Environmental Factors in Honey Bee Heath: Do Neonicotinoids Matter?

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Abstract

Since 2006, beekeepers around the world have reported unusually high rates of honeybee colony loss. In the last two years, attention has turned to neonicotinoids as a potential factor in honeybee disease and mortality. While fatal at high doses, neonicotinoids are primarily used as seed treatments, and researchers debate whether honeybees are regularly exposed to these pesticides at sufficient doses to do harm. We combine unique geocoded data on apiary pollen samples and pest loads across 40 US states over the past 4 years with crop data to ask where and when we observe evidence of neonicotinoid exposure in the hive, and what effect that exposure has on honey bee health. We find that neonicotinoids are largely found in hives near neonicotinoid-treated crops during planting, and that colonies with neonicotinoid contamination have higher levels of nosema, a virus associated with colony loss. We find no evidence of an effect of neonicotninoids on Varroa mites.

Introduction

Honey bees are valuable to global agriculture. A third of all food is dependent on pollinators. In the United States in particular, this pollination service adds approximately $15 billion in crop value every year (USDA 2013). In addition, harvested honey produced by operations with 5 or more colonies was worth approximately $287 million in 2012 (USDA NASS 2013), not including other byproducts including beeswax and bee pollen. But honey bees are under treat. Beekeepers have lost around 30 % of their colonies each winter since 2006/07. (National Honey Bee Health Stakeholders Conference 2012). . Even though the winter losses from 2014 to 2015 are among one of the lowest in eight years, two-thirds (66%) of beekeepers still exceeded their acceptable loss rate of 19% .Recent data show a jump in summer losses generating record total losses of 40% for last year (Steinhauer et al. 2015). Recent policy attention has turned to neonicotinoids as a potential source of colony decline. In this paper we ask whether the presence of neonicotinoid-treated crops increases the probability of neonicotinoids found in the hive, and whether those contaminated colonies have higher levels of pests known to contribute to colony loss.

While the causes of the decline are still not completely understood, parasites such as Varroa mites (Guzman-Novoa et al. 2010) and Nosema (Higes et al. 2008) are known contributors to colony loss. Varroa destructor, a virus-transmitting parasite that was introduced to the United States in the mid-1980s, has been identified as the most detrimental pest for honey bees. Nosema is a gut parasite that harms bee colonies (USDA 2013). Both diseases are highly prevalent in colonies throughout North America. Other factors of honey bee loss include colony management practices, and poor nutrition (Lee et al. 2014). With the expansion of crop land and loss of land from the Conservation Reserve Program, honey bee habitat is decreasing. This trend results in diminished food availability and nutritional diversity for both wild and managed bees. Habitat loss is particularly troubling because research has found that honey bee colonies near greater areas of open land sustain fewer colony losses and produce more honey compared with colonies located near a greater portion of developed land (Naug and Dhruba, 2009). Another study found that plant diversity from natural areas is essential for maintaining large enough bee populations to pollinate cultivated crops (Kremen, Williams and Thorp 2002). Research on Britain and the Netherlands has also found a link between a decrease in plants pollinated by bees and decreases in the bee population (Biesmeijer, et al. 2006).

Recently, attention has turned to pesticides as a possible contributor to colony decline. In particular, a class of nicotine-derived pesticides, neonicotinoids (neonics), including Acetamiprid, Clothianidin, Dinotefuran, Imidacloprid, Thiacloprid and Thiamethoxam, have been implicated as a cause of bee deaths. Neonics were introduced in the late 1990s to replace the more toxic mass spraying of organophosphate and pyrethoid pesticides (Entine, 2013). Most neonicotinoid pesticides protect plants from insects and are water-soluble and slowly break down in the environment (Hunt, 2012). In the United States, neonicotinoids are currently used on about 95 percent of corn and canola crops, the majority of cotton, sorghum and sugar beets, about half of all soybeans, and a vast majority of fruit, vegetable and grain crops (Grossman, 2013). In particular, the use of Clothianidin on corn in Iowa alone has almost doubled between 2011 and 2013 (USGS 2014).With the popular adoption of neonicotinoid seed treatments in current farming practices, there is a growing concern that neonics' potential negative impact on bees might harm the world's food production and supply. Therefore, the European Union had declared a 2-year ban on three neonicotinoids (Clothianidin, Imidacloprid and Thiametoxam) in 2013 as a precautionary action (European Commission 2013). Recently, the White House has released National Strategy to Promote the Health of Honey Bees and Other Pollinators with new steps to bolster pollinator health. Aside from restoring habitat for pollinators and providing more funding for bee research, the EPA is required to re-evaluate the neonicotinoid class of pesticides (Naylor, 2015).

Unlike previous work that uses lab and field experiments to explore the relation between neonicotinoid seed treatments and honey bee health, we use a large number of samples collected from 40 U.S. states over 4 years to first ask whether we observe evidence of neonicotinoid exposure in a real world crop setting. We ask which nearby crops and what times of year are correlated with evidence of this exposure. Second, we ask whether observed neonicotinoid contamination in the hive is correlated with higher disease loads. We use multivariate regression analysis to compare colonies located near neonicotinoid-treated crops to those further away, during planting, blooming versus other times of year. We control for other environmental factors known to affect honey-bee health such as forage availability and weather. We see our work as complementing previous field studies that find evidence that honey bees may be exposed to neonicotinoids during planting and that low-level doses of neonicotinoids can affect honey bee health. By considering active apiaries placed in active agricultural landscapes, our work contributes to the existing literature by asking whether we observe these potential causal pathways in a standard commercial setting.

Literature Review

With the EU recently banning the use of some neonicotinoids due to their suspected effect on honeybee heath, calls are increasing in the United States for a similar regulatory response. Even though the U.S.

has continued to allow the wide use of neonicotinoid seed treatments due to insufficient evidence of their harm on bees, the EPA is now required to re-assess the impacts of this class of pesticides (White House, 2015).

Some researchers suggest that under typical crop conditions, bees are not exposed to high enough doses of neonicotinoids to cause health concerns. According to research conducted by Dr. Gus Lorenzo, neonicotinoids are not expressed in the reproductive part of corn, soy, or cotton plants in high enough levels to harm honey bee health (Lorenzo, 2014). In fact, no neonicotinoids were detected in cotton and soy flowers. He therefore concludes that neonicotinoid seed treatments are not harmful to bees in terms of exposure to contaminated nectar and pollen. Using 2 groups of 8 honeybee colonies, Faucon et al. (2005) demonstrate that bees' chronic exposure during the spring and summer to crops treated by neonicotinoids at the highest recommended rate does not affect the mortality of overwinterized colonies (Faucon et al. 2005, Cutler and Scott-Dupree 2007). The United Kingdom Department of Environment, Food and Rural Affairs compiled evidence on neonicotinoid exposure to honey bees and concluded that neonicotinoids do not harm bees under normal circumstances and that laboratory studies on the sub-lethal level of neonicotinoids created extreme situations that are not applicable to real world conditions (United Kingdom Department of Environment, Food and Rural Affairs 2013).

In contrast, many researchers and beekeepers argue that bees are exposed to neonicotinoids and that neonicotinoids have a negative impact on honeybee health. Using the liquid chromatography-tandem mass spectrometry (LC/MS-MS) analysis, Dr. Krupke has found that bees' exposure to neonicotinoid compounds happen in several ways throughout the foraging period, especially during the planting season of treated maize (Krupke, 2012). Dr. Greg Hunt finds an extremely high concentration of Clothiandin and Thiamethoxam in talc, which is a seed treater that helps with seed flow during planting with an air seeder and improves seed spacing. A gram of talc containing 1.0% Clothianidin could theoretically kill a million bees if they ingest it, and could threaten about half as many bees if they come into contact with the dust (Laurino et al. 2011; Tremolada et al. 2010). He thus concludes that bees may be exposed to a sub-lethal level of pesticides throughout the growing season even though the greatest danger occurs during planting (Hunt, 2012). The popular adoption of neonicotinoid seed treatments which are persistent in plants makes it very difficult for bees to avoid exposure to these toxic chemicals. A controversial study by Dr. Chensheng Lu suggests that even sub-lethal exposure to neonicotinoids would impair honey bee winterization and thus lead to colony loss (Lu, et al. 2014). Even though Lu claimed that he had replicated CCD, there was not any support from prominent entomologists. Instead, several entomologists have argued that his sample size was too small to reach a conclusion and that he might have killed the bees himself by overdosing them in a cold winter (Entine 2014, Helman 2013).

Recent research has also addressed concerns over the potential negative impact of neonicotinoids on bees. Paul Towers, from the Pesticide Action Network said that even though the amount of pesticide in the pollen of neonic-treated plants might be too small to kill bees, it was enough to disorient and reduce the ability for them to get food and communicate (Charles, 2013). Even though Bayer CropScience, the biggest seller for neonicotinoid pesticides claim that neonics have been proven safe by most studies, they are taking precautionary action to work on a new system for planting corn that will reduce neonic release (Charles, 2013). According to research by USGS, neonics have been found in surface water throughout the Midwest, where corn and soybean production are most prevalent (USGS, 2014). Studies have also shown that the negative effect of neonicotinoids are not limited to bees; they harm birds, mammals, worms and aquatic insects as well (Thomson, 2014). The prevalence of neonicotinoids is undisputed. Whether and how this class of pesticides affects honey bees is still not well known.

Data and Methods

We spatially join the USDA Animal and Plant Health Inspection Services (APHIS) Survey of Honey Bee Pests and Disease with NASS Cropscape data using the geographic coordinates of the apiaries and year the sample was taken. We specifically focus on those colonies that are not migratory to ensure that the nearby cropscape appropriately represents the landscape at the time the sample was taken (Holt, 2014). We consider apiaries as migratory if beekeepers list their operations as migratory or their primary purpose as pollination and non-migratory otherwise. If the type of operation is listed as both stationary and its primary purpose is pollination, we consider this apiary as non-migratory as well since while it may not move across state lines, the immediate surrounding area may not reflect the landscape that the bees are using for forage when the sample was collected.

The USDA APHIS conducts the Honey Bee Pest and Disease Survey as a means of identifying pests, pathogens, and disease affecting honey bees in the United States. This data set contains information on apiary samples collected from 2009 to 2014 throughout the United States. Forty states with 2552 samples are in the data set. In each sampled apiary, at least 8 colonies are tested for a number of diseases and pests. Not all samples are tested for pollen residue; only 676 samples have pollen sample results. Since there is no crop information for samples in Hawaii, we exclude these areas from our analysis as well.

Along with excluding migratory colonies, this leaves us with a sample of 429 apiaries in 33 states with most represented in the North East and the Mid-west (see Table 1).

We use Varroa mites and Nosema parasite loads as indicators of honey bee health and explore what environmental factors contribute to a higher prevalence of these diseases. . Using geocoded data, we plot the raster density maps for Varroa mites and Nosema parasites for non-migratory apiaries with pollen results and find a correlation between the detection of neonics and higher levels of diseases (see Figure 1). This suggests that bees' exposure to neonics may potentially contribute to higher disease levels.

To estimate the degree of neonicotinoid exposure, we first identify the major field crops that are traditionally seed treated with neonicotinoids, including corn, soy, cotton, canola, sorghum, barley, rice and wheat. Then we map the sampled non-migratory apiaries in APHIS onto NASS cropscape data determine the crops grown within a 2-mile radius of each apiary. The resolution of these data is set at 30 meters squared per pixel (USDA NASS n.d.). We extract the crop area within two miles of each apiary as this is vicinity in which bees typically do most of their foraging (Eckert, 1933). Therefore, this two mile area, which comprises over 8,000 acres, provides the best estimate of the crops and landscape that bees would interact with during their foraging. We then calculate the percentage of the two mile buffer area occupied by each crop with the assumption that a linear relationship exists between changes in treated crop area and morbidity loads.

The top land cover near all sampled apiaries is forested upland; it is comprised of deciduous forests, mixed forests and evergreen forests and makes up about 25% of the 2-mile buffers on average. Several neonicotinoid-treated crops are also among the top 10 landcover categories, including corn, soybean and winter wheat (see Table 2). When we look at the land covers by contamination status of the apiaries, we find that corn, apples and oranges are significantly more prevalent near apiaries where neonicotinoids have been detected (see Table 3).

With geographic coordinates for non-migratory apiaries, we also extract potential forage and weather data within the 2-mile buffers from NASS' Vegscape layers and Oregon State University's Prism database. USDA NASS provides data about on the vegetation cover of the United States over the period from 2000-2014. For this study, we use data on the Normalized Difference Vegetation Index (NDVI), which measures the density of vegetation within pixels representing 15 acres of landscape (Mueller and Minchenkov 2013). Data on the NDVI is provided on a daily, weekly and biweekly basis. We use apiaries' locations as well as sample collection time, and obtain the biweekly NDVI data, which provides information about the average NDVI within a 16 day window.

Weather is known to be an important determinant of honey bee health as well. Cold weather is commonly associated with increased stress on bees because the bees will not venture out of the hive if temperatures are below 8 degrees Celsius, reducing their food intake (British Columbia Ministry of Agriculture, 2012). We extract minimum average temperature as well as the total precipitation in the month the sample was collected. The data provided by Prism are supplied by calendar month, so for all sample taken on or before the 14th of the month, we use the weather data for the previous calendar month. For samples taken on the 15th or later, we use the month of the collection.

To control for the timing of exposure to pesticides and more abundant nectar sources, we collect information on the time of planting and blooming for neonicotinoid-treated crops. NASS collects agricultural plant timing data for select crops in some states. We compile information on the planting percentage by month for the United States each year. Corn, soy, cotton, canola, rice, sorghum, barley and spring wheat are planted in the spring. Winter wheat is planted in the fall. Most spring planting occurs between April and June. Fall planting occurs between September and November. Due to a lack of information, we estimate the planting window for canola to be from April 20 to June 10 every year (Canola Council of Canada, 2013). Information on bloom timing of honeybee forage plants is provided on HoneyBeeNet, which not only lists the plants that bees frequently forage within each region within each state, but also whether each plant is significant nectar source or not (Nickeson, 2010).

Many of the honey bee forage crops fall into the natural area landscape category, so we consider the entire area to be in bloom if at least one of the forage crops is in bloom within the natural area category. Bloom timing for neonic-treated crops are also included in the data set to estimate pesticide exposure from pollen. Spring wheat, winter wheat, barley and rice are not considered as forage crops for honey bees and thus are missing bloom timing information from HoneyBeeNet. These crops are wind-pollinated are not adapted to attract pollinators. However, honey bees can consume pollen from these crops (Burlew 2013).

To control for unobserved regional effects, we use USDA census regions. These regions are selected to increase comparability with studies on overwintering losses and to isolate regional cropping patterns. Forested upland, developed areas and grasslands are among the top 5 crops in every region (see Table 4). Both corn and soybeans are very prevalent in USDA Region 1, which is includes most Northeastern states and parts of the eastern Midwest including New York, New Jersey, Wisconsin, Ohio, Michigan, Illinois.

This region largely coincides with the US corn belt and has 10 apiaries detected with neonicotinoids among the total 18 contaminated ones. USDA Region 3 is made up of southern states, including Florida, Louisiana, and Texas, and 5 apiaries in this region have been detected with neonicotinoids. The other 3 contaminated apiaries come from Regions 2, 4 and 6.

For our analysis, we first use a logit regression to ask what factors are associated with finding neonicotinoid contamination in the hive. Second, we use a multivariate regression to estimate the effect of neonicotinoid contamination on colony Nosema and Varroa loads. We use several specifications, first with no fixed effects, then adding fixed effects for region and year. Then we include other controls for forage availability and weather. In the first stage, we compare those apiaries that are near neonicotinoid-treated crops whose samples are taken during planting to other apiaries near neonocotinoid-treated crops whose samples are taken other times of year, and to apiaries who are not near treated crops. For the second analysis on health outcomes, using the fixed effects, we compare disease outcomes of those apiaries where neonicotinoids are found to apiaries tested in the same region, in the same year and during the same time of year.

Results

First Stage – Factors associated with neonicotinoid contamination

The first stage examines whether an apiary with a large share of neonicotinoid-treated crops within the foraging radius have a higher probability to being contaminated by neonicotinoids during certain times of the year. In other words, we ask at which time of the year do we observe neonicotinoid exposure in the apiary, and does this timing align with planting or blooming of neonicotinoid-treated crops. We aggregate the percent area of all 9 commonly neonicotinoid-treated crops and interact these numbers with planting and bloom time. Planting time and bloom time are both dummy variables indicating whether any treated crops within the 2-mile radius are being planted or in bloom on the date of the sample collection.

All the specifications below show strong evidence that the share of treated crops nearby during planting time positively contributes to the likelihood of apiaries to be contaminated by neonicotinoids. When we control for year fixed effects and region fixed effects, the coefficients on the interaction between neonicotinoid-treated crops and planting time increases, and the model fit improves. When we control for bloom time, we observe that, if anything, shares of treated crop nearby during bloom time are associated with a decrease in the probability that apiaries are contaminated by neonicotinoids. NDVI, an indicator of nearby vegetation and thus natural forage, is negatively correlated with the likelihood of observing neonicotinoids in the apiary but this effect is not statistically significantly different from zero. Precipitation and minimum temperature show some evidence of being slightly positively correlated with the probability of contamination.

TABLE: First Stage Regressions - Proximity to Neonic-treated Crops and the Probability of Contamination

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crop acreage	-0.0015**	-0.0021***	-0.0002	-0.0006	-0.0018**	-0.0012	-0.0019**	-0.0009
	(0.0007)	(0.0007)	(0.0009)	(0.0009)	(0.0008)	(0.0011)	(0.0009)	(0.0011)
Planting time	-0.0349	-0.0431*	-0.0062	0.0014	-0.0397	0.0014	-0.0404	-0.0166
	(0.0224)	(0.0237)	(0.0248)	(0.0218)	(0.0323)	(0.0340)	(0.0324)	(0.0348)
Crop acre*Planting time	0.0050***	0.0053***	0.0066***	0.0070***	0.0033**	0.0050***	0.0033**	0.0045**
	(0.0012)	(0.0012)	(0.0013)	(0.0013)	(0.0015)	(0.0017)	(0.0015)	(0.0017)
Bloom time			-0.1154***	-0.1632***		-0.1673***		-0.1772***
			(0.0367)	(0.0360)		(0.0487)		(0.0455)
Crop acre*Bloom time			-0.0027**	-0.0027**		-0.0015		0.0016
			(0.0012)	(0.0012)		(0.0015)		(0.0015)
NDVI					-0.0015	-0.0012	-0.0015	-0.0015
					(0.0010)	(0.0010)	(0..0010)	(0.0009)
Minimum Temperature					0.0070	0.0044	0.0070	-0.0022
					(0.0047)	(0.0046)	(0.0047)	(0.0036)
Precipitation							0.0001	0.0002
							(0.0003)	(0.0002)
Month Quadratic Trend	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	N	Y	N	Y	Y	Y	Y	Y
Region FE	N	Y	N	Y	Y	Y	Y	Y
N	392	392	392	392	291	291	291	291
R-Squared	0.1741	0.2067	0.2149	0.2526	0.1957	0.2366	0.1967	0.2501

Standard errors in parenthese. **p<0.1* ***p<0.05* ****p<0.01*

<u>Second Stage – Disease Levels</u>

In the second stage, we examine whether being contaminated by neonicotinoids is associated with an increase in disease loads. We run two sets of specifications for the commonly identified diseases: Nosema and Varroa. For Nosema, we first run a simple regression with a binary variable indicating the contamination status of apiaries and month quadratic time trend to capture the fact that Nosema is often highest earlier in the year. Then, we include year and region fixed effects and other control variables. When we control for local forage and weather, an apiary that is contaminated by neonics tends to have about 0.41 million spores per bee higher Nosema loads than one that is not contaminated. Since Nosema is one of the indicators for bee health, this result suggests that apiaries contaminated by neonics tend to have higher morbidity rates. Because Nosema is truncated at zero, we also use a tobit regression and find qualitatively similar results (reported in the appendix).

We run the same regressions with mites loads as the outcome variable and find little evidence that neonicotinoid contamination affects Varroa mite levels.

TABLE: Second Stage Regressions - Nosema Parasite

	(1)	(2)	(3)	(4)
Neonics	0.2268	0.2314	0.4175**	0.4090**
	(0.1659)	(0.1690)	(0.1956)	(0.1957)
NDVI			0.0013	0.0015
			(0.0027)	(0.0027)
Minimum Temperature			-0.0185	-0.0184
			(0.0121)	(0.0121)
Precipitation				-0.0007
				(0.0007)
Month Quadratic Trend	Y	Y	Y	Y
Year FE	N	Y	Y	Y
Region FE	N	Y	Y	Y
N	359	359	286	286
R-Squared	0.0897	0.1017	0.1439	0.1476

*Standard errors in parenthese. *p<0.1 **p<0.05 ***p<0.01*

TABLE: Second Stage Regressions - Varroa Mites

	(1)	(2)	(3)	(4)
Neonics	0.0697	-0.1869	-0.1664	-0.2376
	(1.6717)	(1.6411)	(1.7910)	(1.7930)
NDVI			-0.0309	-0.03
			(0.0249)	(0.0249)
Minimum Temperature			-0.0169	-0.0159
			(0.1110)	(0.1111)
Precipitation				-0.0059
				(0.0063)
Month Quadratic Trend	Y	Y	Y	Y
Year FE	N	Y	Y	Y
Region FE	N	Y	Y	Y
N	358	358	285	285
R-Squared	0.0765	0.166	0.198	0.2006

*Standard errors in parenthese. *p<0.1 **p<0.05 ***p<0.01*

Conclusions

Many regions are considering taking severe measures to reduce the use of neonicotinoids because of their hypothesized negative effect on honey bees. The scientific evidence behind this presumed association is mixed. One debate in the literature is whether honey bees are exposed to neonicotinoids, which are primarily used as a seed treatment, in a regular agricultural setting. Two possible mechanisms of exposure are through the talc used along with the seed treatment to facilitate planting by air seeders, and from the nectar of neonicotinoid-treated crops. Further, there is a debate about whether these potentially low-levels of neonicotinoid-exposure are sufficient to affect honey bee health. Most work to date has focused on lab based or small field trials. To our knowledge, ours is the first paper to use a geographically-diverse set of data collected from commercial apiaries to ask whether we find evidence of the effect of neonicotinoid-treated crops in a real-world setting.

Using pesticide load and health data for 358 geocoded apiaries across 33 states, we first ask whether neonicotinoid contamination is associated with proximity to neonicotinoid-treated crops during planting or bloom time. Second, we ask whether those apiaries where neonicotinoids are found have higher levels of nosema or varroa, where both pests are strongly associated with colony loss. We find that apiaries sampled during the time that nearby neonicotinoid-treated crops are being planted are more likely to be contaminated by neonics, implying that even in real-world settings, honey bees may be exposed to neonics. Second, we find that those apiaries with neonicotinoid residue have higher levels of nosema, but not significantly different levels of varroa mites. Our work complements earlier smaller scale field studies that show a relation between low-level of neonicotinoid exposure and an increase in the level of nosema. This is consistent with Pettis' finding that bee colonies exposed to low levels of neonicotinoid imidacloprid had higher Nosema levels compared with the control group (Pettis, et al. 2012)

Because we use observational data, we cannot rule out all other factors that may affect both neonicotinoid contamination and disease. For example, most neonicotinoid-treated crops are planted using air seeders, so perhaps the dust generated from planting decreases honey bee health, and not neonics per se. Further, we cannot rule out that colonies located near neonicotinoid-treated crops that are tested during planting are different in some unobservable way than other colonies. Thus, our results should be treated as suggestive evidence, not necessarily proving a causal relation. Nonetheless, we believe our results point to the need for further work to explore this relation.

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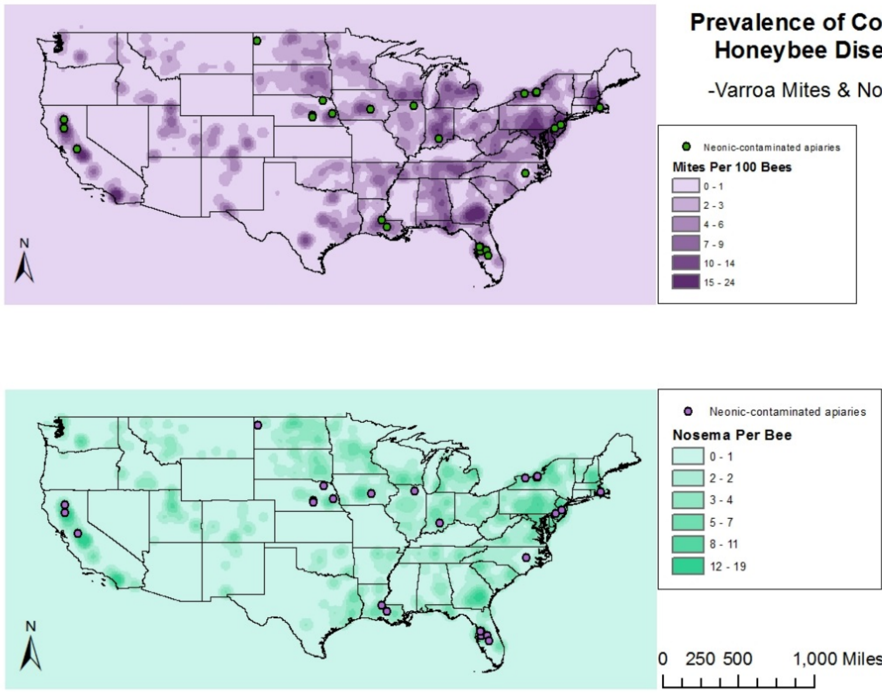
Appendix

TABLE 1: REGIONS AND STATES REPRESENTED IN THE DATASET

USDA Region	Count	Percent	States Represented
1	160	37.30%	IA, IL, MA, MI, NE, NJ, NY, OH, PA, WI, IN
2	111	25.87%	AL, GA, MD, NC, SC, TN, VA, WV
3	55	12.82%	AR, FL, LA, OK, TX
4	59	13.75%	CO, MN, MT, ND, SD, UT
5	12	2.80%	ID, OR
6	32	7.46%	CA

Note: the dataset is expanding as apiaries are still being sampled for the 2014-2015 cycle



Source: Bee Informed Partnership & United States Department of Agriculture Author: Guyu Ye Date: December 5, 2014

TABLE 2: TOP 10 LANDCOVERS WITHIN FORAGING RADIUS

Land Cover	N*	Mean**	Maximum
Forested Upland	407	24.88%	95.08%
Developed	407	17.30%	99.69%
Grasslands	407	16.54%	89.54%
Corn	407	8.35%	67.38%
Soybeans	407	5.99%	54.46%
Wetlands	407	5.32%	76.62%
Shrubland	407	4.82%	73.23%
Other Hay/ Non-Alfalfa	407	2.42%	56.31%
Alfalfa	407	1.75%	41.54%
Winter Wheat	407	1.30%	39.38%

**Number of observation is less than the size of the dataset because some inaccurate or incomplete location data*
***Mean and Maximum both show the percentages of crops within the 2-mile buffers*

TABLE 3: TOP CROPS NEAR CONTAMINATED VS NON-CONTAMINATED APIARIES

Land Cover	Neonics	No Neonic	t-stats	p-value
Corn	17.55%	7.98%	-3.22***	0.00
Grassland	16.55%	16.54%	0.00	0.99
Developed	14.49%	17.43%	0.57	0.57
Wetlands	9.83%	5.11%	-2.00**	0.05
Soybean	9.06%	5.92%	-1.29	0.11
Oranges	8.43%	0.06%	-7.90***	0.00
Forested Upland	6.55%	25.73%	3.27***	0.00
Other Hay/ Non-Alfalfa	1.99%	2.44%	0.35	0.73
Shrubland	1.87%	4.96%	1.01	0.31
Apples	1.16%	0.05%	-5.16***	0.00
Alfalfa	0.73%	1.80%	0.97	0.33
Winter Wheat	0.44%	1.34%	1.00	0.32
Barren	0.24%	0.30%	0.22	0.83
Spring Wheat	0.03%	0.75%	0.83	0.41

****P<0.01   **P<0.05   *P<0.1*

TABLE 4: TOP LAND COVERS BY USDA REGION					
Land Cover	Obs	Mean*	Std. Dev.	Min	Max
Region 1					
Forested Upland	158	7533179	6055118	1800	25400000
Corn	158	5569488	4869948	0	21900000
Developed	158	5538122	6463405	785700	30000000
Grasslands	158	4235380	3784351	900	19100000
Soybeans	158	3580513	3748328	0	15300000
Region 2					
Forested Upland	108	15600000	7991660	1602900	30900000
Developed	108	4953592	6106976	336600	28400000
Grasslands	108	4771300	4404166	0	22100000
Wetlands	108	1362017	2410247	0	9921600
Shrubland	108	918250	1540675	0	6370200
Region 3					
Grasslands	53	9031906	7587761	2700	24100000
Developed	53	5175424	6811826	572400	32400000
Forested Upland	53	4079960	5557120	0	19100000
Wetlands	53	3771721	5356600	0	19100000
Soybeans	53	1890628	4045026	0	17700000
Region 4					
Developed	47	6409360	8505621	92700	32100000
Grasslands	47	5100204	6332538	0	26300000
Shrubland	47	2767615	6113519	0	23800000
Forested Upland	47	2159655	4073831	0	17800000
Alfalfa	47	2123674	3351378	4500	13500000
Region 5					
Forested Upland	11	8079382	7925156	0	19600000
Developed	11	7376482	10400000	1070100	32100000
Grasslands	11	6927873	5314164	90000	14500000
Shrubland	11	6285355	5100323	0	15100000
Alfalfa	11	731209	1679071	0	5567400
Region 6					
Shrubland	30	8374260	8790428	0	23100000
Developed	30	7408050	8008357	0	29000000
Grasslands	30	6963450	8200990	0	29100000
Forested Upland	30	465510	798773	0	3026700
Corn	30	119070	364967	0	1533600

**Unit of observation is square meters. 2-mile radius is roughly 32500000 square meters.*

TABLE: Second Stage Tobit Regressions - Nosema Parasite

	(1)	(2)	(3)	(4)
Neonics	0.4247	0.4046	0.7715**	0.7736**
	(0.3245)	(0.3324)	(0.3752)	(0.3760)
NDVI			0.0053	0.0053
			(0.0058)	(0.0058)
Minimum Temperature			-0.0289	-0.0289
			(0.0225)	(0.0255)
Precipitation				
Month Quadratic Trend	Y	Y	Y	Y
Year FE	N	Y	Y	Y
Region FE	N	Y	Y	Y
N	359	359	285	286
R-Squared	0.0426	0.0572	0.0800	0.0800

Standard errors in parenthese.   **p<0.1*   ***p<0.05*   ****p<0.01*