

Project title: **Assessing Bee Pollination Requirements in Pumpkin**

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## 1. Summary

Pumpkin plants set fruit only if pollinated by bees, and fruit marketability is positively correlated with bee-flower interactions. Pumpkin flowers are short-lived (several hours) and their reproductive viability is strongly influenced by temperature. Because both male and female pumpkin flowers open before dawn and close before noon, bee species that forage at different time intervals register different levels of economic importance in pumpkin pollination. Unlike honeybees, squash bees and bumblebees are active earlier in the day and in inclement weather. This project aimed to assess the bee pollination requirements in pumpkins by measuring the yields from pumpkin plots where both managed (honeybees) and non-managed bee species (bumblebees and squash bees) had access versus pumpkin plots where managed bees were excluded, and only non-managed bees had access. According to the current recommendations, Pennsylvania pumpkin growers can pay up to \$120 per acre in honeybee renting fees. This project determined if in south-central Pennsylvania, there is a need to rent honeybees or if non-managed bees can provide adequate pollination services.

## 2. Introduction

According to the United States Department of Agriculture, the Northeast region ranks first nationwide in pumpkin revenue, with a value that exceeds \$58 million, representing about 41% of the total U.S. pumpkin value. In this region, there are more than 13,400 acres cultivated with pumpkin, or approximately 30% of the entire U.S. pumpkin acreage. For growers, pumpkin represents an important cash crop, and states like New York and Pennsylvania lead in pumpkin production for fresh and processing markets. Furthermore, “pick-your-own” pumpkin sales corroborated with other on-farm activities, such as hayrides and corn mazes, prove to be an ideal way for growers to attract loyal clientele and enhance cash revenues.

Pumpkin crops set yields only if pollinated by bees, and fruit marketability is positively correlated with bee-flower interactions. Pumpkin flowers are short-lived (several hours) and their reproductive viability is inversely correlated with higher temperatures. Because both male and female flowers open before dawn and close well before noon, bee species that start foraging at different hours in the morning register different measures of success in pumpkin pollination. Since pumpkin pollen is relatively large and sticky, pumpkin flowers are visited by only a few bee species, with the most common being squash bees (*Peponapis pruinosa*), bumblebees (*Bombus spp.*) and honeybees (*Apis mellifera*).

The current pollination recommendation for pumpkin growers is to rent two honeybee colonies per acre for setting optimum yields. However, renting honeybees for pollinating pumpkins has some serious disadvantages, and most times this practice is not economically feasible:

- ✓ Due to Colony Collapse Disorder and other pest and pathogen stressors, beekeepers have generally registered 30% yearly losses in the number of overwintering colonies over the past several years. Fewer honeybee colonies corroborated with higher demands for commercial pollination services has resulted in more expensive fees for the commercial pollination services.
- ✓ Because they are highly social, forage on long distances and have the ability to communicate where the best pollen and nectar resources are, honeybees are less likely to stay on the pumpkin crop when better resources are available. Research indicates that, in general, farms that have rented honeybees did not have significantly more honeybees working blossoms than the farms that did not rent them.
- ✓ Compared with squash bees, honeybees start to pollinate later in the day, after 7:00 AM in midsummer, and are less or not active in inclement weather. Cloudy or windy days (<12 mph) can limit honeybee visitation, which will result in delayed or poor pollination services.
- ✓ The current pollination recommendations do not factor in the presence and abundance of native pollinators, such as squash bees and bumblebees. On crops that have a strong population of native bees, the presence of honeybees can be superfluous.

In the Northeastern U.S. region, the most important pumpkin pollinator is the squash bee—*Peponapis pruinosa*, a native solitary species that feeds its offspring solely with pollen from pumpkins and squashes. According to recent research, on more than 90% of farms pumpkin flowers are visited most frequently by squash bees, while honeybees are only occasional visitors. Squash bees time their activity with the pumpkin flowers, being active between dawn and mid morning. Additionally, squash bees are fast fliers and much hairier than honeybees, characteristics that can greatly aid in efficiently vectoring more pollen.

Unfortunately, very few farmers are aware of the role of squash bees, and most of the time unnecessarily rent honeybees. With more accurate information on pumpkin pollination requirements, growers in the Northeast region will be able to make long-term sustainable decisions regarding native pollinator conservation on their farms and ultimately save hundreds of thousands of dollars in pollination fees, while reducing their reliance on the much plagued honeybees.

### **3. Objectives**

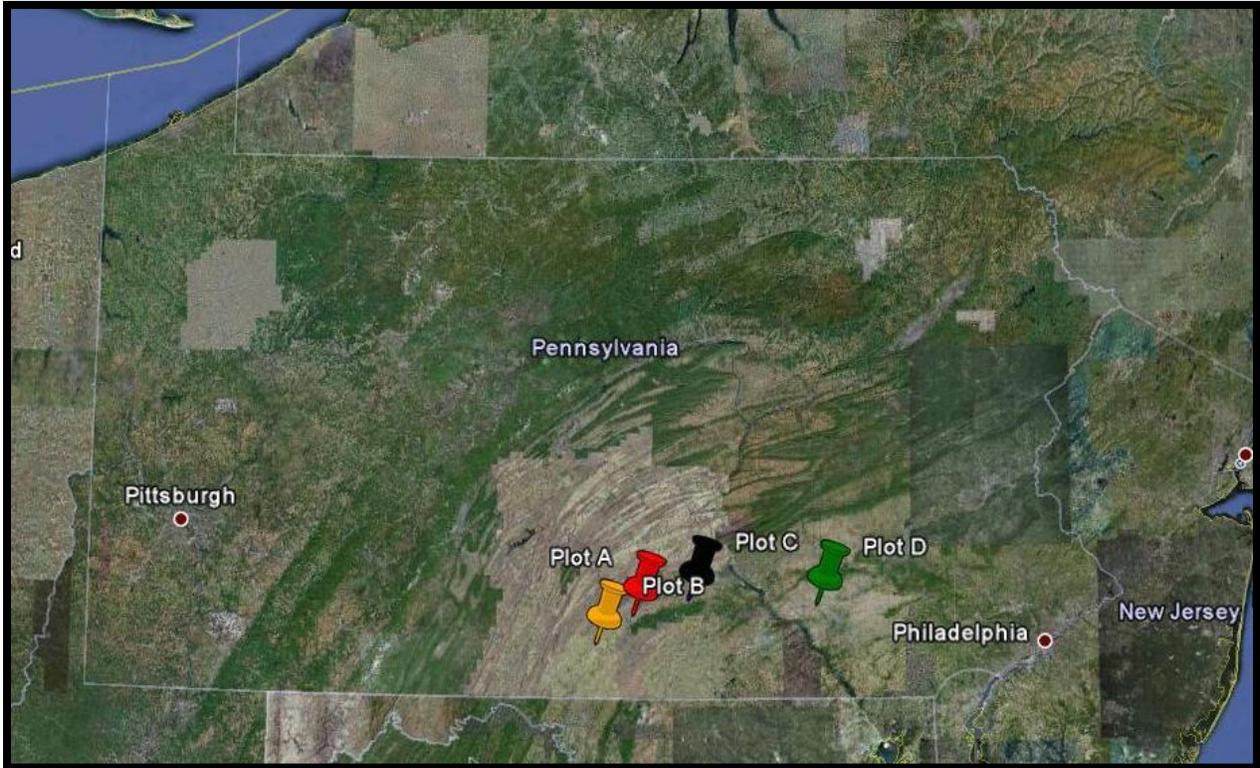
The primary objective of this project was to assess the role managed (honeybees) and non-managed bee species (bumblebees and squash bees) play in pollinating pumpkins. The second objective was to disseminate the results of this project to farmers through presentations and articles.

### **4. Materials and methods**

#### **a) Pumpkin Yields**

Research plots were installed on four farms that were selected for their different pest management approaches. A) Alvin Martin's farm, located in Shippensburg, PA – conventional pest management system; B) Wilson College farm, located in Chambersburg, PA – biorational pest control system; C) Dickinson

College Organic farm, located in Boiling Springs, PA – organic pest management approach; B) PSU Southeast Research and Education Center farm (Plot D), located in Manheim, PA – conventional pest management system.



All farms had cultivated pumpkins in the past, but only SEAREC farm had them cultivated in a no-till system. Each of the farms had two or more colonies of honeybees located in close proximity of the pumpkin research plots. All plots were irrigated through a drip line irrigation system and were kept weed free by having them lined with landscape fabric.



At the end of May, on each of the four farms, six ten-by-ten insect-screened plots (cages) were installed, as indicated in the above pictures. Each cage’s lateral walls were covered with row cover material that was secured to the ground with pins and soil. For this project, Field Trip pumpkin variety has been used, because of its relatively small vining propensity and medium-size fruit. Each cage had four pumpkin plants. The seeds were sown directly in the field on June 11<sup>th</sup> and, as soon as they emerged, pest management practices were employed. On the conventional farms these practices consisted of regular sprayings, while on non-conventional farms all cages were covered with insect screening or row covers, as shown in the below picture.



As soon as the female flowers started to bloom, the bees’ access to flowers was manipulated according to the below diagram. The Monday-afternoon-to-Friday-afternoon schedule was selected in order to work

within the time constraints all four farms had (limited or no work activities on Saturdays and Sundays). To mitigate this, on all farms the first three cages (#1, #2, #3) were covered at all times between Friday afternoon to Tuesday morning (with the exception of cage #1, which was opened Monday afternoon, too). In addition, in order to make sure that the female flowers in cages #2 and #6 were unavailable to the bees that foraged earlier in the morning, the flowers were manipulated during the previous day's afternoon (when all pumpkin flowers were closed).

<b>#1 (screened)</b> Opened part day: PM to 7:00 AM (Mo), Tu, W, Th, and Fr.	<b>#2 (screened)</b> Opened part day: 7:00 AM to PM Tu, W, Th, and Fr.	<b>#3 (screened – 2<sup>nd</sup> control)</b> Opened full day: (Mo), Tu, W, Th, and Fr.	<b>#4 (1<sup>st</sup> control)</b> Opened at all times, all days	<b>#5 (bagged flower)</b> Bee available until 7:00 AM Tu, W, Th, and Fr.	<b>#6 (bagged flower)</b> Bee available after 7:00 AM Tu, W, Th, and Fr.
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### **Activities broken down for each day of the week:**

#### ***Monday***

##### Afternoon (anytime after 1:00 PM)

- ✓ Removed insect screening from cages # 1 and # 3;
- ✓ Bagged female flowers that were to open the following day in cage #6;
- ✓ Removed any female flowers that bloomed over the past Saturday, Sunday, and Monday in cages #5 and #6.

#### ***Tuesday, Wednesday, and Thursday***

##### Morning (7:00 AM)

- ✓ Covered cage #1 with insect screening;
- ✓ Removed insect screening from cage #2;
- ✓ Bagged female flowers that were open in cage # 5;
- ✓ Removed the bags from the previous day's bagged female flowers on cage #6; tagged the flowers.

##### Afternoon (anytime after 1:00 PM)

- ✓ Removed insect screening from cage #1;
- ✓ Covered cage #2 with insect screening;
- ✓ Removed bags from female flowers on cage #5; tagged the flowers;
- ✓ Bagged female flowers that would open the following day in cage #6.

**Friday**Morning (7:00 AM)

- ✓ Covered cage #1 with insect screening;
- ✓ Removed insect screening from cage #2;
- ✓ Removed bags from the previous day's bagged female flowers on cage #6; tagged the flowers
- ✓ Bagged female flowers that were open on cage # 5.

Afternoon (anytime after 1:00 PM)

- ✓ Covered cages #2 and #3 with insect screening;
- ✓ Removed bags from female flowers on cage #6; tagged the flowers.

**Description for each of the treatments**

**Cage #1** (Treatment # 1) – The female pumpkin flowers in this cage were available for pollination only between 6:00 AM and 7:00 AM, from Tuesday to Friday.

By following this treatment, the female pumpkin flowers in this cage were available for pollination only for the early foraging bees, the squash bees and bumblebees. Based on the literature, as well as on personal observations, bumblebees and squash bees are early foragers, while honeybees commence foraging in high numbers on pumpkin flowers sometime after 7:00 AM. By comparing the yields from this treatment with the yields from treatments #2, and #3, the honeybee role in pumpkin pollination could be better understood.

**Cage #2** (Treatment # 2) – The female pumpkin flowers in this cage were available for pollination only between 7:00 AM and 3:00 PM, from Tuesday through Friday.

By following this treatment, the female pumpkin flowers in this cage were available for pollination for squash bees, bumblebees, and honeybees.

**Cage #3** (Treatment #3) – The female pumpkin flowers in this cage were available for pollination all day, from Tuesday to Friday.

By following this control treatment (all day, part week), the pumpkin flowers were available for pollination from the moment they opened until till they closed, from Tuesday to Friday. Comparing the yields from this treatment with the yields from treatment #4 allowed for determining the difference in yields as a result of impeding the bees' access to flowers on Saturday, Sunday, and Monday in treatments #1, #2, #5, and #6.

**Cage #4** (Treatment #4) – By following this treatment (all day, whole week), the female pumpkin flowers in this cage were available for pollination at all times.

**Cage #5** (Treatment #5) – In this cage all opened female flowers were bagged at 7:00 AM, in order to impede the bees' access for the rest of the day. This was done every morning at 7:00 AM on every

Tuesday, Wednesday, Thursday, and Friday. In the afternoon, the mesh bags were removed and the flowers were tagged with duck tape. Each Monday afternoon, female flowers that had bloomed over the previous Saturday, Sunday, and Monday and had started forming fruit, were removed.

By following this treatment, the flowers in this cage were available for pollination only for the early foraging bees, mainly squash bees and bumblebees. By comparing the yields from this treatment with the yields from treatments #6, and #3, the honeybee role in pumpkin pollination could be better understood

**Cage #6 (Treatment #6)** – In this cage all flowers that were ready to open the following day were bagged after 1:00 PM. The bagging of female flowers was done every Monday, Tuesday, Wednesday, and Thursday. The mesh bag was removed the following day in the morning at 7:00 AM, after tagging them with duct tape. Each Monday afternoon, female flowers that had bloomed over the previous Saturday, Sunday, and Monday, and had started forming fruit, were removed.

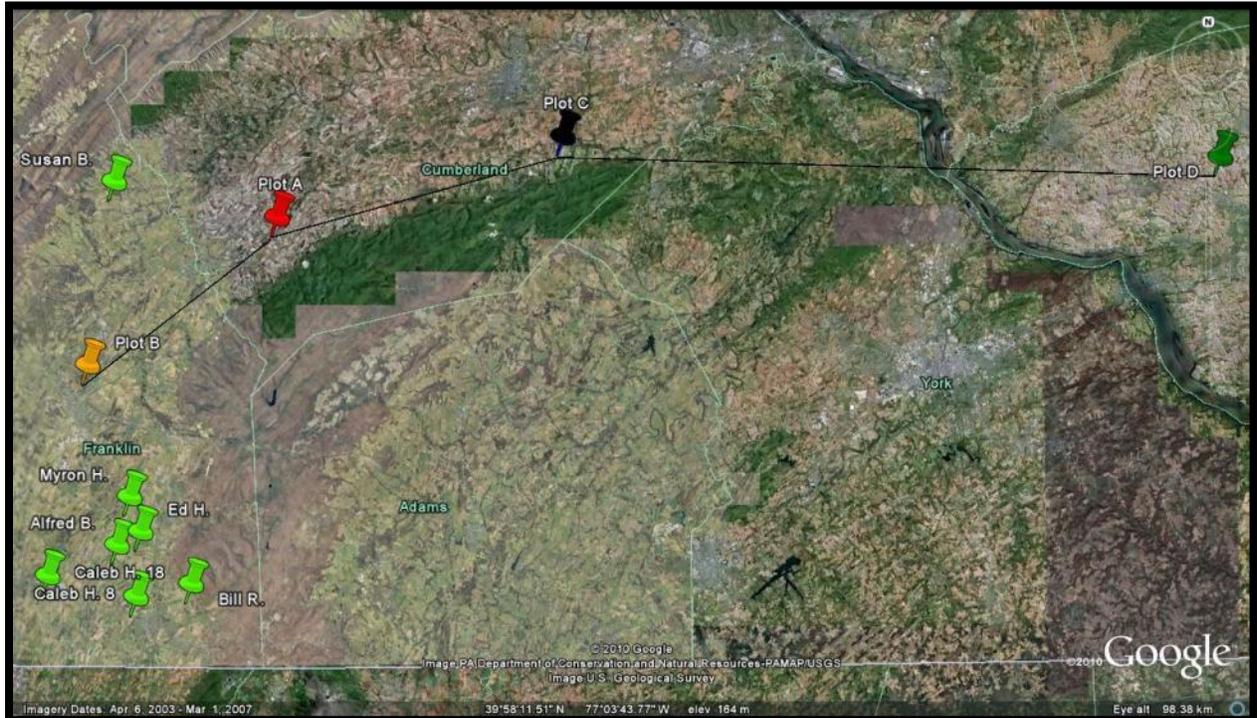
By following this treatment, the flowers in this cage were available for pollination by squash bees, bumblebees, and honeybees.

Note: Treatments #1 and #2 followed the same schedule as treatments #5 and #6. In this way, the results between the two approaches could be verified against each other. However, the results from treatments #5 and #6 were skewed because the yields were negatively affected by a higher-than-normal female flower abortion rate. This was triggered by the flower-bagging process, which had helped spread disease-causing pathogens. As a result, the average # of fruit for treatments #5 and #6 will not be used in the final analysis.



## b) Bee Species Monitoring

Bee species have been monitored on 11 different pumpkin fields located in south-central Pennsylvania. (See the below picture for map of all sites.) The fields were visited around 7:30 in the morning, and visual observations were made by walking the pumpkin rows at a constant pace and counting the bees that were visiting the flowers. The weather conditions were relatively similar on the days when the field observations were done. Pumpkin fields of ten acres or less were observed for 15 minutes, while fields of more than ten acres were observed for 30 minutes. Observations were done in both the center and the edges of each pumpkin field.



The pumpkin fields on the 11 farms ranged from less than one acre to 25 acres of continuous pumpkin crop. With the exception of one farm, all farms had pumpkin fields established on no-till fields that previously had winter rye as a cover crop. Similarly, with the exception of one farm, all farms had the pumpkin fields irrigated through drip irrigation.

## 5. Results and Discussion

### a) Pumpkin Yields

#### ➤ Results

Results for treatment #1 – Averages for all four farms' research cages (#1) that were opened for bee pollination from 1:00 PM (previous day) until 7:00 AM, Tuesday to Friday.

**14.25** pumpkins per cage (**3.56** pumpkins per plant); **1,266 g** per pumpkin (**2.79 lb** per pumpkin); **1,755 ml** per pumpkin (**3.19 US dry pt** per pumpkin);

Results for treatment #2 – Averages for all four farms' research cages (#2) that were opened for bee pollination from 7:00 AM until 1:00 PM, Tuesday to Friday.

**14.25** pumpkins per cage (**3.56** pumpkins per plant); **1,393 g** per pumpkin (**3.07 lb** per pumpkin); **1,966 ml** per pumpkin (**3.57 US dry pt** per pumpkin);

Results for treatment #3 – Averages for all four farms' research cages (#3) that were opened at all times from Monday after 1:00 PM until Friday at 1:00 PM.

**16.5** pumpkins per cage (**4.12** pumpkins per plant); **1,317 g** per pumpkin (**2.9 lb** per pumpkin); **1,852 ml** per pumpkin (**3.36 US dry pt** per pumpkin);

Results for treatment #4 – Averages for all four farms' research cages (#4) that were opened at all times, every day of the week.

**22.25** pumpkins per cage (**5.56** pumpkins per plant); **1,308 g** per pumpkin (**2.88 lb** per pumpkin); **1,833 ml** per pumpkin (**3.32 US dry pt** per pumpkin);

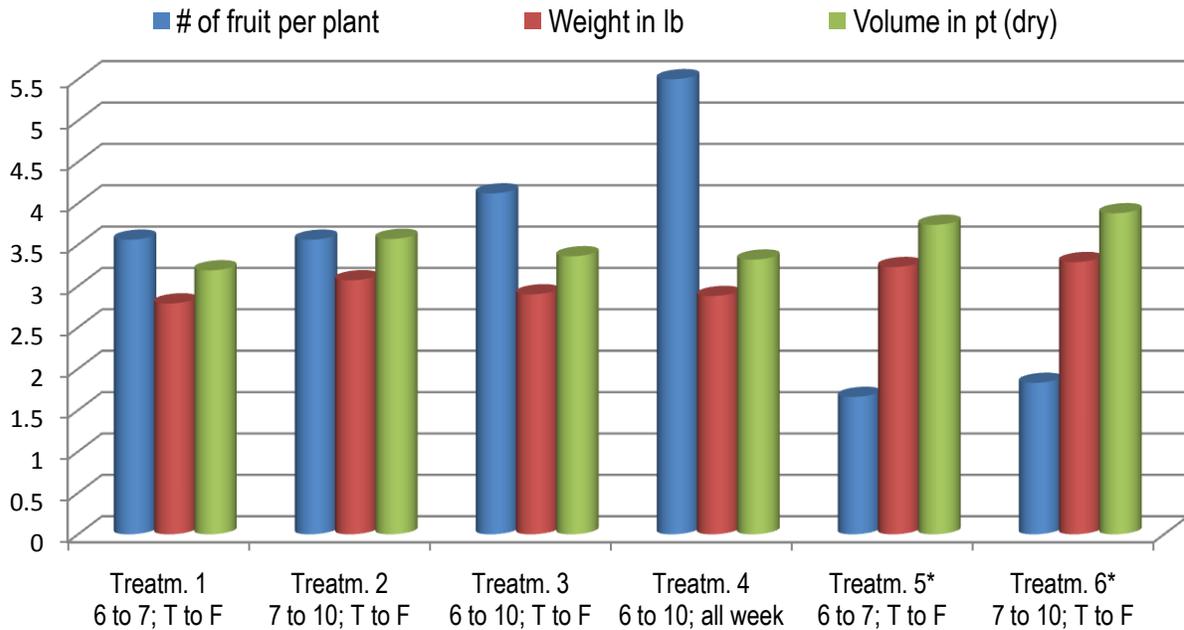
Results for treatment #5 – Averages for all four farms' research cages (#5) that had the open flowers bagged after 7:00 AM, Tuesday to Friday.

**6.67** pumpkins per cage (**1.66** pumpkins per plant)\*; **1,469 g** per pumpkin (**3.23 lb** per pumpkin); **2,058 ml** per pumpkin (**3.74 US dry pt** per pumpkin);

Results for treatment #6 – Averages for all four farms' research cages (#6) that had the open female flowers bagged until 7:00 AM.

**7.33** pumpkins per cage (**1.83** pumpkins per plant)\*; **1,493 g** per pumpkin (**3.29 lb** per pumpkin); **2,135 ml** per pumpkin (**3.88 US dry pt** per pumpkin).

Graph with each treatment's averages on # of fruit, and weight and volume per fruit



\* The average # of fruit per plant for treatments #5 and #6 is not used in the data interpretation, because of a higher-than-normal flower abortion, caused by the flower-bagging process.

➤ Pumpkin Yields Data Interpretation

*Number of fruit per plant*

The above graph indicates that the pollination services offered by non-managed bees (squash bees and bumblebees) from 6:00 AM to 7:00 AM had triggered the formation 3.56 fruits per plant, which was 87% of the number of fruit per plant recorded as being set by female flowers that were available for pollination from 6:00 AM to 10:00 AM. Similarly, the pollination services offered by both non-managed and managed bees from 7:00 AM to 10:00 AM had triggered the formation of the same number of fruit per plant as the pollination services offered only by non-managed bees from 6:00 AM to 7:00 AM.

*Average fruit weight*

The results indicate that the pollination services offered solely by non-managed bees from 6:00 AM to 7:00 AM triggers the formation of fruit that has on average 96 % of the weight registered for the fruit that was formed as result of pollination services offered by both non-managed and managed bees from 7:00 AM to 10:00 AM. The fruit that was formed as result of having the flowers available for pollination from 7:00 AM to 10:00 AM was actually heavier than the fruit that was formed by flowers available for pollination from 6:00 AM to 10:00 AM. Past research in pumpkin pollination indicates that in the first two hours bees transfer the largest quantity of pollen. Later on, as the pollen from male flowers is depleted, bees can actively remove some of the pollen that was made available to female flowers. This bee behavior can explain why the

flowers available for pollination for only three hours will produce heavier fruit than the fruit that was formed by the flowers that were available for pollination the entire time they were viable (6:00 AM to 10:00 AM).

#### *Average fruit volume*

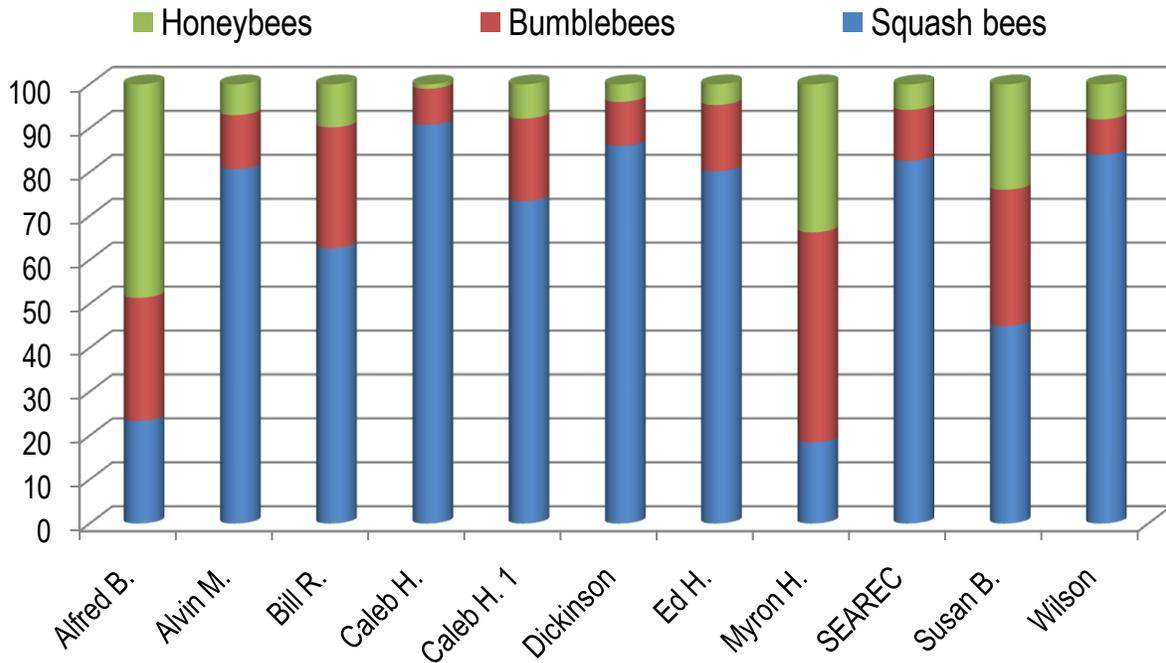
The results registered for the average fruit volume was relatively the same as the results registered for the average fruit weight.

#### b) Bee Monitoring

##### ➤ Results

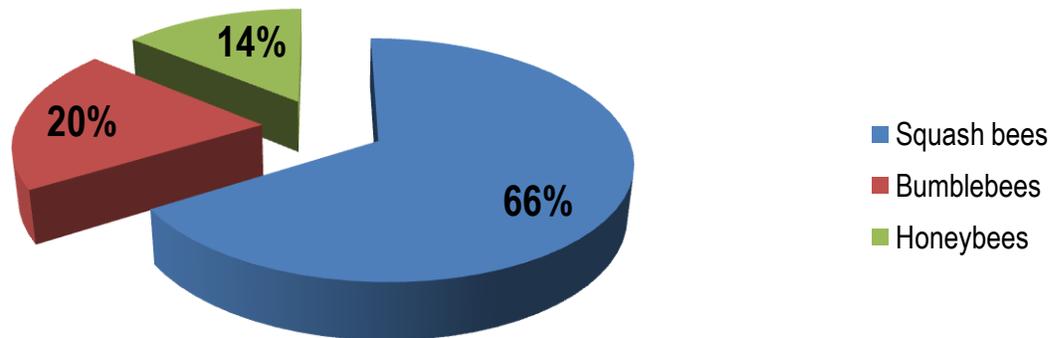
- ✓ Alfred B. – **28%** bumblebees, **48.6%** honeybees, **23.4%** squash bees;
- ✓ Alvin M. – **12.3** bumblebees, **7%** honeybees, **80.7%** squash bees;
- ✓ Bill R. – **27.5%** bumblebees, **9.8%** honeybees, **62.7%** squash bees;
- ✓ Caleb H. – **8.2%** bumblebees, **1.0 %** honeybees, **90.8%** squash bees;
- ✓ Caleb H. 1 – **18.8%** bumblebees, **7.8%** honeybees, **73.4%** squash bees;
- ✓ Dickinson College – **10%** bumblebees, **4%** honeybees, **86%** squash bees;
- ✓ Ed H. – **15.1%** bumblebees, **4.7%** honeybees, **80.2%** squash bees;
- ✓ Myron H. – **47.8%** bumblebees, **33.7%** honeybees, **18.5%** squash bees;
- ✓ Penn State SEAREC – **11.6%** bumblebees, **5.8%** honeybees, **82.6%** squash bees;
- ✓ Susan B. – **31%** bumblebees, **24%** honeybees, **45%** squash bees;
- ✓ Wilson College – **8%** bumblebees, **8%** honeybees, **84%** squash bees.

Graph with the percentage of bees recorded on farms



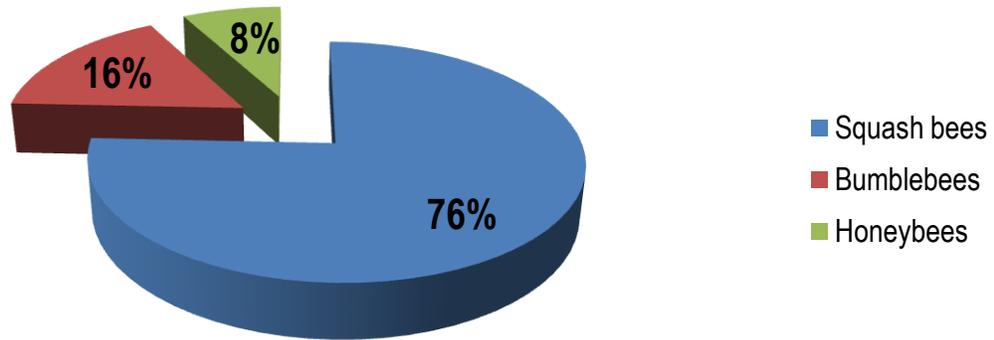
➤ Bee Monitoring Data Interpretation

**Bee Survey Data for All Farms**



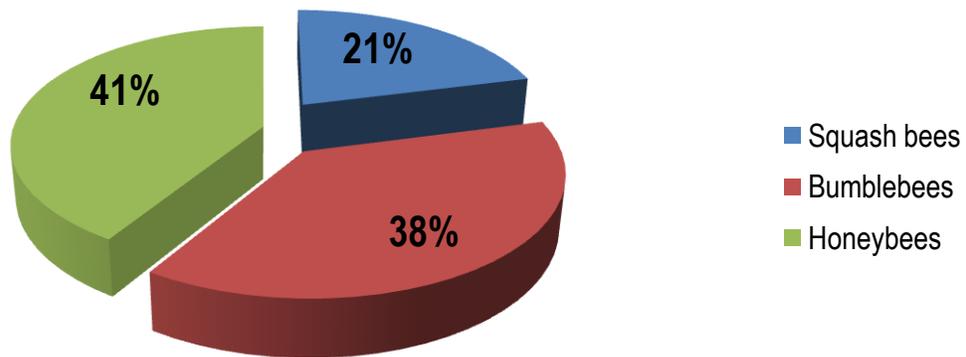
Results indicate that, on average, on all 11 farms that were monitored, squash bees were the most predominant pumpkin pollinators, with bumblebees being the second most predominant, and honeybees being present in relatively few numbers.

**Bee Survey Data on Farms that Had Pumpkins in Previous Years**



On farms that had cultivated pumpkins in previous years in close proximity to the 2010 year’s field, squash bees were the most predominant pollinators between 7:30 AM and 8:00 AM, despite the fact that the fields were stocked with honeybees at the recommended rate of up to two honeybee colonies per acre of pumpkin crop.

**Bee Survey Data on Farms that Did Not Have Pumpkins in the Previous Years**



On farms that did not have pumpkin crops cultivated in previous years in close proximity to the 2010 year’s fields, squash bees were the least predominant pollinators. On these fields honeybees and bumblebees were the most important pollinators.

**Conclusions**

The results of this project indicate that non-managed bees, mostly squash bees, are responsible for pollinating pumpkin crops on the farms that have previously grown pumpkins on fields that were in close

proximity of the newly established ones. Moreover, almost 90% of pumpkin yields are formed as a result of the pollination services provided solely by squash bees and bumblebees between 6:00 AM and 7:00 AM. In our survey, the data did not indicate that the size of the pumpkin field (0.3 or 25 acres), irrigation method (overhead or drip irrigation), or soil management (till or no till) significantly influenced the squash bee population.

Furthermore, honeybees did not visit pumpkin fields where squash bees were abundant, even when present at the highest recommended rate of two colonies per acre. A plausible explanation for that is that in mid-summer, fertilized female squash bees start foraging at full potential about one hour earlier in the morning than honeybees do. Female squash bees are fast fliers and are highly specialized on moving pumpkin pollen and, by the time honeybees are ready to forage, they remove most of the pollen from the pumpkin flowers. Furthermore, when honeybees do start foraging in high numbers, male squash bees and unfertilized females become active as well and start competitively depleting pumpkin flowers of nectar. As a result, honeybees usually have no other option than to forage on other pollen and nectar sources and only occasionally visit pumpkin flowers.

Although squash bees are endemic in the Northeast region and, when in high numbers, are able to provide all the pollination requirements pumpkin crops have, growers need to be cautious when relying solely on them. Squash bee populations can fluctuate from year to year. This project found that on the farms that had previously cultivated pumpkin crops squash bee populations, when reported to the total number of bees observed, had various percentage levels, from as low as 45% to as high as 90.8%. As a result, growers need to be able to identify and monitor squash bee populations before pumpkins start producing female flowers and make an informed decision concerning whether honeybee colonies are necessary for setting optimum yields.

#### 6) Impact of Results/Outcomes

The results of this project will be presented at Mid-Atlantic Fruit and Vegetable Convention in January 2011, and the Pennsylvania Association for Sustainable Agriculture on February 2011. Other presentations will be made at local vegetable grower events.

#### 7) Economic Analysis – Not applicable

#### 8) Publications/Outreach

- ✓ Pumpkin Pollinators, Penn State Cooperative Extension Factsheet

This publication is located at

<http://capitalhort.cas.psu.edu/Factsheets/Pollination/Pumpkin%20Pollinators.pdf> and has appeared in several newsletters, including the Penn State Small Fruit and Vegetable Gazette and Penn State HortReport . These publications are distributed in print and in electronic format to more than 2,000 vegetable growers.

- ✓ Squash Bees: an alternative to renting honeybees for pumpkin pollination

This publication is located at <http://extension.psu.edu/susag/news/Jan-2011/1-squash-bees>.

### 9) Farmer Adoption

The farmer adoption rate will be gauged over the next several years, as more data is gathered.

### 10) Areas Needing Additional Study

To an untrained eye, squash bees are easily mistaken for honeybees because of similar size and coloration. This leads growers to think that honeybees are the ones doing the bulk of pumpkin pollination. This can be a costly assumption that may result in unnecessary honeybee rental fees that can add up to \$120 per acre. In order to avoid this, growers need to have an inexpensive, easy-to-use, non-destructive-to-bees methodology that will allow them to easily identify squash bees and to assess their population density in a given pumpkin field. Such methodology would allow pumpkin and squash growers throughout the Northeastern region to accurately determine squash bee density and know when there is a need to rent honeybees.

For 2011, a grant proposal was submitted to NE-SARE for developing such a methodology. The concept is based on the unique relationship between squash bees and cucurbita plants. Unlike any other species of bees, male and unfertilized female squash bees spend the night in the cucurbita flowers that have wilted during the day. In the morning, they chew their way out and start foraging and mating. At the same time, probably in an effort to attract a strong population of squash bees, cucurbita plants produce male flowers about one week in advance of starting to produce female flowers.

As a result, a grower can collect, in a container, all the freshly wilted male flowers from five randomly selected cucurbita plants. Once this is done, the container will be covered with an insect screen and left in the field until the next day. In the morning of the next day, the squash bees will naturally chew their way out of the blossoms and fly towards the screening, allowing the grower to make accurate counts and release them. The data resulting from this assessment can be compared with the threshold at which squash bees can provide sufficient pollination services. This methodology should allow farmers that grow cucurbita crops to confidently determine squash bee density and make an informed decision about the need to rent or not rent honeybees before cucurbita plants start setting fruit.

In 2011, with support from NE-SARE we aim to test and fine-tune the methodology and establish the density threshold at which squash bees are able to perform adequate pollination services in squash and pumpkin crops. This information will allow us to provide pumpkin and squash growers in the region with an easy-to-use tool for assessing the squash bee population in their pumpkin and squash fields. This will aid growers in making informed decisions regarding the need for pollination services that, consequently, will result in a more sustainable pumpkin and squash production system.

### Acknowledgements

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