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Aspects determining the risk of pesticides to wild bees: risk profiles for focal crops on three continents

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Table of contents

1. Introduction

1.1 Importance of pollination

Pollinators contribute greatly to food security. Effective pollination results in increased crop production, better commodity quality and greater seed production. In particular, many fruits, vegetables, edible oil crops, stimulant crops and nuts are highly dependent on animal pollination. A recent review indicated that the production of 39 of the leading 57 single crops grown worldwide increases due to animal pollination. These crops account for 35% of global food production. In addition, 48 of 67 (globally minor) commodity crops show production increases with animal pollination [1]. Most of these crops are not entirely dependent on animal pollination, and the overall production deficit that would occur in the absence of pollinators ranges from 3-5% in the developed world to about 8% in the developing world [2].

There does not (yet) appear to be a shortage of pollinators affecting crop yields at a global scale, even though this may occur at local scales for individual crops. However, over the last 45 years agriculture has become more pollinator-dependent due to a high increase in the area cultivated with pollinator-dependent crops [3]. In addition, crops with greater pollinator dependence have shown lower yield growth and greater yield variability relative to crops which were less pollinator-dependent [4].

Globally, the total economic value of insect pollination amounts to about €153 billion, which represents 9.5% of the value of world agricultural food production [5].

In the three countries participating in this study, the economic value of pollination services is also very important. It is estimated that Brazilian export of eight important agricultural commodities which are dependent on pollinators represents a value of US$ 9.34 billion annually [6]. The annual economic value of insect pollination in East Africa has been estimated at € 900 million [5]. In the Kenyan district of Kakamega alone, 40% of the annual value of crop production (US$ 3.2 million) could be attributed to bee pollination [7]. In neighbouring Uganda, pollination services were estimated to be worth of US$ 490 million for a total economic value of crop production of US$ 1.16 billion per annum [8]. The value of animal pollination for Dutch agriculture is estimated at € 1 billion annually [9].

1.2 Role of wild pollinators

Honeybees and bumblebees are the best known pollinators, and may be commercially managed. But wild bees, both social and solitary species, are also essential for pollination of many crops, especially in the tropics. In some cases, wild bees complement pollination by honeybees, but for many tropical crops wild bees are the principal or only pollinator [1, 10, 11].

For example, in the Kenyan district of Kakamega, 99% of the crop production value attributable to pollination was provided by wild bees [7]. A recent assessment of the importance of honeybees for crop pollination in the UK concluded that managed honeybees may only supply as little as 12% of optimal pollination services, and that wild pollinators make a substantially greater contribution than previously assumed to crop pollination services, even in north-western Europe [12].

1.3 Threats to pollinators

There is increasing evidence that insect pollinators, both wild and domesticated, are in decline in many regions of the globe, with the clearest cases having been documented from Europe and North America [13]. Colony collapse disorder (CCD) of the honey bee is the most dramatic example of such pollinator losses [14], but bumblebee populations and other wild bees, even though much less well studied, also show clear declines [13, 15, 16].

Various causes for this decline have been identified, including loss, fragmentation and degradation of habitats; reduction in resource diversity; pests and pathogens of pollinators; competition by introduced pollinators; climate change; reduced genetic diversity; and pesticide use leading to direct and indirect adverse effects on pollinator populations. There appears to be agreement that not one of these drivers and pressures is primarily responsible for the observed pollinator decline, but that interactions among multiple factors are likely in play [13, 15, 17, 18].

Losses in wild bee diversity and numbers are particularly strong under intensive agricultural management [19]. So far, no large honeybee losses have been reported from Africa or South America [14, 20], but increasing agricultural expansion and intensification pose a significant risk to both managed and wild pollinators on these continents [20, 21, 22]. As a result, pesticide imports have increased by 38% in Kenya between 2003 and 2008 [23], and pesticide sales in Brazil have tripled between 2000 and 2010 [21].

1.4 Pesticide risk assessment

Pesticide risk assessment for bees in the EU, USA or Australia has so far focussed on honeybees *(Apis mellifera)* only [24, 25, 86, 26]. However, honeybees may have different intrinsic susceptibility to pesticides than wild bees; may be exposed in a different manner due to variations in behaviour and life history; and bee populations may respond in other ways to pesticide impacts because of different population dynamics.

The pesticide risk assessment procedures presently applied for honeybees are thus unlikely to be directly applicable to wild bees. Only recently have pesticide risk assessment methods for wild bees received more attention [27], but no agreed risk assessment procedures have yet been established.

1.5 Pesticide risk profiling

To be able to conduct a proper risk assessment of pesticides to bees, information is needed on three aspects: i. the toxicity of the pesticide, ii. the probability of exposure of the bee to that pesticide, and iii. the population dynamics of the bee species in question.

Pesticide **toxicity** data have mainly been generated for honeybees (*Apis mellifera*), but much less so for other *Apis* species or non-*Apis* bees (both wild and managed). Increasingly, however, toxicity tests are being done with *non-Apis melllifera* species, although not all of these have found their way in the international published literature.

The probability and degree of **exposure** to pesticides depends on cropping and pesticide application practices, pesticide properties, attractiveness of the crop to bees, and bee biology (in particular phenology and behaviour). Data on these aspects of exposure, for a given crop in a given country or region, may be available from agricultural extension services, pesticide registration authorities, bee experts, agronomists and environmental scientists.

Finally, the **population dynamics** of the bee species will determine how an observed effect of the pesticide (either lethal or sublethal) will affect long-term survival of the population.

In this assessment, we have attempted to collect information relevant to pesticide risk assessment for (primarily wild) bees on a limited number of focal crops. Since this is not a proper risk assessment, we use the term "risk profile" to characterize the output of the assessment. Initially, this type of risk profiling aims to better identify gaps in our present knowledge on risk factors that require further research. In the longer term, the established risk profiles may provide inputs into risk assessment models for wild and non-*Apis* managed bees and should lead to recommendations for specific risk mitigation measures.

2. Methodology

2.1 Focal crops

A limited number of focal crops were chosen for which the risk profiling exercise was conducted. Focal crops were selected because of their dependence on (wild) bee pollination, and/or because non-*Apis mellifera* bees were known to be active in the crop.

Table 1. Focal crops for which pesticide risk factors were assessed.

Country	Brazil	Kenya	Netherlands
Focal crops	Melon Tomato	Coffee Cucurbits (watermelon & squash) French beans Tomato	Apple Tomato (greenhouse)

Cucurbits, such as melon *(Cucumis melo)*, watermelon *(Citrillus lanatus)* and squash *(Cucurbita* spp.*)* are highly dependent on bee pollination and production reductions of more than 90% can be expected without effective animal pollination [1]. Both honeybees and non-*Apis* bees are important pollinators.

Highland coffee *(Coffea arabica*) is self-pollinating, but both honeybees and non-*Apis* bees have been shown to increase yields by over 50% [1, 28]. Lowland coffee *(Coffea canephora, or C. robusta)* is self-incompatible, and animal pollination is of great importance for berry production [1, 29].

Tomato *(Solanum lycopersicum)* is self-compatible, but requires wind- or insect-mediated shaking of the flower for self-pollination (buzz pollination) [1]. Pollinators are in particular important in greenhouses, but less so in the open field. Bumblebees, stingless bees and some solitary bee species are good buzz pollinators [91].

French beans *(Phaseolus vulgaris)* are self-compatible, and the importance of insect pollination is limited [1].

Apple *(Malus domestica)* production greatly depends on insect pollination, and honeybees, bumblebees and solitary bees all have been found to increase fruit production [1]

2.1 Risk factors

A preliminary list of was established of factors which were considered to potentially influence the risk of pesticides to bees. It was reviewed by all project partners and amended where needed. The list was intended to cover the main factors that potentially influence pesticide risk, but is not necessarily exhaustive (Table 2).

The factors that were evaluated in the survey may have different possible effects on pesticide risk to bees. In some cases, a clear correlation between the factor and an increase or reduction of risk can be assumed. In other cases this relationship is less clear and would require more detailed information on bee biology or the cropping situation (Table 2).

On the basis of this list, a simple questionnaire was elaborated with the aim to collect information on these various risk factors for the focal crops in the three countries.

Annex 1 contains the most recent version of this questionnaire, updated using insights resulting from the present assessment.

Table 2. Risk factors and their possible effects of pesticide risk to bees.

Risk factor	Possible effect on the risk of the pesticide
Exposure – crop factors	
Surface area under crop:	
- overall size	Larger surface area under the specific crop ➔ higher exposure risk
- patchiness	lower fraction of the crop in the overall area ➔ lower exposure risk
Period(s) in the growing season when pesticides are applied to the crop	*Determinant for factors below*
Period(s) in the year when the crop flowers	If overlap between flowering of crop and pesticide applications ➔ higher exposure risk
Period(s) in the year when bees are active foraging or collecting nesting materials	If overlap between bee activity in crop and pesticide applications ➔ higher exposure risk
Period(s) when weeds are flowering in the crop which may be attractive to wild bees	If overlap between flowering of weeds and pesticide applications ➔ higher exposure risk
Crop has extrafloral nectaries	If extrafloral nectaries present in crop ➔ higher exposure risk
Crop is regularly infested with honeydew producing insects.	If honeydew producing insects present in crop ➔ higher exposure risk
Drinking water is available in the crop	If drinking water in the crop ➔ higher exposure risk
Exposure – bee biology factors	
Location of nest in relation to crop field	In-field and field-border nests ➔ higher exposure risk
	Off-field nests ➔ lower exposure risk (depending on distance)
Bee foraging range	If in-field and field border nests: shorter foraging range ➔ higher exposure risk
	If off-field nests ➔ no clear correlation with risk
Time spent foraging, or collecting nesting materials, per day ("time-out-of-nest/hive")	More hours out-of-nest/hive ➔ higher exposure risk
Period of the day when foraging or collecting nesting materials.	Early/middle in the day ➔ possibly lower exposure risk (if pesticide is applied afterwards and has very low persistence)
	All-day/late in the day ➔ higher exposure risk
Number of days spent foraging on the crop (for an individual bee)	More days spent foraging ➔ higher exposure risk
Number of days spent foraging on the crop (for the colony)	More days spent foraging ➔ higher exposure risk
Number of different nectar and pollen plant species used during crop flowering	Fewer species ➔ higher exposure risk
Quantity of pollen collected per day	Higher quantity ➔ higher exposure risk
Quantity of nectar collected per day	Higher quantity ➔ higher exposure risk
Quantity of nectar consumed per day	Higher quantity ➔ higher exposure risk
Body weight	Higher body weight ➔ possibly lower exposure or impact risk
	Determinant for other factors
% of pollen self-consumed	More self-consumed ➔ higher exposure risk to adult
% of pollen fed to brood	More fed to brood ➔ higher exposure risk to brood
	If transformed by nurse bees ➔ possibly lower exposure risk to brood
% of nectar self-consumed	More self-consumed ➔ higher exposure risk to adult

Risk factor	Possible effect on the risk of the pesticide
% of nectar fed to brood	More fed to brood ➔ higher exposure risk to brood
Collective pollen and/or honey storage in the nest (social bees)	If collective pollen and honey storage ➔ lower exposure risk due to mixing and microbial action
Exposure & impact – pesticide use/application practices	
Formulation type	Some formulations types (e.g. micro-encapsulation, sugary baits, DP, WP) ➔ higher exposure risk
Pesticide is systemic	Specific exposure/impact assessment
Pesticide is IGR	If IGR ➔ specific impact on brood
Mode of application	Some modes of application (e.g. dusting, aerial application) ➔ higher exposure risk Some modes of application (e.g. seed/soil treatment with non-systemic pesticide; brushing) ➔ lower exposure risk
Application rate	For the same pesticide product: higher application rate ➔ higher exposure/impact risk
Application frequency	Higher application frequency ➔ higher exposure risk
Systemic pesticides are applied as soil treatment or seed treatment to a previous rotational crop	If systemic pesticides applied to a previous rotational crop ➔ higher exposure risk
Impact & recovery – pesticide properties	
Contact LD_{50} (adult)	Lower LD_{50} ➔ higher impact (for similar exposure levels)
Oral LD_{50} (adult)	Lower LD_{50} ➔ higher impact (for similar exposure levels)
Oral LD_{50} (brood)	Lower LD_{50} ➔ higher impact (for similar exposure levels)
Foliar residual toxicity	Higher residual toxicity➔ higher impact (for similar exposure levels) & ➔lower likelihood of recovery after pesticide impact
Impact & recovery – life history and population dynamics factors [1]	
(Worker) metabolic rate	Higher metabolic rate ➔ lower impact (increased detoxification)
Degree of sociality	High degree of sociality with one or more reproductive queens and separate foragers ➔ lower risk of impact to the population/colony because pesticide effects primarily on foragers (except for IGRs)
Fraction of population/colony active out of the nest/hive (social bees)	Higher fraction of population of colony active out of the nest/hive ➔ higher risk of impact for the whole population/ colony
Time to reproductive age of queen/reproductive female (egg-adult)	Shorter development time ➔ lower exposure risk (if development partly overlaps with flowering)
Number of offspring per queen/reproductive female	Greater number of offspring ➔ greater likelihood of population recovery after pesticide impact
Number of generations per year	Greater number of generations per year ➔ greater likelihood of population recovery after pesticide impact
Population growth rate [note: is product of previous 3 factors]	Higher population growth rate ➔ greater likelihood of population recovery after pesticide impact
Number of swarms per colony per year	More swarms per year ➔ greater likelihood of population maintenance, if swarming occurs before pesticide impact & ➔ greater likelihood of population recovery after pesticide impact
Migration distance of swarms	Greater swarm migration distance ➔ greater likelihood of population recovery after pesticide impact (if cropping is patchy)

[1] Life history and population dynamics factors were originally not included in the survey, but later added based on literature data.

2.3 Data collection

The methodology used to collect, compile and evaluate the information was not identical in the three countries.

In **Brazil**, cropping and bee data were collected through discussions with crop and pollination experts and by consulting published and unpublished literature. Pesticide use information was obtained from crop experts and the pesticide registration authority (Ministério da Agricultura, Coordenação-Geral de Agrotóxicos e Afins) through the Sistema de Agrotóxicos Fitossanitários – Agrofit [30].

In **Kenya**, cropping and bee data were collected through discussions with crop and pollination experts and by consulting published and unpublished literature. Pesticide use information was obtained from crop experts and the Kenya Pest Control Products Board (PCPB) [31]. In addition, an extensive survey was carried out on pollinator knowledge and crop protection practices covering approximately 100 farmers in Athi River district, and Mwea and Kiambu counties.

In **the Netherlands**, cropping and bee data were collected through discussions with crop and pollination experts and by consulting published and unpublished literature. Pesticide use information was obtained from Statistics Netherlands (CBS) [32]

Pesticide toxicity data for bees were collected centrally, using various databases and literature sources.

For this assessment, acute LD_{50} values for **honeybee** (*Apis mellifera*) were obtained from a recently compiled database [33], which is based on multiple regulatory and non-regulatory data sources. The lowest (generally 48h) LD_{50} value of both oral and contact tests, as calculated using the rules defined for the database, was used in this report. When LD_{50} values were not available in this database, the Footprint Pesticide Property Database [34] and the Footprint Biopesticides Database [35] were consulted. Results from brood tests, or sublethal toxicity tests, have not been taken into account in the report.

Toxicity data for **bumblebees** (*Bombus spp.*) are increasingly being collected, and were recently reviewed [36]. We have used this review to check whether acute LD_{50} values for bumblebees were available for the pesticides used in the focal crops.

Pesticide toxicity data for **non-*Apis mellifera*** and **non-*Bombus* bees** are still relatively rare. No public database of such data appears to exist. We have therefore not included toxicity data for other bees in this assessment.

Pesticide types and modes of action were noted according to the Pesticide Manual [37] or the Footprint Pesticide Property Database [34].

The **foliar residual toxicity** is the duration that a pesticide remains toxic to bees on foliage. In the USA, foliar residual toxicity is generally assessed for pesticides with an acute LD_{50} < 11 µg/bee [86]. Foliar residual toxicity durations as reported by various US agricultural extension services were used in this assessment [87, 88]. These have been determined for the honeybee at maximum normal US application rates.

3. Results

3.1 Presence of bees

The main groups of bees visiting the focal crops in the three countries are listed in Table 3.

Although the honeybee *(Apis mellifera)* is found on all three continents, the subspecies are different. In Brazil, the Africanized honeybee is most common (hybrids between *A. m. scutellata* and often *A. m. mellifera or A. m. iberiensis)*, although it has been argued the genetic and behavioural characteristics of the African honeybee *(A. m. scutellata)* have been largely preserved [38]. In Kenya, the subspecies present are *A. m. scutellata*, *A. m. monticola* and *A. m. litorea.* In the Netherlands, honeybees are mainly *A. m. mellifera* and *A. m. carnica*.

Table 3. Main groups of bees visiting the focal crops, and their role as pollinator of those crops.

Country	Crop	Bee group/species visiting the crop	
		Important pollinator	**Not an important pollinator**
Brazil	Melon	*Apis mellifera* (honeybee)	*Xylocopa spp.* (carpenter bees) *Frieseomelitta doederleini* (stingless bee)
	Tomato	*Bombus transversalis* (bumblebee) *Bombus atractus* (bumblebee) *Bombus morio* (bumblebee) *Xylocopa grisescens* (carpenter bee) *Augochlora* sp. (sweat bee) *Exomalopsis auropilosa* (long-horned bee) *Melipona spp.* (stingless bees)	*Apis mellifera* (honeybee)
Kenya	Cucurbits	*Apis mellifera* (honeybee) Halictidae (sweat bees)	*Xylocopa* spp. (carpenter bees)
	Coffee	*Apis mellifera* (honeybee) *Patellapis* spp. (sweat bees) *Xylocopa* spp. (carpenter bees) Megachilidae (leafcutter bees)	
	French beans		*Apis mellifera* (honeybee) *Xylocopa* spp. (carpenter bees) Megachilidae (leafcutter bees)
	Tomato	*Xylocopa spp.* (carpenter bee) Halictidae (sweat bees)	*Apis mellifera* (honeybee)
Netherlands	Apple	*Apis mellifera* (honeybee) *Osmia rufa (=O. bicornis)* (red mason bee) *Bombus* spp. (bumblebees) (mainly *B. terrestris/lucorum; B. pascuorum; B. lapidarius)* *Andrena* spp. (sand bees)	
	Tomato	*Bombus terrestris* (bumblebee)	

The main pollinator on **melon** in north-eastern Brazil is the honeybee [39], although the crop is also visited by e.g. *Xylocopa* carpenter bees and stingless bees (Meliponini). The honeybee is also the main pollinator of **watermelon** in Kenya, while various species of halictid bees (e.g. *Lasioglossum* spp.), carpenter bees (Xylocopinae) and stingless bees (e.g. *Hypotrigona* spp.) are also observed on this crop [40, 41]. Similarly, honeybee was the most common bee pollinator found on **bottle gourd** in Kenya [42]. The importance of wild bees (in addition to honeybees) for the pollination of **cucurbits** has also been observed elsewhere, e.g. in Brazil on *Cucurbita* sp. [55], in Ghana on sponge cucumber *(Luffa aegyptiaca)* [43], and on squash/pumpkin *(Cucurbita pepo)* in the USA [44, 45].

Tomato requires buzz pollinators for effective pollination. A wide variety of bee pollinators were identified to pollinate field tomato in Brazil, including bumblebees, carpenter bees, sweat bees, a long-horned bee and stingless bees. The latter group is also being investigated as pollinator for greenhouse tomato in Brazil [46]. Halictids and carpenter bees are reported as pollinators of field tomato in Kenya, but bumblebees are not naturally present in Africa. In the Netherlands, tomato is mainly grown in greenhouses, and commercially reared bumblebees *(Bombus terrestris)* are the main pollinators in this crop.

French beans are self-compatible and pollinators appear to contribute little to production [1]. However, both wild bees and honeybees are regular visitors on this crop in Kenya, which is often intercropped with other (bee pollinated) vegetables, and may thus be exposed to pesticides.

Highland **Coffee** in Kenya is reportedly pollinated by honeybees, halictids, leafcutter bees and carpenter bees [47]. This are similar pollinator groups as found in lowland coffee in neighbouring Uganda, although stingless bees were also particularly important there [29]. The importance of wild bees for pollination and subsequent quantity and quality of coffee production has been explicitly underlined for Kenya [54] and for Central America [28, 48, 49].

Honeybees, sand bees *(e.g. Andrena carantonica, A. flavipes, A. haemorrhoa),* mason bees *(Osmia rufa)* and bumblebees *(e.g. Bombus pascuorum and Bombus terrestris/lucorum)* are important pollinators of **apple** in the Netherlands [50]. In a recent study, wild bees were the most frequent flower visitors (59% of observations), followed by honeybees (29%) and hover flies (12%) [50]. This is not limited to the Netherlands, as populations of mason bees (e.g. *O. rufa* and *O. cornuta* in Europe; *O. cornifrons* and *O. lignaria* in the USA) are artificially increased in apple orchards because of their high pollination efficiency [51, 52]. The sand bee *Andrena barbara* was found to be an important pollinator of in apple in southwest Virginia (USA) [53].

In conclusion, in all focal crops, except probably melon in Brazil, do wild bees contribute significantly to pollination in addition to, or instead of, the honeybee. Furthermore, in all focal crops, the groups and/or species of bees that are regular visitors appear to be relatively well know. In many cases, important pollinators have been identified, although for some crops the exact importance of wild bees as pollinators requires more study (e.g. *Xylocopa* and Halictidae in cucurbits and tomato in Kenya; *Andrena* spp. in apple in the Netherlands).

3.2 Risk factors

3.2.1 Exposure – crop factors

Various crop-related factors may increase the risk of bees being exposed to pesticides, such as: overlap between the presence of bees in the crop and flowering of the crop or weeds; overlap between activity of bees in the crop and pesticide application; the presence of extrafloral nectaries, honeydew producing insects or drinking water in the crop. These factors are summarized in Table 4 for the focal crops addressed in this assessment.

Table 4. Factors related to cropping practices which may influence the risk of pesticide exposure of bees in the focal crops.

Exposure – crop factors	**Brazil**		**Kenya**				**Netherlands**	
	Melon	**Tomato**	**Cucurbits**	**Coffee**	**French beans**	**Tomato**	**Apple**	**Tomato**
Pesticide application in the crop overlaps with the period when the crop is flowering.	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Pesticide application in the crop overlaps with the period when weeds are flowering in the crop.	No	No?	?	No	?	?	Yes	No
Pesticide application in the crop overlaps with the period when bees are active foraging or collecting nesting materials in the crop.	Yes	Yes	Yes	No?	Yes	Yes	Yes	Yes
Crop has extrafloral nectaries.	No	No	Some?	No	Yes	No	No	No
Crop is regularly infested with honeydew producing insects.	No?	No?	Yes	Yes	Yes	Yes	Yes	No
Crop may be visited for drinking water.	Yes	Yes	?	?	?	?	Yes	Yes
Overall likelihood of exposure	**high**	**high**	**high**	**low**	**high**	**high**	**high**	**high**

? = data not available

Sources: Questionnaires of this study. For the Netherlands, also see Annex 4 for details on timing of pesticide applications.

The main factors influencing risk to bees are probably the overlap of pesticide applications with crop flowering or with bee activity in the crop. In all but one of the crops, pesticides are being applied during flowering and bee activity in the crop. Only in coffee production in Kenya, pesticide applications during flowering are explicitly being avoided. In most crops, weeds are being mulched or otherwise controlled, and only in apple in the Netherlands there is a risk of exposure of bees foraging on Dandelion flowers just before the apple flowering period. In Kenya, the presence and timing of flowering weeds were not known for most of the crops.

Only French beans and (possibly) certain cucurbits in Kenya have extrafloral nectaries. On the other hand, most crops are regularly infested by honeydew producing insects such as aphids and scale insects. In all three countries these pests are controlled with insecticides, and to what extent bees will be attracted to them to forage honeydew requires further study. The focal crops in both Brazil and the Netherlands may contain sources of drinking water for bees; this was not assessed in Kenya. In the Netherlands, bumblebees may drink (potentially contaminated) condensed water from the greenhouse walls, but generally only after the sugar water provided in the colony boxes is depleted.

Overall, the likelihood of pesticide exposure of bees in the focus crops in the three countries, based on crop-related aspects, can be considered high. The only exception is coffee in Kenya, where pesticides tend not to be applied during flowering.

3.2.2 Exposure – bee biology factors

Bee biology may affect both the risk of exposure of the bee to a pesticide, as well as the resulting impact. Parameters related to bee biology which may influence exposure, as collected in the survey, are summarized in tables 5,6 and 7 below. This includes the period, duration and range of foraging, nest location, and nectar and pollen consumption. In the tables a comparison is made between *Apis mellifera* (local subspecies) and the main other bees that are active in the crop.

It should be noted that many of the listed factors are highly variable for individual species, but even more so when they refer to entire groups of bees. For instance, foraging ranges will depend on the availability of suitable flowering plants; the timing of foraging may be greatly influenced by weather conditions; the quantity of pollen en nectar collection and/or consumption will depends on the size of the colony, but also the sugar content of the nectar; etc. In the tables, averages, median values or ranges are generally shown. If country or crop/specific data were available, these were listed with priority. Otherwise, more general values for the bee group are provided, generally obtained from review articles. Sources for the data are provided in each table.

For **Brazil**, no specific information for the Africanized honeybee was found and therefore the data of the European honeybee have been listed in Table 5. However, Africanized honeybees have been reported to collect greater quantities of pollen [38], although this was not quantified. Limited information was available for the other groups of bees identified as tomato pollinators in Brazil. Due to this lack of information, it is not possible to make clear inferences about the relative likelihood of exposure of wild bees in tomato in Brazil, based on bee biology factors.

For **Kenya**, information on the African honeybee *(A. m. scutellata*) was available, and limited information for *Xylocopa* spp. and Halictidae. No information on relevant bee biology factors could be obtained for leafcutter bees and the specific halictid *Patellapis* spp. Based on the limited bee biology data available, there is no reason to expect higher pesticide exposure of *Xylocopa* than of honeybee in Kenya, but some key factors could not be quantified.

Halictidae in tomato in Kenya may be more exposed to pesticides than the honeybees in the same crop, based on bee biology factors. The nests are closely located to the field which, in combination with the more limited foraging range, is likely to increase exposure risk. Furthermore, sweat bees are generally smaller than honeybees and the time spent foraging of individual bees is longer. Finally, almost 100% of collected pollen are fed untransformed to the brood, which may lead to higher exposure of offspring than is the case in honeybee.

Table 5. Factors related to bee biology which may influence the risk of exposure of bees in the focal crops – Brazil

Exposure – bee biology factors	**Brazil**					
	Melon Tomato	**Tomato**				
	Apis mellifera *(africanized)*	***Bombus* spp.**	***Xylocopa grisescens***	***Augochlora* sp**	***Exomalopsis auropilosa***	***Melipona* spp.**
Location of nest in relation to crop field (approximate distance from crop field)	Outside (100 – 500m)	Outside	Outside	Outside?	Outside	Outside (or inside)
Average bee foraging range (maximum distance from nest)	~1500m (10km)	?	(12km)	Limited?	?	500 – 1000m (2100m)
Time spent foraging or collecting nesting materials, per day	1.5 – 10 hours	Up to 10 hours	~12 min/flight; numerous flights/days	?	?	?
Period of the day when foraging or collecting nesting materials	Entire day	?	Entire day?	?	?	Morning/ Entire day
Number of days spent foraging on the crop (for an individual bee)	~20 days	?	?	?	?	?
Number of days spent foraging on the crop (for the colony)	30-60 days	30-40 days	n.a.	n.a.	n.a.	30-40 days
Quantity of pollen collected per day	200 – 300 mg/day	15 – 31 mg	?	?	?	?
Quantity of nectar collected per day	250 µl	70 µl/load	?	?	?	?
Quantity of nectar consumed per day	80 – 320 mg (adult)	?	?	?	?	7-12µl/load
Body weight	75 – 105	40 – 850	?	?	?	?
% pollen self-consumed	100%	0%	?	?	?	?
% pollen fed to brood	Transformed	100%	?	?	?	?
% nectar self-consumer	Almost 100%	?	?	?	?	?
% nectar fed to brood	Limited	?	?	?	?	?
Collective pollen and/or honey storage in the nest	Yes	Yes	Limited?	No	Limited?	Yes
Overall likelihood of exposure compared to the honeybee	**--**	**Similar?**	**Unclear**	**Unclear**	**Unclear**	**Unclear**

? = data not available; n.a. = not applicable

Sources: Questionnaire of this study, and: *Apis* [38, 74, 77, 78]; *Bombus* [56, 57, 79]; *Xylocopa* [58, 59, 60, 61, 62, 63, 64]; *Augochlora* [65]; *Exomalopsis* [66]; *Melipona* [67, 68, 69, 70, 71, 72]; General [73]

[1] *Melipona* has been used on a limited scale to pollinate tomato in greenhouses in Brazil.

Table 6. Factors related to bee biology which may influence the risk of exposure of bees in the focal crops – Kenya

Exposure – bee biology factors	**Kenya**				
	Coffee Cucurbits French beans Tomato	**Coffee Cucurbits French beans Tomato**	**Coffee**	**French beans Coffee**	**Tomato Cucurbits**
	Apis mellifera *scutellata*	***Xylocopa spp.***	***Patellapis* sp.**	**Megachilidae**	**Halictidae**
Location of nest in relation to crop field (approximate distance from crop field)	Inside & field borders (50–100 m)	Field borders (10–50 m) Fringes of woodlands/forest	?	?	Outside & field borders Fringes of woodlands/forest
Average bee foraging range (maximum distance from nest)	~1500m (10km)	700-1000m (6 km)	?	?	50–100 m
Time spent foraging or collecting nesting materials, per day	1.5 – 10 hours	1 – 2 hours Median flight duration 30 min	?	?	4 – 10 hours?
Period of the day when foraging or collecting nesting materials	(Early) morning All day (on cool days)	Early & late in day	?	Mid day	Throughout the day
Number of days spent foraging on the crop (for an individual bee)	~20 days	Coffee: 30 days French beans: 100 days Tomato: 90 days	?	?	60
Number of days spent foraging on the crop (for the colony)	Coffee: 30 Cucurbits: ? French beans: 100 Tomato: 90	n.a.	n.a.	n.a.	?
Quantity of pollen collected per day	200 – 300 mg/day	?	?	?	<30 mg/d
Quantity of nectar collected per day	250 µl	?	?	?	?
Quantity of nectar consumed per day	80 – 320 mg (adult)	?	?	?	?
Body weight	90 – 120 mg	Larger than honeybee	?	?	3 – 95 mg; generally much smaller than honeybee
% pollen self-consumed	100%	?	?	?	?
% pollen fed to brood	Transformed	Almost 100%	?	?	Almost 100%
% nectar self-consumed	Almost 100%	?	?	?	?
% nectar fed to brood	Limited	?	?	?	?
Collective pollen and/or honey storage in the nest	Yes	Limited?	?	No	Limited?
Overall likelihood of exposure compared to the honeybee	--	**Similar?**	**Unclear**	**Unclear**	**Greater**

? = data not available; n.a. = not applicable

Sources: Questionnaire of this study, and: *Apis* [38, 74, 75, 77, 78, 29, 40, 43]; Xylocopa [40, 43, 64]; Megachilidae [29]; Halictidae [65]; General [73]

Table 7. Factors related to bee biology which may influence the risk of exposure of bees in the focal crops – Netherlands

Exposure – bee biology factors	**Netherlands**				
	Tomato	**Apple**			
	Bombus terrestris	***Apis mellifera** mellifera*	***Osmia rufa***	***Andrena* spp.**	***Bombus* spp.**
Location of nest in relation to crop field (approximate distance from crop field)	Inside (0 m)	Inside or outside (0 – 1500 m)	Mainly orchard borders (~50 m)	Mainly inside (0 m)	Inside or outside (0 – 50 m)
Median/average bee foraging range (maximum distance from nest)	~50 m (~100 m)	1180m (10 000m)	50 – 100 m (200 m)	10 – 50 m	*B. pascuorum*: 500-2300m (310-3200m) *B terrestris*: 270-2800m (625-3900m) *B. lapidarius* : 260m (450-1500m)
Time spent foraging or collecting nesting materials, per day	?	1.5 – 5	2?	?	?
Period of the day when foraging or collecting nesting materials	Entire day	Mainly morning	Mainly morning	Mainly morning	Mainly morning
Number of days spent on the crop (for an individual bee)	?	~20	~20	~20	~20
Number of days spent on the crop (for the colony)	~45	~20	n.a.	n.a.	~20
Quantity of pollen collected per day	Limited	200 – 300 mg/day	?	?	15 – 31 mg/day 430 – 680 mg/individual (total)
Quantity of nectar collected	None	250 µL	?	?	70 µl/load 7 – 8 ml/individual (total)
Quantity of nectar consumed per day	None	80 – 320 mg (adult)	?	?	Most of what is collected?
Body weight	215 mg ± 59	120 – 135 mg	85 - 110 mg	?	100 – 270 mg
% pollen self-consumed	0%	100%	0%	0%	0%
% pollen fed to brood	100%	Transformed	100%	100%	100%
% nectar self-consumer	--	Almost 100%	Almost 100%	Almost 100%	Almost 100%
% nectar fed to brood	--	Limited	Limited	Limited	Limited
Collective pollen and/or honey storage in the nest	Yes	Yes	No	No	Yes
Overall likelihood of exposure compared to the honeybee	**Greater**	**--**	**Greater**	**Greater**	**Unclear**

? = data not available; n.a. = not applicable

Sources: Questionnaire of this study, and: *Apis* [74, 77, 78]; *Bombus* [79, 80, 81, 82, 83, 84, 90]; *Osmia* [50, 51, 52, 53, 85]

For the **Netherlands**, information was available for *A. m. mellifera* and commercially reared *Bombus terrestris*. Only limited information could be obtained about *Osmia rufa* and in particular *Andrena* spp.

Bumblebees in greenhouse tomato in the Netherlands are likely to be more exposed to pesticides than honeybees in open field crops, because they are constrained to the greenhouse where all treatments take place. So both colony location and foraging are located entirely in the treated crop. Only bumblebee body weight is higher than of honeybees, which may reduce relative exposure per unit body weight. However, bumblebees in tomato do not consume pollen and tomato does not produce nectar, which means that exposure is mainly through contact. Bumblebee larvae, on the other hand, may be exposed to pesticide contaminated pollen, mainly by systemic pesticides as tomato flowers are very closed and spray contamination of pollen is likely to be limited.

In apple, both *Osmia rufa* and *Andrena spp*. are likely to be more exposed to pesticides than honeybees, when reviewing bee biology factors. They nest inside the field or in field borders, and have a more limited foraging range. Furthermore, collected pollen are fed untransformed to brood. Other biology-related factors were either similar to the honeybee, or data were missing. Biological exposure factors of bumblebee in apple similar to the two species of wild bees, but their body weight higher and foraging range wider, potentially reducing exposure.

Overall, it can also be concluded from this initial assessment that there are still major data gaps regarding elements of bee biology which may influence the risk of exposure bees to pesticides. For most groups of bees, information was available on daily and seasonal flight activity and on foraging patterns; On the other hand, information was lacking on foraging duration, quantities of pollen/nectar collected and consumed.

3.2.4 Exposure – pesticide use/application practices

The number of pesticide products and active ingredients registered and/or used on the focal crops in the three countries are summarized in Table 8.

In late 2011, 392 pesticide products were registered on tomato in **Brazil**, containing a total of 130 active ingredients. In melon, 152 products were registered, containing 64 active ingredients.

Annex 2 provides details on active ingredients used on both crops in Brazil. Pesticide application rates can also be obtained from the AgroFit database, but were not further analysed in this assessment. Systemic pesticides were applied by soil or seed treatments to previous crops, which might pose a risk for exposure of bees to contaminated pollen or nectar in the subsequent melon or tomato crop.

Pesticide use on the focal crops in **Kenya** was assessed through farmer surveys. Annex 3 provides details on active ingredients used on all four crops in the country.

In coffee, 17 pesticide products were used in the survey area, containing 12 active ingredients; all but three of these products was registered for use on coffee. Of the 17 products, at least 12 were used only after flowering, so when bees would be not or less active in the coffee crop.

In cucurbits (mainly watermelon), 42 products were used in the survey areas, containing 29 different active ingredients. Of these, 17 products (11 a.i.'s) were registered for use on cucurbits; the others were registered in Kenya but on other crops. This is due to the fact that watermelon is considered a minor crop and agrochemical companies have shown little interest in submitting registration applications for this crop. Only 5 products were used at planting or emergence of the watermelons, when bees would not be active (however 3 of these were systemic). Most other pesticides were used throughout the growing season, including during flowering.

In total, 33 pesticide products were used on French beans in the survey areas, containing 20 active ingredients. Three products (3 a.i.'s) were not registered on French beans, but were authorized for use on other crops in Kenya. All pesticides were used throughout the crop cycle, or no specifications were given as to the period of use.

In tomato, 53 pesticide products were used in the survey areas, containing 29 active ingredients. Of these, 7 products (6 a.i.'s) were not registered for use on tomato, but were authorized for use on other crops in Kenya. Most pesticides were used throughout the crop cycle, or no specifications were given as to the period of use; 5 active ingredients were used at emergence or just after transplanting and would be less likely to expose bees (although 2 had systemic properties).

Application rates were available for most products, but were not further used in this assessment. The use of systemic pesticides in previous rotational crops is not relevant in perennial crops such as coffee. In the other crops in Kenya, it was not known whether any systemic pesticides had been applied to previous rotational crops.

Table 8. Number of pesticides registered and/or used in the focal crops.

	Brazil		Kenya				Netherlands	
	Melon	**Tomato**	**Cucurbits**	**Coffee**	**French beans**	**Tomato**	**Apple**	**Tomato**
Number of active ingredients registered for use on the crop	64	130	11	9	17	23	?	?
Number of active ingredients used per crop	--	--	29	12	20	29	57	66
Number of active ingredients used in period when bees are active in the crop	--	--	25	0?	20	22	54	60
Number of insecticide/acaricide active ingredients used in period when bees are active in the crop	--	--	13	0?	11	15	13	21
Systemic pesticides are applied as soil or seed treatment to a <u>previous</u> rotational crop.	yes	yes	?	n.a	?	?	n.a.	no
Number of systemic pesticides used or registered per crop	35	49	14	5	10	12	28	24
Number of insect growth regulators used or registered per crop	4	15	0	0	0	0	3	6

? = data not available; n.a. = not applicable

The number and types of pesticides registered per crop in **the Netherlands** could not be easily obtained. The public pesticide registration database maintained by the Dutch Board for the Authorization of Plant Protection Products and Biocides (Ctgb) does not allow searches by crop.

Pesticide consumption data, however, were available from Statistics Netherlands (CBS), for the year 2008 on a monthly basis (see Annex 4 for details). In tomato, 66 different active ingredients were used, of which 60 were applied during the period that bumblebees would be active in the greenhouse. In apple, 57 active ingredients were used, of which 54 were applied in periods that either honeybees or wild bees could be active in the apple orchard. No data were available about individual products and application rates.

In the Netherlands, greenhouse tomato production always starts with fresh substrate, and previous crops are not relevant. Similarly, the use of systemic pesticides in previous rotational crops is not relevant in perennial crops such as apple.

3.2.5 Impact & recovery – pesticide properties

Pesticide toxicity data were available to a varying degree, depending on the bee species.

Acute toxicity data for the **honeybee** (*A. mellifera*) are reported for most pesticides, as these tend to be required for pesticide registration. However, in many cases, only acute contact and oral test results obtained on adult worker bees are available.

On average, acute honeybee LD_{50} values were available for 94% of the active ingredients used in the various focal crop (Table 9 and annexes 2, 3, 4). For only 70% of a.i.'s used on tomato in the Netherlands could an acute LD_{50} found. This was partly due to the relatively large number of biopesticides and general disinfectants being used in that crop. Only few acute LD_{50} values for **bumblebees** were available.

Since application rates were not available for all crops, a simple comparison of hazards was made of the pesticides used in the different focal crops. The LD_{50} values (the lowest of the oral or contact LD_{50} was used) were classified according to the US-EPA hazard ranking for honeybees [25] (Table 9). The majority of pesticides used in both focal crops in the Netherlands were classified as practically non toxic to bees. In Kenya the largest fraction of pesticides used was classified as highly toxic to bees, and this concerned all four crops. Both Brazilian crops were intermediate as to the hazard of the pesticides being used. The crop with the highest pesticide hazard to bees were cucurbits in Kenya; the least hazardous was apple in the Netherlands.

Table 9. Number of acute LD_{50} values available for honeybee and bumblebee in the focal crops, and their associated hazard.

Country	Crop	Number of pesticides registered/ used	Number of pesticides with an acute LD_{50} for honeybee	Number of pesticides with an acute LD_{50} for bumblebee	% pesticides (no.) which are		
					Highly toxic[1] (LD_{50} < 2 µg/bee)	Moderately toxic (2 ≤ LD_{50} ≤ 11 µg/bee)	Practically non toxic (LD_{50} > 11 µg/bee)
Brazil							
	Melon	64	61	4	28% (17)	13% (8)	59% (36)
	Tomato	130	119	13	36% (43)	5% (6)	59% (70)
Kenya							
	Coffee	12	12	2	42% (5)	8% (1)	50% (6)
	Cucurbits	29	29	9	52% (15)	7% (2)	41% (12)
	French beans	20	20	5	40% (8)	5% (1)	55% (11)
	Tomato	29	28	7	50% (14)	7% (2)	43% (12)
Netherlands							
	Apple	57	52	5	10% (5)	11% (6)	79% (41)
	Tomato	66	52	5	21% (11)	8% (4)	71% (37)

[1] Hazard classification for honeybees according to the US-EPA [25]
For more details, see annexes 2,3 and 4

The US-EPA toxicity classification primarily addresses the hazard of pesticides applied as a spray. Systemic pesticides applied as seed or soil treatment are not explicitly covered. A relatively large number of systemic pesticides are being used on the focal crops (Table 8). We therefore also calculated the worst case toxicity exposure ratio (TER), as defined by EPPO for pesticides with systemic action [24] (the oral LD_{50} value was always used for this assessment, even when it was not the lowest acute LD_{50}). However, whenever this systemic TER resulted in a high risk classification, the pesticide had already been categorized as highly toxic by the EPA oral/contact toxicity classification. One can thus conclude that the EPA hazard classification is also "protective" for bees when systemic pesticides are concerned.

Insect growth regulators (IGRs) tend to have a relatively low toxicity to adult bees, but may be very toxic to the larvae. A hazard classification based on acute LD_{50} obtained from adult bees is then not appropriate and toxicity data on bee brood are required [24]. Relatively few IGRs are being used on the focal crops (Table 7), and therefore no specific assessment of their risk was conducted.

F**oliar residual toxicity** data for honeybees were available for 42-71% of the pesticides with an LD_{50} < 11 µg/bee, the trigger used by the US-EPA to generate such data (Table 10 and annex 2, 3 & 4). These foliar residual toxicity data refer to maximum normal application rates in the USA, and these may not be the same in the three study countries. The values compiled in the annexes should therefore be considered as indicative.

In Kenya pesticides had on average the highest residual toxicity, in the Netherlands the lowest. A relatively large fraction of pesticides with low residual toxicity were highly or moderately toxic to bees. This suggests that risk mitigation through good timing of the application might be possible for these products (e.g. application during late evening).

Table 10. Foliar residual toxicity of pesticides in the focal crops

Country	Crop	Number of pesticides with LD_{50}<11 µg/bee	Number of pesticides with foliar residual toxicity data	Number of pesticides with[1]		
				Low residual toxicity (< 4 hours)	Moderate residual toxicity (4 – 8 hours)	High residual toxicity (> 8 hours)
Brazil						
	Melon	26	11	4 {3}[2]	1	6
	Tomato	49	30	6 {4}	2	22
Kenya						
	Coffee	6	4	0	0	4
	Cucurbits	17	12	1 {1}	0	11
	French beans	9	6	1 {1}	0	5
	Tomato	16	10	1 {1}	0	9
Netherlands						
	Apple	11	5	3 {3}	0	2
	Tomato	15	10	7 {5}	0	3

[1] Residual toxicity categories are based on [88].
[2] Between brackets {..} is the number of pesticides with an acute LD_{50} < 11 µg/bee and having low residual toxicity.
For more details, see annexes 2,3 and 4

3.2.6 Impact & recovery – life history and population dynamics

The life-history and population dynamics of the bee species will determine to a large extent how its populations will resist to or recover from such pesticide impact (Table 2). Tables 11, 12 and 13 summarize information compiled on such factors for the bee groups present on the focal crops. It should be noted that these tables do not represent a complete literature review of the population dynamics of the listed species, and should therefore be considered indicative.

Table 11. Factors related to bee life-history and population dynamics which may influence the impact of a pesticide to bees in the focal crops – Brazil

Impact – bee life history and population dynamics factors	**Brazil**					
	Melon **Tomato**	**Tomato**				
	Apis mellifera *(africanized)*	***Bombus* spp.**	***Xylocopa grisescens***	***Augochlora* sp**	***Exomalopsis auropilosa***	***Melipona* spp.**
(Worker) metabolic rate	Hybrids lower than non-hybrid African or European subspecies					
Degree of sociality	Eusocial	Primitively eusocial	Parasocial	Solitary	Parasocial	Eusocial
Fraction of adult population/colony active out of the nest/hive (social bees)	<100%	<100%	Up to 100%	100%	100%	<100%
Time to reproductive age of queen/reproductive female (egg-adult)	16 days?		35 – 69 days			
Number of offspring per queen/reproductive female	Many Greater than European subspecies		5 – 8			
Number of generations per year			1 – 4			
Population growth rate [note: is product of previous 3 factors]	16-fold colony increase per year	Lower than honeybee	Lower than honeybee	Lower than honeybee	Lower than honeybee	?
Number of swarms per colony per year	Greater than European subspecies	n.a.	n.a.	n.a.	n.a.	
Migration distance of swarms		n.a.	n.a.	n.a.	n.a.	
Overall likelihood of pesticide impact compared to the honeybee	**--**	**Greater**	**Greater**	**Greater**	**Greater**	**Unclear**

? = data not available; n.a. = not applicable

Sources: *Apis* [38]; *Xylocopa* [60, 61, 62]; *Melipona* [] ; General [73]

For **Brazil**, limited specific information was available for Africanized honeybee and the carpenter bee *X. grisescens*. In addition, it can be assumed that population growth rates of all the bees except possibly the Meliponini (stingless bees), are lower than of the honeybee. Also, the fraction of the total colony/population which will be actively out of the nest/hive foraging or collecting nesting materials will be greater for the solitary, parasocial and primitively eusocial bees, than for honeybees and stingless bees. As a result, it is likely that pesticide impact on individual bees will affect more of the populations of the carpenter bees, the solitary sweat bees, the long-horned bees and to a lesser extent the bumblebees, than of the more social bees. In addition, the lower population growth rates would result in less rapid population recovery of these groups.

Table 12. Factors related to bee life-history and population dynamics which may influence the impact of a pesticide to bees in the focal crops – Kenya

Impact – bee life history and population dynamics factors	**Kenya**				
	Coffee Cucurbits French beans Tomato	**Coffee Cucurbits French beans Tomato**	**Coffee**	**French beans Coffee**	**Tomato Cucurbits**
	***Apis mellifera** scutellata*	***Xylocopa spp.***	***Patellapis* sp.**	**Megachilidae**	**Halictidae**
(Worker) metabolic rate	African subspecies higher than European subspecies				
Degree of sociality	Eusocial	Parasocial	Solitary	Variable	Variable (solitary to primitively eusocial)
Fraction of adult population/colony active out of the nest/hive (social bees)	<100%	Up to 100%	100%	Variable	Variable
Time to reproductive age of queen/reproductive female (egg-adult)	~16 days?				
Number of offspring per queen/reproductive female	Many Greater than European subspecies				
Number of generations per year					
Population growth rate [note: is product of previous 3 factors]	16-fold colony increase per year	Lower than honeybee	Lower than honeybee	Lower than honeybee	Lower than honeybee
Number of swarms per colony per year	Greater than European subspecies	n.a.	n.a.	n.a.	n.a.
Migration distance of swarms		n.a.	n.a.	n.a.	n.a.
Overall likelihood of pesticide impact compared to the honeybee	--	**Greater?**	**Greater?**	**Greater?**	**Greater?**

? = data not available; n.a. = not applicable

Sources: *Apis* [38]; Halictidae [65]; General [73]

For **Kenya**, limited information was available for African honeybee. No specific data on life history and population dynamics for the other bee groups was found. Based on the same reasoning as for Brazil about the degree of sociality and related fraction of adult bees that is active out of the nest, as well as the likely lower population growth rates, one could argue that population impact may be greater for the non-*Apis* bees, and potential for recovery lower. However, this is not based on much locally specific data.

Table 13. Factors related to bee life-history and population dynamics which may influence the impact of a pesticide to bees in the focal crops – Netherlands

Impact – bee life history and population dynamics factors	**Netherlands**				
	Tomato	**Apple**			
	Bombus terrestris	***Apis mellifera** mellifera*	***Osmia rufa***	***Andrena* spp.**	***Bombus* spp.**
(Worker) metabolic rate		Lower than African subspecies			
Degree of sociality	Primitively eusocial	Eusocial	Solitary	Parasocial?	Primitively eusocial
Fraction of adult population/colony active out of the nest/hive (social bees)	<100%	<100%	100%	100%	<100%
Time to reproductive age of queen/reproductive female (egg-adult)		~16 days	100 days		
Number of offspring per queen/reproductive female		many	Up to 20		
Number of generations per year	1	1-2	1	1	1
Population growth rate [note: is product of previous 3 factors]	Lower than honeybee	3 – 6 -fold colony increase per year	2.4 – 2.8 -fold population increase per year	Lower than honeybee	Lower than honeybee
Number of swarms per colony per year	n.a.	1-2	n.a.	n.a.	n.a.
Migration distance of swarms	n.a.		n.a.	n.a.	n.a.
Overall likelihood of pesticide impact compared to the honeybee	**Greater**	**--**	**Greater**	**Greater**	**Greater?**

? = data not available; n.a. = not applicable

Sources: Questionnaire of this study, and: *Apis* [38]; *Osmia* [85, 89]; General [73]

For the Netherlands, information on life history and population dynamics was available for the honeybee and the red mason bee *(Osmia rufa)*, and less so for bumblebees. No data were obtained for the sand bee *(Andrena* spp*).*

Greater population impact and less potential for recovery is very likely after adverse pesticide impact on the red mason bee when compared to the honeybee. This is because all of the adult (reproductive) females of *O. rufa* are active foraging outside the nest, contrary to the honeybee. Furthermore, population growth rates of *O. rufa* are lower than of the honeybee.

Data for bumblebees were more limited. In tomato production in the Netherlands, colonies of bumblebees are commercially placed in the greenhouse and population effects are not very relevant, although a lower population growth rate might temporarily affect bumblebee numbers. Queens of wild bumblebee species in northern Europe will hibernate as mated reproductive adults and start foraging and building a new colony in spring. Any pesticide impact on such reproducing bees will directly affect the colony size and, if mortality occurs, preclude population recovery.

4. Discussion

4.1 Data availability

One of the objective of this assessment of aspects determining risk of pesticides to wild bees was to identify data gaps for proper risk assessment. The availability of data is summarized in table 14.

With respect to the **presence of bees** in the focal crops, generally it was known which groups of bees were active on the crop, although in a number of cases identification was only known along fairly broad taxonomic groups. The role of the wild bees as pollinators was relatively well known for melon in Brazil, coffee and French beans in Kenya, and tomato in the Netherlands. For the other crops, it is important to obtain better data on the exact role of wild bees as pollinators. While such information is not needed for the pesticide risk assessment *per se*, it is required to be able to interpret the agronomic and economic importance of any risk of the pesticide on the bees.

With respect to **exposure**, data were generally available for crop factors and for pesticide use and application factors, although in many cases these data were not complete. Data were limited or lacking for factors related to bee biology. As a consequence, it is often possible to infer the overall likelihood of exposure of wild bees in the focal crops. However, it is often not possible to further qualify or quantify the degree of exposure of individual bee species or groups.

With respect to **impact and recovery**, toxicity data were available for most pesticides used in the focal crops. However, these were mainly limited to acute toxicity to honeybees. Few toxicity studies have been published for bumblebees, and even less so for other bee species. Foliar residual toxicity data were only obtained for roughly half of the more toxic pesticides for which these are normally generated. Availability of data on life history characteristics and population dynamics of, in particular, wild bees was poor or completely absent.

In conclusion, information was often available to give a first assessment of the likelihood of exposure of bees to pesticides in the focal crops, and the potential for adverse effects. However, it was generally not possible to make more detailed inferences about the size and duration of adverse effects of the pesticide, nor the potential for recovery by the bees. In particular, bee biology, life-history and population dynamics would need to be studied in more detail. Furthermore, it is not know to what extent pesticide toxicity for honeybees is representative for wild bees. Finally, inclusion of application rates in the assessment would allow for a better quantification of risk, e.g. by calculating hazard quotients.

The need for further research on bee biology and ecology has also been expressed in the past, with the aim to gaining better understanding of pollination in Africa [92] and in Brazil [93]. Much of the research needed on pollination biology would also be of high value to pesticide risk profiling and assessment. Given the limited resources available for such research, it seems important that pesticide ecotoxicologists and pollination biologists seek active collaboration to optimize and mutually complement ongoing and planned research efforts.

Table 14. Availability of data on factors that may influence pesticide risk to bees for the focal crops.

Risk factor	Brazil		Kenya				Netherlands	
	Tomato	Melon	Coffee	Cucurbits	French beans	Tomato	Tomato	Apple
Presence of bees								
Taxonomy	Limited	Good	Limited	Limited	Limited	Limited	Good	Limited
Pollination role	Limited	Good	Good	Limited	Good	Limited	Good	Limited
Exposure								
Crop factors	Good	Good	Good	Limited	Limited	Limited	Good	Good
Bee biology factors	Poor	Limited	Limited	Limited	Poor	Limited	Good	Limited
Pesticide use and application practices	Limited	Limited	Good	Good	Good	Good	Limited	Limited
Impact & recovery								
Pesticide properties	Limited (independent of country or crop)							
Life-history and population dynamics	Limited	Poor	Poor	Poor	Poor	Poor	Limited	Limited

4.2 Risk profiles

The risk profiling approach used in this study was developed because a comprehensive risk assessment method for wild bees, or even for honeybees in non-temperate cropping systems, is not yet available. The results of the study indicate that important data gaps still exist with respect to, in particular, bee biology and quantification of exposure that may preclude the establishment of a proper risk assessment procedure for wild bees in the near future. However, the elaboration of a risk profile, as outlined in this study, may provide a preliminary qualification of the risk of pesticide use to (wild) bees in specific crops.

There are important differences between a risk assessment and a risk profile. A risk assessment for bees, conducted for the registration of a pesticide, tends to focus on a specific pesticide product, includes a quantitative estimate of exposure and of effect, and refers to explicit acceptability criteria (e.g. the hazard quotient or toxicity-exposure ratio, in the EU/EPPO approach).

A risk profile, on the other hand, focusses on the cropping system, includes where possible a quantitative measure of effect, but generally only a qualitative (or semi-quantitative) estimate of exposure, and can therefore not quantify risk. As a result, explicit acceptability criteria are not used.

We consider risk profiling a particularly useful approach to:

- conduct a qualitative evaluation of pesticide risk to bees in specific cropping systems;
- compare potential risks of pesticide use to bees among cropping systems
- facilitate discussion among researchers, regulators, farmers, beekeepers on pesticide risks to (wild) bees;
- identify data/information gaps;
- set priorities for further research (e.g. with respect to crops, bee groups, types of pesticides);
- set priorities for risk mitigation.

In the absence of agreed quantitative risk assessment procedures for wild bees, or honeybees in (sub-) tropical cropping systems, establishing a risk profile provides a structured assessment of potential risks of pesticides to bees in a given crop situation while making explicit any data and knowledge gaps. This forms, in our view, an excellent basis for discussion among researchers, regulators, farmers and beekeepers on how to value potential pesticide risks to bees and pollination in specific cropping systems.

The establishment of a risk profile further helps to set priorities for research, by identifying crops, species or groups of bees, or types of pesticides that merit additional study. For instance, additional research efforts would clearly be justified for pollinator-dependent cropping systems, where there is a great likelihood of exposure of bees to pesticides, and a large fraction of moderately toxic pesticides is being used (for which the resulting impact on bees may not be clear). Another priority example for research would be a pollinator-dependent crop, in which many highly toxic pesticides are being used, but where the likelihood and extent of exposure of bees is not clear. Obviously, the focus of research would be different according to the uncertainties that need to be clarified for the cropping system in question.

Even though risk profiling will often lead to less concrete conclusions about risk than formal risk assessment, the establishment of a risk profile could also lead to risk mitigation. In a number of cases, the outcome of a risk profile will be clear enough to warrant risk mitigation measures to be developed and/or to be taken. This would, for instance, be the case if there is a great likelihood of exposure of bees to various highly toxic pesticides in a highly pollinator-dependent crop. In our view, the risk of adversely affecting pollinators and crop production in such cases is so great that immediate implementation of risk mitigation measures is justified. The requirement for risk mitigation should, in such high risk cases, not be made conditional to the generation of further data or information (although it obviously would not preclude further research work to be done).

In Table 15 we provide suggestions for priority setting for research and for developing (additional) risk mitigation on the basis of the outcome of a risk profiling exercise. Priorities are mainly based on the likelihood of exposure of bees on the one hand and the toxicity of the pesticides used in the crop on the other. Priorities are further dependent on the pollination dependency of the crop and the population dynamics of the bee.

It is important to realize that this type of priority setting is relevant to risks of pesticides to bees in crops, in particular those that are to some extent dependent on pollination. It does not guide research or risk mitigation priorities unrelated to pollination, e.g. which focus on biodiversity protection. Other criteria are important for such aspects of bee conservation.

Table 15. Priority setting for research or for (additional) risk mitigation, based on the outcome of a risk profile for a given cropping system.

Priority for research "R", **or for (additional) risk mitigation** "M" (if in brackets [ ], the priority is secondary to the main priority)			**Crop dependence on pollination**						
			High			Limited			No
			Likelihood of exposure of bees to pesticides			**Likelihood of exposure of bees to pesticides**			
			High	Low	Unclear	High	Low	Unclear	
Severity of impact	Large fraction of the pesticides used in the crop are:	Highly toxic	**M** [**R**]		**R** [**M**] §	**M** §		**R** §	
		Moderately toxic	**R** [**M**] §		**R** §				
		Practically non- toxic	**R** §						

§ In particular if bee population dynamics or life history are likely to increase the severity of pesticide impact or reduce the speed of recovery

On the basis of the criteria in Table 15, and taking into account the data gaps which exist in many of the studied cases, the cropping situations assessed in this study can be categorized, in a preliminary manner, as shown in Table 16.

A high priority for identification and implementation of risk mitigation measures would be needed for cucurbits and tomato in **Kenya**, since these crops are highly dependent on pollination, there is a high likelihood of exposure of bees, and many highly toxic pesticides are being applied in the crop. On the other hand, since there is a relatively low likelihood of exposure of bees in coffee, to a large extent because farmers already avoid spraying during flowering, immediate development of additional risk mitigation does not seem warranted, and there is a lower priority for research about pesticide risks in this crop. French beans are not pollinator-dependent, and for that reason this crop is not a priority for risk mitigation or research (but note that this may be the case from a biodiversity point of view).

In **Brazil**, there is a relatively high fraction, and in particular a high number, of highly toxic pesticides being used in melon and tomato, and the likelihood of exposure of bees is great. In addition, the information obtained about the life history and population dynamics of the wild bees points to an increased severity of pesticide impact and a lower capacity for population recovery. As a result, the priority would be to develop and implement risk mitigation measures for these crops.

Even though the likelihood of exposure of bees to pesticides is high in apple and tomato in **the Netherlands**, most pesticides being used have a relatively low toxicity to bees. Apparently, risk mitigation in these crops has focussed on the choice of the pesticides being authorized and used. There is a priority for research into pesticide effects however, in particular in apple, since population dynamics and life histories of the wild bees active in this crop may possibly result in increased severity of pesticide impact and reduced potential for population recovery.

We would like to stress that if the outcome of this type of priority setting is that there is less need for the development of risk mitigation measures, this does not mean that risk mitigation is not necessary at all in that crop. It may, for instance, be the case that effective risk mitigation is already being implemented, leading to lower exposure of bees to pesticides or use of less hazardous pesticides. Priorities are set for future (additional) risk mitigation, and cropping systems where this is likely to have the greatest positive impact are identified.

Also, the fact that there is no immediate priority being identified for research in a specific crop, does not mean that additional research would not be useful. However, if resources are limited (which they almost always are), research in priority crops is expected to provide the greatest benefits in reducing pesticide impact on bees.

Table 15. Priority setting for research or for risk mitigation, based on the outcome of a risk profile for a given cropping system.

Priority for research "R" , **or for risk mitigation** "M" (if in brackets [ ], the priority is secondary to the main priority)			**Crop dependence on pollination**						
			High			Limited			No
			Likelihood of exposure of bees to pesticides			**Likelihood of exposure of bees to pesticides**			
			High	Low	Unclear	High	Low	Unclear	
Severity of impact	Large fraction of the pesticides used in the crop are:	Highly toxic	**M**, [**R**] *Kenya:* cucurbits & tomato *Brazil:* melon & tomato	*Kenya:* Coffee					*Kenya:* French beans
		Moderately toxic							
		Practically non- toxic	**R**§ *Netherlands:* apple & tomato						

§ Because bee population dynamics or life history are likely to increase the severity ofpesticide impact or reduce the speed of recovery

This structured profiling exercise of pesticide risks to (wild) bees in different cropping systems on different continents has, according to our knowledge, not been carried out previously. The list of risk factors (Table 2) used in the assessment is definitely not exhaustive, and the possible effects these factors may have on pesticide risks to bees will clearly need further research. We hope that similar studies will be carried out elsewhere, using the present work as a basis (see annex 1). Over time, this should result in a more precise set of risk factors, and progressively generate a more comprehensive database of risk profiles for different cropping systems and situation. In the long term, this risk profiling approach is expected to contribute to the development of formal risk assessment procedures for wild bees and for honeybees in non-temperate ecosystems.

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Annex 1 – Aspects determining risk of pesticides to bees: survey form to establish a risk profile

To be able to a risk profile for bees of pesticide use in a specific crop, information is needed on three aspects: i. the toxicity of the pesticide, ii. the probability of exposure of the bee to that pesticide, and iii. the population dynamics of the bee species in question.

Pesticide **toxicity** data have mainly been generated for honeybees (*Apis mellifera*), but much less so for other *Apis* species or non-*Apis* bees (both wild and managed). Increasingly, however, toxicity tests are being done with *non-Apis melllifera* species, although not all of these have found their way in the international published literature.

The probability and degree of **exposure** to pesticides depends on cropping and pesticide application practices, pesticide properties, attractiveness of the crop to bees, and bee biology (in particular phenology and behaviour). Data on these aspects of exposure, for a given crop in a given country or region, may be available from agricultural extension services, pesticide registration authorities, bee experts, agronomists and environmental scientists.

Finally, the **population dynamics** of the bee species will determine how an observed effect of the pesticide (either lethal or sublethal) will affect long-term survival of the population.

It is not likely that the information listed in the questionnaire is all available from one institution or person in the country. It is certainly necessary to consult with agronomists, extension services and farmer associations working in the focal crops to obtain cropping and pesticide use data; with the pesticide registration authority and research organizations to obtain pesticide property and toxicity data; and with bee and pollination experts to obtain bee biology information. All the information has been compiled in one questionnaire, however, to underline the interdisciplinary nature of pesticide risk assessment.

Some information will be available from the published literature; other data may be obtained from local unpublished report or studies, or be provided through expert opinion. All such information can be very relevant for risk assessment and should be compiled. However, to be able to allow proper interpretation of the data, it is important to provide the source(s) of each input in the table, irrespective of whether they are published reports/articles or personal communications. If data/information is unavailable or unknown, please also explicitly mention this as it will help identify gaps in our knowledge. Finally, it is helpful to list all the institutions and persons that were consulted for the assessment.

A. Case identity

The assessment can be done on a country-wide basis if the cropping systems and bee complexes are similar throughout the country, or on a regional basis if important differences exist within the country.

Country:	
Region *(optional)*:	
Crop:	Number of growing seasons per year:
Main bee species/groups visiting the crop:	Is species an important pollinator of the crop?
1.	yes/ no/ not known
2.	yes/ no/ not known
3.	yes/ no/ not known

B. Exposure – crop factors

Assessment of whether there is a possibility of exposure of bees to the pesticide in this crop.

Aspect		***Remarks***	**Source of information** *(refer to section G)*
Surface area under the crop		Within the overall area for which the assessment is done	
• Overall size		ha	
• Patchiness		% of total area with this crop	
Period(s) in the growing season when pesticides are applied to the crop:		(note the month(s)/ date(s)/ or timing relative to emergence, flowering or harvest).	
Period(s) in the year when the crop is grown:		Note the months	
Period(s) in the year when the crop flowers:		Note the month(s)	
Period(s) in the year when the bee species/groups are active foraging or collecting nesting materials outside the nest/hive:	1. 2. 3.	Note the species/group and the months	

Aspect	***Remarks***	**Source of information** *(refer to section G)*
Are any weeds flowering in the crop that may be attractive to bees? *If yes:* Period(s) during the crop season when weeds are flowering:	yes/no if yes: note the months	
Does the crop have extrafloral nectaries that may be attractive to bees?	yes/no	
Is the crop regularly infested with honeydew producing insects (e.g. aphids, scale insects) that may be attractive to bees?	yes/no	
Do the bees likely visit the treated crop for drinking water (e.g. dew on crop?; open water in/near crop?)	yes/no	
Are any systemic pesticides applied as soil treatment or seed treatment to a previous rotational crop?	yes/no	

This information should allow a first evaluation as to whether bees may be exposed to pesticides in the crop. This is the case when they are likely to be active foraging for pollen or (extrafloral) nectar in the crop, or when they are collecting nesting materials, when (or just after) pesticides are applied to that crop. Bees may also be exposed if a systemic pesticide has been applied to a previous rotational crop. If exposure is unlikely, pesticide risk to wild bees is considered to be low, and obtaining information on the aspects below is not necessary.

C. Exposure – bee biology factors

This section contains relevant information on bee biology that may partly determine pesticide risk. Please provide information for each bee species/group identified under A. Please also provide references to published literature or unpublished research reports when possible. Indicate when information is expert opinion, and note the name(s) of the expert(s). If the information is unavailable, please explicitly note this.

Aspect	Bee species/group			Remarks	Source of information *(refer to section G)*
	1:	2:	3:		
Period of the day when foraging or collecting nesting materials (outside the nest):					
Time spent foraging, or collecting nesting material, per day ("time-out-of-nest/hive"):				hours	
Number of days spent foraging on the crop (for an individual bee):				days	
Number of days spent foraging on the crop (for the colony):				days	
Number of different nectar and pollen plant species used during crop flowering					
Quantity of pollen collected per day:				mg per bee per day	
Quantity of nectar collected per day:				mg per bee per day	
Quantity of nectar consumed per day:				mg per bee per day	
Body weight:				mg	
% of pollen self-consumed:					
% of pollen fed to brood:					
% of nectar self-consumed:					
% of nectar fed to brood:					
Location of nest in relation to crop field –					
Inside/outside crop field:					
Approximate distance from crop field:				m	

Aspect	Bee species/group			Remarks	Source of information *(refer to section G)*
	1:	2:	3:		
Bee foraging range –					
Average distance from nest:				m	
Maximum distance from nest:				m	
Collective pollen and/or honey storage in the nest (social bees)				yes/no	
Other aspects of bee biology or behaviour that may impact exposure:					

D. Exposure & impact – pesticide use/application practices

This section contains relevant information on the types of pesticides used in the focal crop, and the application practices. If actual pesticide use data are unavailable, pesticide registration data can also be used. If the information is unavailable, please explicitly note this as well.

Product name	**Formu-lation type** (code)	**Common name (a.i.)**	**Registered?** (yes/no)	**Used?** (yes/no)	**Systemic?** (yes/no)	**IGR?** (yes/no)	**Mode of application** (spray, seed treatment, soil treatment, dusting, …)	**Application rate** (g a.i. per ha)	**Application frequency** (number of applications per growing season)	**Application timing** (date/ or month/ or timing relative to crop emergence, flowering or harvest)	**Source of information** (registration data, farmer, extension, other (*specify*)) *(refer to section G)*

E. Impact & recovery – pesticide properties

This section contains relevant information on the properties of all the pesticide active ingredients used on the crop. These aspects are independent of the actual pesticide use practices described above. Provide references to published literature or unpublished research reports when possible. If the information is unavailable, explicitly note this as well. Use more pages, if needed.

Pesticide property	**Bee species/group**				**Remarks**	**Source of information** *(refer to section G)*
	1:	**2:**	**3:**	**4:** *Apis mellifera*		
Pesticide i.:						
Contact LD_{50} (adult)					µg/bee	
Oral LD_{50} (adult)					µg/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	
Pesticide ii.						
Contact LD_{50} (adult)					µg/bee	
Oral LD_{50} (adult)					µg/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	
Pesticide iii.						
Contact LD_{50} (adult)					µg/bee	
Oral LD_{50} (adult)					µg/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	
Pesticide iii.						
Contact LD_{50} (adult)					µg/bee	
Oral LD_{50} (adult)					µg/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	

Etc.

F. Impact & recovery – life history & population dynamics factors

This section contains relevant information on bee life histories and population dynamics that may partly determine pesticide risk. Please provide information for each bee species/group identified under A. Please also provide references to published literature or unpublished research reports when possible. Indicate when information is expert opinion, and note the name(s) of the expert(s). If the information is unavailable, please explicitly note this.

Aspect	**Bee species/group**			**Remarks**	**Source of information** *(refer to section G)*
	1:	**2:**	**3:**		
(Worker) metabolic rate					
Degree of sociality					
Fraction of population/colony active out of the nest/hive (social bees)					
Time to reproductive age of queen/reproductive female (egg-adult)				days	
Number of offspring per queen/reproductive female					
Number of generations per year					
Population growth rate [note: is product of previous 3 factors]				Colony multiplication factor per unit time; or number per reproductive female per unit time	
Number of swarms per colony per year					
Migration distance of swarms				km	

G. Sources

In this section, all the institutions and persons consulted are listed, even if they were not able to provide information or data.

Reference in previous sections (No.)	**Institution or person consulted**	**Aspect**	**Contact details** (email address and/or telephone number)

Etc.

Furthermore, references to reports, articles, studies (etc.) can be listed here.

Reference in previous sections (No.)	**Title of report, article, study**	**Author(s)**	**Publication details**

Etc.

Annex 2 – Pesticides registered on the focal crops – Brazil

Sources:

Registered pesticides: AgroFit database, Ministério da Agricultura, Pecuária e Abastecimento (2011) [30]

Type, systemicity, IGR: Tomlin (2011) [37], Footprint PPDB (2011) [34]

Acute LD_{50} honeybee (oral or contact) : FAO/OSU (2011) [33]. If missing in previous, Footprint PPDB (2011) [34] and Footprint BPDB (2011) [35] – *in italics in table*

Acute LD_{50} bumblebee: Mommaerts & Smagghe (2011) [36]

Foliar residual toxicity: Pacific Northwest Extension [88] & Florida Cooperative Extension Service [87]; determined for the honeybee at maximum normal US application rates.

Active ingredient	**Type**	**Systemic**	**IGR**	**LD_{50} honeybee** (µg/bee)		**LD_{50} *Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	**Registered on**	
				lowest	**oral**	**lowest**		**Melon**	**Tomato**
Abamectin	I, A	Lim.	No	*0.002*			8-72h	X	X
Acephate	I, A	No	No	0.36		3.69 *(B. terrestris)*	>72h	X	X
Acetamiprid	I	Yes	No	8.1	14.5	2.1 *(B. patagiatus)*		X	X
Alanycarb	I	No	No	0.80					X
Alpha-cypermethrin	I	No	No	0.036		0.15 *(B. terrestris)*			X
Anilazine	F	No	--	*100*					X
Azocyclotin	A	No	No	>5					X
Azoxystrobin	F	Yes	--	>25				X	X
Bacillus thuringiensis	I	No	No	*>0.1*				X	X
Benalaxyl	F	Yes	--	*>100*					X
Benfuracarb	I	Yes	No	0.29					X
Benzalkonium chloride	F, B	?	--	n.a.					X
Beta-cyfluthrin	I	No	No	*0.001*				X	X
Beta-cypermethrin	I	No	No	0.13					X
Bifenthrin	I, A	No	No	0.013			>24h	X	X
Bitertanol	F	No	--	104				X	
Boscalid	F	Lim.	--	*100*				X	X
Bromuconazole	F	Yes	--	100					X
Buprofezin	I, A	No	Yes	>200				X	X
Captan	F	No	--	26.4				X	X
Carbaryl	I, PGR	Lim.	No	1.70		3.84 *(n.i.)*	2-14d		X
Carbofuran	I, N	Yes	No	0.15			>5d		X
Carbosulfan	I	Yes	No	0.68			3.5d		X
Cartap hydrochloride	I	Yes	No	*10*				X	X
Chlorfenapyr	I, A	Lim.	No	0.12			<4h	X	X
Chlorfluazuron	I	No	Yes	>100					X
Chromafenozide	I	No	Yes	>100					X
Chlorothalonil	F	No	--	181				X	X
Clethodim	H	Yes	--	>100					X
Clothianidin	I	Yes	No	0.044	9.92			X	X
Copper hydroxide	F	No	--	>100				X	X
Copper oxychloride	F	No	--	15				X	X
Copper oxyde	F	No	--	*>116*					X

Active ingredient	**Type**	**Systemic**	**IGR**	**LD_{50} honeybee** (µg/bee)		**LD_{50} *Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	**Registered on**	
				lowest	**oral**	**lowest**		**Melon**	**Tomato**
Copper sulfate	F	No	--	>11				X	
Cyazofamid	F	No	--	>100					X
Cyfluthrin	I	No	No	0.019		0.13 *(n.i.)*	>24h		X
Cymoxanil	F	Yes	--	25	100				X
Cypermethrin	I	No	No	0.03			>3d		X
Cyproconazole	F	Yes	--	100	1000			X	
Cyprodinil	F	Yes	--	316					X
Cyromazine	I	Yes	Yes	20			<2h	X	X
Deltamethrin	I	No	No	0.017		0.6 *(B. terrestris)*	<4h	X	X
Diafenthiuron	I	No	No	1.5				X	X
Difenoconazole	F	Yes	--	101	187			X	X
Diflubenzuron	I	No	Yes	100					X
Dimethoate	I, A	Yes	No	0.098		4.8 *(B. terrestris)*	3d		X
Dimethomorph	F	Yes	--	100					X
Dodec-7-enyl acetate	Ph	No	--	n.a.					X
Esfenvalerate	I	No	No	0.045			24h		X
Ethion	I, A	No	No	4.18				X	X
Etofenprox	I	No	No	0.13					X
Etoxazole	A	No	Yes	200					X
Famoxadone	F	No	--	>63					X
Fenamidone	F	Yes	--	75	160			X	X
Fenamiphos	N	Yes	No	1.43				X	X
Fenarimol	F	Yes	--	100				X	
Fenpropathrin	I, A	No	No	0.05			24h		X
Fenpyroximate	A	No	Lim.	*15.8*					X
Fenthion	I	No	No	0.056				X	
Flazasulfuron	H	Yes	--	>100					X
Fluazifop-P-butyl	H	Yes	--	112	200				X
Fluazinam	F	No	--	100					X
Fluquinconazole	F	Yes	--	>100				X	
Flutriafol	F	Yes	--	5				X	
Folpet	F	No	--	33.8				X	
Formetanate	I, A	No	No	10.6					X
Gamma-cyhalothrin	I	No	No	*0.005*					X
Hexadec-11-enyl acetate	Ph	No	--	n.a.					X
Hexadeca-E-11	Ph	No	--	n.a.					X
Imibenconazole	F	Yes	--	125				X	
Imidacloprid	I	Yes	No	0.004		0.02 *(B. terrestris)*	>24h	X	X
Indoxacarb	I	No	No	0.40				X	X
Iprodione	F	No	--	400				X	X
Iprovalicarb	F	Yes	--	>199				X	X
Kasugamycin	F, B	Yes	--	>25					X
Kresoxim-methyl	F	No	--	14				X	X
Lambda-cyhalothrin	I	No	No	0.093		0.11 *(n.i.)*	>24h		X

Active ingredient	Type	Systemic	IGR	LD_{50} honeybee (µg/bee)		LD_{50} *Bombus* spp. (µg/bee)	Foliar residual toxicity (hours or days)	Registered on	
				lowest	oral	lowest		Melon	Tomato
Lufenuron	I, A	No	Yes	197					X
Malathion	I	No	No	0.47			5.5d		X
Mancozeb	F	No	--	>20				X	X
Maneb	F	No	--	12					X
Metalaxyl-M	F	Yes	--	200				X	X
Metam sodium	F, N, H, I	No	No	36.2					X
Methamidophos	I, A	Yes	No	0.1			24h		X
Metconazole	F	Yes	--	97				X	X
1-methylcyclopropene	PRG	No	--	n.a.				X	X
Methiocarb	I, A, M	No	No	0.37			>3d		X
Metiram	F	No	--	40				X	X
Methomyl	I, A	Yes	No	0.42		0.57 *(B. terrestris)*	1.5d		X
Methyl bromide	I, A, N	No	No	n.a.				X	
Methyl-eugenol	Ph	No	--	n.a.					X
Methoxyfenozide	I	No	Yes	>100					X
Metribuzin	H	Yes	--	35					X
Mevinphos	I, A	Yes	No	0.086			<1.5d	X	X
Milbemectin	A	Lim.	No	0.025	0.46				X
Myclobutanil	F	Yes	--	>7				X	
Napropamide	H	Yes	--	121					X
Novaluron	I	No	Yes	>100					X
Oxytetracycline	B	Yes	--	>100					X
Permethrin	I	No	No	*0.029*		0.81 *(B. terrestris)*	0.5-2d		X
Phenthoate	I, A	No	No	0.3					X
Phorate	I, A, N	Yes	No	1.12		1-2 *(B. lucorum)*	24h		X
Pirimicarb	I	Yes	No	6.21		8.5 *(B. terrestris)*	<2h		X
Prochloraz	F	No	--	37.4					X
Procymidone	F	Yes	--	100				X	X
Profenofos	I, A	No	No	1.23					X
Propargite	A	No	No	15					X
Propamocarb hydrochloride	F	Yes	--	100	116				X
Propiconazole	F	Yes	--	14.1					X
Propineb	F	No	--	200					X
Prothiofos	I	No	No	n.a.					X
Pymetrozine	I	?	No	117			<2h	X	X
Pyraclostrobin	F	Lim.	--	73				X	X
Pyrazophos	F	Yes	--	0.65	0.84			X	
Pyridaphenthion	I	No	No	*0.08*					X
Pyrimethanil	F	Lim.	No	>100				X	X
Pyriproxyfen	I	No	Yes	>100				X	X
Quinomethionate	A, F	No	No	n.a.				X	
Quintozene	F	No	--	*100*					X
Quizalofop-P-ethyl	H	No	--	71					X
Spinosad	I	No	No	0.003			<2h		X

Active ingredient	Type	Systemic	IGR	LD_{50} honeybee (µg/bee)		LD_{50} ***Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	Registered on	
				lowest	**oral**	**lowest**		**Melon**	**Tomato**
Spirodiclofen	I, A	No	Yes	*>196*					X
Spiromesifen	I, A	No	Yes	*>200*				X	X
Streptomycin	B	Yes	--	>100					X
Sulphur	F, A	No	--	1051				X	X
Tebuconazole	F	Yes	--	176				X	X
Tebufenozide	I	No	Yes	234			<8h		X
Teflubenzuron	I	No	Yes	1000					X
Tetraconazole	F	Yes	--	>130				X	X
Tetradec-3,8,11-enyl acetate	Ph	No	--	n.a.					X
Tetradec-3,8-enyl acetate	Ph	No	--	n.a.					X
Tetradec-9-enyl acetate	Ph	No	--	n.a.					X
Tetradifon	A	No	No	60.4					X
Thiabendazole	F	Yes	--	>10				X	
Thiacloprid	I	Lim.	No	*17.3*				X	X
Thiamethoxam	I	Yes	No	0.005			7-14d	X	X
Thiophanate-methyl	F	Yes	--	>70				X	X
Triadimefon	F	Yes	--	25				X	
Triazophos	I, A, N	No	No	0.06					X
Trichlorfon	I	No	No	0.4			3-6h	X	X
Triflumizole	F	Yes	--	56.6				X	
Triflumuron	I	No	Yes	>100					X
Trifluralin	H	No	--	62.3					X
Triforine	F	Yes	--	>10				X	
Zeta-cypermethrin	I	No	No	*0.002*			>1d		X
Zoxamide	F	No	--	>153					X
(Z,Z,Z)-3,6,9-tricosatriene	Ph	No	No	n.a.					X

Annex 3 – Pesticides registered and used on the focal crops – Kenya

Sources:

Used pesticides : Farmer surveys (this study)

Registered pesticides : Pest Control Product Board (PCPB) of Kenya [31]

Type, systemicity, IGR: Tomlin (2011) [37], Footprint PPDB (2011) [34]

Acute LD$_{50}$ honeybee (oral or contact) : FAO/OSU (2011) [33]. If missing in previous, Footprint PPDB (2011) [34] and Footprint BPDB (2011) [35] – *in italics in table*

Acute LD$_{50}$ bumblebee: Mommaerts & Smagghe (2011) [36]

Foliar residual toxicity: Pacific Northwest Extension [88] & Florida Cooperative Extension Service [87]; determined for the honeybee at maximum normal US application rates.

Active ingredient	**Type**	**Systemic**	**IGR**	**LD$_{50}$ honeybee**		**LD$_{50}$ *Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	**Used (and registered) on[1]**			
				lowest	**oral**	**lowest**		**Coffee**	**Cucurbits**	**French beans**	**Tomato**
Abamectin	I, A	Lim.	No	*0.002*			8-72h		X §	X	X
Acephate	I, A	No	No	0.36		3.69 *(B. terrestris)*	>72h		X §		
Acetamiprid	I	Yes	No	8.1	14.5	2.1 *(B. patagiatus)*			X	X	X
Alpha-cypermethrin	I	No	No	0.036		0.15 *(B. terrestris)*			X §	X	X
Azoxystrobin	F	Yes	--	>25				X	X §	X	X §
Bacillus thuringiensis (kurstaki)	I	No	No	*>0.1*							X
Beta-cyfluthrin	I	No	No	*0.001*					X §	X	X
Bifenthrin	I, A	No	No	0.013			>24h		X §		
Bronopol	B	No	--	n.a.							X
Carbendazim	F	Yes	--	>20					X §		
Carbofuran	I, N	Yes	No	0.15			>5d	X			
Carbosulfan	I	Yes	No	0.68			3.5d		X §	X §	X §
Chlorothalonil	F	No	--	181				X			
Chlorpyrifos	I	No	No	0.059		1.58 *(B. terrestris)*	4-6d	X	X	X	X
Copper hydroxide	F	No	--	>100				X			
Copper oxychloride	F, B	No	--	15				X		X	X
Cymoxanil	F	Yes	--	25	100				X	X	X

[1] If marked with §: the active ingredient is registered Kenya but not for use on the crop in question.

Active ingredient	**Type**	**Systemic**	**IGR**	**LD$_{50}$ honeybee**		**LD$_{50}$ *Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	**Used (and registered) on**[1]			
				lowest	**oral**	**lowest**		**Coffee**	**Cucurbits**	**French beans**	**Tomato**
Cypermethrin	I	No	No	0.03			>3d		X §		X
Deltamethrin	I	No	No	0.017		0.6 *(B. terrestris)*	<4h		X	X	X
Diazinon	I	No	No	0.27			2d				X
Dimethoate	I, A	Yes	No	0.098		4.8 *(B. terrestris)*	3d	X §	X		X
Dithianon	F	No	--	100					X §		
Ethoprophos	I, N	No	No	*5.56*					X §		X §
Fenitrothion	I	No	No	0.059				X	X §		X §
Glyphosate	H	Yes	--	>100				X	X §	X §	X
Imidacloprid	I	Yes	No	0.004		0.02 *(B. terrestris)*	>24h		X §		
Lambda-cyhalothrin	I	No	No	0.093		0.11 *(n.i.)*	>24h		X	X	X
Malathion	I	NO	No	0.47			5.5d	X §			
Mancozeb	F	No	--	>20					X	X	X
Metalaxyl	F	Yes	--	200					X §	X	X
Methomyl	I, A	Yes	No	0.42		0.57 *(B. terrestris)*	1.5d		X	X	X
Paraquat dichloride	H	No	--	26.8				X			
Pencycuron	F	No	--	>100					X §		
Propargite	A	No	No	15						X §	X §
Propineb	F	No	--	200					X	X	X
Spiroxamine	F	Lim.	--	4.21				X §			
Sulphur	F	No	--	1051					X	X	X
Tetradifon	A	No	No	60.4							X
Thiamethoxam	I	Yes	No	0.005			7-14d		X		X
Thiophanate -methyl	F	Yes	--	>70					X §	X	X §
Triadimefon	F	Yes	--	25					X §	X	X

Annex 4 – Pesticides used on the focal crops – Netherlands

Sources:

Used pesticides: CBS (2008) [32]

Type, systemicity, IGR: Tomlin (2011) [37], Footprint PPDB (2011) [34]

Acute LD_{50} honeybee (oral or contact) : FAO/OSU (2011) [33]. If missing in previous, Footprint PPDB (2011) [34] and Footprint BPDB (2011) [35] – *in italics in table*

Acute LD_{50} bumblebee: Mommaerts & Smagghe (2011) [36]

A – Tomato (greenhouse)

Active ingredient	Type	Systemic	IGR	LD_{50} honeybee (ug/bee)		LD_{50} *Bombus* spp. (µg/bee)	Foliar residual toxicity (hours or days)	Distribution of pesticide use during the year (% of total)											
									Continuous tomato flowering period										
				lowest	oral	lowest		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abamectin	I,A	Lim.	--	*0.002*			8-72h	8	0	23	0	0	4	4	20	30	0	0	11
Acetamiprid	I	Yes	No	8.1	14.5	2.1 *(B. patagiatus)*		0	0	0	0	0	0	2	64	34	0	0	0
Azaconazole	F	No	--	n.a.				0	100	0	0	0	0	0	0	0	0	0	0
Azoxystrobin	F	Yes	--	>25				0	0	0	0	4	16	0	31	50	0	0	0
Bacillus thuringiensis	I	No	No	*>0.1*				0	47	0	10	10	9	8	6	3	4	0	3
Benzoic acid	I, F	No	No	n.a.				0	0	0	0	0	0	0	0	0	0	26	74
Bifenazate	A	No	--	8.14				0	0	0	0	63	15	7	13	2	0	0	0
Bitertanol	F	No	--	104				0	3	2	23	0	0	5	8	29	32	0	0
Boscalid	F	Lim.	--	*100*				0	10	7	19	10	5	13	15	5	6	10	0
Brodifacoum	R	No	--	n.a.				0	0	0	0	0	0	0	0	0	0	100	0
Bromadiolone	R	No	--	n.a.				0	0	0	0	54	0	4	0	0	3	38	0
Bupirimate	F	Yes	--	50				0	0	36	0	0	25	8	8	8	8	0	7
Buprofezine	I	No	Yes	>200				0	0	29	35	0	5	1	8	0	17	6	0
Carbendazim	F	Yes	--	>20				0	22	22	15	19	23	0	0	0	0	0	0
Chlorothalonil	F	No	--	181				0	0	0	14	0	3	13	27	28	3	13	0
Cyromazine	I	Yes	Yes	20			<2h	5	0	0	9	28	16	24	0	17	0	0	0
Deltamethrin	I	No	No	0.017		0.6 *(B. terrestris)*	<4h	0	0	0	0	0	0	0	1	21	78	0	0
Difenoconazole	F	Yes	--	101	187			0	0	0	100	0	0	0	0	0	0	0	0
Difethialone	R	No	--	n.a.				0	32	0	0	0	37	0	0	0	0	30	1

Active ingredient	Type	Systemic	IGR	LD_{50} honeybee (ug/bee)		LD_{50} ***Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	**Distribution of pesticide use during the year** (% of total)											
									Continuous tomato flowering period										
				lowest	**oral**	**lowest**		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Ethephon	PGR	Yes	--	34.8				0	0	0	0	2	0	42	4	3	18	15	17
Etridiazole	F	No	--	n.a.				11	0	10	6	12	17	15	8	13	7	0	0
Fenarimol	F	Yes	--	100				0	0	0	0	0	0	0	100	0	0	0	0
Fenbutatin oxide	A	No	--	100				0	10	0	0	0	44	9	12	14	11	0	0
Fenhexamid	F	No	--	102				9	20	7	13	7	9	12	14	3	5	0	2
Fenmedifam	H	No	--	23				0	0	0	100	0	0	0	0	0	0	0	0
Formaldehyde	F	No	--	n.a.				0	0	0	0	0	0	0	0	0	0	100	0
Glyphosate	H	Yes	--	>100				0	0	0	0	13	10	4	61	11	0	0	0
Hexythiazox	A	No	--	>20				0	18	0	0	0	18	5	25	35	0	0	0
Imazalil	F	Yes	--	39				13	1	0	0	9	25	17	10	6	19	0	0
Imidacloprid	I	Yes	No	0.004		0.02 *(B. terrestris)*	>24h	0	0	0	0	0	0	47	0	0	53	0	0
Indoxacarb	I	No	No	0.40				1	0	0	88	0	0	2	2	2	3	2	0
Iprodione	F	No	--	400				9	5	1	47	4	7	6	1	7	7	7	0
Potassium iodide	F	No	--	>0.78				0	0	6	10	14	10	27	3	11	19	0	0
Potassium thiocynate	F	No	--	>1.0				0	0	6	10	14	10	27	3	11	19	0	0
Lecanicillium muscarium VE6	I	No	No	*>110*				0	0	0	0	0	0	0	5	5	1	89	0
Maneb	F	No	--	12				0	0	0	0	0	0	100	0	0	0	0	0
MCPA	H	Yes	--	100				0	0	0	0	33	33	0	0	33	0	0	0
Mecoprop P	H	Yes	--	>21				0	0	0	0	33	33	0	0	33	0	0	0
Methomyl	I	Yes	No	0.42		0.57 *(B. terrestris)*	1.5d	0	0	0	0	0	0	0	0	0	26	52	22
Methoxyfenozide	I	No	Yes	>100				5	0	8	38	11	3	4	10	4	3	15	0
Paecylomyces fumosoroseus apopka 97	I, A	No	No	n.a.				0	0	0	0	0	0	0	0	0	0	0	100
Peracetic acid	F	No	--	n.a.				0	0	0	0	0	0	0	0	0	0	0	100
Piperonil butoxide	I	No	No	>10				0	0	0	0	0	0	0	40	60	0	0	0
Primimicarb	I	Yes	No	6.21		8.5 *(B. terrestris)*	<2h	0	0	0	0	0	100	0	0	0	0	0	0
Propamocarb	F	Yes	--	n.a.				0	16	16	16	0	0	23	30	0	0	0	0
Propamocarb	F	Yes	--	100	116			0	0	5	52	8	6	8	7	5	1	8	1

Active ingredient	Type	Systemic	IGR	LD_{50} honeybee (ug/bee)		LD_{50} ***Bombus* spp.** (μg/bee)	Foliar residual toxicity (hours or days)	Distribution of pesticide use during the year (% of total)											
									Continuous tomato flowering period										
				lowest	oral	lowest		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
hydrochloride																			
Pymetrozine	I	No	No	117			<2h	0	0	7	23	11	18	7	16	13	7	0	0
Pyraclostrobin	F	Lim.	--	73				0	10	7	19	10	5	13	15	5	6	10	0
Pyrethrins	I	No	No	0.053			<2h	0	0	0	0	0	0	0	40	60	0	0	0
Pyridaben	I	No	No	0.024			<2h	0	0	0	0	35	0	0	0	16	16	17	17
Pyrimethanil	F	No	--	>100				7	8	3	34	5	4	13	6	7	3	11	0
Pyriproxifen	I	No	Yes	>100				11	0	6	20	13	5	12	8	14	0	11	0
Spinosad	I	No	--	0.003			<2h	0	0	0	0	12	12	29	16	14	16	0	0
Spiromesifen	I	No	Yes	*>200*				10	21	0	0	0	0	0	20	11	12	24	1
Teflubenzuron	I	No	Yes	1000				21	0	0	0	0	0	0	0	30	15	15	19
Thiacloprid	I	Lim.	No	*17.3*				0	0	0	0	0	43	0	25	32	0	0	0
Thiophanate methyl	F	Yes	--	>70				15	0	7	15	7	8	0	9	7	4	28	0
Thiram	F	No	--	74				27	2	7	0	0	0	28	22	14	0	0	0
Tolylfluanide	F	No	--	92				0	0	0	100	0	0	0	0	0	0	0	0
Trichoderma harzianum rifai T22	F	No	--	n.a.				9	11	10	25	8	9	10	8	10	0	0	0
Triclopyr	H	Yes	--	100				0	0	0	0	100	0	0	0	0	0	0	0
Triflumizole	F	Yes	--	56.6				7	6	12	0	34	4	10	11	15	0	0	0
Verticillium lecanii	I	No	No	n.a.				0	0	22	49	10	19	0	0	0	0	0	0
Hydrogen fluoride	F, B	No	--	n.a.				0	0	0	0	0	0	0	0	0	0	100	0
Hydrogen peroxide	F, B	No	--	n.a.				0	0	0	0	0	0	0	0	0	0	0	100
Sulphur	F	No	--	1051				4	9	4	6	13	8	6	5	7	4	34	0

B – Apple

Active ingredient	Type	Systemic	IGR	LD_{50} honeybee (ug/bee)		LD_{50} *Bombus* spp. (µg/bee)	Foliar residual toxicity (hours or days)	Distribution of pesticide use during the year (% of total)							
								Control of aphids; honeydew							
									All bees: flowering of apple & dandelion		**Bumblebees:** only nesting+ not foraging in crop				
				lowest	oral	lowest		Jan-Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Dec
1-naftyl acetic acid	PGR	Yes	--	*>120*				0	0	0	0	4	91	5	0
2,4-D	H	Yes	--	97.4				0	48	15	24	13	1	0	0
Acetamiprid	I	Yes	No	8.1	14.5	2.1 *(B. patagiatus)*		20	41	39	0	0	0	0	0
Aluminium phosphide	I, R	No	No	*0.24*				0	0	0	0	100	0	0	0
Amitrole	H	Yes	--	100				0	3	0	0	0	0	35	63
Azadirachtine A	I	No	No	2.5			<2h	30	32	37	0	0	0	0	0
Bacillus thuringiensis	I	No	No	*>0.1*				48	52	0	0	0	0	0	0
Benzyladenine	PGR	?	--	n.a.				0	0	100	0	0	0	0	0
Boscalid	F	Lim.	--	*100*				0	0	0	0	33	32	35	0
Bromadiolone	R	No	--	n.a.				0	100	0	0	0	0	0	0
Bupirimate	F	Yes	--	50				0	23	21	20	23	13	0	0
Calcium hydroxide	F	No	--	n.a.				0	0	0	0	0	0	0	100
Captan	F	No	--	26.4				18	9	8	10	9	6	6	34
Codlemone	Ph.	No	--	85				0	0	100	0	0	0	0	0
Cydia pomonella granulosis virus	I	No	No	n.a.				0	0	0	25	29	46	0	0
Cyprodinil	F	Yes	--	316				39	61	0	0	0	0	0	0
Deltamethrin	I	No	--	0.017		0.6 *(B. terrestris)*	<4h	0	35	18	34	13	0	0	0
Dicamba	H	Yes	--	15.3				0	0	0	96	0	4	0	0
Difenoconazole	F	Yes	--	101	187			1	27	18	18	20	0	0	16
Diquat dibromide	H	No	--	27.8				0	0	53	0	0	47	0	0
Dithianon	F	No	--	100				17	14	17	20	16	15	0	0
Dodine	F	Yes	--	4.9				36	11	0	15	10	14	14	0

Active ingredient	Type	Systemic	IGR	LD_{50} **honeybee** (ug/bee)		LD_{50} ***Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	**Distribution of pesticide use during the year** (% of total)							
								Control of aphids; honeydew							
									All bees: flowering of apple & dandelion		**Bumblebees:** only nesting+ not foraging in crop				
				lowest	**oral**	**lowest**		**Jan-Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct-Dec**
Epoxiconazole	F	No	--	>100				50	50	0	0	0	0	0	0
Ethephon	PGR	Yes	--	34.8				0	0	18	8	12	25	20	17
Fenoxycarb	I	No	Yes	>100			24h	0	37	28	18	17	0	0	0
Flonicamid	I	Yes	No	*>51000*				14	17	17	7	22	22	0	0
Fluazifop-p-butyl	H	Yes	--	112	200			0	0	0	37	0	63	0	0
Gibberillic acid A3	PGR	Yes	--	*>25*				0	0	100	0	0	0	0	0
Gibberillin A4 A7	PGR	Yes	--	*>25*				0	33	26	40	0	0	0	0
Glufosinate ammonium	H	Lim.	--	>100				0	15	19	22	24	20	0	0
Glyphosate	H	Yes	--	>100				0	18	25	25	14	2	0	16
Imidacloprid	I	Yes	No	0.004		0.02 *(B. terrestris)*	>24h	25	18	24	14	1	0	0	17
Indoxacarb	I	No	No	0.40				0	21	20	21	16	23	0	0
Copper oxychloride	F	No	--	15				73	14	14	0	0	0	0	0
Kresoxim methyl	F	No	--	14				15	24	29	31	0	0	0	0
Linuron	H	Yes	--	160				0	0	7	53	40	0	0	0
Mancozeb	F	No	--	>20				38	62	0	0	0	0	0	0
MCPA	H	Yes	--	100				0	0	15	17	21	33	0	14
Mecoprop P	H	Yes	--	>21				0	51	25	22	2	0	0	0
Metazachlor	H	No	--	>20				0	0	0	0	100	0	0	0
Methoxyfenozide	I	No	Yes	>100				0	23	19	30	29	0	0	0
Metiram	F	Yes	--	40				0	13	18	9	8	52	0	0
Mineral oil	A, I	No	No	n.a.		500 *(n.i.)*		84	13	0	3	0	0	0	0
Pirimicarb	I	Yes	No	6.21		8.5 *(B. terrestris)*	<2h	0	14	15	18	16	26	0	11
Prohexadione calcium	PGR	Yes	--	100				0	48	25	15	12	0	0	0

Active ingredient	**Type**	**Systemic**	**IGR**	**LD$_{50}$ honeybee** (ug/bee)		**LD$_{50}$ *Bombus* spp.** (µg/bee)	**Foliar residual toxicity** (hours or days)	**Distribution of pesticide use during the year** (% of total)							
								Control of aphids; honeydew							
									All bees: flowering of apple & dandelion		**Bumblebees:** only nesting+ not foraging in crop				
				lowest	**oral**	**lowest**		**Jan-Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct-Dec**
Pyraclostrobine	F	No	--	73.1				0	0	0	0	33	32	35	0
Pyrimethanil	F	No	--	>100				33	31	36	0	0	0	0	0
Spirodiclofen	I, A	No	Yes	*>196*				0	0	40	35	25	0	0	0
Tebufenpyrad	A	No	No	3.29				0	0	0	100	0	0	0	0
Thiacloprid	I	Lim.	No	*17.3*				34	34	32	0	0	0	0	0
Thiophanate methyl	F	Yes	--	>70				0	0	0	0	0	0	0	100
Thiram	F	No	--	74				0	0	38	37	25	0	0	0
Tolylfluanid	F	No	--	92				0	0	50	0	50	0	0	0
Triadimenol	F	Yes	--	*>200*				0	21	21	19	18	22	0	0
Triclopyr	H	Yes	--	100				0	100	0	0	0	0	0	0
Trifloxystrobine	F	No	--	>200				0	19	25	26	29	0	0	0
Sulphur	F	No	--	1051				12	13	11	19	25	21	0	0