put to and the extent to which translocation has been studied. It may not be advertised as a systemic but there still might be measurable translocation within the plant because of its physico-chemical properties – hence a potential risk to pollinators currently not being considered. We propose to quantify systemic activity in all pesticides whether or not they are systemic enough (or effective against pests for which systemic activity would be useful) to be marketed as such. We will therefore estimate the extent of pesticide translocation into plant tissues in order to develop a chemical-specific risk factor for uptake and expression of residues in pollen, nectar or guttation fluids for all pesticides.

A potentially useful concept of systemic activity developed by Shone and Wood in 1974 (Referenced in Briggs 1982) is termed the 'Transpiration Stream Concentration Factor' (TSCF). It is a ratio of the chemical concentration around the roots to that of the shoots, most of the pesticide typically being in the upper section of the shoots, close to the site of evapotranspiration. Most of this movement of chemical is through the xylem. Briggs and colleagues (1982, 1983) established the relationship between the TSCF and lipophicity in

[7] Because the timeline of contact and oral exposures differs, the concept of 'peak time' will vary depending on the route of exposure.

barley plants for a series of neutral (non-ionic) pesticides. Burken and Schnoor (1997) worked out a similar relationship for different organic chemicals in poplar trees. North American regulators (USEPA/PMRA/CDPR 2012, 2014) are currently looking at variations on these algorithms to predict the risk of nectar and pollen contamination. The algorithms are based entirely on the octanol-water partition coefficients of pesticide active ingredients, and invariably show maximal systemic activity at intermediate Kow values based on a small sample of neutral (non-ionic) compounds that have been studied to date.

We initially derived TSCF factors for a number of in-use pesticides of diverse uses and structures intending to use this as our indicator of systemic activity also. Unfortunately, all of our analyses indicated that the TSCF was a very poor predictor of whether a pesticide is listed by various authorities (e.g. the Footprint database, the Pesticide Manual) as a systemic compound with the ability to translocate within plants. Large discrepancies in the TSCF of different active ingredients acknowledged to have comparable systemic activity made us question the approach also. **Instead, we constructed an empirically-derived 'Index of Systemic Activity' (ISA) based on the probability that any given pesticide would be marketed as a systemic product given its physico-chemical properties.** A database of 'commercially recognised systemic activity' was constructed from descriptions given in the Pesticide Manual, the Footprint database as well as a list of potato pesticides assembled by the Minnesota Department of Agriculture (2014) in concert with extension specialists at North Dakota State University. Although these three sources usually agreed, there were some differences of opinion and those compounds given conflicting ratings were removed from the analysis. Similarly, compounds noted as having only 'some' or 'partial' systemic activity were left out of the analysis.

The list of pesticides available for this modeling exercise contained 369 systemics and 126 non-systemics. Logistic models were built using all easily available phys-chem (mol. wt., Log water sol., Log Kow, neutral vs. ionic, pKa) and derived (e.g. predicted TSCF) variables to predict whether a pesticide was noted by the above sources as systemic or non-systemic. The best predictor variables were consistently water solubility and ionization potential. Interestingly, calculated TSCF did not come up as a significant predictor, even in the case of neutral pesticides (the type of compounds for which the Briggs and Burken & Schnoor algorithms were developed). Best results were obtained by entering the acid dissociation constant (pKa) of the pesticide active ingredient; those noted as neutral (non-dissociated) pesticides being given an arbitrary pKa value of 14.0 and those noted as 'fully dissociated' a value of -5.0. Systemic pesticides tended to be those with the higher water solubility and lower pKa values. The sample of pesticides with known water solubility and ionic status was reduced to 228 systemic and 57 non-systemic pesticides. Because of this sample imbalance, 4 separate models were derived with the sample of non-systemic pesticides being matched to a quarter of the systemic compounds at a time, the latter having been split alphabetically (Appendix 1). Non systemic pesticides were correctly identified as such 72-77% of the time; 79-83% of systemic pesticides were correctly identified.

We used the probability that a pesticide was identified as 'systemic' (averaged between the four separate models) as our 'Index of Systemic Activity'. This index ranged from a high of 0.99 (glyphosate trimesium) to a low of 0.05 (deltamethrin). Because data on nectar and pollen contamination following translocation from a seed treatment or soil application has been obtained (see section below) for the three neonicotinoid insecticides: imidacloprid (ISA=0.55), clothianidin (ISA=0.62) and thiamethoxam (ISA=0.65), **we calculated a 'Relative Index of Systemic Activity' (RISA) as a score relative to the mean score (0.61) of these three insecticides**.

i.e. $RISA_x = ISA_x / ISA_{ref}$ .... where $_x$ refers to the specific pesticide of interest and $_{ref}$ refers to the average of the three aforementioned neonicotinoid insecticides.

Appendix 2 provides a list of insecticides only ranked by their ISA & RISA alongside a description of their mode of action as well as an indication of their recognised systemic status (where available) and the solubility and pKa variables entered into the analysis.

Part of the classification errors evident from the list of tabulated insecticides (but undoubtedly not all) can be ascribed to pesticides having some systemic activity despite not being marketed as such. Other classification 'errors' can be explained by specific properties of the insecticides. For example, carbosulfan is described as a systemic insecticide despite its low ISA (0.27). However, this active ingredient is a proto-insecticide which breaks down to carbofuran, a compound with recognised systemic activity. Another apparent error (diazinon) is interesting. It is not marketed as a systemic insecticide despite a high calculated ISA (0.77). Yet, this insecticide is described (Pesticide Manual) as being registered against several 'chewing and sucking insect species', a use pattern more commonly associated with systemic compounds.

We propose that using a relative index such as the RISA, despite its uncertainties, will result in a reasonable risk index. The alternative would have been to rely on marketing claims, potentially missing systemic activity on one hand and having to assume that all 'systemic' pesticides are endowed with an equal degree of systemic activity on the other. In addition, many pesticides are of unknown 'systemic' status based on standard references. Use of the RISA described above will be a provisional measure until a better algorithm can be developed with less overall classification error. An alternative strategy also needs to be developed for cases where the needed physico-chemical data (usually pKa) is not known or reported.

7. CALCULATION OF SUB-INDICES AND COMPONENTS THEREOF

7.1. CONTACT EXPOSURE

7.1.1. SPRAY DRIFT

There are several potential routes of contact exposure. Traditionally, droplet drift was considered to be the only potential route although how the bees were actually exposed was not explicitly defined. Droplets may directly contact the bees or contact the surfaces on which bees are foraging or the soil in which they are nesting in the case of many bee species.

In the case of spray applications, we will base the calculation of the contact sub-index on the same source used by USEPA/PMRA/CDPR (2012) in their review of contact toxicity – the fluorescent tracer studies of Koch and Weisser (1997). These authors made applications in two different conditions: flowering apple trees sprayed by axial fan 'airblast' sprayer and fields of blooming *Phacelia tanacetifolia* sprayed with a boom sprayer. Phacelia is a rotational crop in the borage family highly attractive to bees. Measurements were made immediately after application and represent a single foraging trip.

As reported by USEPA/PMRA/CDPR (2012), maximum values recorded worked out to 2.7 and 2.0 µg a.i./bee for *Phacelia* and apple, respectively, once adjusted to a 1 lb/A application rate (corresponding to 2.4 and 1.8 µg a.i/bee for a 1kg/ha application). As argued by USEPA et al. (op.cit.), even though these are maximum values, they are likely reasonable (and therefore not overly protective) in light of the fact that another study in oilseed rape (with cypermethrin) gave mean residue levels of 2.7 µg a.i./(lb/acre applied)/bee (Delabie et al. in USEPA/PMRA/CDPR 2012). Also, it should be noted that the fields were quite small (0.4-1.6 ha for apples, 0.1-1ha for Phacelia), possibly 'diluting' the extent of exposure of individual bees.

The difference between the two crops – apple and *Phacelia* - if real, may reflect the 3D nature of the fruit tree crop and/or different application method resulting in a lower deposit per flower. **For our off-crop scenario which places emphasis on bees foraging in vegetated field borders, we will consider that a foraging bee is exposed to 2.4 ug/bee for a 1 kg a.i./ha of drift from each foraging trip. The on-crop risk will use 2.4 and 1.8 µg a.i/bee per kg/ha application in field crops and fruit trees respectively.** Of the extent of pesticide drift will be calculated differently in those two situations (see section 7.2).

This will be used to calculate the number of LD_{50} equivalents per bee. In their most recent guidance, USEPA/PMRA/CDPR (2014) mandate the use of 2.4 ug/bee per kg a.i./ha of application without regard for the crop type. Koch and Weisser (1997) in their conclusions, recommended the use of 1.8 ug/bee (the highest mean sample level) as a reasonable transfer quotient

Given that the acute bee index strives to cumulate lethal doses over the course of a day, it is unclear whether the data of Koch and Weisser (1997) should be assumed to hold for each possible foraging trip. (It would be reasonable to assume that the average forager makes about 10 foraging trips per day, each trip lasting an hour on average – see section 7.4, table 8). At worst, we might want to multiply the estimates of 1.8 or 2.4 ug/bee by 10, or even by the number of hours left in the day following application. However, the data of Koch and Weisser (1997) suggest that most of the contamination occurs during or very shortly after application, suggesting that **most of the bee contamination takes place as the droplets are falling or while the spray is still wet on the plants. At this point in time, our index will assume that our composite bees are only contaminated for their first foraging trip after application**.

7.1.2. DUST DRIFT

Recently, it was discovered that dust dispersed during the planting of coated seeds could also expose bees in an analogous fashion to droplets[8]. The risk is thought to be higher under high humidity conditions, (Girolami et al. 2012; Halm et al. 2012). These authors theorized that the high humidity may help in the absorption of the systemic insecticides through the cuticle. If so, the effect may be dependent on the water solubility of different products. It is also likely that high humidity at the time of application will allow dust to more effectively stick to the bodies of the insects. Tapparo and colleagues (2012) conducted experiments where individual bees were captured after merely flying over a corn field in the process of being sown in order to reach a food source (the entire test running for 1h). They measured amounts of 0.078-1.240 ug/bee (N=5, mean=0.570 ug/bee) for clothianidin at 1.25 mg a.i./seed and 0.128-0.302 ug/bee (N=4, mean=0.189 ug/bee) for thiamethoxam at 1 mg a.i. /seed. Given that bees could be exposed to contaminated dust for much longer periods, both in the air and once the dust has settled on plant surfaces, **an estimated exposure of 1 ug/bee for a 1 mg a.i./seed application (the highest value recorded by Tapparo and colleagues (2012)) will be used as a provisional value in the index.**

Finally, it is clear that dust is generated also during the application of granular formulations (EFSA 2013). We are not aware of any information that would relate bee

[8] In North America, it is customary for farmers to use talc or graphite as lubricants in their seeding machinery (e.g. Krupke et al. 2012). This definitely increases the visibility of the dust cloud but it is not sure whether it changes the fundamentals of exposure.

exposure to granule-generated dust and therefore propose to use the information of Tapparo and colleagues (2012) on dust generated from seed. Given an approximate weight of 377 mg for a corn seed (Mineau and Palmer 2013), 1 mg of active ingredient per corn seed means that the seed 'particle' is 2.7% a.i. by weight. **Assuming that the loss of a.i. through dust is proportional to the percentage of active ingredient on each particle, we propose to scale bee contact figures accordingly.** Granular products are typically in the 1-20% range of a.i. concentration; table 2 proposes values that can be used to estimate loading from different granule concentrations.

Table 2. Proposed bee loading rates (contact exposure) from dust generated in the course of granule applications.

Granule concentration	Proposed bee loading[a] (ug/bee)
1G	0.37
3G	1.1
5G	1.85
10G	3.7
15G	5.6
20G	7.4

[a] This is the loading figure for exposure on-crop. Because granules are typically applied at a time when the field is not attractive to pollinators, the tabulated figures will be used in conjunction with an estimate of drift into field margins.

Proposed values for the risk index contact scenarios are therefore summarized in table 3.

Table 3. Proposed values to be used as contact transfer values for PRT's composite bees.

Type of application	Type of crop	Chosen exposure value
Spray	Field	2.4 ug/bee/kg a.i./ha
	Tree or vine	1.8 ug/bee/kg a.i./ha
	Off-crop[9]	2.4 ug/bee/kg a.i./ha
Seed treatment	Off-crop[10]	1.0 ug/bee/mg a.i./seed[11]

[9] But the application rate in kg a.i./ha is moderated to account for % drift – see below

[10] It is clear that some individual pollinators could be exposed while transiting across fields in the process of being seeded. However, the index will assume that the main risk occurs when the dust cloud is allowed to drift unto more attractive flowering areas – whether non-crop or neighbouring fields as was the case in many of the documented European kills.

[11] % drift is also taken into account. See below

Granular	Of-crop[10]	0.37 ug/bee/ each % concentration of granule[11]

We will assume that fine dust produced from either seed treatment or granule (see below) applications have the potential to contaminate pollen and nectar off-crop to the same extent as spray applications.

It is noteworthy that, in their most recent guidance, North American regulators (USEPA/PMRA/CDPR 2014) have chosen to not formally include the dust route of exposure in their assessment despite ample evidence of recorded incidents, both in Europe and North America.

Other sources of contact exposure exist. For example, the relevance of soil residues in the case of ground-nesting solitary bees needs to be ascertained as do residues in wax in terms of the exposure of hive bees or larvae especially (FIFRA SAP 2012) but these will not be considered in the current version of the index.

7.2. MEASUREMENT OF DRIFT INTO FIELD MARGINS

To compute risk posed by pesticide deposits in field borders, and short of directly modeling drift from every application, we propose to use the shortcut proposed by EFSA (2013). They based % deposit values on the work of Candolfi and colleagues (2001) following the European Escort project on pesticide exposures to non-target arthropods. The single drift values proposed make use of a reasonably protective deposit measurement (90th percentile) and assume a droplet spectrum and conditions typically associated with insecticide spraying. As such, they will overestimate the extent of herbicide drift[12] (typically larger droplet spectrum, lower height of application). However, they strive for more realism by taking into account that pollinators will not always be foraging directly downwind and will therefore often receive less exposure than calculated. Different factors are invoked for oral and contact exposures (see table 4) because, in the former, further dilution of residues is expected by foraging at different angles relative to the direction of drift whereas the direct impingement scenario has the bee flying directly downwind of the field. For a detailed discussion of those values, please refer to appendix H of EFSA (2013).

Table 4. Default deposition percentages for spray drift and dust drift into field margins to be used for the different combinations of application technique and types of plants. From EFSA (2013; Appendix H)

Application	Crop

[12] We do not foresee this will present any problems here since herbicides are less likely to be of concern for acute pollinator toxicity.

type		For purpose of measuring concentrations in nectar and pollen	For purpose of contact exposure assessment
Spray applications (spray drift)	Field crops	0.92	2.8
	Early fruit	9.7	29.2
	Late fruit	5.2	15.7
	Early grapevine	0.90	2.7
	Late grapevine	2.7	8.0
	Hops	6.4	19.3
Seed treatments (dust drift)	Maize with deflector	0.56	1.7
	Maize without deflector	5.6	17
	Oil seed rape with deflector	0.22	0.66
	Oil seed rape without deflector	2.2	6.6
	Cereals with deflector	0.33	0.99
	Cereals without deflector	3.3	9.9
	Sugar beets with deflector	0.001	0.003
	Sugar beets without deflector	0.01	0.03
Granule applications (dust drift)	All crops	3.2	9.6

7.3. ORAL EXPOSURE

7.3.1. POLLEN AND NECTAR EXPOSURE FROM DIRECT IMPINGEMENT

As shown by Crailsheim et al. (1992), pollen consumption typically peaks in the first week of life for adult honey bees. They are then in the 'nurse' caste and need the high protein intake to develop their hypopharyngeal and mandibular glands to transform honey and pollen into royal jelly to feed the larvae. All adult honey bees consume nectar (Rortais et al. 2005). However, the exact proportion of nectar and processed honey consumed by foragers is not known (or likely is variable depending on conditions, time of the year etc…); for that reason, forager needs are typically expressed as sugar ingestion. For example, Rortais et al (2005) estimated that for a honey bee, each mg of sugar required would represent the consumption of 2.5mg of fresh sunflower nectar or 1.25mg of sunflower honey. In this index, we will assume that the sugar requirements of our 'composite' bee will be nectar-based in order to reflect the toxicity of collected nectar – whether the 'recipient' of the exposure is the forager or another hive bee[13]. This will allow us to match nectar demands

[13] … or indeed a larva. The index attempts to account for toxic potential across several castes and life stages.

with known contamination levels measured in nectar. Residues in honey, wax, propolis and royal jelly will be ignored at this point.

EFSA (2013) proposed values for residue levels in pollen or nectar shortly following foliar applications of pesticides based on an internal compilation of data (mostly from industry sources). All data are expressed as a RUD (Residue per Unit Dose) meaning that they are standardized to a 1 kg/ha application. These data include both systemic and non-systemic insecticides and likely represent applications to plants in bloom. However, the data were obtained from a variety of crop plants with different flower and stamen morphologies and orientation. Not surprisingly, the data are quite variable. We separated the data provided into systemic and non-systemic products – based on standard reference material (see section 6; analysis not shown). Based on this limited sample, the median pollen concentration for systemic products was actually lower than that of the non-systemics (RUD of 3.4 ppm vs 8.05 ppm). Similarly, the median nectar concentration was also lower for the systemics (RUD of 1.7 ppm vs. 6.0 ppm). In both cases, the range of values was such that differences were clearly not significant.

Given that measurements were made soon after application, it is reasonable to assume that there had not been any time for translocation of residues. Uncertainty therefore remains as to the extent to which the foliar use of a systemic product can contaminate pollen and nectar through foliar uptake and translocation[14] (see section below). Based on the above, and until better data are available, it will be assumed that this route of exposure is small relative to direct impingement of spray droplets on flower parts if plants happen to be in bloom. **Therefore, for spray applications to crops in bloom or spray drift to field margins, we propose to use residue concentration values as indicated in Table 5. In keeping with other PRT indicators which strive for realism rather than worst case scenarios, we decided to use the median residue value recognizing that it will not always be sufficiently protective.** These values are substantially lower (but probably more realistic) than the most recently proposed (USEPA/PMRA/CDPR 2014) Tier 1 value of 98 mg/kg based on standard EPA nomogram values for 'tall grass'.

Table 5. Proposed Residues per Unit Dose (RUD) values resulting from direct impingement from foliar applications (after EFSA 2013).

	RUD (mg/kg) in pollen	RUD (mg/kg) in nectar
Number of data points	42	31
Lowest value	0.0002	0.1429
Median value	6.1	2.9
90th % value	51.9	11.3

[14] As discussed, we assume that the studies were not designed to measure the possibility of nectar and pollen contamination following a delayed translocation of residues, either from soil or from foliar impingement.

95th % value	82.1	12.0
Highest value	149.8	20.7

7.3.2. POLLEN AND NECTAR EXPOSURE FROM TRANSLOCATED RESIDUES FROM FOLIAR OR SOIL APPLICATIONS

At this time, the PRT acute pollinator indicator will only consider the peak risk in the year of application. It has been shown that systemics having long soil persistence can be translocated into plant tissues in the year(s) following application. Likewise, systemic pesticides could be returned to soil after crop residues decompose post-harvest. These scenarios are not considered in the current acute indicator.

7.3.2.1. FOLIAR APPLICATIONS (PRE-BLOOM)

Much evidence exists that soil-applied systemic pesticide can translocate into pollen and nectar. Similarly, Dively and Kamel (2012) showed that both soil drip and foliar applications of two neonicotinoid insecticides gave roughly similar residue levels in the nectar and pollen of pumpkin plants. Until more information becomes available, we will assume an equivalent degree of uptake through either the soil or foliar route. **Therefore, for pre-bloom applications, the on-crop risk will assume that all of the applied spray, whether it impinges on the crop or on the soil surface is equally available for translocation.** This greatly simplifies calculating the index; a differential rate of translocation from soil or leaf surfaces would have required exact knowledge of crop development stage so as to estimate a crop interception factor.

Because it will be difficult to estimate the amount of time elapsed between application and bloom in any given crop, **we will assume no breakdown of the active ingredient when calculating the amount of a.i. available for translocation following a pre-bloom application.** An exact calculation would require that we separately calculate foliar and soil half-lives; this may be implemented in future refinements of the index.

These calculations will not be made for the off-crop risk; as detailed earlier, risk in the off-crop areas will be based on the more stringent scenario of residues impinging directly onto flowers – regardless of the degree of systemic activity of the compound (see section 7.3.1.).

7.3.2.2. SEED-TREATMENT APPLICATIONS

Data for seed treatment applications are based entirely on the three systemic neonicotinoid insecticides imidacloprid, clothianidin and thiamethoxam in a variety of seed types. EFSA (2013) proposes the following values (Table 6):

Table 6. Proposed Residue per Unit Dose (RUD) values for seed treatment applications after EFSA (2013)[a].

	RUD (mg/kg) standardised to 1 mg a.i./seed	RUD (mg/kg) standardised to 1 mg a.i./seed	RUD (mg/kg) standardised to 1 kg a.i./ha	RUD (mg/kg) standardised to 1 kg a.i./ha
	Pollen	Nectar	Pollen	Nectar
Number of data	37	11	49	21
Lowest value	0.0020	0.0024	0.0201	0.0166
Median value	0.0091	0.0093	0.0823	0.0458
90th % value	0.0416	0.0767	0.2187	0.1592
95th % value	0.1213	0.1040	0.2758	0.1727
Highest value	0.2875	0.1313	0.5739	0.2000

[a] We propose to extend these values to granular or liquid applications to soil also as discussed in the accompanying text.

It is noteworthy that, in their most recent guidance (USEPA/PMRA/CDPR 2014), and following on deliberations of a Pellston workshop topic on the subject (Wisk et al. 2014), North American regulators have opted <u>not</u> to attempt estimating pesticide concentration in pollen and nectar from the existing empirical data; rather, they have decided to set their Tier 1 exposure level at a fixed 1 mg a.i./kg (i.e. 1 ppm) regardless of the type of product or application rate. Clearly, more than an order of magnitude separates this value from those proposed by EFSA after a review of the empirical data (table 6). **In keeping with other PRT indicators which strive for realism rather than worst case scenarios, we decided to use the median residue value in Table 6 above, recognizing that it will not always be sufficiently protective.**

7.3.2.2. APPLICATIONS TO SOIL

There are fewer data with which to compare other application methods – granulars, soil drenches or drip irrigation or to estimate the on-crop risk from spray applications taking place before flowering. These routes of application were not considered in the majority of works consulted. Once application rates are converted to an equivalent rate per ha, we see no compelling reason not to use the values compiled for the seed treatments in order to estimate residues for various field crops, at least until better data are obtained for these other application methods. With both granulars and drenches, the majority of the application is targeted at the seed furrow in close proximity to the seed (or plant) – as is the case with a seed treatment. (The situation is somewhat different for spray applications where most of the material reaching the soil is expected to do so between the rows.)

Support for using table 6 values to estimate pollen and nectar residue levels from liquid application also can be found in the work of Stoner and Eitzer (2012) in squash flowers. They compared the movement of imidacloprid and thiamethoxam into pollen and nectar (as well as in their surrounding structures – female flower bases and male synandria) from either soil application pre-seeding or drip irrigation to transplants. Results among years and insecticides were inconsistent with respect to the extent of contamination resulting from those two methods of application but gave data quite comparable to those obtained with seed treatments tabulated above. Their documented levels of contamination in pollen and nectar, once corrected to RUD values agree well with tabled values although it does suggest that thiamethoxam is much more efficient than imidacloprid at contaminating both pollen and nectar[15]. RUD values (mean, +/- SD) for imidacloprid were 0.026 (0.013-0.036) mg/kg nectar and 0.036 (0.016-0.073) mg/kg pollen; for thiamethoxam, they were 0.077 (0.035-0.141) mg/kg nectar and 0.085 (0.035-0.246) mg/kg pollen[16].

Recent work performed by researchers at the U. of California and at Bayer corp. (Byrne et al. 2013) investigated the movement of imidacloprid from the soil to the nectar of citrus trees. The way information is presented (mostly as graphs) makes it difficult to use the data fully but imidacloprid values were said to range between 2.9 and 39.4 ng/mL depending on the tree sampled. Two other metabolites (both of which are of roughly equivalent toxicity to bees) were analyzed, increasing the total concentration to approx. 3.7 – 50.8 ng/mL, and this, 50-62 days following application of 560 g a.i/ha. This represents a RUD value of 0.006.6 to 0.090.7 mg/kg a.i. with a mean of 0.0472 mg/kg a.i., in good agreement with the median value of 0.046 reported by EFSA in the table above. One issue of concern in the Byrne et al. study is that nectar concentrations were also measured in the spring following a fall application (approx. 230d after application). The average measured RUD value then was higher, 0.0585 mg/kg (16.39 ng/mL following a 280 g a.i./ha application)[17].

7.4. CONSUMPTION DATA

Consumption data (Table 7) were obtained from a compilation by EFSA (2012, 2013). The sugar content of different plant nectars is not always known and, in any case, may vary depending on variety, time of day, season etc… EFSA (op. cit.) recommended using a low

[15] This would have been correctly predicted by our systemic score (see above)

[16] These values are approximate since the authors pooled two years of data with slightly different application rates. The average inter-year mean rate of application was used to convert residue levels to RUD values.

[17] This article points to a number of important risk factors unrelated to our needs for the indicator. Having residues persist in the citrus trees for such a long period means that pollinators will be exposed to unwavering residues throughout the flowering period and may also rise with every succeeding application to the orchard. Another issue of concern is that residue levels in the nectar sampled from uncapped hive combs in the Byrne et al. 2013 study had increased almost 4-fold in concentration, presumably through water evaporation (approx. 24% sugar in fresh nectar vs. 62% in uncapped 'honey').

(conservative) value of 15% for crop plants[18] but an average value of 30% for arable weeds in the field margin. We will use these recommended values.

Table 7. Data on sugar and pollen consumption of bees and bee larvae after EFSA (2012, 2013)[a].

	Consumption of adult bees (mg/bee/day)		**Consumption of larvae (mg/larva)**	
Organisms	Sugar	Pollen	Sugar	Pollen
Honey bee	forager: 32–128 Nurse: 34–50	Forager: 0 Nurse: 6.5–12	59.4/5 day period	1.5–2/5 day period
Bumble bee	73–149	26.6–30.3	23.8/day	10.3–39.5/day
Solitary bee	18–77	10.2	54/30 day period	387/30 day

[a] based in part on a literature review by Rortais (2005).

The sugar needs of foraging bees will clearly depend on the extent to which individuals forage in a day as well as on the energetic costs of foraging. Table 8 summarizes some of the key variables from our own review of the literature for forager bees only, starting with the values proposed by EFSA (2012, 2013) shown in table 7.

Table 8. Data on costs and time of foraging in honeybees.

Type of foraging	Foraging (flying) cost (mg sugar/bee/h)	No. Foraging trips per day	Time per trip (min)	Total time flying (min)	Total sugar requirement (mg/bee/day)	Source
Nectar foraging	8-12	10	30-80	240-640 (80% of foraging time)	32-128	EFSA (2012, 2013) after Rortais 2005
Pollen foraging	8-12	10	10	80	10-16	EFSA (2012, 2013) after Rortais 2005
Water foraging	8-12	46			72-110	EFSA (2012, 2013) after Seeley 1995
Nectar (sugar solution) foraging	12.6-13					Balderrama et al. (1992) from CO_2 respiration
Nectar (sugar solution)	8.1-11.2					Balderrama et al. (1992) review of 6 older studies

[18] This is actually the value proposed for bumble bees and honeybees. A value as low as 10% was proposed for solitary bees.

foraging						
Nectar (sugar solution) foraging	14.8					Balderrama et al. (1992) Calculated theoretical maximum based on flow rate of nectar from proventriculous
Undefined worker (forced flight)	8.3-8.5					Gmeinbauer and Crailsheim (1993) and one other reviewed study

Seen in the light of this broader review, the EFSA values appear to be entirely appropriate and definitely not 'worst case' compared to estimates obtained through different methods. Wolf et al. (1989) showed that bees full of nectar (up to 75% of their own body mass) had flying costs 42% higher than when the bee is running 'empty'. The energetic costs of a 'tanked up' flying bee were more than 10 fold that of a quietly sitting bee. This is why great caution needs to be exercised when looking at effect studies where dose levels are reported as concentrations in dosing solutions, especially if bees are being kept under controlled conditions with minimal energetic demands.

Byrne et al. (2013) in their attempt to convert nectar concentrations into dose levels used the higher 12.6-13 mg/bee/h obtained by Balderrama et al. (1992) but then estimated that individuals would forage for only 360 min/day, a low value compared to the range proposed by EFSA from the literature (300-800 min total foraging, 80% of which is in flight).

As noted above, for the purpose of the PRT risk score, we will use scenario parameters for a composite bee combining the exposure characteristics of both a forager and nurse bee. This avoids having to calculate sub-indices for different bee castes and generating a multiplicity of indices for each pesticide. A recommendation of EFSA (2012, 2013) is to consider only the upper range of ingestion values for the calculation of acute risk to adults, the full range for chronic risk. **As the PRT index is an acute risk index, we propose to use the midpoint of the upper half of the distribution (minimum of upper quartile) of daily sugar ingestion values.** The chosen values, corrected for the nectar sucrose concentrations proposed above are calculated as follows[19]:

mg nectar/bee = mg sugar/bee x (mg nectar/mg sugar)

… and tabulated in table 9 below:

[19] Because residue concentrations are given in ppm or ppb, nectar consumption values are also given in weight units assuming a specific density (g/mL) of 1.06 and 1.13 for 15% (crop) and 30% (field margin) nectar concentrations respectively.

Table 9. Values for nectar and pollen consumption proposed for the calculation of the PRT pollinator risk score.

Weight of sugar (mg sugar/bee/day)	Volume of nectar obtained from a crop plant (ul/bee/day)	Weight of nectar obtained from a crop plant (mg/bee/day)	Volume of nectar obtained from field margins (ul/bee/day)	Weight of nectar obtained from field margins (mg/bee/day)	Weight of pollen in crops or margins (mg/bee/day)
104	693	735	347	392	10.6

By way of comparison, the recent North American guidance (EPA/PMRA/CDPR 2014) recommends using the median estimate of 292 mg nectar/bee/day for a nectar forager (close to our proposed 308 mg/bee/day for field margins) but this is based on a set nectar concentration of 30% for any and all plant species whether crop or wildflower.

As for our chosen pollen ingestion value of 10.6 mg/bee/day, after recommendations by EFSA (2013), it is close to the value used by others in their risk assessments; e.g. 9.5 mg/bee/day used by Stoner and Eitzer (2013) after Crailsheim et al. (1992).

7.5. EXPOSURE THROUGH CONTAMINATED WATER

Water needs in bees are expected to be quite variable, and are thought to be dependent on temperature and local nectar yields. A low availability of nectar means that water needs to be obtained from extraneous sources rather than from nectar alone (Kühnholtz and Seeley 1997). Ironically, this suggests that extraneous water needs might be high in intensively-farmed landscapes with low nectar yields dominated by corn or other field crops. Regardless, water needs in spring and early summer are typically large, in part to dilute winter stores (Butler 1940). At one of their study sites, Kühnholtz and Seeley (op.cit.) noted that the bees favoured the muddy wet ground on the edge of a pond for water collecting. Mineau and Kegley (2014) reported on the observation that bees appeared to prefer wet muddy ground to a nearby pond. It has been known for a long time (e.g. Butler 1940) that bees are often attracted to ‘unsanitary’ sources of water, such as rainwater gutters choked with organic debris, sewage effluents or puddles on top of cow dung in preference to clean water supplies provided for their use. Through a rigorous experimental latin square design, Butler (op. cit.) was able to confirm that bees preferred some concentrations of sodium and ammonium chloride to distilled water. However, dilute organic solutions (leaf debris, manure, and urine) proved more popular still. In the context of an agricultural field, this raises interesting questions. For example, the attractiveness of water puddles may vary depending on the use of fertilizers (both natural or synthetic) and possibly even some pesticides (especially dissociated ionic compounds).

In addition to surface water bodies and temporary puddles on the soil surface, other sources of water may include spray solutions, either as droplets after spray or accumulated in leaf axils, dew or guttation water in plant species where this phenomenon occurs. Finally, Visscher at al. (1996) reviewed older evidence that water-collecting bees took heavier loads of water when the water was warm; any source of water in fields is likely to heat up when exposed to the sun. These authors calculated that a water collecting bee is restricted to obtaining water within a 2.1 km radius of the hive based on energetics – compared to the 13.5 km that has been observed for nectar foragers.

7.5.1. WATER NEEDS OF INDIVIDUAL BEES

EFSA (2013) recommended using a consumption figure of 11.4 μL/day per foraging bee or 111 uL/day per larva but did not provide further justification for those figures other than to mention they were at the high end of values obtained from the literature. The USEPA/PMRA/CDPR (2012) looked at two estimates of water consumption rates in honey bees. One of those estimates (450-1800 μL /day) was based on direct observations and calculations from water forager bees. References were supplied to show that between 30-60 μL are collected per foraging trip (e.g. see the work of Visscher et al. 1996) and that 30% of all water collected is consumed by the bee. However, because these estimates relate to water foragers and not to other worker bees and because the estimates work out to a very high (5-20X) turnover of body water, the US EPA privileged another estimate, this one based on water flux in a similarly-sized species, the brown paper wasp. Indeed, their analysis concluded that, depending on conditions and food supply, bee food (i.e. nectar, honey) represent between 7 – >100% of daily water needs. They arrived at a maximum water consumption estimate of 47 μL/day which they recommend for risk assessment purposes – although as discussed below, they backed away from carrying out the assessment. This water intake level was also the one chosen by Samson-Robert et al. (in press) in their recent assessment of surface water exposure. **We will use the value of 47 μL/bee/day also.**

The possibility of exposure through water is made more complicated by the fact that pesticides can be absorbed from the bee's foregut; i.e. from water being brought back to the hive by water foragers rather than taken in by the bee as part of its own water needs (Conner et al. 1978). Based on very limited experimental evidence, it appears that pesticide penetration thought the foregut follows similar rules as penetration through skin or other biological membranes; it is highly dependent on the lipophicity of the pesticide and there is an optimal Log K_{ow} at which absorption is maximized. In addition, absorption was found to be highest at low sucrose concentrations – i.e. the situation in a water forager vs. the usual test situation in oral toxicity tests. Nevertheless, we will ignore this complication and use the aforementioned water intake of 47μL/day as the sole drinking water exposure with which to compare exposure to oral toxicity. In carrying out this calculation, we need to keep in mind that, as argued by Samson-Robert and colleagues (in press), using daily water needs as a way to carry out risk assessments may underestimate the true exposure and risk because it ignores pesticide transfer from the larger volume of water that is being transported by some bees in their foregut.

7.5.2. SPRAY SOLUTION

Spray solution may be available to pollinators following an application. It may accumulate in leaf whorls and axils or simply be available as discrete droplets although the presence of wetting agents in most spray solutions makes the presence of discrete droplets less likely than the presence of a film of spray solution on leaf surfaces. Birds have been lethally exposed when drinking spray solution directly from leaf whorls. It is difficult to see why this would not be a plausible source of exposure in the case of bees. Based on a review of pesticide labels, **we propose to assess the toxicity of spray solutions by assuming that the per ha amount of active ingredient is diluted into 1000 L/ha for all fruit, grape and berry crops and 300L/ha for all vegetable and field crops.** For the time being, we will ignore the possibility that accumulated spray solution can be concentrated through evaporation or diluted through subsequent precipitation.

7.5.3. SURFACE WATER

Samson-Robert and colleagues (in press) measured the concentration of pesticides in rain puddles at seeding (while planting was still in progress) and one month after seeding in corn. The puddles were large ones – described as 1.5-3 sq. meter in size and between 4-6 cm in depth. No field spiking was carried out, so reported values should be considered minimum values. Based on two years of sampling, all water samples taken from corn fields contained residues of either clothianidin or thiamethoxam; 83% of samples contained both. Several other pesticides were also detected but, in samples taken one month after seeding, only clothianidin, thiamethoxam and the fungicide azoxystrobin were still found at levels exceeding the level of quantification (1 ppb). Levels were higher immediately after seeding suggesting that dust production during seeding was an important pathway by which puddles became contaminated. For clothianidin, mean and maximum concentrations were 4.6 and 56 ppb; for thiamethoxam, 7.7 and 63 ppb.

The USEPA devised a hydrological model to estimate the concentration of pesticides in puddles.[20] However, the model is very complex and unworkable for the purpose of PRT. Instead, **we propose to use our existing modeling of water concentration in PRT and assume that puddles will be completely filled with runoff water without further dilution**.

[20] See /http://www.epa.gov/oppefed1/ecorisk/fifrasap/rra_chap_three.htm

The concentration of clothianidin and thiamethoxam was not tied to any one product but, it is possible to relate these water concentrations to probable application rates per ha. For example, based on the label for Poncho 600 FS (PCP 27453), use of clothianidin on corn seed for rootworm control would require 166.7 ml of product or 100 g a.i./80,000 seed. According to Thibault (2000), the average seeding rate in Quebec is 30,000 plants per acre or 74,131 per ha. This represents an application rate of clothianidin of 92.6 g a.i./ha.

7.5.4. GUTTATION DROPLETS

Several researchers have documented concentrations of various neonicotinoid insecticides in guttation water following their use as seed treatments in corn (Table 10). They reported that, on corn plants, experimenters were able to reliably and easily collect guttation droplets for at least three weeks after seeding under field conditions. Unlike what had been suggested in the literature, and used by regulatory authorities to downplay this exposure route, they found that the phenomenon was not restricted to situations of high soil moisture and high humidity; moreover, droplets tended to pool in the leaf whorl of the developing plant. Only evaporation reduced the availability of droplets; however, they proposed that concentrations could increase over time following repeated drying and droplet formation cycles.

Table 10. Measured concentrations of neonicotinoids and fipronil in guttation water from seed-treated corn.

Insecticide	Rate of a.i. per seed (mg)	Concentration (mg/L) Mean (SE) or range (days 1-6 after germination)	Concentration (mg/L) Reported maxima	RUD adjusted to 1mg/seed (mg/L)	Equivalent amount of transpired water to achieve measured dilution (geometric mean of range)	Ref
imidacloprid[21]	0.5 (field)	47 (9.96)	>200	94	10.6 mL	Girolami et al. 2009
imidacloprid	0.5 (pots)	82.8 (14.07)		166	6 mL	Girolami et al. 2009
imidacloprid	1.25	103-346 (leaf tip)	346	82-277	3.6 - 12.2 mL	Tapparo et al. 2011

[21] It is noteworthy that Girolami and colleagues also carried out toxicity tests by offering guttation water as well as graded doses of the insecticides. They found that the concentration of liquid reliably producing wing paralysis in all tested bees within 1h of administration was 6 mg/L. They were unable to transform this concentration into an actual dose because bees showed much variation with regards to regurgitation and inherent sensitivity.

					(6.6)	
imidacloprid	1.25	8.2-120 (whorl)	120	6.6-96	10.4 – 151 mL (39.6 mL)	Tapparo et al. 2011
clothianidin	1.25	23.3 (4.2)	>100	19	52.6 mL	Girolami et al. 2009
clothianidin	1.25	76-102 (leaf tip)	102	61-82	12.2 – 16.4 mL (14.1)	Tapparo et al. 2011
clothianidin	1.25	7.3-47 (whorl)	47	5.8-38	26.3 – 172 mL (67.2)	Tapparo et al. 2011
clothianidin	1.25	7.5 - 8		6.0-6.4	156 mL	Reetz et al. 2011
thiamethoxam	1	12 (3.3)	>100	12	83.3 mL	Girolami et al. 2009
thiamethoxam	1	16-41 (leaf tip)	41	16-41	24.4 – 62.5 mL (39.0)	Tapparo et al. 2011
thiamethoxam	1	2.9-26	26	2.9-26	38.5 – 345 mL (115)	Tapparo et al. 2011
fipronil	1	Below detection				Girolami et al. 2009

In table 10 above, we calculated the amount of transpired water the seed treatment chemical would have had to be dissolved into in order to achieve the measured concentration of guttation water. Tapparo and colleagues (2011) estimated that the yield of guttation water ranged from 30-150 ul/plant/day. Over the 20 days of the experiment, this represents 0.6 – 3.0 mL of transpired water. A comparison with the calculated dilution volumes reported in table 9 shows that not all of the active ingredient on the seed ends up in guttation water even in those plants where the phenomenon occurs. Indeed, systemic pesticides are broadly distributed within plant tissues.

Hoffman and Castle (2012) measured imidacloprid concentrations in melon guttation fluids following a drip application of 422 g ai/ha immediately before bloom. This was described as double the label rate on an area basis but in keeping to the usual rate on a per plant basis because of the higher density of planting under the experimental conditions. Five samples taken from different plants ranged from 1.1 to 4.1 mg/L (mean = 2.2 mg/L). Following these preliminary results, further applications of 282 and 422 g/ha were made to fall-planted melons to investigate guttation droplets under conditions conducive to their production. These rates correspond to 14.7 and 21.8 mg imidacloprid per plant, clearly a much higher rate than the 0.5-1.25 g/plant delivered through a seed treatment in the corn studies tabulated above. A maximum guttation fluid concentration of 37 mg/L was detected at the higher application rate. At that higher rate, the majority of sampled plants had guttation fluid residues between 0.25 and 0.5 mg/L, 1 day after application and between 1 and 5 mg/L, 5 days after application.

Reetz and colleagues (2011) measured clothianidin in guttation water from an untreated plot because of the proximity of treated plots. **For our purposes, however, the risk from guttation water will only be calculated as part of the on-crop risk (and following seed treatment use only) because of the difficulty in assessing offsite movement of the active ingredient once applied and the lack of data relating guttation water concentration to soil residue levels**.

EFSA (2013) proposed that guttation water be assumed to have as concentration, the water solubility of the active ingredient. This may be somewhat exaggerated in view of the corn data presented above (standardized to 1 mg/seed): imidacloprid = 6.6 – 277 mg/L (solubility = 610 mg/L); clothianidin = 6 – 82 mg/L (solubility = 340 mg/L); thiamethoxam = 2.9 – 41 mg/L (solubility = 4100 mg/L).

7.5.5. CURRENT REGULATORY STANCE

In their proposed problem formulation, the US EPA (2012) downplays exposure through drinking water for two reasons: 1) because some of those sources such as dew or guttation droplets are not always present and ephemeral when present; and 2) because the majority of foraging bees are expected to obtain most of their water needs through nectar. However, the US EPA does acknowledge that, if water is indeed obtained through puddles or guttation fluids, these routes of exposure <u>would completely dwarf</u> other routes of exposure such as direct spray impingement or dietary exposure through nectar or pollen. It is known that worker bees do collect water to cool the hive etc. This may not be equivalent to drinking the water in question but, as argued above, does undoubtedly lead to difficult-to-measure exposure.

EFSA (2013) recommend that guttation water be included in the first tier of assessment but that there also be an assessment of the likelihood of guttation droplet formation based on location conditions and calendar date.

USEPA/PMRA/CDPR (2014), in their most recent guidance document opted <u>not</u> to include exposure from drinking, citing on-going uncertainties with their model to predict pesticide concentrations in puddles. There does not appear to be any intent to include spray solution droplets or guttation fluids as routes of exposure.

We concur with Blacquiere and colleagues (2012) that prudence requires that drinking water routes of exposure be considered, at least until more information is obtained on its real world importance.[22] This is especially true if this route of exposure has the potential to dominate all others.

We propose to make the inclusion of a drinking water component optional (meaning it can be toggled on or off to see how the index changes) for PRT users. **For liquid applications (sprays, drenches), the higher of puddle water concentration (derived from our existing runoff measurement procedure), or spray tank concentration will be used. For solid applications (granular or seed treatment), the concentration of guttation water will be estimated by assuming that the calculated amount of a.i. per seed or plant is distributed into 10 mL of guttation water.**

Based on table 9, this should approximate the 90th percentile value of available measurements. This is considered prudent given the few data points available. We will apply the RISA to guttation fluids, recognizing that this index of systemic activity may be a better reflection of movement through the xylem rather than the phloem. However, given that water solubility is undoubtedly important in both cases, we estimate that this is preferable to assuming that all pesticides can achieve equivalent concentrations in guttation water.

Where data on planting/seeding density are not available to estimate the amount of a.i./plant, we propose to use a value of 5 mg/L for a 422 g/ha application after Hoffman and Castle (2012) (see above) which corresponds to 11.8 mg/L/kg a.i./ha. This will be applied to granular applications as well.

NOTE TO READERS: TEST RUNS OF THE PRT INDEX SUGGEST THAT EXPOSURE THROUGH DRINKING WATER, WHEN FACTORED IN, OVERWHELMS OTHER KNOWN EXPOSURE ROUTES AND DOMINATES THE RISK ASSESSMENT TO BEES. BECAUSE THERE IS NOT YET UNIVERSAL AGREEMENT ON THE IMPORTANCE OF THIS ROUTE OF EXPOSURE, THE PRT POLLINATOR INDEX, AS OF MARCH 2019, DOES NOT HAVE THIS EXPOSURE ROUTE 'WIRED IN' YET.

8. STEP BY STEP PROCEDURES FOR COMPUTING INDICES

8.1. ASSEMBLING CONTACT AND ORAL EXPOSURE SUB-INDICES

Table 11 describes how the various exposure components reviewed to date are to be assembled for the on- and off-crop pollinator indices. At this point in time, it is assumed that crop fields pre- or post-bloom have little attraction to pollinators and that most of the

[22] We add that this evidence should be collected not only for the honey bee but for other bee species as well.

risk to pollinators is in the areas immediately outside of the field. However, this ignores the possibility that the fields have flowering weeds or have been under-sown with a companion crop that may be flowering and attractive to pollinators, or that orchards or vineyards might have been under-sown with clover or other cover crop.

> The possibility that pollinators may be attracted to a crop field because of weed growth or the use of under seeded ground cover (such as legumes) places us in a difficult position. Ideally, a more limited use of herbicides, companion planting or the provision of ground cover should be encouraged on environmental grounds. However, it is clear that such practices may increase the risk to pollinators (i.e. become a trap) should any insecticide spraying or use of systemic pesticides take place in the crop. We believe that we need to revisit this issue following a broader consultation with users of the PRT system.

It is further assumed that pollinators may be at risk in field margins at any time of the year when applications are taking place and that there will always be some plant species flowering or producing pollen. Drift into margins is assumed to be minimal from drips or drenches. Dust drift is assumed to occur at seeding or when granules are applied. In the case of granules as with seeds, the type of machinery being used (e.g. pneumatic air-seeders vs. gravity-fed seeders) will make a huge difference as to the prospective exposure. Further refinements of this index may include a differentiation by seeder/granule applicator type if this is deemed desirable.

Table 11. Summary of the different possible components of the acute pollinator risk index depending on the type of application and the timing of the application.

Type of application	**Site**	**Timing of application**	**Type of exposure**	**Relevant factor(s)**	**Exposure estimates for daily dose calculation**[23]
Spray	On crop	Bloom	Contact component	Application rate per area	2.4 ug/bee/kg a.i./ha (field crop) 1.8 ug/bee/kg a.i./ha (vine, tree)

[23] The calculated dose will be converted to LD50 equivalents based on the relevant (oral or contact) LD50 measure

			Oral component	Application rate per area RISA[24]	Pollen 6.1 mg/kg pollen/kg a.i./ha 10.6 mg pollen/bee Nectar 2.9 mg/kg nectar/kg a.i./ha 735 mg nectar/bee
Spray	On crop	Pre-bloom	Oral only	Application rate per area RISA	Pollen 0.0823 mg/kg pollen/kg a.i./ha 10.6 mg pollen/bee Nectar 0.0458 mg/kg nectar/kg a.i./ha 735 mg nectar/bee
Spray	Off crop	Anytime	Contact component	Application rate per area Drift estimate (Table 3)	2.4 ug/bee/kg a.i./ha (field crop) 1.8 ug/bee/kg a.i./ha (vine, tree)
			Oral component	Application rate per area Drift estimate (Table 3)	Pollen 6.1 mg/kg pollen/kg a.i./ha 10.6 mg pollen/bee Nectar 2.9 mg/kg nectar/kg a.i./ha 392 mg nectar/bee
Seed treatment	On-crop	Anytime	Oral	Application rate per seed (or) per area RISA	Pollen 0.0823 mg/kg pollen/kg a.i./ha (or) 0.0091 mg/kg pollen/mg a.i./seed

[24] Relative Index of Systemic Activity

					10.6 mg pollen/bee Nectar 0.0458 mg/kg nectar/kg a.i./ha (or) 0.0093 mg/kg nectar/mg a.i./seed 735 mg nectar/bee
Seed treatment	Off-crop	Anytime	Contact component	Application rate per seed Drift estimate (Table 3)	1.0 ug/bee/mg a.i./seed
			Oral component	Application rate Drift estimate (Table 3)	Pollen 6.1 mg/kg pollen/kg a.i./ha 10.6 mg pollen/bee Nectar 2.9 mg/kg nectar/kg a.i./ha 392 mg nectar/bee
Granular	Off-crop	Anytime	Contact component	Application rate per seed Drift estimate (Table 3)	0.37 ug/bee/ % concentration of a.i./granule
			Oral component	Application rate per area Drift estimate (Table 3)	Pollen 6.1 mg/kg pollen/kg a.i./ha 10.6 mg pollen/bee Nectar 2.9 mg/kg nectar/kg a.i./ha 392 mg nectar/bee
Spray	Optional addition to index	Anytime	Drinking surface water	The higher of: Tank spray concentration Or	47 ul/bee

				Runoff concentration	
Granule or seed treatment	Optional addition to index	Anytime	Drinking guttation water	Concentration equivalent to the amount of a.i. per plant dissolved into 10mL.	<u>47 ul/bee</u>

8.2. DETERMINING THE SPECIFICS OF EXPOSURE FOR EACH POTENTIAL PESTICIDE USE

It would be easiest to ask the PRT user to state whether any spray application is going to be pre-bloom, during the bloom period or post bloom. The alternative is to enter a calendar date of application and construct a Crop X Calendar date X State lookup table that will map to the table above and control which index subcomponents are tallied for any given application. This may prove difficult given year to year variation etc… Also, in order to assess the on-crop risk, information will be needed on the attractiveness of different crop types to bees. Unfortunately, it is likely that information will be found wanting for many crops especially with regards to wild bee species. In the absence of definitive information for North America, we propose to use a similar list assembled by EFSA (2013) for Europe (Reproduced in Appendix 3). Pollen and/or nectar consumption will be combined into the risk index if it is reported that honey bees make use of one or the other <u>or</u> if bumble bees or solitary bees have been observed foraging on that crop <u>and</u> if the crop is not typically harvested before flowering.

9. SCALING OF THE RISK INDICES

The ideal will be to have all values scale from 0 to 1 although it may not be possible to have the index be the probability of impact as all the other environmental indices. If we could estimate the extent of mortality, we could talk of the probability of colony death – but this is a tall order!

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APPENDIX 1

Development of a Relative Index of Systemic Activity (RISA).

Our index of systemic activity (ISA) is the probability (p) that an active ingredient will be marketed as a systemic pesticide calculated as:

$$p = \left(\frac{e^{a+bx+cy)}}{1 + e^{a+bx+cy)}} \right)$$

...where p has been averaged based on running four separate models with an arbitrarily chosen (alphabetical) quartile of the officially recognized systemic pesticides. The model coefficients are as follows:

	Model for first quartile	Model for second quartile	Model for third quartile	Model for fourth quartile
a	1.010287	0.316356	0.121737	1.338235
b	-0.166708	-0.085609	-0.089952	-0.186828
c	0.456235	0.531090	0.586276	0.410634

With ....

x = PKa (with extremes fixed at -5.0 for fully disassociated chemicals, 14.0 for neutral chemicals)

y = Log10 water solubility at 20^{o}C (occasionally 25^{o}C) in mg/L

The relative index of systemic activity (RISA) fixes at 1 the average ISA value for the three neonicotinoid insecticides: imidacloprid, clothianidin and thiamethoxam.

APPENDIX 2

Tabulated list of insecticides with known solubility and ionic status arranged by their calculated RISA. Mode of action, solubility and pKa from the Footprint database. Classification of systemic activity based on consensus from Footprint, the Pesticide Manual as well as Minnesota Dept. of Agriculture.

Active	Chemical Group	Mode of action	Systemic activity[a]	Log_sol (mg/L)[b]	TSCF[c]	pKa	Calculated index of systemic activity (ISA)	Relative index of systemic activity (RISA)
oxamyl	carbamate	Systemic with contact action. Acetylcholinesterase (AChE) inhibitor.	1	5.17	0.03	-2.11	0.97	1.59
formic acid	carboxylic acid			6.00	0.02	3.74	0.96	1.57
nitenpyram	neonicotinoid	Systemic with translaminar activity, stomach and contact action affecting insects nervous system. No long term activity. Acetylcholine receptor (nAChR) agonist.	1	5.77	0.02	3.10	0.96	1.57
thiocyclam	nereistoxin analogue	Selective, stomach acting with some contact action. Acetylcholine receptor (nAChR) agonist.		4.92	0.06	3.95	0.93	1.53
formetanate	formamidine	Contact and stomach action. Acts by inhibiting acetylcholinesterase.		5.91	0.07	8.10	0.93	1.52
acephate	organophosphate	Broad-spectrum, contact and ingestion systemic action. Acetylcholinesterase (AChE) inhibitor.	1	5.90	0.01	8.35	0.92	1.51
acetamiprid	neonicotinoid	Systemic with translaminar activity having both contact and stomach action. Acetylcholine receptor (nAChR) agonist.	1	3.47	0.25	0.70	0.91	1.49

thiocyclam hydrogen oxalate	Unclassified	A nereistoxin analogue insecticide. Selective, stomach acting with some contact action. Nicotinic acetylcholine receptor agonist/anatagonist.		4.21	0.06	3.95	0.91	1.48
disodium octaborate tetrahydrate	Inorganic salt	Mechanism depends on action: antifeed for insects distrupting insect enzyme & digestive systems		5.35		9.00	0.89	1.47
cyromazine	triazine	Contact action, interfering with moulting and pupation. Chitin synthesiser.		4.11	0.08	5.22	0.89	1.45
benzoic acid	aromatic carboxylic acid	Contact action, non-selective		3.70	0.65	4.19	0.88	1.44
pirimicarb	carbamate	Selective, systemic with contact, stomach and respiratory action. Acetylcholinesterase (AChE) inhibitor.	1	3.49	0.59	4.40	0.86	1.42
boric acid	Inorganic acid	Stomach poison. Antifeed for insects distrupting insect enzyme & digestive systems		4.76	0.01	9.24	0.86	1.41
oxydemeton-methyl	organophosphate	Systemic with contact and stomach action. Rapid knockdown effect. Acetylcholinesterase (AChE) inhibitor.	1	6.08	0.01	14.00	0.85	1.40
pentachlorophenol	organochlorine	Accelerates aerobic metabolism and increases heat production		3.00	0.58	4.73	0.83	1.35
azobenzene	bridged diphenyl	Acts by inhibiting oxidative phosphorylation.		0.81	0.38	-2.95	0.80	1.31
pymetrozine	pyridine	Selective, neural inhibition of feeding behavior that eventually starves insect.	1	2.43	0.05	4.06	0.80	1.30
trichlorfon	organophosphate	Non-systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	0	5.08	0.14	14.00	0.79	1.29

dinotefuran	neonicotinoid	Systemic, with contact and stomach action, effects insects nervous system. Nicotinic Acetylcholine receptor agonist /antagonist.	1	4.60	0.02	12.60	0.78	1.28
diazinon	organophosphate	Non-systemic with respiratory, contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	0	1.78	0.44	2.60	0.77	1.26
methomyl	carbamate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	1	4.74	0.08	14.00	0.76	1.24
cymiazol	benzenamine	Contact, detachant		2.18	0.19	5.20	0.75	1.23
dimethoate	organophosphate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	1	4.60	0.22	14.00	0.75	1.22
chlordimeform	formamidine	Broad spectrum acaricide that appears to interfere with the amine-mediated control of nervous and endocrine systems		2.43	0.71	6.80	0.73	1.20
flonicamid	pyridine compound	Systemic, selective with long term activity. Thought to distrub insect feeding pattern.	1	3.72	0.04	11.60	0.73	1.19
dichlorvos	organophosphate	Respiratory, contact and stomach action. Acetylcholinesterase (AChE) inhibitor.		4.26	0.66	14.00	0.71	1.17
fosthiazate	organophosphate	Soil applied, systemic. Acetylcholinesterase (AChE) inhibitor.	1	3.95	0.58	14.00	0.69	1.12
icaridin	piperidine	Topically applied, repellent		3.91	0.73	14.00	0.68	1.12
azinphos-methyl	organophosphate	Non-systemic, contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	0	1.45	0.70	5.00	0.68	1.11
bendiocarb	carbamate	Systemic, with contact and stomach action resulting in rapid knock-down. Acetylcholinesterase (AChE) inhibitor.	1	2.45	0.59	8.80	0.68	1.11

aldicarb	carbamate	Systemic with contact and stomach action absorbed through roots. Acetylcholinesterase (AChE) inhibitor.	1	3.69	0.37	14.00	0.66	1.08
pirimiphos-methyl	organophosphate	Broad-spectrum with contact and respiratory action. Acetylcholinesterase (AChE) inhibitor.		1.04	0.35	4.30	0.65	1.07
thiamethoxam	**neonicotinoid**	**Broad spectrum, systemic with contact and stomach action. Acetylcholine receptor (nAChR) agonist.**	**1**	**3.61**	**0.05**	**14.00**	**0.65**	**1.06**
clothianidin	**neonicotinoid**	**Translaminar and root systemic activity. Acetylcholine receptor (nAChR) agonist.**	**1**	**2.53**	**0.28**	**11.10**	**0.62**	**1.01**
spinetoram	spinosym	Acts through a novel site in the nicotinic receptor. Shows high residual, contact and ingestion activity		1.46	0.25	7.70	0.60	0.98
ethoprophos	organophosphate	Non-systemic with contact action. Acetylcholinesterase (AChE) inhibitor.	0	3.11	0.69	14.00	0.59	0.97
mecarbam	organophosphate	Contact and stomach action with slight systemic properties	1	3.00	0.74	14.00	0.58	0.95
imidacloprid	**neonicotinoid**	**Systemic with contact and stomach action. Acetylcholine receptor (nAChR) agonist.**	**1**	**2.79**	**0.18**	**14.00**	**0.55**	**0.91**
sulfoxaflor	neonicotinoid	Unique interaction with the nicotinic acetylcholine receptor	1	2.75	0.25	14.00	0.55	0.90
XMC	carbamate	acetylcholinesterase (AChE) inhibitor.		2.67	0.73	14.00	0.54	0.89
cyantraniliprole	diamide	Exhibits larvicidal activity as an orally ingested toxicant by targeting and disrupting the Ca2+ balance, Second generation ryanodine receptor, Foliar and systemic activity	1	1.15	0.66	8.80	0.53	0.86

carbofuran	carbamate	Systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	1	2.51	0.63	14.00	0.52	0.86
cadusafos	organothiophosphate	Broad spectrum activity with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.		2.39	0.37	14.00	0.51	0.83
spirotetramat	tetramic acid	Stomach acting, broad spectrum, long acting insecticide that is rapidly translocated, inhibition of lipogenesis in treated insects	1	1.48	0.76	10.70	0.50	0.83
thiacloprid	neonicotinoid	Contact and stomach action with some systemic properties. Acetylcholine receptor (nAChR) agonist.	0.5	2.26	0.42	14.00	0.49	0.81
malathion	organophosphate	Broad-spectrum, non-systemic with contact, stomach and respiratory action. Acetylcholinesterase (AChE) inhibitor.	0	2.17	0.74	14.00	0.48	0.79
dimethylvinphos	organophosphate	Contact and stomach acting, acetylcholinesterase (AChE) inhibitor.		2.11	0.65	14.00	0.47	0.78
fenazaquin	Unclassified	A mitochondrial electron transport inhibitor with contact action		-0.99	0.02	2.44	0.47	0.77
imiprothrin	pyrethroid	Similar to other synthetic pyrethoids, acts by over stimulation of the nervous system. Sodium channel modulator.		1.97	0.75	14.00	0.46	0.75
carbaryl	carbamate	Stomach and contact activity with slight systemic properties. Acetylcholinesterase (AChE) inhibitor.	0.5	0.96	0.75	10.40	0.45	0.74
sulfluramid	sulfonamide	Toxin with stomach action, acts by inhibiting insect energy production.		0.70	0.66	9.50	0.45	0.73
benzoximate	bridged diphenyl	Non-systemic with contact and stomach action	0	1.48	0.75	14.00	0.40	0.65
pyriproxyfen	Unclassified	A juvenile hormone mimic. Inhibits insect maturation process		-0.43	0.03	6.87	0.40	0.65

profenofos	organophos phate	Non-systemic with contact and stomach action. Acetylcholinesteras e (AChE) inhibitor.	0	1.45	0.59	14.00	0.39	0.65
methiocarb	carbamate	Non-systemic with neurotoxic contact and stomach action. Acetylcholinesteras e (AChE) inhibitor.	0	1.43	0.63	14.00	0.39	0.64
thiodicarb	carbamate	Mainly stomach action but some contact effects. Acetylcholinesteras e (AChE) inhibitor.		1.35	0.56	14.00	0.38	0.63
fenitrothion	organophos phate	Non-systemic, broad spectrum with contact and stomach action. Acetylcholinesteras e (AChE) inhibitor.	0	1.28	0.58	14.00	0.37	0.61
phosmet	organophos phate	Non-systemic with predominately contact action. Acetylcholinesteras e (AChE) inhibitor.	0	1.18	0.70	14.00	0.36	0.60
azocyclotin	organotin	Contact action. Inhibits oxidative phosphorylation.		-1.40	0.03	5.36	0.34	0.55
benfuracarb	carbamate	Systemic, stomach and contact action. Acetylcholinesteras e (AChE) inhibitor.	1	0.92	0.24	14.00	0.33	0.55
fenoxycarb	carbamate	Non-neurotoxic with contact and stomach action, acts by mimicing the action of the juvenile hormone keeping the insect in an immature state		0.90	0.29	14.00	0.33	0.54
chlorantranili prole	anthranilic diamide	Exhibits larvicidal activity as an orally ingested toxicant by targeting and disrupting the Ca2+ balance; Ryanodine receptor (Group 28)	1	-0.06	0.72	10.88	0.32	0.52
diofenolan	Unclassifie d	Insect growth retardant, moulting inhibitor with juvenile hormone activity		0.69	0.20	14.00	0.31	0.51
bifenazate	hydrazine carboxylate	Neuronal inhibitor, non-systemic having contact and residual action	0	0.31	0.55	12.94	0.30	0.49

fipronil	phenylpyrazole	Broad-spectrum with contact and stomach action. GABA-gated chloride channel antagonist.	1	0.58	0.41	14.00	0.30	0.49
methoxyfenozide	diacylhydrazine	A moulting accelerator that is an agonist of the hormone 20-hydroxyecdysone		0.52	0.42	14.00	0.29	0.48
tebufenpyrad	pyrazole	A mitochondrial electron transport inhibitor, non-systemic with contact and stomach action	0	0.38	0.08	14.00	0.28	0.45
amitraz	amidine	Non-systemic having contact and respiratory action. Octopaminergic (nervous system) agonist.	0	-1.00	0.02	9.80	0.25	0.41
alpha-cypermethrin	pyrethroid	Non-systemic with contact and stomach action. Sodium channel modulator.	0	-2.40	0.02	5.00	0.25	0.41
chlorpyrifos	organophosphate	Non-systemic with contact and stomach action. Acetylcholinesterase (AChE) inhibitor.	0	0.02	0.12	14.00	0.24	0.40
tebufenozide	diacylhydrazine	Accelerates molting, mainly stomach action		-0.08	0.23	14.00	0.23	0.38
bensultap	nereistoxin analogue	Contact and stomach action affecting the pest central nervous system.		-0.12	0.57	14.00	0.23	0.38
chlorfluazuron	benzoylurea	Acts as an anti-moulting agent killing larvae and pupae. Inhibitor of chitin biosynthesis, type O.		-1.80	0.01	8.10	0.22	0.37
lufenuron	benzoylurea	Systemic, selective, stomach acting, chitin synthesis inhibitor	1	-1.34	0.05	10.20	0.21	0.35
bistrifluron	benzoylurea	Chitin synthesis inhibitor		-1.52	0.01	9.58	0.21	0.35
buprofezin	Unclassified	Contact and stomach action. Inhibitors of chitin biosynthesis.		-0.34	0.08	14.00	0.21	0.35
tefluthrin	pyrethroid	Contact and respiratory action with some repellant effects. Sodium channel modulator.		-1.80	0.00	9.00	0.20	0.33

diflovidazin	tetrazine	Contact, ovicide, selective with translaminar activity		-0.64	0.43	14.00	0.19	0.31
propargite	sulfite ester	Non-systemic with contact action, inhibits oxidative phosphorylation	0	-0.67	0.01	14.00	0.19	0.30
teflubenzuron	benzoylurea	Systemic, chitin synthesis inhibitor	1	-2.00	0.22	9.20	0.18	0.30
indoxacarb	oxadiazine	Contact and stomach action. Voltage-dependent sodium channel blocker.	0	-0.70	0.13	14.00	0.18	0.30
dieldrin	chlorinated hydrocarbon	Central nervous system stimulant. GABA-gated chloride channel antagonist.		-0.85	0.43	14.00	0.17	0.28
spiromesifen	tetronic acid	Non-systemic. Inhibitors of lipid synthesis.	0	-0.89	0.15	14.00	0.17	0.28
chlorfenapyr	pyrrole	Limited systemic activity, mainly stomach but some contact action. Uncoupler of oxidative phosphorylation.	0.5	-0.95	0.09	14.00	0.17	0.27
carbosulfan	carbamate	Systemic with contact and stomach action. Acetylcholine esterase inhibitor.	1	-0.96	0.00	14.00	0.16	0.27
chlordane	cyclodiene organochlorine	Non systemic with contact, stomach and respiratory action. GABA-gated chloride channel antagonist.	0	-1.00	0.73	14.00	0.16	0.27
hexythiazox	carboxamide	Non-systemic with contact and stomach action	0	-1.00	0.75	14.00	0.16	0.27
cyhalothrin	pyrethroid	Non-systemic with contact and stomach action. Some repellant properties. Sodium channel modulator.	0	-2.40	0.00	9.00	0.16	0.26
cycloprothrin	pyrethroid	Contact and stomach action, also has anti-feeding and repellent effects. Sodium channel modulator.		-1.04	0.25	14.00	0.16	0.26
TDE	organochlorine	Non-systemic stomach and contact action	0	-1.07	0.00	14.00	0.16	0.26
etoxazole	diphenyl oxazoline	Non-systemic with contact action	0	-1.15	0.02	14.00	0.15	0.25

diafenthiuron	thiourea	Broad spectrum, contact and stomach action with some ovicidal activity, acts by inhibiting oxidative phosphorylation		-1.22	0.01	14.00	0.15	0.24
transfluthrin	pyrethroid	Broad spectrum, effects insects presynaptic voltage gate sodium channels in nerve membranesrapid causing knockdown.		-1.24	0.03	14.00	0.15	0.24
flufenoxuron	benzoylurea	Growth regulator with contact and stomach action. Inhibitors of chitin biosynthesis.		-2.37	0.05	10.10	0.14	0.23
zeta-cypermethrin	pyrethroid	Contact and stomach action. Acts mainly on the nervous system. Sodium channel modulator.	0	-1.41	0.00	14.00	0.14	0.22
aldrin	organochlorine	Central nervous system stimulant. GABA-gated chloride channel antagonist. Also stomach and contact toxin		-1.57	0.00	14.00	0.13	0.21
fenpyroximate	pyrazole	Mitochondrial electron transport inhibitor with contact action		-1.64	0.07	14.00	0.12	0.20
etofenprox	pyrethroid	Broad spectrum with contact and stomach action. Sodium channel modulator.		-1.65	0.00	14.00	0.12	0.20
pyridaben	pyridazinone	Non-systemic with rapid knock down action and long residual activity	0	-1.66	0.00	14.00	0.12	0.20
fenbutatin oxide	organotin	Selective, non-systemic with contact and stomach action, acts by inhibiting oxidative phosphorylation	0	-1.82	0.05	14.00	0.11	0.19
cyphenothrin	pyrethroid	Non-systemic, rapid knockdown with contact and stomach action damaging insects nervous system. Sodium channel modulator.	0	-2.00	0.00	14.00	0.11	0.17
cypermethrin	pyrethroid	Non-systemic with contact and stomach action. Sodium channel modulator.	0	-2.05	0.04	14.00	0.10	0.17

acequinocyl	Unclassified	Mainly contact action but some via ingestion. Mitochondrial complex III electron transport inhibitor.		-2.15	0.00	14.00	0.10	0.16
cyfluthrin	pyrethroid	Non-systemic with contact and stomach action and rapid knock-down effect. Sodium channel modulator.	0	-2.18	0.01	14.00	0.10	0.16
lambda-cyhalothrin	pyrethroid	Non-systemic, contact and stomach action. Some repellant properties. Sodium channel modulator.	0	-2.30	0.00	14.00	0.09	0.15
acrinathrin	pyrethroid	Contact and stomach action		-2.70	0.00	14.00	0.08	0.13
metaflumizone	semicarbazone	Broad-spectrum, attacks insect nervous system causing paralysis		-2.74	0.14	14.00	0.08	0.12
beta-cyfluthrin	pyrethroid	Non-systemic with contact and stomach action. Sodium channel modulator.	0	-2.92	0.01	14.00	0.07	0.11
tau-fluvalinate	pyrethroid	Contact and stomach action. Sodium channel modulator.		-2.99	0.00	14.00	0.07	0.11
bifenthrin	pyrethroid	Contact and stomach action with some residual effect. Sodium channel modulator.	0	-3.00	0.00	14.00	0.07	0.11
esfenvalerate	pyrethroid	Contact and stomach action. Sodium channel modulator.	0	-3.00	0.00	14.00	0.07	0.11
deltamethrin	pyrethroid	Non-systemic with contact and stomach action. Sodium channel modulator.	0	-3.70	0.14	14.00	0.05	0.08

Notes:

[a] **0=non-systemic; 1=systemic, 0.5=some systemic action**

[b] **in water at 20 (occasionally 25) Deg C**

[c] **based on the Burken and Schnoor (1997) algorithm and Log Kow**

APPENDIX 3

Attractiveness of the main agricultural crops to bees in Europe (Slightly modified from a compilation in EFSA 2013). The level of attractiveness for pollen and/or nectar is indicated only for honey bees (–, not attractive; +, lowly attractive; ++, highly attractive). For bumble bees and solitary bees, it is indicated if they were observed to visit the crop. (*These crops are usually harvested before flowering).

Crops	**Definition and notes for EU commerce**	**Honey bees**		**Bumble bees**	**Solitary bees**
		Pollen	**Nectar**		
Alfalfa	*Medicago sativa*. A deep-rooted perennial herb used for green fodder, for hay or silage, and for pasture.	–	++	+	+
Almonds	*Prunus amygdalus*; *P. communis*; *Amygdalus communis*. Produced mainly in Mediterranean countries, the United States and Asia	++	+	+	*Osmia*
Anise, badian, fennel, coriander (*)	Include: anise (*Pimpinella anisum*); badian or star anise (*Illicium verum*); caraway (*Carum carvi*); coriander (*Coriandrum sativum*); cumin (*Cuminum cyminum*); fennel (*Foeniculum vulgare*); juniper berries (*Juniperus communis*).	+	+		+
Apples	*Malus pumila*; *M. sylvestris*; *M. communis*; *Pyrus malus*	++	+	+	*Andrena, Anthophora, Halictus, Osmia*
Apricots	*Prunus armeniaca*	++	++		*Osmia*
Artichokes (*)	*Cynara scolymus*	+	+		
Asparagus	*Asparagus officinalis*	++	++		
Avocados	*Persea americana*	+	+		+
Bananas	*Musa sapientum*; *M. cavendishii*; *M. nana*.	–	+		
Barley	*Hordeum* spp.: two-row barley (*H. disticum*) six- row barley (*H. hexasticum*) four- row barley (H. *vulgare*). Tolerates poorer soils and lower temperatures better than does wheat. Varieties include with husk and without (naked).	–	–		
Beans	*Phaseolus* spp.	+	+	+	

Blueberries	European blueberry, wild bilberry, whortleberry (*Vaccinium myrtillus*); American blueberry (*V. corymbosum*). Trade data may include cranberries, myrtle berries and other fruits of the genus *Vaccinium*	+	++	+	*Andrena, Colletes, Osmia, Habropoda*
Broad beans, horse beans, dry	*Vicia faba*: horse-bean (var. *equina*); broad bean (var. *major*); field bean (var. *minor*)	++	++	+	*Anthophora, Eucera, Megachile, Xilocopa*
Buckwheat	*Fagopyrum esculentum* (Polygonaceae). A minor cereal cultivated primarily in northern regions. Buckwheat is considered a cereal, although it does not belong to the gramineous family	+	++	++	+
Cabbages and other brassicas (*)	Chinese, mustard cabbage, pak-choi (*Brassica chinensis*); white, red, Savoy cabbage, Brussels sprouts, collards, kale and kohlrabi (*Brassica oleracea* all varieties except *botrytis*)	++	++		+
Carobs	*Ceratonia siliqua* Carob tree, locust bean. Includes also seeds. Mainly used as an animal feed and for industrial purposes. Rich in pectin	+	++		
Carrots (*)	*Daucus carota*	+	++		
Castor oil seed	*Ricinus communis*. Valued mainly for their oil, which is used in pharmaceutical products. Ground seedcakes are used as fertilisers (castor oil pomace)	+	–		
Cauliflowers and broccoli (*)	*Brassica oleracea* var. *botrytis*, subvarieties *cauliflora* and *cymosa*. Includes headed broccoli	++	++		+
Cherries	Mazzard, sweet cherry (*Prunus avium*; *Cerasus avium*); hard-fleshed cherry (var. *duracina*); heart cherry (var. *juliana*)	++	++	+	*Osmia, Andrena*
Chestnuts	*Castanea* spp.: *C. vesca*; *C. vulgaris*; *C. sativa*. Produced mainly in Europe and Asia	++	++		+
Chick peas	Chickpea, Bengal gram, garbanzos (*Cicer arietinum*)	+	++		
Chicory roots (*)	*Cichorium intybus* subsp. *sativum*. Unroasted chicory roots	+	+		*Andrena, Anthidium, Halictus, Osmia*

Chillies and peppers	Red and cayenne pepper, paprika, chillies (*Capsicum frutescens*; *C. annuum*); allspice, Jamaica pepper (*Pimenta officinalis*)	+	+		+
Clover for forage and silage	*Trifolium* spp. Various species grown for pasture, green fodder or silage	++	++		*Megachile*, *Osmia*, *Andrena*, *Anthidium*
Coffee, green	*Coffea* spp. (*arabica*, *robusta*, *liberica*). Raw coffee in all forms	+	–		+
Cow peas	Cowpea, blackeye pea/bean (*Vigna unguiculata*)	–	+ (extrafloral nectaries)	+	
Cranberries	American cranberry (Vac*cinium macrocarpon*); European cranberry (*V. oxycoccus*). Trade data may include blueberries, myrtle berries and other fruits of the genus *Vaccinium*	+	++	+	*Megachile*
Cucumbers and gherkins	*Cucumis sativus*	+	–	+	
Currants	Black (*Ribes nigrum*); red and white (*R. rubrum*). Trade data may sometimes include gooseberries	–	+	+	+
Dates	*Phoenix dactylifera*. Includes fresh and dried fruit	+	+		
Eggplants (aubergines)	*Solanum melongena*. Also called aubergines	–	–	+	+
Elder	*Sambucus nigra*	+	+		+
Figs	*Ficus carica*	–	–		
Garlic (*)	*Allium sativum*	+	++		*Halictus*
Gooseberries	*Ribes grossularia*. Trade data may sometimes include black, white or red currants	–	+		
Grapefruit (inc. pomelos)	*Citrus maxima*; *C. grandis*; *C. paradisi*	++	++	+	
Grapes	*Vitis vinifera*. Includes both table and wine grapes	++	–		*Halictus*
Grasses for forage; Silage	Including *inter alia:* bent, redtop, fiorin grass (*Agrostis* spp.); bluegrass (*Poa* spp.); Columbus grass (*Sorghum almum*); fescue (*Festuca* spp.); Napier, elephant grass (*Pennisetum purpureum*); orchard grass (*Dactylis glomerata*); Rhodes grass (*Chloris gayana*)	–	–		

Groundnuts, with shell	*Arachis hypogaea*. For trade data, groundnuts in shell are converted at 70 % and reported on a shelled basis	+		+	*Lasioglossum*, *Megachile*, *Anthidium*, *Nomia*
Hazelnuts, with shell	*Corylus avellana*. Produced mainly in Mediterranean countries and the United States	+	-		
Hemp	*Cannabis sativa*. This plant is cultivated for seed as well as for fibre	+	–		
Hops	*Humulus lupulus*. Hop cones, fresh or dried, whether or not ground, powdered or in the form of pellets. Includes lupuline, a yellow resinous powder that covers the hop cones. Mainly used in the brewing industry to give flavour to beer	–	–		
Kiwi fruit	*Actinidia chinensis*	+	–	+	+
Leeks, other alliaceous vegetables (*)	Leeks (*Allium porrum*); chives (*A. schoenoprasum*); other alliac	+	++	+	
Leguminous for silage	Including *inter alia*: birdsfoot, trefoil (*Lotus corniculatus*); lespedeza (*Lespedeza* spp.); kudzu (*Pueraria lobata*); sesbania (*Sesbania* spp.); sainfoin, esparcette (*Onobrychis sativa*); sulla (*Hedysarum coronarium*).	+	++	+	+
Leguminous vegetables, nes	*Vicia faba*. For shelling	++	++	+	+
Lemons and limes	Lemon (*Citrus limon*); sour lime (*C. aurantifolia*); sweet lime (*C. limetta*)	++	++		
Lentils	*Lens esculenta*; *Ervum lens*	+	+ (extrafloral nectaries)		
Lettuce (*)	*Lactuca sativa*	–	–		
Linseed	*Linum usitatissimum* Flaxseed. An annual herbaceous that is cultivated for its fibre as well as its oil	+	+		
Lupins	*Lupinus* spp. Used primarily for feed, though in some parts of Africa and in Latin America some varieties are cultivated for human food	+	–	++	
Maize	*Zea mays* corn, Indian corn, mealies. A grain with a high germ content. At the national level, hybrid and ordinary maize should be reported separately owing to widely different yields and uses. Used largely for animal feed and commercial starch production	++	–		

Melonseed	*Cucumis melo*. Includes seeds of other Cucurbitaceae	–	+	+	*Ceratina*
Mushrooms and truffles	Including *inter alia*: *Boletus edulis*; *Agaricus campestris*; *Morchella* spp. and *Tuber magnatum*. Cultivated or spontaneous. Includes truffles	Not applicable			
Mustard seed	White mustard (*Brassica alba*; *B. hirta*; *Sinapis alba*); black mustard (*Brassica nigra*; *Sinapis nigra*). In addition to the oil extracted from them, white mustard seeds, may be processed into flour for food use.	++	++	+	+
Oats	*Avena* spp., mainly *Avena sativa*. A plant with open, spreading panicle-bearing large spikelets. Used primarily in breakfast foods. Makes excellent fodder for horses	–	–		
Okra	*Abelmoschus esculentus*; *Hibiscus esculentus*. Also called gombo	+		+	
Olives	*Olea europaea*. Includes table olives and olives for oil	+	–		
Onions (*)	*Allium cepa*	+	++		*Halictus*
Oranges	Common, sweet orange (*Citrus sinensis*); bitter orange (*C. aurantium*). Bitter oranges are used primarily in the preparation of marmalade	++	++	+	*Andrena*, *Xylocopa*
Peaches and nectarines	*Prunus persica*; *Amygdalus persica*; *Persica laevis*	++	++	+	*Osmia*
Pears	*Pyrus communis*	++	+	+	*Osmia*
Peas	Garden pea (*Pisum sativum*); field pea (*P. arvense*)	+	+	+	*Eucera*, *Xylocopa*
Peppermint	*Mentha* spp.: *M. piperita*. Leaves and flowers are used in the perfumery, food and other industries	+	++	++	++
Persimmons	*Diospyros kaki*: *D. virginiana*.	+	+	+	+
Pistachios	*Pistacia vera*. Produced mainly in the Near East and the United States	+	–		
Plums and sloes	Greengage, mirabelle, damson (*Prunus domestica*); sloe (*P. spinosa*)	++	++	+	*Osmia*
Poppy seed	*Papaver somniferum*. The source of opium, poppy seeds are also used in baking and confectionery	++	–		

Potatoes	*Solanum tuberosum* Irish potato. A seasonal crop grown in temperate zones all over the world, but primarily in the northern hemisphere	-	-	+	
Pumpkins, squash and gourds	*Cucurbita* spp. Includes marrows	–	+	++	*Peponapis*, *Xenoglossa*
Pyrethrum, dried	*Chrysanthemum cinerariifolium*. Includes leaves, stems and flowers. For insecticides, fungicides and similar products.	+	+		
Quinces	*Cydonia oblonga*; *C. vulgaris*; *C. japonica*	+	+		
Rapeseed	*Brassica napus* var. oleifera. Valued mainly for its oil. Older varieties are rich in erucic acid, which is considered unhealthy	++	++	+	+
Raspberries (and similar berries)	*Rubus idaeus*. Trade data may include blackberries, mulberries and loganberries (a cross between the raspberry and blackberry)	+	+	+	*Osmia and many other genera*
Rice, paddy	*Oryza* spp., mainly *Oryza sativa*. Rice grain after threshing and winnowing. Also known as rice in the husk and rough rice. Used mainly for human food	–	–		
Rye	*Secale cereale*. A grain that is tolerant of poor soils, high latitudes and altitudes. Mainly used in making bread, whisky and beer. When fed to livestock, it is generally mixed with other grains	–	–		
Rye grass for forage and silage	Italian ryegrass (*Lolium multiflorum*); English, perennial ryegrass (*L. perenne*). Quick- growing grasses	–	–		
Safflower seed	*Carthamus tinctorius*. Valued mainly for its oil. Minor uses include as a human food and as poultry feed	+	+	+	+
Seed cotton	*Gossypium* spp.: Unginned cotton. Grown for both seed and for fibre	–	++ (mainly on extra floral nectaries)	+	*Halictus*, *Anthophora*, *Xylocopa*, *Megachile*, *Nomia*
Serradella/birds foot	*Ornithopus sativus*	+	++		

Sesame seed	*Sesamum indicum*. Valued for its oil, but also as a food, either raw or roasted, as well as in bakery products and other food preparations.	+	+		+
Sorghum	*Sorghum* spp.: guinea corn (*S. guineense*); common, milo, feterita, kaffir corn (*S. vulgare*); durra, jowar, kaoliang (*S. dura*). A cereal that has both food and feed uses. Sorghum is a major food grain in most of Africa, where it is also used in traditional	–	–		
Soybeans	*Glycine soja*. The most important oil crop. Also widely consumed as a bean and in the form of various derived products because of its high protein content, e.g. soya milk, meat, etc.	+	+	+	+
Spices, nes	Including *inter alia*: bay leaves (*Laurus nobilis*); dill seed (*Anethum graveolens*); fenugreek seed (*Trigonella foenum-graecum*); saffron (*Crocus sativus*); thyme (*Thymus vulgaris*); turmeric (*Curcuma longa*)	++	++		
Spinach (*)	*Spinacia oleracea*. Trade figures may include New Zealand spinach (*Tetragonia espansa*) and orache (garden) spinach (*Atriplex hortensis*)	–	–		
Strawberries	*Fragaria* spp.	+	+	+	*Osmia*
Sugar beet	*Beta vulgaris* var. *altissima*. In some producing countries, marginal quantities are consumed, either directly as food or in the preparation of jams	–	+		+
Sugar cane	*Saccharum officinarum*. In some producing countries, marginal quantities of sugar cane are consumed, either directly as food or in the form of juice	–	–		
Sunflower seed	*Helianthus annuus*. Valued mainly for its oil. Minor uses include as a human food and as feed for birds	++	++	++	*Halcitus plus many other genera*
Sweet potatoes	*Ipomoea batatas*. A seasonal crop grown in tropical and subtropical regions. Used mainly for human food. Trade data cover fresh and dried tubers, whether or not sliced or in the form or pellets	–	–		

Tangerines, mandarins, clementines	Mandarin, tangerine (*Citrus reticulata*); clementine, satsuma (*C. unshiu*)	++	++	+	*Andrena, Xylocopa*
Tobacco, unmanufactured (*)	*Nicotiana tabacum*. Unmanufactured dry tobacco, including refuse that is not stemmed or stripped, or is partly or wholly stemmed or stripped	+	–		
Tomatoes	*Lycopersicon esculentum*	–	-	+	+
Triticale	A minor cereal that is a cross between wheat and rye, combining the quality and yield of wheat with the hardiness of rye	–	–		
Turnips for Fodder (*)	*Brassica rapa* var. *rapifera*. Especially cultivated for fodder	++	++	+	+
Vetches	Spring/common vetch (*Vicia sativa*). Used mainly for animal feed	++	++	+	
Viper‘s grass*	*Scorzonera hispanica*	+	+		
Walnuts, with shell	*Jugland* spp.: *J. regi*a. Produced in temperate zones of the northern hemisphere, particularly in the United States	+	–		
Watermelons	*Citrullus vulgaris*	+	+	+	+
Wheat	*Triticum* spp.: common (*T. aestivum*) durum (*T. durum*) spelt (*T. spelta*). Common and durum wheat are the main types. Among common wheat, the main varieties are spring and winter, hard and soft, and red and white.	–	–		