Testing the Effect of non-lethal Insecticides on honey bee hives over a period of six weeks through AI model simulations

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Abstract

This paper is exploring the effects of small doses of the non-lethal insecticide dietary neonicotinoid which is explored by Wu-Smart and Spivak ([2016](#_ENREF_2)) where they took test hives and introduced the insecticide to the food supply and monitored the effects over a three-week period. The purpose of this paper is to model the hives in NetLogo to explore the longer lasting effects of a continued dose of Neonicotinoid to three hive sizes of 1500, 3000 and 7000 to see if the results that Wu-Smart and Spivak ([2016](#_ENREF_2)) documented hold true for longer periods of time such as a six-week period.

There are several benefits of using an AI model over a real hive. These tests are uniform over all subjects whereas in real hives some bees can be affected more than others. The three-week test can be simulated numerus times in quick succession in a number of hours to test the hypothesis. The use of an AI model can also increase the time used to test from three to six weeks to monitor the effects over a longer period which is less ethical to do with living subjects.

Introduction

Honey bees, Apis mellifera L., are integral to the pollination of crops not just in the UK and Europe but Worldwide. The use of insecticides like the neonicotinoid are affecting the population of hives and in turn the health of crops providing lower yields and effecting farmers income.

Neonicotinoids are used to control the population of sucking and chewing insect pests and are used by 24% of the market which is valued at US $2.6 billion (“[Samson-Robert et al" 2014](#_ENREF_1)) but the insecticide transfers to the pollen and water supply which will be transferred to the hives by the worker bees, this in turn effects the hive and reduces its effectiveness.

In this experiment Netlogo is used to develop a model of a beehive , with populations of 1500, 3000 and 7000 worker bees with one poisoned food supply and with the poison rate adjusted in each run of the model. Behaviour space was used to run the model and monitor the population of workers queens and larvae to visualise the effect of the poison. Four percentages of poison concentration were used to model the amount from the refence paper with a control at 0% then there were runs at 50%, 55%, 60%, and 65%.

Your work

A model was created in NetLogo (2017) to computationally simulate the scenario described in the paper (Wu-Smart & Spivak, 2016) for testing our hypothesis.   
Testing of our hypothesis was done by running simulations using the model, with the poison-strength, hive-size and number-of-workers variables based on the paper. This means 1500,3000 and 7000 workers in hives with lengths of 70, 105 and 185 patches. The hive size was taken from a table in the study showing cell usage in the hives. The cell usage was taken and added together to get the total number of cells for each colony size and then it was square rooted, to get the length from that area. Then all 3 of these hive-size/number-of-workers pairs were tested with poison strengths of 0,50,55,60 and 65% with 1 poison source, where the single poisoned food source out of a total of 4 food sources is used to mimic the choice the bees have between the poisoned syrup and pollen from flowers. Flowers and the outside of the hive have been abstracted as food sources at the edges of the hive as pollen from flowers is functionally identical to our poisoned syrup and we are only interested in the inside of the hive. The percentages are deduced from the effect of poison ppb (parts per billion) values on the percentage decrease of the population under the effect of that poison strength, as a paper stating numerical equivalence between ppb and effectiveness was unable to be found.

Worker, queen and larvae bees are represented as agents and the cells of their hive represented as patches. When setup is pressed, the model is setup. Any previous simulation is cleared, and the hive is created with size based on the “hive-size” slider, and food-sources based on the “number-of-food-sources-poisoned” slider. This results in yellow (representing empty) patches being created for the size of the hive, with a black border around it and some food sources at each cardinal point, with blue representing a healthy food source and green a poisoned one, with there being poisoned food sources equal to the value of the slider. Following this the selected number of worker bees are created as agents in random positions within the hive, with random ages, as in the paper an existing colony was migrated to the test hives and these colonies would contain a variety of generations of bees. One queen is then created and placed in the centre of the hive, as this is where queens begin laying their eggs ("The Life of the Queen Bee in the Honey Bee Hive", 2017). Sets of patches are then initialized, such as “empty-patches” which contains all the yellow patches with no larvae on them. This is done purely for optimization purposes that the bees don’t have to search every patch for something, just suitable patches (with this causing large hives to go from reaching 400 ticks after 12 hours, to being completed in less than a third of the time).

When “Go” is pressed the simulation begins. Units of time called ticks pass, wherein every bee in the hive performs multiple actions (equal to actions-per-day/ticks-per-day), which with our values is six actions.   
The queen moves to empty patches around the centre of the hive and births larvae. Un-poisoned, she moves instantly in our model to keep up with the observed egg laying rate in the study of 6 eggs per 15 minutes.   
Larvae check if there’s a queen alive and if not then they are marked to be queen. Normally a larva is selected by workers to be queen based on genetics but as our bees are all the same, the first one to find that there’s no queen is marked to be queen. Larvae also check whether they are of age and if they are, then they are born into a worker or queen.  
Workers get assigned an action to perform based on their age ("Worker bees - Beekeeping", 2017) or if the hive is in a state where there’s nobody fulfilling that role (Khoury, Myerscough & Barron, 2017).   
Bees older than 12 days old gather food. To gather food bees must go to the food sources and take food from them and then store it as honey in empty patches close to the centre. We chose close to the centre as this means food is equidistance from the edges of the hive. This then leaves a honey patch or poisoned honey patch (depending on whether the food was poisoned) with “honey-uses” number of uses, which we set to 2 based on the idea that if it was 1 then bees would use energy gathering the honey and then immediately eat it to cover the costs of gathering the food and bees having two stomachs.  
Bees younger than 16 clean the hive. They move to any unclean (grey) cells if there are any and they turn then back to clean (yellow) cells.   
Bees between 7 and 12 days old must feed larvae. If any Larvae are below a percentage of their energy they are fed. Young larvae (< 3 days old) are fed on worker jelly, or queen jelly if they are marked to become a queen. In this case they move to the larvae and its energy is increased as they “feed it”. Older larvae (3-7 days old), as well as workers and queens must be fed honey. Before this can happen, bees must first gather honey to feed them, which they do by moving to honey or poisoned honey cells, which are shown red and orange patches, and then taking a use from that patch and setting their carrying attribute to the honey that they “picked up”.  
All workers can feed themselves if they are below a certain percentage of their energy. Workers feed themselves simply by eating the honey that they are carrying, increasing their energy value and setting their poisoned value to true, if the honey they ate was poisoned. Alternatively, if they are not carrying any honey they must gather some first.  
Workers between the ages of 7 and 12 must feed the queen if she is below a certain percentage of her energy. Queens and larvae are fed by workers by the worker moving to them and feeding them using the same process they use to feed themselves. For the Queen bee however, the worker needs to instantly move to the queen, as she moves instantly herself to keep up with the egg laying rate. If they did not move like this then they would be chasing a queen around that they would have serious issues in catching up with her.   
As workers and the queen can both consume poisoned honey, they can all become poisoned.

When a bee is poisoned, any actions they do first have to go through a random number check. A random number is rolled between 0 and 100 and the number must be more than the poison-strength that they’re poisoned with or else they do not get to make that action. This is to emulate bees being worse at their jobs when poisoned due to being slower and less coordinated.   
Larvae can also consume honey but as they do not perform any actions in our model other than aging, there was no way for poison to affect them.  
   
Energy is limited at the end of a tick to ensure that the bees do not have more energy than their maximum, otherwise they wouldn’t need to feed/be fed regularly – only once.

Lastly, any bees that have no energy or have reached their maximum age die. When they die, if they are on a clean empty patch, that patch becomes unclean (grey) and must be cleaned before it can be used again.

The main observation of the model is the effect of an action being skipped due to the poison on the population of the hive and that is what was measured during the simulation. Results of each test were output into a spreadsheet and graphs and figures created from them.

Results & evaluation

Graphs representing the results can be observed in the figures section (figs. 1-8) alongside some figures from the initial study.

Initially the simulations were a success when using 1500 bees at a 70 unit squared hive, however the larger hives suffered from not being able to feed themselves or the larvae and as such losing large numbers. This differs drastically from the study and makes comparison of any data following this quite difficult.

More appropriate experiments could have been carried out by recording more data points, such as birth rates and death rates of larvae, which would make comparisons between data and the causes of some phenomenon to be more readily obvious.

Avoiding the introduction period where many bees died would allow more accurate and comparable data to a real life scenario to be used, whereas the data in this study compares more the data of known values from the simulations or the original study.

Perhaps by trying different number of initial bees at every hive size would allow more information from the simulations and their behaviour to be known. One reason why the smallest hive could have not suffered this initial death period could be that the food sources were closer to the centre of the hive, where as in the larger hives much larger distances needed to be travelled to collect food.

Analysis & conclusion

In regard to the population of the worker bees, all runs begin with a sharp decline in population. This can be attested to the fact that the bees have been introduced to the new hive with no larvae present and as such it takes around 1224 ticks before any new honey bees can hatch. In the larger hive experiments, 3000 and 7000 bees, the population can be seen with an even steeper decline which is indicative of the bees’ inability to feed their large numbers early in the model without any honey reserves. Although the 1500 bee model appears to not have this issue, as very few bees are lost which possibly could be due to natural causes.

Similarly, a large drop in population can be seen amongst all runs around the 500 tick mark, this can explained by the fact that in the model all bees begin with their energy set to the maximum value and a random age. This ~500 tick mark is the beginning of bees dying from lack of energy, whereas any deaths before can be attested to old age. This is further evidence for the bees’ inability to feed themselves. The exception to this is the 1500 bee un-poisoned run where no visible drop is evident, meaning the bees were able to establish themselves without losing a number of their population at the first opportunity due to starvation. After approximately 1200 ticks the rate of dying bees is counteracted by the hive beginning to hatch its larvae and create new bees and as such the hive population becomes much more stable, at least for the un-poisoned runs.

After this 'introduction period' the hives populations rate of change become more stable with all the poisoned run average population's dwindling and displaying a negative trend. And the un-poisoned run average populations slowly building while maintaining the equilibrium between increasing population and feeding themselves.

The neonicotinoid exposure had a fairly evident negative affect on the bee population throughout all experiment runs which conforms to the findings of the original study (Wu-Smart & Spivak, 2016). More interestingly the results of the simulations do show that larger populations receive a proportionally less drastic reduction in the populations, at least initially.

In fig.1 the final average population of each variation of hive size and poison level can be seen. Opposite to expectations the 1500 bee runs had the highest ending population numbers across all poison percentages, one possible explanation for this could be the size of the hive being smaller meaning less distance is required to travel to a food source. This could mean there is a less of a strain throughout the experiment for the bees to feed the larvae and avoid starvation.

The 3000 bee runs fared the worst of all the scenarios across all poison levels. Possibly due to the size of the hive and population being above a threshold where the population can comfortably adapt to the new hive and avoid starvation during the 'introduction period'.

Finally, the 7000 bee runs ended a close second to the 1500 bee run but were still marginally worse across all poison levels. However, when comparing the 7000 and 3000 bee runs an improvement in the final population can be observed. Whereas the 1500 runs did not suffer a sharp decrease in initial population the 3000 & 7000 did. This could be interpreted as after both runs stabilised the effect of the neonocotinoids were reduced or delayed and so conforms to the conclusion of the original study.

Analysing the population of the larvae throughout the study is a useful tool to see how the hive is fairing, specifically the rate of larvae births and its direct relation with the effect of exposure to neonocotinoids. In the original study the effects of the neonocotinoid were measured by the number of eggs the queen hatched per 15-minute observation period. As such the rate of change in the larvae graphs (figures 4,5 and 6) can be used to observe the health of the queen and by association the hive.

Across all three hive sizes the effects of exposure to neonocotinoids was evident, with the initial number of larvae being laid being heavily affected. The larvae laying rate is cut nearly in half when comparing the 7000 bee unpoisoned rate of change is compared to the 7000-bee poisoned rate of change up to 738 ticks. This is the peak for the number of larvae present during the experiment as the larvae begin starving and hatching, and the queen produces at the same rate as bees are born, this means the population of larvae would remain constant given none die of starvation and the queen still lays eggs.

At this point the queen will continue her job of producing new larvae and the old larvae will either hatch or starve. In the larger two experiment runs (3000 and 7000 bees) after the sharp peak there is a sharp decline which is where the hives cannot keep up with the food demand and some of larvae die, this allows the larvae to hit a sustainable population where they can be fed in time and avoid losing the hive valuable future workers.

When observing the results from the 1500 bee runs they largely 'dodge' the effect of not being able to feed the larvae, possibly due to the more stable worker bee population and less demanding number of eggs to feed.

In fig.2 the average increase in larvae per tick can be observed. This can be used as a secondary tool to see the fecundity of the hive queen. Alongside fig.9 a comparison can be made between the study and the simulation. It can be seen to have a similar affect in both scenarios regardless of the time span, further conforming to the conclusion drawn from the study that the exposure time is not relevant to the behaviours of the bees and the health of the hive.

Furthermore fig.2 can be used to further reinforce the findings that hive size does indeed act as a 'buffer' and delay the onset of modified behaviour in a hive. When comparing the 1500,3000 and 7000 bee experiments at 50% and 55% poison strength a clear decrease in performance and fecundity can be seen across the 1500 and 3000 bee experiments. Whereas in the 7000 bees experiment the two are the same, this could be indicative of a delayed affect caused by a larger hive size.

Figure 10 can be seen and used to compare the final number of eggs from the study to the number of eggs at 3 weeks from the simulations. Significantly more eggs can be seen in the simulations than in the study, even after taking into account larvae and eggs were combined for the purpose of the simulation. This could be a possible reason for the starvation periods of the simulations, where the hive cannot keep up with the demand of having too many brood to feed.

In conclusion the experiment was a success in that it showed a somewhat accurate representation of a hive under the conditions outlined in the study. However, it is unfortunate the initial 'introduction period' in the larger experiment sizes suffered from being unable to fully utilise their large numbers due to starvation and overall hive shrinking.

When comparing the hypothesis that “larger hives have a delayed 'buffer' effect when exposed to neonocotinoids” it can be assumed that more study or simulations are required, perhaps over a longer time span and perhaps with already established hives to avoid the larger populations starving. This would also be more consistent with naturally occurring hives.

The levels of neonicotinoids certainly have an effect on the population when exposed however no obvious trend is shown with change in hive size or prolonged exposure. The poison seemed to affect the final population by shrinking it to ~10 to ~20% depending on the poison concentration, although this is drastically more impactful than in the original study where the effects shrank the population to around 90% at worst (fig.10).

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Figures

















