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Healthy honey bees and sustainable maize production: why not?

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Abstract

In the early 2000s, Italian beekeepers began to report bee mortality events linked to maize sowing. Evidence pointed to three neonicotinoids (imidacloprid, clothianidin, thiamethoxam) and a phenylpyrazole (fipronil) used for seed dressing that were dispersed in the environment during sowing. Following these events and based on the precautionary principle, in September 2008, the Italian Ministry of Health suspended these four active ingredients as maize seed dressing. Here we show that in Italy after the precautionary suspension, the number of bee mortality events linked to maize sowing drastically declined. At the same time, the average annual maize production per hectare remained unchanged. This finding is indicative of the possibility to maintain stable maize productions without affecting honey bee health status. The implementation of Integrated Pest Management for maize production is discussed.

Key words: *Apis mellifera*, bee mortality, *Zea mays*, neonicotinoids, imidacloprid, clothianidin, thiamethoxam, fipronil, precautionary suspension, EU moratorium.

Historical background

Since 1994, many beekeepers in France have been reporting alarming signs of abnormal behaviours and losses of honey bees (i.e. forager bees not returning to their hives) in areas where sunflower and maize seed-dressed with the systemic insecticide imidacloprid (Gaucho®) were cultivated (Doucet-Personeni *et al.*, 2003). Following these events the French Government decided to apply the precautionary principle and in 1999 and 2004 suspended the use of Gaucho® in sunflower and maize, respectively (Maxim and van der Sluijs, 2013). Restrictions in the use of imidacloprid and other insecticides (thiamethoxam, clothianidin and fipronil) were introduced in 2008 also in Italy and in other countries (Germany and Slovenia), after important bee mortality events reported during maize sowing (Bortolotti *et al.*, 2009; Alix *et al.*, 2009; Pistorius *et al.*, 2009). In fact, it was proved that during this practice, dust containing relevant amounts of pesticides originating from dressed seeds may escape from the pneumatic sowing machine to the environment and fall on the wild vegetation surrounding the sown area (Greatti *et al.*, 2003; Greatti *et al.*, 2006). Therefore, bees may be poisoned by foraging on contaminated flowers near the maize fields, by collecting contaminated dew or by directly intercepting the toxic dust in flight (Girolami *et al.*, 2012).

From 2008 to 2014 the number of publications dealing with neonicotinoids and bees increased dramatically (from ca 10 to ca 45 items/year) (Lundin *et al.*, 2015). The role this class of insecticides plays in bee decline, appeared thus evident (Tennekes and Sánchez-Bayo, 2011; Goulson, 2013; Lu *et al.*, 2014; Woodcock *et al.*, 2016). As a consequence, in 2013 the European Commission introduced a restriction in the use of imidacloprid, thiamethoxam, clothianidin and fipronil for seed treatment, soil application (granules) and foliar treatment (in all pre-flowering stages) in crops attractive to bees (EU, 2013a; 2013b). After this decision, strong debates arose. Doubts about the stability of crop production without the use of these plant protection products and concerns regarding the effectiveness of this moratorium as mitigation measure against bee decline were the main discussed topics (Stokstad, 2013). In this context, Italy represents a model to evaluate the effectiveness of the EU moratorium, given that the three mentioned neonicotinoids and fipronil have been suspended for maize seed dressing since September 2008 (Ministero della Salute, 2008).

The output of this Italian case study may be considered also outside Europe. For example, in Ontario (Canada), a restriction in the sale and use of neonicotinoid-dressed maize and soybean seeds has been introduced on July 1, 2015 with the aim to limit their use only when there is a demonstrated pest problem (https://www.ontario.ca/page/neonicotinoid-regulations).

Here we compare the bee mortality events and the maize production in Italy, before and after the precautionary suspension of the maize seeds dressing with neonicotinoids and fipronil. We also discuss whether it is possible to conciliate the honey bee health with sustainable maize production.

Honey bee health

In the early 2000s, many beekeepers in Northern Italy started reporting events of bee mortality and colony weakening in spring (March-May), associated with maize sowing (Mutinelli *et al.*, 2009; Bortolotti *et al.*, 2009). However, only since 2008 these reports were systematically collected by Local Veterinary Authorities in collaboration with the Istituto Zooprofilattico Sperimentale delle Venezie (Legnaro, Padua), the CREA-API (Bologna) and the Dipartimento di Scienze Agrarie of the University of Bologna. Later, this activity was organized with the creation of the Bee Emergency Service Team (BEST) in the framework of ApeNet (2009-2010) and BeeNet projects (2011-2014) funded by Italian Ministry of Agriculture (Mutinelli *et al*., 2010; Lodesani *et al.*, 2013; Porrini *et al.*, 2014; 2016; Martinello *et al*., 2017). This service was built to study the events of bee mortality and colony losses when the causes are difficult to identify and to analyse them in real time, when the phenomenon is still in progress. Every Italian beekeeper may request the BEST intervention through a dedicated website or directly contacting the BEST coordination by phone, fax and email (Porrini *et al.*, 2014). The BEST procedure (in collaboration with the Local Veterinary Authorities) follows a standardized methodology, consisting in the collection of environmental data, evaluation of the sanitary status of the affected hives and apiaries, as well as the sampling of bee matrices for chemical, pathological and palynological analysis. All these data are analysed in an integrated way in order to understand the causes of colony damages. We should also point out that the number of adverse events registered on a regular basis is likely only a small fraction of the real number of bee mortality and bee losses observed by beekeepers. Since this is a "passive" surveillance based on voluntary action of beekeepers, only few of them report these events officially to BEST and the competent authorities.

In Northern Italy the number of adverse events (e.g. abnormal behaviours, high bee mortality, colony weakening) affecting honey bees reported by beekeepers and linked to maize sowing dramatically declined from 2008 [the last year before the precautionary suspension of imidacloprid, clothianidin, thiamethoxam and fipronil for seed-dressing in maize decreed by the Italian Ministry of Health on September 20, 2008 (Ministero della Salute, 2008) and its further extensions] to the following years (figure 1). As a rule, an event was associated to maize sowing only when there was a spatial and temporal correlation with this practice. The anamnesis (e.g. abnormal behaviours, presence and number of dead bees in front of the hives) and the results of the chemical and pathological analysis of different matrices collected during the hive inspections were also taken into account for the determination of damage causes (table 1). All bee mortality events reported in spring 2008 were associated with the sowing of maize seeds dressed with the suspended neonicotinoids. According to the hive inspection, all affected bees showed symptoms of intoxication and the results of virological analysis were negative. Residues of clothianidin, imidacloprid and thiamethoxam were also found in several specimens (table 1). Even though these events were not recorded regularly till 2008, similar cases were reported by several beekeepers also the years before. The sporadic cases reported from 2009 to 2016 were linked to the use of seed dressing with other compounds toxic to bees, such as chlorpyrifos, or the home-made seed dressing containing mixtures of the suspended neonicotinoids. Overall, these data show that the suspension definitely contributed to reduce the number of bee mortality and colony weakening events during maize sowing in Italy.

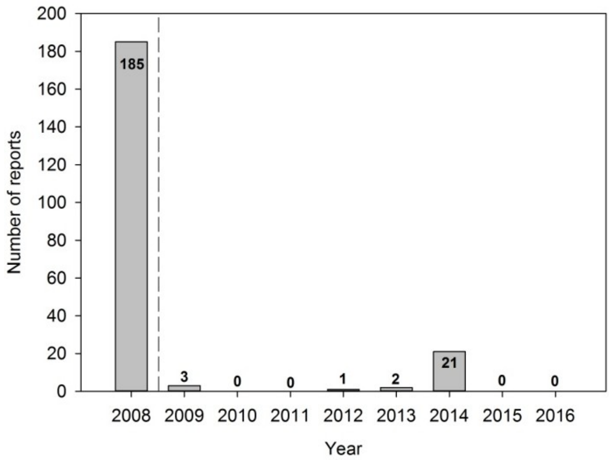

Figure 1. Number of adverse events (e.g. abnormal behaviours, high bee mortality, colony weakening) officially reported in maize-cultivation area of Northern Italy linked to maize sowing. The dashed line indicates the beginning of the precautionary suspension.

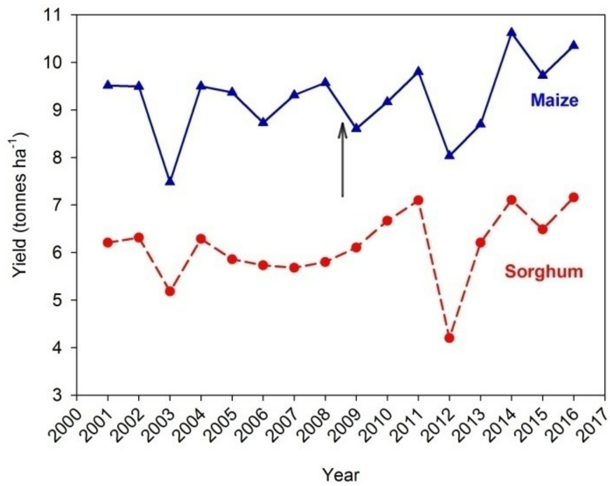

Figure 2. Maize and sorghum production (yield per hectare) in Italy before and after the precautionary suspension of imidacloprid, clothianidin, thiamethoxam and fipronil for maize seed dressing. Data of 2001-2014 from FAOSTAT (2017), 2015-2016 from ISTAT (2017). Arrow indicates when the precautionary suspension was applied in Italy.

Maize production

Figure 2 reports the yearly maize production per hectare for the years 2001-2016 in Italy (FAOSTAT, 2017; ISTAT, 2017). The average yield during the eight years before the precautionary suspension was similar to that of the subsequent eight years (9.12 vs 9.38 tonnes/ha

Table 1. Summary of the beekeeper reports regarding anomalous bee mortality observed during maize sowing from 2008 (before the precautionary suspension in Italy) to 2016 (after the suspension). Total samples as well as those with positive analytical results are reported.

	2008			2009			2010			2011			2012			2013			2014			2015			2016		
	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)	Dead bees	Bee-bread	Other mat. (1)
Total samples	105	4	0	2	0	4							No sampling						12	5	7						
Positive	52	3	-	1	-	4	No mortality events linked with						-	-	-	-	-	-	5	2	4	No mortality events linked with					
Imidacloprid	27	3	-	0	-	2							-	-	-	-	-	-	2	0	1						
Thiamethoxam	3	0	-	0	-	2	maize sowing						-	-	-	-	-	-	0	0	2	maize sowing					
Clothianidin	27	1	-	1	-	3							-	-	-	-	-	-	0	0	1						
Other compounds	0	0	-	0	-	0							-	-	-	-	-	-	3*	4**	16***						
Number of reports		185			3			0			0			1			2			21			0			0	

(1) Other matrices: maize seed and seedlings, wild vegetation surrounding maize fields;
* Chlorpyrifos (n = 2 samples), Dodine (n = 1); ** Terbuthylazine (n = 3), Metolachlor-S (n = 1); *** Terbuthylazine (n = 2), Metolachlor-S (n = 1), Methiocarb (n = 2), Methiocarb-Sulfoxide (n = 2), Metalaxil (n = 2), Fludioxonil (n = 3), Thiram (n = 3), Lambda-Cyhalothrin (n = 1).

respectively; t-test: $t = -0.63$, $p = 0.54$, $df = 14$) although with strong between-years fluctuations. This pattern was similar to that of the sorghum (*Sorghum bicolor* L.) production (correlation between yearly yield per hectare of the two crops during the period 2001-2016: $r = 0.80$, $p = 0.0002$, $n = 16$) (figure 2). We chose sorghum for the comparison with maize because its seeds are not dressed with insecticides, the two crops have similar agronomical requirements and are both cultivated in the same area in Italy. Their between-years fluctuations seem to be related to particular weather conditions during summer. According to Staggenborg *et al*. (2008) the yield of both crops increases with high precipitations during the growing season and decreases with high average maximum temperatures in June, July and August. The parallel strong decline in maize and sorghum yield in 2012 occurred in coincidence with the anomalous warm temperatures recorded during that summer in Southern Europe. The negative effects of extreme warm temperatures on maize production are in accordance with Hawkins *et al*. (2013), and Hatfield and Prueger (2015).

How to conciliate honey bee health with maize production

In this paper, we show that the number of honey bee mortality events related to the maize sowing practice declined in Italy after the precautionary suspension of September 2008. These data indirectly confirm that the contaminated dust, dispersed during sowing, represented a relevant way of exposure for honey bees, as observed also in several studies (Krupke *et al*., 2012; Tapparo *et al*., 2012; Sgolastra *et al*., 2012; Pistorius *et al*., 2015; Pochi *et al*., 2015). At the same time, no negative effects of the precautionary suspension were observed on maize yield in Italy. The average production per hectare before and after the suspension remained stable during the last 16 years. Although we do not know exactly what pest control strategies the farmers adopted on maize after the Italian suspension (probably clothianidin or chlorpyrifos as granules and thiacloprid as seed-dressing), they did not negatively affect honey bee health and maize production. In fact, as reported by Furlan and Kreutzweiser (2014), it is evident that the widespread use of insecticide seed dressing has little positive contribution to maize yield and more sustainable alternatives for pest control are available. The economic benefit of neonicotinoids on crop production has been questioned also by Goulson (2013) who showed that in several crops the extensive prophylactic use of these compounds is not justified by their economic return. Budge *et al.* (2015), for example, showed that, while the use of imidacloprid seed dressing on oilseed rape in England and Wales was clearly related to the proportion of dead honey bee colonies, its economic benefit to farmers is unstable and not always justified. Moreover, neonicotinoids residue in the soil for several years and their accumulation pose a strong risk not only for pollinators but also for other organisms (Goulson, 2013). Thus, their negative impact on the whole ecosystem should also be quantified and included in their evaluation of environmental costs.

The prophylactic use of neonicotinoids and other compounds for seed dressing is in contrast with the main principle of the integrated pest management (IPM) which requires an assessment of the density of pest populations and their economic importance, in order to determine if an insecticide treatment is needed, and after the consideration of alternative (non-chemical) pest control practices. Under the IPM strategy, pesticides should be used only as the last measure to contrast the pest. Unfortunately, this rule seems to be disregarded in our modern pest management (Hokkanen, 2015). In Italy, it has been estimated that the application of the IPM strategies would result in a maximum of 4% of maize-cultivated area being treated with soil insecticides or insecticide seed dressing (Furlan *et al.*, 2017). A low risk of soil-pest damage to maize was also demonstrated at European level (Furlan *et al.*, 2016).

In conclusion, we think that it is possible to conciliate bee health with maize production but a more sustainable use of pesticides, as well as the strictly application of IPM strategies, should be encouraged (Maini *et al.*, 2010; Burgio *et al.*, 2012). The case of the precautionary suspension of imidacloprid, clothianidin, thiamethoxam and fipronil on maize as seed dressing in Italy can be a model for the evaluation of the European moratorium of December 2013, although we highlight some limitations:

- Because of many factors and situations affecting bees, it is often difficult to link the general enhancement of bee health to the European moratorium. In the case of Italy, it was possible to demonstrate the effectiveness of the precautionary suspension on bee health only for the adverse events reporting during maize sowing;
- The European moratorium of imidacloprid, clothianidin, thiamethoxam and fipronil is not complete, but limited to some uses and crops (e.g. spray application in the pre-flowering phases and as seed dressing in bee-attractive crops). This means that bees can still be exposed to these compounds and, considering their high level of persistence in soil and water, their potential impact on bees (and other organisms) may persist for many years longer.

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