Grower Summary

PE 031a

Tomato: Phase 2 of an investigation into poor pollination performance by the native bumblebee, Bombus terrestris audax

Final Report

Project title:	Tomato: Phase 2 of an investigation into poor pollination performance by the native bumblebee, *Bombus terrestris audax*
Project number:	PE 031a
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Report:	Final report, 30 November 2018
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Date project completed:	30 November 2017

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[The results and conclusions in this report are based on a series of investigations conducted over a six-month period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- Most Bta colonies go into decline soon after placement in tomato crops
- Peak pollen flow in cv Piccolo usually occurs around mid-day
- Bta flights in glasshouses are much reduced compared with outdoors and not always well synchronised to peak pollen flow
- A system has been developed to remotely monitor Bta activity within hives

Background

Bumblebees were introduced to British tomato growers in 1989 via trials in glasshouse crops in West Sussex. The benefits in reduced labour and improved fruit set were so great that by 1992 bumblebees were being used to pollinate all long-season tomato crops in the UK. The system was so reliable that users came to expect perfect fruit set with minimal maintenance.

In the 1980s, the three bumblebee producers tested many populations *of Bombus terrestris* to determine which could be reared most efficiently and which provided the best results in tomato crops. They independently selected two non-native sub-species; *B. terrestris terrestris* (Btt) from central Europe and *B. terrestris dalmatinus* (Btd) from south east Europe. A native sub-species, *B. terrestris audax* (Bta), was tested but dismissed due to inferior performance. In the 27 years since the first release of Btt/Btd in UK tomato crops, there has been no evidence of establishment outside glasshouses or detrimental effect on natural bumblebee populations.

We know that each commercial Btt/Btd colony begins with a single queen producing a small batch of about 8 eggs which she raises to become infertile workers. Thereafter she focuses on producing eggs while the workers take over foraging and brood maintenance tasks. The colony rapidly grows in size and is transferred to the tomato crop about 12 weeks from initiation with 50-60 workers present. Those workers forage among the tomato plants and the colony continues to grow for a further 6-8 weeks. At that point, fertile males and females emerge and leave the hive to mate with adults from other colonies. This marks the end of the cycle.

In 2014, Natural England (NE) produced a document which suggested that non-native bumblebees could escape from glasshouses and hybridise with wild Bta leading to the local extinction of Bta. Following an open consultation, NE revised its policy and permission to use

non-native bumblebees in unscreened glasshouses was withdrawn from 31 December 2014. Commercially reared native Bta could still be used without a license. However, the use of Bta in 2015 proved to be far from the reliable and maintenance-free experience to which growers had become accustomed.

British tomato growers are keen to use Bta if this can be done without significant economic loss. In 2017, the British Tomato Growers' Association's Technical Committee (TGA TC) organised an in-depth survey of UK tomato growers to gather more precise information about the situation at that time. Growers representing 98% of the UK production area participated in that survey. Based on those results, the TGA TC organised the present project to investigate:

1. Bta colony life in greenhouses and the impact this has on hive input schedules.
2. Bta biology and behaviour under different environmental conditions with particular emphasis on synchrony between bumblebee foraging and optimum pollen flow.
3. 9Flower quality and pollen flow in the small fruiting cultivars which now make up 76.9% of UK production.

Summary

What was done

Thirteen growers participated in the survey of Bta colony life in their tomato crops. This provided a spread of locations throughout the main tomato growing areas in the UK as well as different bumblebee suppliers and types of tomatoes. The growers followed an agreed protocol to collectively monitor 161 hives between mid-June and the end of September 2018. During that time, 777 individual colony assessments were completed. An estimate was made of the number of adult bees and the hive was assigned to one of the following indices:

- Index 1 = 1-15 adult bees in view
- Index 2 = 16-30 adult bees in view
- Index 3 = over 31 adult bees in view

The study of Bta biology and behaviour was done at three sites: a small crop of tomatoes (cv Piccolo) at Warwick Crop Centre (WCC), a commercial tomato crop and an outside orchard. 'Bee traffic' was recorded as the rate at which bees entered and exited the hive per hour. This was done by manually counting the numbers of bees entering and exiting the hive every minute from sunrise to sunset. Data were then aggregated as numbers of bees entering / exiting per hour. In addition, an important task was to develop a method of remotely monitoring Bta activity that could be used in future studies. The work was done in

collaboration with ‘Arnia Hive Monitors’ and involved adapting their honeybee remote monitoring system (HRMS) to work with bumblebee hives. The HRMS records changes in honeybee hive weight, brood temperature, brood humidity, outside temperature, rainfall and bee colony acoustic data. The latter provides an indication of whether the bees are foraging normally or performing other tasks such as ‘fanning’ to cool the brood. Our challenge was to modify the HRMS to collect similar data from much smaller bumblebee colonies housed in considerably lighter structures of completely different design. Prototypes of the adapted HRMS were tested at the three sites used for manual bee counts. Data was recorded in real time, continuously uploaded to the ‘Cloud’ via a portal and accessed remotely in the researchers’ own offices.

The study of flower quality and pollen flow in small fruiting cultivars was done in a small experimental crop of cv Piccolo at WCC. Plants were grown to commercial standards under the guidance of TGA members. A scale representing discrete and recognisable stages in the development of flowers of cv Piccolo was devised. It comprised Stage 1 (flower buds visible); Stage 2 (petals visible); Stage 3 (bright yellow petals held at right angles to the pedicel); Stage 4 (flower open, petals reflexed); Stage 5 (flower closing, petals becoming pale); Stage 6 (flower closed, petals dying). This scale was then used to monitor the development of flowers along selected trusses initially every hour from dawn until dusk and later every 4 hours from 07:00h to 17:30h each day. The observations were confirmed using continuous time-lapse photography and validated in the commercial tomato crop. Pollen flow was assessed on the same flowers; initially using a simple established method of tapping flowers over a black card and later using a purpose built ‘electric bee’. In addition, fruits were removed and their weight, diameter and number of seeds recorded.

Summary of findings

Of the monitored Bta colonies, 62% went into decline within 2 weeks of being placed in a tomato crop and this increased to 90% within 4 weeks of delivery (Figure 1). There were variations in numbers of adult bumblebees in hives upon delivery from all suppliers but this was also known to be the case with the non-native bumblebees. The Bta hives generally contained good active colonies upon delivery and we would have expected these to continue to increase in size before completing their cycle. The rapid decline was in contrast to our expectations based on previous studies with the non-native bumblebees. There were no consistent differences between bumblebee supplier, geographical location or tomato type. The only two common factors across all the sites appeared to be Bta bumblebees and tomato crops; thus suggesting that the former either do not like the tomato growing environment or the plants do not provide a satisfactory food source. We must stress that these results relate

to the duration of the colonies and do not necessarily mean that the bumblebees failed to provide good fruit set during the monitored period. However, the results do begin to explain why more Bta hives are required than was the case with Btt/Btd and why some growers have obtained improved results by moving to a weekly hive input schedule.

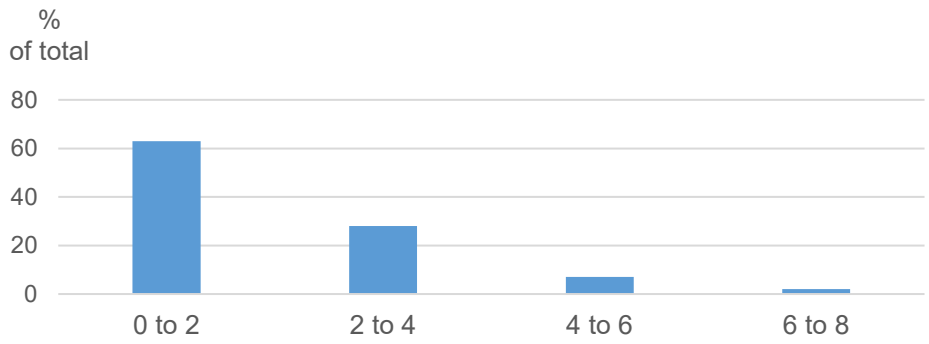

Figure 1. The time after delivery that 161 Bta colonies, across 12 UK tomato production sites, went into decline after delivery to those sites

The manual recording of Bta activity showed that adults were generally active over a 12 hour period of the day. Activity followed a similar pattern regardless of hive location, temperature or time of year, with the first activity seen just after sunrise, rising to a peak in activity between 11:00h and 14:00h followed by a fall in activity around 18:00h. Two short peaks of daily activity were often recorded in colonies within the tomato crops but only one, albeit more prolonged, peak was observed in hives kept outdoors. One very notable feature was that activity in colonies kept outdoors was considerably higher than that observed when kept in the glasshouse tomato crops (Figure 2).

The Arnia remote hive monitors not only provided continual and more detailed information on hive activity than the time consuming, labour intensive manual counts but they also provided in depth information on the hive environment / health and will provide a valuable tool for future studies. The collected data showed that brood and glasshouse temperatures never exceeded 30°C and there was no evidence that the recorded flight activity was correlated with temperature. Available literature suggests that *B. terrestris* will generally only cease to forage at temperatures above 32°C.

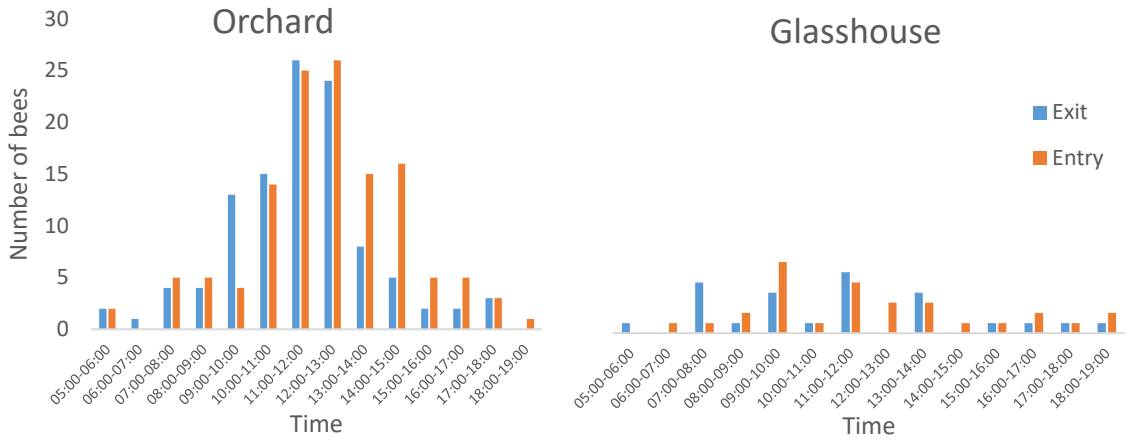

Figure 2. Comparison of Bta activity in a tomato crop and outside – expressed as numbers of bees entering and exiting the hives 14 August 2018

Our study of flower development and pollen flow in cv Piccolo revealed that each flower was usually open on two successive days although it usually released most of its pollen on the first day. The peak of pollen release usually occurred between 12:30h and 13:30h each afternoon but, for some flowers the peak occurred much earlier and for others it occurred much later. The tomato flower is normally self-pollinated and it was evident that the anthers of each cv Piccolo flower had the potential to produce many more pollen grains than were required to fertilise all the ovules in the same flower's ovary. In our experiment, the anther of each flower could produce at least 20,000 pollen grains while the fruit contained fewer than 120 seeds. Although it appeared that each flower produced and released a vast excess of pollen when the flower was shaken with the mini electric bee, further work is required to establish that similar amounts would be released by the actions of bumblebees or by the actions of growers.

Our observations suggest that pollen production and pollen release are inhibited by high day temperatures of 29^{0}C or more which is also the conclusion reached in the published literature. High day temperatures may also have contributed to the variability in pollen production by different flowers, as that was more noticeable in August than in September, and the high temperature may also have affected pollen viability. It is therefore important to establish the proportion of the pollen grains that are viable and able to germinate.

Although various factors could contribute to the failure to transfer enough viable pollen to the stigmas of tomato flowers, a major cause could be that the bumblebees fail to visit all of the flowers at a time when they are each producing adequate quantities of viable pollen and may even be a failure of the bumblebees to release the pollen from the flower's anthers.

Financial Benefits

The economics of tomato production in the UK have changed considerably since bumblebees were first introduced for pollination. Pressure from retail customers has greatly reduced financial margins and growers have become dependent upon the benefits that are obtained from using biological pollination. It is difficult to generalise about the financial value of British tomato crops due to the wide range of products supplied to retail customers. However, if we assume the farm gate value to be about £850k / ha / season, then the total value of the British crop is about £162m / season. Long season tomato plants produce 35-40 trusses per season. The loss of set due to inadequate pollination on just two trusses equates to about 5.3% of annual production which is in the region of £45k / ha / season. The equivalent losses across the British industry would be over £8.6m.

Action Points

Projects PE031 and PE031a have advanced the TGA's (*i.e.* the UK tomato industry's) understanding of the poor pollination performance of Bta in tomato crops with particular emphasis on the small fruited cultivars, such as cv Piccolo, which made up 76.9% of UK production in 2016. We have now developed the methods required to obtain more detailed information on how Bta performs within a commercial tomato crop. This knowledge provides a solid foundation upon which the TGA can progress towards our ultimate objective; *i.e.* to reduce financial losses resulting from production deficit, increased labour and excessive input caused by the enforced change from non-native bumblebees to Bta for pollination of UK tomato crops.

In the short term, growers can:

- Liaise with their bumblebee supplier to produce a hive input programme that compensates for the shorter colony life of Bta bumblebees.
- Monitor Bta foraging activity around mid-day, when most open flowers have peak pollen flow, and supplement with manual pollination when there is little activity.

