EIP-AGRI Focus Group
Bee health and sustainable beekeeping

MINIPAPER 06: Developing and enhancing good practices to mitigate major bee health stressors: pesticides and lack of resources

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1. Introduction – Motivation

Bees are essential for the pollination of wild plants and crops, contributing to the EU food production (fruits, vegetables, seeds, etc). However, agricultural practices can impact directly on the bee health, and agroecosystems expose bees to pesticides and nutritional stress (for example, low-quality food resources). Though, farmers are not always aware of the importance of insect pollination in the elaboration of yield and product quality.

It is possible to reduce stress to bees and thus improve bee health by adapting or changing agricultural practices. There are already some initiatives in several EU member states to raise awareness of farmers about honeybees. Some measures are effective or could be improved. Other are not adapted or not adopted by the farmers for several reasons (technical problem, "lock-in"). In some cases, farmers ask the help of beekeepers to improve pollination and partnerships are established by pollination contracts.

By gathering and sharing these experiences, we will be able to identify some good practices for the bee health targeting beekeepers and farmers, that could be promoted at the EU and national level.

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2. Dissertation

Stress from pesticides and lack of food resources

In the following chapter, the state of the art and the most relevant and recent discoveries on the topic are highlighted below.

Pesticides

Pesticides can cause lethal and sublethal effects on bees, for example making them less productive and weaker in terms of nourishment and immunity. Pesticides also interact with other bee stressors like pathogens, nutritional deficiencies or adverse climatic conditions. Pesticide-exposed bees are more susceptible to overcome harsh conditions, such as overwinter (Lu *et al.* 2014).

a) Exposure

Pesticides are typically used on crops to control pests (insects, pathogens, weeds), and they can be sprayed, used in the soil or as seed dressing. Bees are exposed to pesticides during spraying operations when they are foraging in the fields, but also by drift from treated field, or by dust during seeding with coated seeds. They can also be indirectly exposed when foraging in crops, weeds or wildflowers near and in the crops, where they can be exposed to residues in the fields just after spraying. As systemic products are mostly persistent in soil and water, they can be found at significant concentrations in pollen or nectar that bees will collect in buffer zones, flowering strips, cover crops and catch crops. Systemic pesticides can in fact move up into all aerial plant parts (stems, leaves, nectar, and pollen). Bees can as well be exposed through pesticide residues in water, or by guttation water from plants they collect in the first hours of the day (EFSA, 2013).

b) Acute and chronic toxicity

Mechanisms of pesticide toxicity can be summarized in two major categories:

- Acute toxicity occurs in the field when bees are exposed to high levels of pesticides by contact or ingestion. In the laboratory, acute toxicity is measured by the LD50, which estimates the dose of the chemical (in µg per bee) required to kill 50% of the exposed population of bees.
- Chronic toxicity occurs when bees are exposed to low doses of pesticides for a long period. It can affect adult worker honeybees but also larvae in the beehive through contaminated nectar, pollen water (even in long-term storage of food reserves) and wax.

c) Sublethal effects

Pesticide exposure can lead to sub-lethal effects (Henry *et al.*, 2015, Tong *et al.*, 2019), such as reduction in learning, navigation, foraging, flight, locomotion disrupting their ability to return to the nest (i.e. homing) and thermoregulation, all of which are essential to honeybee colony survival. With the development of functional analysis, alteration in the levels of expression of some proteins, translation and protein synthesis, and ATP synthesis are also detected in honeybee exposed to pesticides. These sublethal effects are a major concern for bees (Ruiz-Martínez, 2018).

Nutritional stress

Nutritional stress is a common problem for bee colonies that is often involved in bee losses.

a) Exposure and hazard

Industrialized (high input) agriculture changes land use, reduces plant diversity and natural habitats, and impacts the quality and quantity of food resources (i.e. nectar and pollen). Honeybees are vulnerable to

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such reduced food quality and availability, because nutritional stress plays a crucial role in colony health and dynamic (disruption of egg laying, brood and worker activities) and is therefore closely linked to the bee losses and poor colony health. Numerous studies observed a link between nutrition and immunity (DeGrandi-Hoffman & Chen, 2015). Immune functions are affected by restriction of protein (pollen) and carbohydrates (nectar and honey). The flower abundance and richness are key elements to guarantee a good nutrition to bees, and nutritional stress can depend upon the lack of plant biodiversity (Naug, 2009). Nutritional limitations can also be caused by beekeeping management: excessive density of beehives in relation to the nutritional resources available, unbalanced artificial diets (sugar and protein supply). In addition, with global warming, a change in the resources available to bees in time and space are observed. Nutritional deficits were identified as one of the major causes of honeybee colony losses by beekeepers in the USA between 2007 and 2015 (21-58%) (Seitz *et al.* 2016).

b) Interaction nutritional stress-pesticides

A nutritional stress, such as starvation, can interact synergistically with pesticide exposure and reduce honeybee survival, hemolymph energy levels and food consumption (Tosi *et al* 2017). The combination of these stresses can have individual level impacts on bee behaviour and physiology (Tong *et al.*, 2019) and likely affect the health of the colony.

Interaction between bee stressors

One most concerning aspect for bees is related to multi exposure of bees to stressors. Combined effect of multiple stressors are indeed often more harmful than stressors alone. Even one stressor that does not incur any significant effect can result in sub-lethal or lethal effect in combination. Yet it is well known now that bees are chronically exposed to a wide range of pesticides mixtures. For example, fungicides such as ergosterol biosynthesis inhibitors (EBI), have very low toxicity in themselves but can synergistically increase the toxicity of neonicotinoids (Sgolastra *et al.* 2017), pyrethroids, and even novel insecticide classes such as butenolides (Tosi and Nieh, 2019), in certain cases up to 1,000-fold (Goulson *et al.*, 2015). Recent studies indicate that interactive effects between pesticides-nutritional stress (Tosi *et al.*, 2017) and pesticides-pathogens (Alaux *et al.*, 2010) could be especially harmful. A large number of infectious and parasitic agents affect bee colonies too, interacting with pesticide residues and other stress factors (lack of food for example) to which bees may be exposed both concomitantly and successively. The role of co-exposure to pesticides, nutritional stress, and infectious agents play a major role in bee health (ANSES report, 2015).

Limitations of risk assessment

The risk assessment is currently based both on the probability of exposure to stress and its hazard. To the light of scientific knowledge, this risk assessment procedure has some limits (Decourtye *et al* 2013). For example, it is difficult to determine exactly the pesticide exposition. For example, non-attractive crops for bees can also be a source of exposure (Simon-Delso *et al* 2017). In addition, we observe multiple and unpredictable pesticides combination (cocktail) in the hive, even including non-authorised products (Simon-Delso *et al.*, 2014; Tosi *et al.* 2018). The hazard study of all these cocktails is complex, especially because pesticide toxicity is altered by numerous stressors (diseases, nutrition) and factors (bee age, seasonality, climatic conditions) further complicating the risk assessment (Tosi and Nieh 2019).

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Existing best practices, tools, projects

Reducing pesticides risk to bees

Figure 1 Many regulations apply to limit pollinators exposure to pesticide (France, Nouvelle-Aquitaine)
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In the last few years, some actions were established to reduce pesticide risk to honeybee at European or state level. Other measures coming could be implemented. Some measures are given in Annex 1. In addition, EFSA published in 2013 a Guidance document intended to extend testing requirements in risk assessment, with the need to better take into account for sub-lethal effects to bees, effects on brood or larvae and better determine effects in bees from exposure to systemic pesticides (EFSA 2013).

Farmers can put in place several strategies and mitigation measures in order to reduce the risk from pesticides to bees as presented in table 1. The selection of pesticides with low persistence, systemicity and toxicity for bees is likely the most effective and feasible strategies in the reduction of pesticide risk. The other strategies may locally and/or temporally reduce the risk but show some limitations if highly toxic, systemic and persistent pesticides are used. For several strategies, their feasibility is low for obvious practical reasons. For example, pesticide application in the absence of wind is difficult to observe if the optimal timing of pesticide application coincides with a windy period.

Mitigation strategies/measures	Effectiveness	Feasibility
Selection of pesticides with low persistence, systemicity and toxicity for bees	High	Medium/High
Avoid pesticide drift (e.g. do not apply in the presence of wind or use anti-drift nozzle)	Medium	Medium/High
Apply pesticides when bees are not foraging on the target crop, either at dusk or when plant is not flowering	Medium	Low/Medium
Reduce surface water contamination	Medium	Medium
Avoid tank mixtures with pesticides that can interact synergistically.	High	Medium
Avoid pesticide application in an area (buffer zone) at the edge of the crop	Medium	Medium
Know where managed bee colonies are located and notify beekeepers when pesticides are applied	Medium/High	Low/medium

Table 1 List of mitigation strategies/measures to reduce pesticide risk and their relative effectiveness and feasibility for farmers

Reducing nutritional stress

Bee nutrition is becoming better known with still some shadow areas about bee requirements. Nutritional aspects of honeybee were recently integrated in the reflection of agricultural landscape. Resources can be improved by off-field and on field practises (Garibaldi *et al* 2014). Off-field practices consists to diversify

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and increase the abundance of resources outside the crop field, without affecting crop management: nesting resources, hedgerows and flower strips, conserving or restoring (semi-) natural areas, enhancing farmland heterogeneity and smaller crop fields.

Figure 2 Catch crop providing food for pollinators (France, Nouvelle-Aquitaine)
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In contrast on-field practices are all applied directly in the crop field: reducing the use of herbicides, no-tillage farming, enhancing flowering plant richness within crop fields, organic farming. For example, agri-environment measures were developed to support farmers in creating flower-rich feeding fields and strips for beneficial insects and pollinators. However, studies are needed to know in the field the real benefits of these measures.

In any case, the maximum livestock load has to be suited to the nutritional support of the environment (urban, nature, several types of rural ecosystems) and the season (flowering of agri or natural monocultures, other flowering).

Artificial feeding goal is the maintenance of the colonies (usually in winter) to its stimulation for the population increase (in different seasons, for long periods, and with protein foods in addition to sugary ones). It takes place at the end of summer or the beginning of autumn to replace harvested honey (so that the population does not rapidly decay or renew the old summer bee for a new bee for winter), at the end of winter (for a rapid development of colonies before spring) and between blooms or times of drought. In the European beekeeping practices, nutritional supply is often limited to provide sugar syrup before the winter or solid sugar during the winter. North American beekeeping is more interventionist with for example pollen patties supplements. Nutritional supply becomes a tool that can help both the health of bees, reducing nutritional stress, and the sustainability of professional beekeeping.

In Annex 2, some measures and practices favourable to bee nutrition are presented.

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Listing of partnerships of farmers - beekeepers

Figure 3 Farmers and beekeeper meeting at an apiary for a better understanding and cohabitation (France)
© Association de Développement Apicole Nouvelle-Aquitaine

Partnerships of farmers – beekeepers are developed in different contexts as in the pollination service. By bringing hives in the crop, the farmer increases the chance of the crop pollination and thus probability of harvest increase in quantity but also in quality. For the beekeeper, many advantages can be back of the partnerships like knowing farmer's practices around the hives (like using pesticides), honeybee use the resource to the colony development, and in addition the beekeeper can receive a monetary benefit.

Some projects exist and are listed in Annex 3.

3. Conclusions/Key messages

Bee stressors such as pesticides and nutritional resources are becoming better known. However, novel challenges are appearing like new exposure routes, chemical products, and interactions (synergism) with other stressors (climate change).

To reduce stressors effect on bees, numerous mitigation measures are known, but scarcely implemented and mostly local - those already implemented should be more widely adopted by the farmers. A lack of farmer awareness and lock-ins exist. With the help of agricultural advisers and enhancing incentive measures supported by political authorities, mitigation measures would be more efficient and a transition towards bee-friendly agriculture must be initiated. Pollinators preservation in agroecosystem is not incompatible with an agriculture generating yields and gross margins (Catarino *et al*. 2019, see also results of the EIP-AGRI Focus Group on Ecological Focus Areas).

4. Research needs

Increase the scientific knowledge about exposure and effects of stressors from agriculture

New pesticides coming on the market can cause threats via novel mechanisms, like the recent butenolides (flupyradifurone) and sulfoxamines (sulfoxaflor). To assure safety, research is needed to develop ecotoxicological methods able to detect sublethal effects at the bee and colony level before releasing the substance in the fields. In addition, these new pesticides that have potential new fate and behaviour in the environment could be leading to chronic exposure or exposure outside the treated field.

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Therefore, monitoring efforts should be reinforced, especially for new substances, and to identify new exposure routes (intercrops, persistent substances). This is even more important in the context of climate change with unknown consequences on the behaviour and toxicity of substances and leading to a fast agricultural practice changes. All of these elements could give unexpected adverse effects.

Food resources are also a challenging and relevant topic for bee health research. Assessing resource capacity of environments must be improved, as well as the investigation of resource quantity and quality from new hybrid varieties in comparison to current ones. On the other hand, progress must be made in understanding bee nutrition and its role for honeybee health. For example, it appears important to determine the nutritional needs of colonies to support bee fitness (for example, immune function) throughout the year. The role of microbiome in nutrient processing and immunity should also be investigated. Links between nutrition and other stressors, such as pesticides toxicity and pathogen development should be further developed.

Interactive effect between stressors is a crucial point because bees are not exposed to a single stressor but to a large number of stressors in the field, acting together or subsequently. Interactions exist between pesticides and nutrition, pesticides and pathogens, or pathogens-pesticides-nutrition together. It is important to improve the risk methodologies to deal with these field interactions.

Implementation of mitigation agricultural practices to reduce stressors on bees in agroecosystem

Mitigation practises are essential to reduce stressors on bees in agroecosystem. Research is needed to develop new mitigation practises and assess impacts on bee health, for example via large scale assessments. Mitigation and support measures to bees must be complementary and integrated with the existing approach of Integrated Pest Management (IPM) (Figure 1). In this way, the development of Integrated Pest and Pollinator Management (IPPM) concept should be useful (Biddinger *et al.* 2015). This approach must include practices to support bees (flower strips) and reduce risks (pesticide drift, use of harmful pesticides, mowing of potential contamination sources such as wildflowers in orchards).

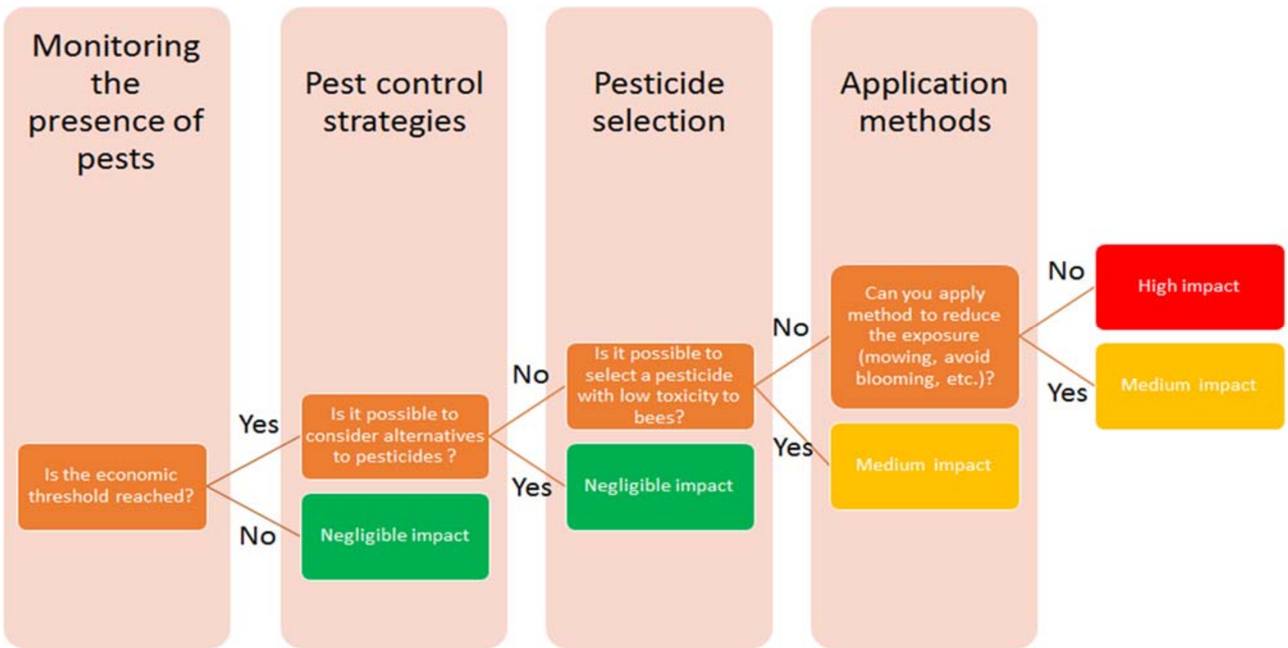

Figure 1 Decision tree of an IPM approach taking into account of pollinators

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Once mitigation practises are validated, a dissemination work should be done by different ways not only about mitigation practise but also on the importance of bees for agriculture. This dissemination work should be realized by independent advisers and also advisory bodies on pollination health and consequent benefits for farmers. Agreements between beekeepers and farmers, enforced by local authorities could also be developed. Associations should agree upon indicators, tools, and practices to measure added value of pollinator preservation.

5. Ideas for innovations

Bees in agricultural landscapes need a better environment. Some ideas to achieve this goal:

Further research needs coming from practice, ideas for EIP AGRI operational groups and other proposals for innovation can be found at the final report of the focus group, available at the FG webpage https://ec.europa.eu/eip/agriculture/en/focus-groups/bee-health-and-sustainable-beekeeping

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Annexes

Annex 1 - Initiatives to reduce pesticide risk

Goal	Measures / Practices	Country	(1) Frame work	(2) Adopted	(3) Efficacy	(4) Improvement	Description	Link
Reduce PPP exposure in attractive crops	Spraying at the end of the day, outside foraging periods	BE, FR, GR	Yes	Yes	Yes	More farmer sensitization, not only for toxic product to bee		http://adana.adafrance.org/infos/Communication.php
Reduce PPP exposure in attractive crops	Ban on some systemic insecticides (i.e. neonicotinoids) on flowering crops (2013-2018)	EU	Yes	Yes	Yes		Regulatory	
Reduce PPP exposure in attractive crops	Ban on systemic pesticide for all crop	FR	Yes	Yes	Yes	Reduce residues in non-target crop (especially melliferous crops such as sunflower and rapeseed) and wildflowers	Regulatory	
Reduce PPP exposure by reducing drift towards outside the crop (wild flowers, hedge, water,...)	Use specific spray nozzle, avoid pesticide spraying when windy weather	BE,	Yes	Yes	Unknown			https://protecteau.be/fr/phytos/professionnels/pulverisation/reduction-de-la-derive
Reduce PPP risk	Pesticide selectivity list for pollinator	USA	-	-	-	Reduce toxicity risk when a pesticide is sprayed in orchard		Example from USAA Pesticide Decision-Making Guide to Protect Pollinators in Tree Fruit Orchards
Reduce PPP risk	Ban / restriction of pesticide mixture in tank (ex triazol with pyrethrinoids)	FR (but no in BE)	Yes	?	?	Extend to all EU members		https://bourgognefranchecomte.chambres-agriculture.fr/fileadmin/user_upload/Bourgogne-Franche-Comte/061_Inst-Bourgogne-Franche-Comte/CA71/71AGRI_Techniques/71Grandes_cultures/reglementation_aout2018.pdf
Reduce PPP exposure in attractive crops	Do not apply pesticides dangerous to bees and other insect pollinators during bloom	IT	Yes	Yes	Yes		Regional regulatory	http://bur.regione.emilia-romagna.it/dettaglio-inserzione?i=2408a8b35f2047258a402224bcb742b0

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Goal	Measures / Practices	Country	(1) Frame work	(2) Adopted	(3) Efficacy	(4) Improvement	Description	Link
Controling pesticide uses	Introduction to organization and implementation of training activities on the sustainable use of plant protection products in compliance with provisions of Directive 2009/128/EC	EU, GR	Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/01._Introduction_to_EU_legislation_regarding_PPP_and_their_use.pdf
	Legal requirements		Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/02._Legal_requirements.pdf
	Safe use – Identification of hazards and risks to humans		Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/02._Legal_requirements.pdf
	Safe use – Measures to minimize risks to humans		Yes	Yes	Unknown	?	Regulatory	
	Safe use – application equipment		Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/05._Safe_use_-_application_equipment.pdf
	Environmental aspects and sustainable use of PPPs: Drift		Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/06._Environmental_aspects_and_sustainable_use_of_PPPs_Drift.pdf
	Environmental aspects and sustainable use of PPPs: IPM		Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/07._Environmental_aspects_and_sustainable_use_of_PPPs_-_IPM.pdf
	Minimisation of side effects of PPPs for the environment		Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/08._Minimisation_of_side_effects_of_PPPs_for_the_environment__new.pdf
	Post-training dissemination		Yes	Yes	Unknown	?	Regulatory	http://www.minagric.gr/images/stories/docs/agrotis/Georgika_Farmaka/elenxoi/09._Post-training_dissemination.pdf

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Annex 2 - Initiatives to reduce nutritional stress

Goal	Measures / Practices	Country	(1) Frame work	(2) Adopted	(3) Efficacy	(4) Improvement	Description	Link
Increase food availability in time and space	Flower strips	BE	Yes Agri environ mental scheme			Species composition must be selected more specifically for bees	-	Natagriwal
Facilitate the selection of bee-friendly crops	Publish a list of crops/flowers of interest	FR	No	_		Need of financial/regulatory scheme	Database with information regarding attractivity for bees, and interest for pollen/nectar	http://www.interapi.itsap.asso.fr/ https://agriculture.gouv.fr/decouvrez-la-liste-des-plantes-attractives-pour-les-abeilles
Limitation hives load	Total amount of bee colonies is determined and cannot be increased	IL	Yes	?	?			-
Increase food resources (indirect effect)	Sowing lavender and other aromatic plants among the olive trees	ES						Honey olive grove (https://revistaalmaceite.com/2017/01/31/el-olivar-de-miel-evita-la-erosion-potencia-el-oleoturismo-y-diversifica-la-produccion/)
Increase food availability in time and space	National platform for sharing initiatives	NL	No	Yes	?	More flowers for bees in general	Nederland Zoemt! : national platform for the promotion of initiatives by governments, farmers and civilians to improve more flowers in agricultural and urban areas	https://www.nederlandzoemt.nl/?gclid=EAIaIQobChMInrH0s7Dk5QIVF-R3Ch1LgQS-EAAYASAAEgK7A_D_BwE
Protect beekeeping flora	It is forbidden to cut or eradicate beekeeping plants and trees	GR	Yes	Yes	?	Aid for planting bee plants	Also through the EC directive for the honey	Law 657/2-11-1963
Protect beekeeping flora	Permission to place honey bee colonies in the forests	GR	Yes	Yes	Yes			Law 190/4-3-81

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Annex 3 - Farmer-beekeeper partnerships

Which producer?	Description	Country	Contract (yes/no)	Reward (yes/no)	Conditions	Improvement	Description	Link
Farmers (orchards, …)		BE	No systematically	Not always	Yes		Contract example provide	Contract pollinisation
Farmers		BE						http://www.cari.be/article/offres-et-demandes-de-pollinisation/
Farmers and beekeepers	Survey of apiaries in connection with farmers and advisers	FR	No	No	Experimental project for cooperation	Understanding of relationships between contaminations in beehives and farming practices		SURVapi
Farmers (especially for seed production)	Platform for networking between beekeepers and farmers	FR	Yes	Yes/no		Written contracts not always expected by seed producers nor beekeepers	Beewapi : networking plateform created by ANAMSO, GNIS, UFS, ITSAP	http://www.beewapi.com/
Mutual understanding between farmers and beekeepers	Meeting at an apiary	FR	No	No	None		ADA NA actions	http://adana.adafrance.org/infos/Communication.php
Beekeepers	Protection of the local subspecies of Apis mellifera	IT	No	No			Regional regulatory	http://bur.regione.emilia-romagna.it/dettaglio-inserzione?i=2408a8b35f2047258a402224bcb742b0
Mutual understanding between farmers and beekeepers	Memorandum of understanding between seed producers and beekeepers	IT	No	No	Yes			http://www.sementi.it/comunicato-stampa/450/firmato-protocollo-intesa-per-valorizzare-colture-sementiere-e-tutelare-il-patrimonio-apistico
BeeWeb	Platform for farmers and beekeepers for pollination purposes	RS	Yes	Yes	Depends on producers		Contracts for pollination	https://www.beeweb.co/en
Beepath	Increase awareness of bees in Lijubljana and collaboration with farmers	SL	No	No		The relationship and understanding is improved	They form common exhibitions	https://urbact.eu/bee-path
BeepathNet	Increase awareness of bees in several cities, collaboration with farmers	SL, GR, IT, PT, HU PL	No	No		The relationship and understanding is improved	In progress!	https://urbact.eu/beepathnet
Save the bees and farmers	Towards a bee friendly agricultural environment	DE			A new initiative		New citizens initiative starting the collection of 1.000.000 signatures	https://beesfarmers.armada.digital/

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