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Use of pollen blowers and pollen dispensers to pollinate kiwifruit artificially

Goodwin RM, McBrydie HM

June 2013

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Contents

Executive summary

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The aims were to:

- Repeat previous observations that honey bees redistribute dry pollen blown onto pistillate kiwifruit flowers and the effect of the amount of dry pollen applied on pollen redistribution
- Investigate the direct effect of increasing the rate of pollen blown on to flowers
- Investigate the effectiveness of pollen dispensers used to dust honey bees with kiwifruit pollen as they leave their hives.

Increasing the rate of pollen blown onto the flowers did not increase the average fruit weights or seed numbers. This is a similar result to that achieved in 2010. It does, however, indicate that the 2010 shallow rate response curve was not necessarily a function of increasing the rates by repeated pollen applications. Without a clear understanding for the reasons for the flat rate response curve, it is not possible to give a recommendation on the optimum pollen rates that should be used with the leaf blower technology.

Honey bees transferred enough pollen to produce 156.6 seeds (S.E. = 23.8) per fruit.

Because of competing flowers, only very small numbers of bees from the hives were visiting kiwifruit in the pollen dispenser trial. Half way through the trial, no bees were observed returning to the hives with dispensers in a 10-min count, so the dispensers were moved to new hives. Even then at the end of the trial when there was still significant numbers of kiwifruit flowers present, only 35 bees could be caught returning to the four hives with dispensers when they were blocked for 30 min.

Even with these problems, the pollen dispensers were able to place enough staminate pollen on to honey bees leaving the hives to produce an average of 515 seeds per fruit (S.E. = 41.4). The dispenser design appeared to be very good at separating outgoing bees from incoming bees; however, it appeared to waste pollen. The device needs to be modified to drop pollen slowly into the dispenser over time.

It would be expected that in a commercial block there would be more hives and a smaller edge effect, so most of the bees foraging in the orchard would be coming from the hives in the orchard. The seed count could therefore conceivably be 25% higher (616 seeds per fruit). Assuming eight hives per ha and a 5-day peak flowering period, this would require 640 g of pollen. Considering the large amount of pollen that was wasted, dispensers with some small modifications might achieve these results while using much less pollen.

Further research

1. Establish the cause of the shallow rate response curve for the modified leaf blower technology.
2. Establish the reason for the lower than predicted cumulative effect of repeated days of using the pollen inserts
3. Redesign pollen dispensers to reduce pollen wastage and to automatically refill.
4. Repeat the pollen dispenser trial on a larger scale.

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1 Introduction

Both staminate and pistillate 'Hayward' kiwifruit flowers *Actinidia deliciosa* (A. Chev.) produce pollen, but neither produces nectar (Hopping 1990). The pollen produced by pistillate flowers is not viable (Hopping 1990); however, honey bees (*Apis mellifera* L.) still collect it and thus visit both staminate and pistillate flowers (Goodwin & Steven 1993). 'Hayward' flowers liberate pollen for 5 days post anthesis (Goodwin 1986) and the stigma are fully receptive for all this time (Goodwin 1987).

Kiwifruit pollination requires viable pollen to be moved from the anthers of staminate flowers to the stigma of pistillate flowers. In New Zealand this occurs though honey bee pollination (Goodwin & Steven 1993) with some artificial pollination (Hopping & Jerram 1980), and a small amount of wind pollination (Goodwin et al. 2013).

Artificial pollination of 'Hayward' kiwifruit was first suggested by the then Ministry of Agriculture and Fisheries (MAF) in the late 1970s (Hopping 1979). They described the methods and economics of hand pollination (Hopping 1982). They also developed the first mechanical pollination in the early 1980s (Hopping & Hacking 1983). This included the development of machinery for the collection of pollen. MAF also developed a solution with which pollen could be mixed, so it could be sprayed onto flowers using Cambrium or Air Shear sprayers (Hopping et al. 1987).

In 1982 it was suggested by the Development Finance Corporation that there may not be enough honey bee colonies to meet the requirements of the developing kiwifruit industry (Ivens 1982). Although the shortfall of hives never eventuated, it encouraged the development of a range of other artificial pollination devices e.g. Turbobee, Airflow pollinator (Atkinson 1989), (Anon 1989), Rollon pollinator, and Polli (Anon 1992). Since then the KiwiPollen™ backpack (Anon 1991) and boom sprayers, KiwiPollen blower, PollenPlus™ blower and Allterrain boom sprayers have been developed.

Although some of these devices are capable of fully pollinating 'Hayward' kiwifruit (Cambrium® and Airshear PollenAid® sprayers, Polli and Rollon pollinators), they are usually not used for this purpose. Almost all artificial pollination is used to enhance honey bee pollination. Because honey bee pollination is not always sub-optimal, artificial pollination sometimes results in no increase in fruit size or at least no economic increase (Hopping & Martyn 1986; Goodwin et al. 1993; Goodwin & Perry 1994).

The problem with artificial pollination of kiwifruit is that most methods are very inefficient for placing pollen on the stigma. With general broadcast methods of applying pollen, most pollen, (>99%) is wasted because it never reaches a stigma. As pollen is relatively expensive, this negatively affects the economics of artificial pollination.

The amount of artificial pollination carried out has been increasing over the last 10 years and may continue to do so if more staminate 'Hayward' vines are adversely affected by *Pseudomonas syringae* pv. *actinidiae* (Psa).

In trials carried out in 2010/11 (Goodwin 2011), it was reported that increasing the amounts of pollen applied with the PollenPlus QuadDuster quad bike and hand-held blowers increased the number of seeds in 'Hayward' fruit. However, subsequent applications produced fewer additional seeds than the seed numbers produced during the first application. The highest rate tested with the blower (1.268 kg pollen/ha) only produced an average of 640 seeds per fruit. Whether this issue of a very shallow dose response curve was because the higher pollen rates were achieved with multiple pollen applications that might have been interfering with each other, or because there was an inherent problem associated with blowing high rates of pollen on flowers, is untested.

Honey bees have been demonstrated to enhance the effectiveness of artificial pollination using dry pollen(Goodwin 2011). This has been hypothesised to be due to honey bees picking up artificially applied pollen which was inadvertently applied to the anthers of pistillate flowers and redistributing it to the stigma of the same flower and to other pistillate flowers.

Pollen can also be applied to honey bees as they leave their hives with pollen dispensers (Dag et al. 2000). The devices fit to the front of hives and contain a tray of pollen that bees walk through to leave their hives. This pollen is then carried to the flowers.

The aims were to:

- Repeat previous observations that honey bees redistribute dry pollen blown onto pistillate kiwifruit flowers and the effect of the amount of dry pollen applied on pollen redistribution
- Investigate the direct effect of increasing the rate of pollen blown on to flowers
- Investigate the effectiveness of pollen dispensers used to dust honey bees with kiwifruit pollen as they leave their hives.

2 Methods

2.1 Dry pollen redistribution and rates trials

2.1.1 Treatments

The trial was conducted in a 1-ha all-pistillate pergola 'Hayward' kiwifruit orchard situated near Te Puna and managed by PollenPlus. Eight hives were introduced to the orchard from the Ruakura Research Centre.

Six orchard bays (5 x 4 m) were used in the trial. Each bay consisted of a quarter of four different pistillate vines. The quadrates were at least 16 m apart. The day before the trial was carried out (20 November 2012), all the flowers in the canopy between the quadrates received a commercial PollenAssist treatment using Cambrium sprayers (Figure 1).

Figure 1. Applying PollenAssist® to 'Hayward' kiwifruit vines.

Different rates of pollen were then applied to each of the six bays and the surrounding 24 bays using a PollenPlus pollen blower between 1000 and 1130 h (Figure 2).

It was not possible to put on predetermined rates of pollen with the commercially available hand-held equipment used to blow pollen onto flowers. The rate applied depends on a combination of a setting on the PollenPlus pollen blower and the speed of walking through the area to be pollinated. The different rates were achieved by systematically adjusting both these factors.

Figure 2. Applying pollen to 'Hayward' kiwifruit vines using a PollenPlus™ pollen blower.

2.1.2 Pollination assessments

On the day the trial was carried out (21 November 2012):

Pollen-proof paper bags (Figure 3) were placed over 10 one- and two-day-old pistillate flowers, as determined by their stage of dehiscence, before 0800 h in each quadrat. There, flowers acted as controls to determine the background rate of pollination.

Twenty newly opened pistillate flowers in each quadrat were hand pollinated with artificially collected pollen and a paint brush to act as a positive control. The flowers were immediately enclosed in pollen-proof bags after being pollinated.

Pollen-proof paper bags were placed on 20 newly opened flowers before the pollen application. These bags were removed within 5 min of the dry pollen being applied, to measure the amount of pollen transferred between flowers by bee activity. The flowers were bagged again after the end of bee activity between 1700 and 1800 h.

Figure 3. A pollen-proof bag on a 'Hayward' kiwifruit flower.

Pollen-proof bags were placed on a 20 further one-day-old pistillate flowers within 5 min of the blower being used on the quadrats, to determine the number of seeds produced by the blown pollen.

Forty newly open flowers that opened on the day of the trial were marked and 20 enclosed in paper bags between 1700 and 1800 h on the same day to measure the effect of receiving blown pollen and bee pollen transfer. The remaining 20 flowers were bagged between 1700 and 1800 h on the following day to determine if the effect lasted for a second day.

All the paper bags were removed on 21 January 2013. The fruit were picked when mature, weighed, and the seeds extracted and counted.

2.2 Pollen dispensers

2.2.1 Trial site

The pollen dispenser trial was carried out in a small 'Hayward' kiwifruit orchard at the Ruakura Research Centre near Hamilton. The orchard consisted of four rows of 'Hayward' vines. The first two rows were trained partly on pergola trellis and the other two rows on T-bars (Figures 4 and 5). Staminate vines were the third and fourth vine in every row. The staminate vines were pruned to remove all staminate flowers before the pistillate flowers opened. Rows 1 and 2 were used to estimate the effectiveness of the pollen dispensers.

All the pollen used at Ruakura was sourced by PollenPlus from Nelson to minimise the Psa risk.
Rows 3 and 4 were treated three times during the flowering season with 4 g of pollen/litre of PollenAid so fruit could be produced for other trials.

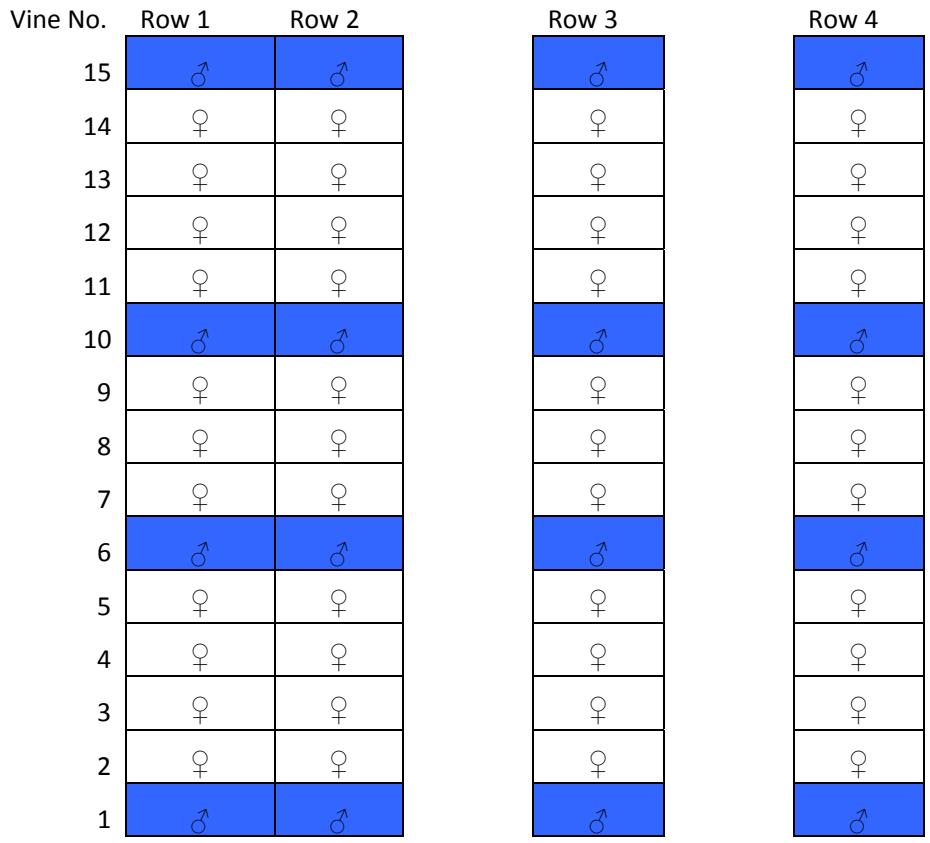


Figure 4. Plan view of the Ruakura 'Hayward' block.

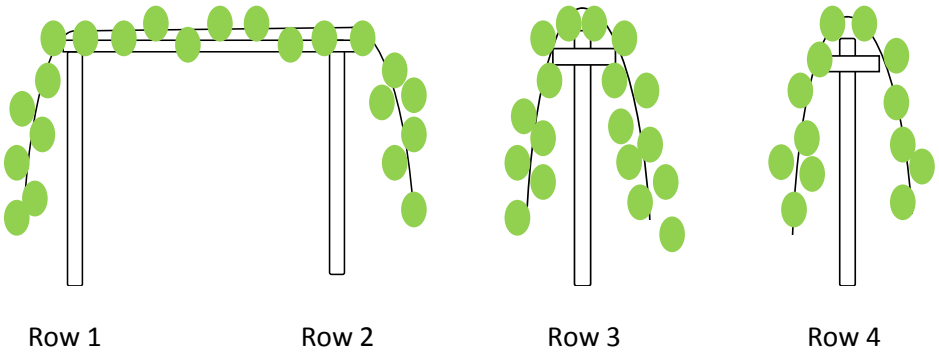


Figure 5. End elevation of the Ruakura 'Hayward' block.

2.2.2 Beehives

Four beehives were introduced to the block on the morning of 22 November 2012. The hives were placed approximately 8 m from the pergola section of the block. The colonies were each fed 2 L of 50% sugar syrup between 0800 and 0815 h on 24, 26, and 28 November.

Because very few of the bees from these hives were observed returning with kiwifruit pollen, six additional colonies were introduced on 28 November. The pollen dispensers were removed from the original hives and fitted to the four new hives that were observed with the most returning foragers carrying kiwifruit pollen pellets.

2.2.3 Bee counts

The pergola canopy between Rows 1 and 2 was divided into 10 plots containing between 100 and 300 open pistillate flowers depending on the stage of flowering. The number of open flowers that still had all their petals in each plot was counted. The number of bees visiting these flowers was estimated by slowly walking through the plots hourly between 0900 h or 1000 h and 1600 h and counting the numbers of foraging bees. This was repeated on 25, 26 and 29 November and 2 December.

2.2.4 Pollen dispensers

Pollen dispensers (Figure 6) without pollen were placed on the hives at 0800 h on 23 November to allow the bees to acclimatise to the devices. Four g of pollen was placed in each dispenser at 0900, 1000, 1100, and 1200 h on 24, 25, 26 and 27 November.

This was repeated with 1 g of pollen each hour on 29, 30 November and 1, 2 and 3 December.

Figure 6. A pollen dispenser fitted to the front of a beehive.

2.2.5 Foraging bee captures

From flowers

Twenty honey bees were captured from pistillate flowers in the two rows (rows 3 and 4) that were not being assessed for pollination during the time that the pollen dispensers were used, on 24, 26 and 29 November and 1 and 3 December, to determine the amount of staminate pollen they were carrying. Each bee was caught in a separate plastic bag that was held under the foraging bee so it fell into it when it left the flower. The bee was then allowed to fly up to a corner of the bag and immobilised with a twist tie. Nine bumble bees (*Bombus terrestris*) that were also visiting flowers were captured.

At the hives

The dispensers were removed from the hives and the entrances blocked on 4 December at about 1210 h. Any bee that returned to the hives carrying kiwifruit pollen (35 bees) was captured in a separate bag.

Enumeration of staminate pollen grains

All bees were frozen until analysis. To determine the number of staminate pollen grains the bees were carrying, they were each placed in a 2-ml eppendorf Eppendorf ® tube with 1 ml of Alexander stain (Alexander 1980), which differentially stains cellulose and cytoplasm to identify staminate and pistillate pollen grains. The bees were vigorously shaken in the stain to dislodge any pollen grains they were carrying. Further shakings did not increase the number of pollen grains dislodged. The concentration of staminate pollen grains was calculated using a haemocytometer.

2.2.6 Pollination assessments

The degree of pollination was assessed by exposing flowers to honey bee visits for different lengths of time, after which they were enclosed in pollen-proof bags to prevent further pollination, and marked with jeweller's tags.

Day 1 (23 November)

1) Twenty one-day-old flowers were marked and bagged at the end of each day (after 1700 h) to determine the background rate of pollination.

2) Twenty one-day-old flowers were hand pollinated using a paintbrush and artificially collected pollen sourced from Nelson to minimise the Psa risk (Figure 7). The flowers were then enclosed in pollen-proof paper bags to ensure bees did not have the opportunity of transferring this pollen to other flowers.

Figure 7. Hand pollinating a 'Hayward' kiwifruit flower.

Day 2 (24 November) Twenty one-day-old flowers were marked before 1000 h, hand pollinated later in the day, and bagged as described on Day 1. Two hundred and fifty one-day-old flowers were marked with a short piece of coloured wool. Thirty of these flowers were marked enclosed in paper bags after 1700 h.

Days 3 – 4 (25-27 November) Each day, twenty newly opened flowers were hand pollinated as described above, and in the late afternoon (after 1600 h), 30 flowers that had opened on that day were bagged, along with of 30 of the 250 flowers that had been marked on Day 2.

This series of pollination assessments was repeated between 28 November and 3 December.

3 Results

3.1 Dry pollen redistribution and rates trials

There was a strong relationship between seed number and fruit weight in the Te Puna orchard (Figure 8). The control fruit had 5% fruit set (95% C.I. = 1-13.95) and an average of 58 seeds (S.E. = 34) excluding zero values for missing fruit.

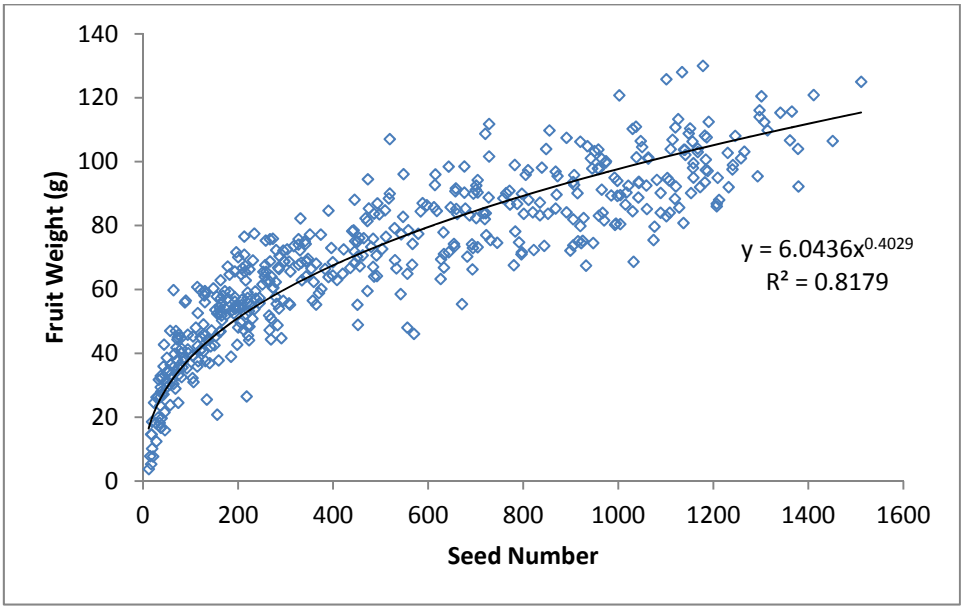


Figure 8. Relationship between seed number and fruit weight in the 'Hayward' kiwifruit pollination trial, 2012-13.

There was no significant difference (P>0.77) in seed number and fruit weight of fruit produced by flowers receiving different rates of blown pollen (Figure 9).

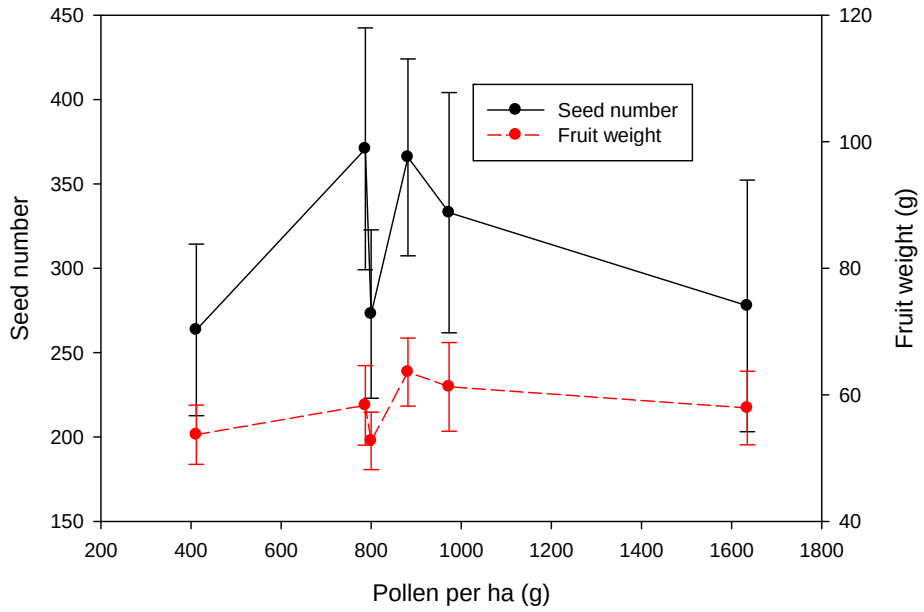


Figure 9. Relationship between the rate of pollen blown onto flowers and the average seed number and fruit weight in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars.

There was also no effect of the rate of pollen applied on the seed number of fruit produced by pollen transferred between flowers by bees (Figure 10).

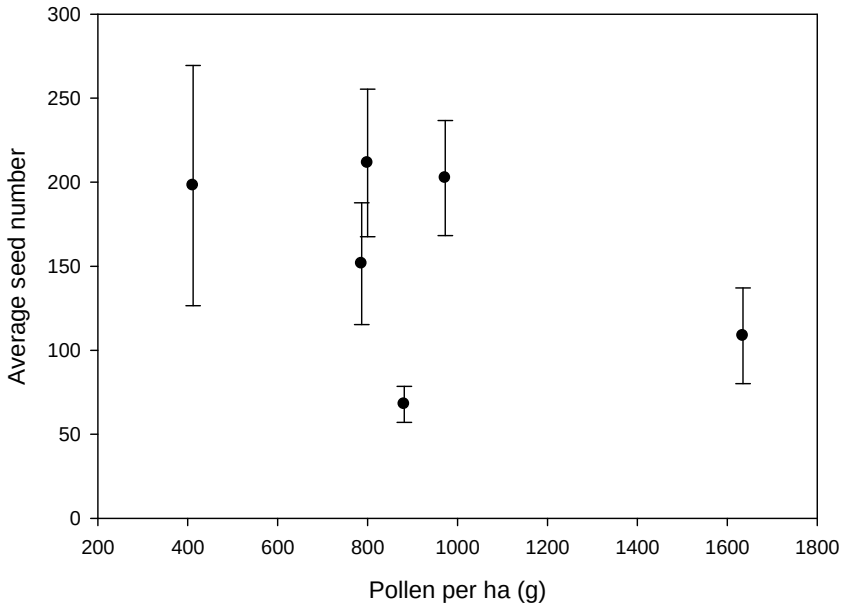


Figure 10. The average seed number of fruit produced by flowers that had pollen transferred to them by bees that had visited flowers that had received different rates of pollen, in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars.

Honey bees transferred enough pollen (when averaged over all the rates) to produce fruit with an average of 156.6 seeds (S.E. = 23.8). There was no significant difference in the seed number of fruit produced by flowers that received blown pollen, and bee-transferred pollen for one and two days without and with including zeros for missing fruit (Figure 11a and b).

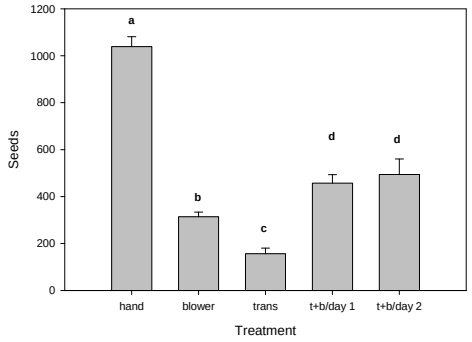


Figure 11a.Average seed number of hand-pollinated fruit, fruit produced by the blower, fruit produced by bee transfer (trans) and fruit produced by the blower and bee transfer on the first day (t+b/day 1) and the second day (t+b/day 2) in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars. Bars with different letters are significantly different (t-test P < 0.05).

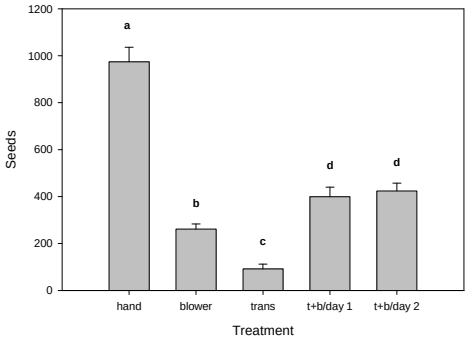


Figure 11b. Average seed number of hand-pollinated fruit, fruit produced by the blower, fruit produced by bee transfer (trans) and fruit produced by the blower and bee transfer on the first day (t+b/day 1) and the second day (t+b/day 2) including the missing fruit as zero values, in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars. Bars with different letters are significantly different (t-test P < 0.05).

With all the rates added together, the blower treatment resulted in 82.5% fruit set (95% C.I. = 74.5 - 88.8), the bee transfer treatment resulted in 57.5% fruit set (95% C.I. = 48.1 – 66.5%) and the blower plus bee transfer treatment resulted in 84% fruit set (95% C.I. = 79.4 – 88.9%). The frequency distributions of seed numbers of the blower plus bee transfer treatment and blower treatment were similar (Figure 12).

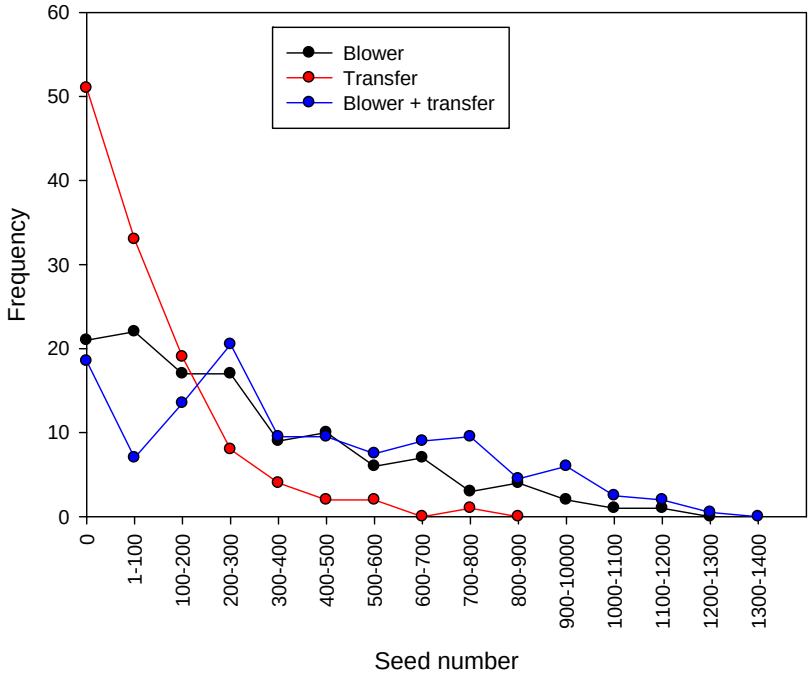


Figure 12. Frequency distribution of seed numbers of blower plus bee transfer treatment blower treatment, and the bee transfer treatment in the 'Hayward' kiwifruit pollination trial, 2012-13.

3.2 Pollen dispenser

Only one bee (3%) (95% C.I. = 0.1-15.8%) of the bees returning with kiwifruit pollen that were caught at the entrance of the hives that were fitted with pollen dispensers was not carrying staminate pollen, whereas 37.1% (95% C.I. = 28- 42.6%) of the bees caught on flowers while the pollen dispensers being used were not carrying staminate pollen (Figure 13). None of the bumble bees caught while visiting kiwifruit flowers was carrying staminate kiwifruit pollen.

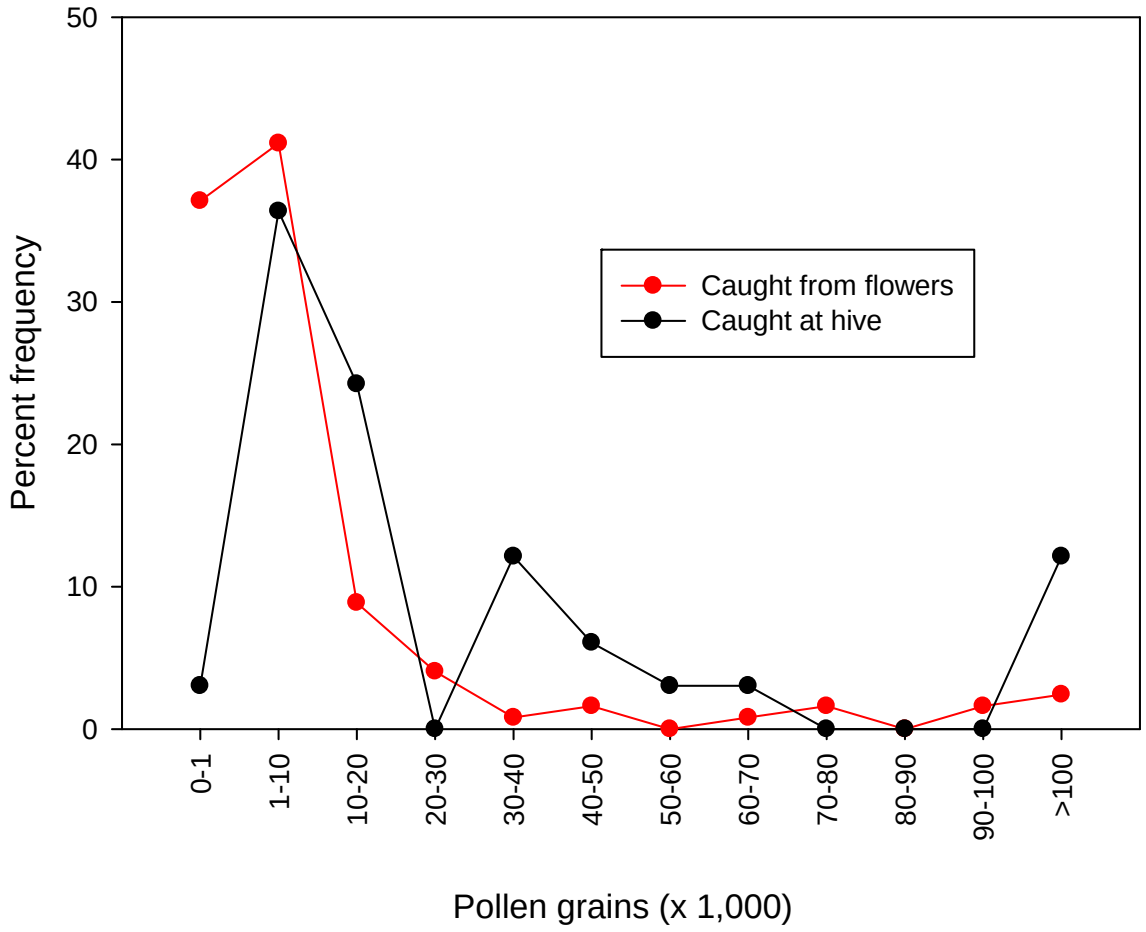


Figure 13. Frequency distribution of the number of staminate pollen grains carried by honey bees caught on flowers in Rows 3 and 4 and honey bees caught as they returned to the hives fitted with pollen dispensers, in the 'Hayward' kiwifruit pollination trial, 2012-13.

The number of bees visiting pistillate flowers in rows 1 and 2 varied throughout the day and between days (Figure 14a and b). The peak in foraging occurred between 1100 and 1300 h. The maximum number of bees per 1000 flowers that occurred during a day varied between 8 and 21.

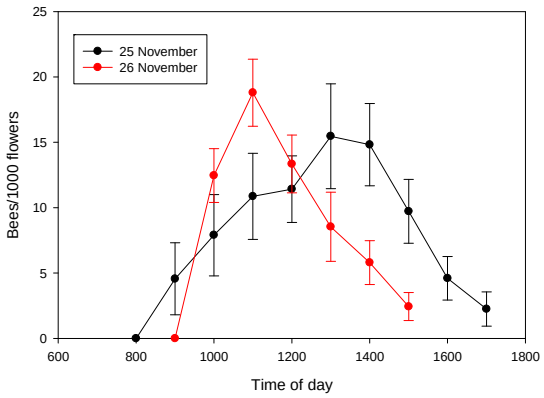


Figure 14a. Bees per 1000 flowers on 25 and 26 November in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars.

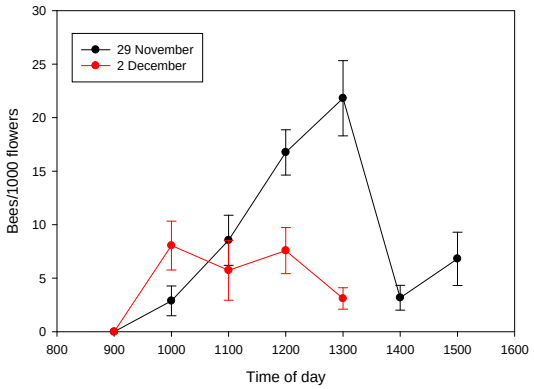


Figure 14b. Bees per 1000 flowers on 29 November and 2 December in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars.

Seed number and fruit weight were related in the Ruakura orchard (Figure 15).

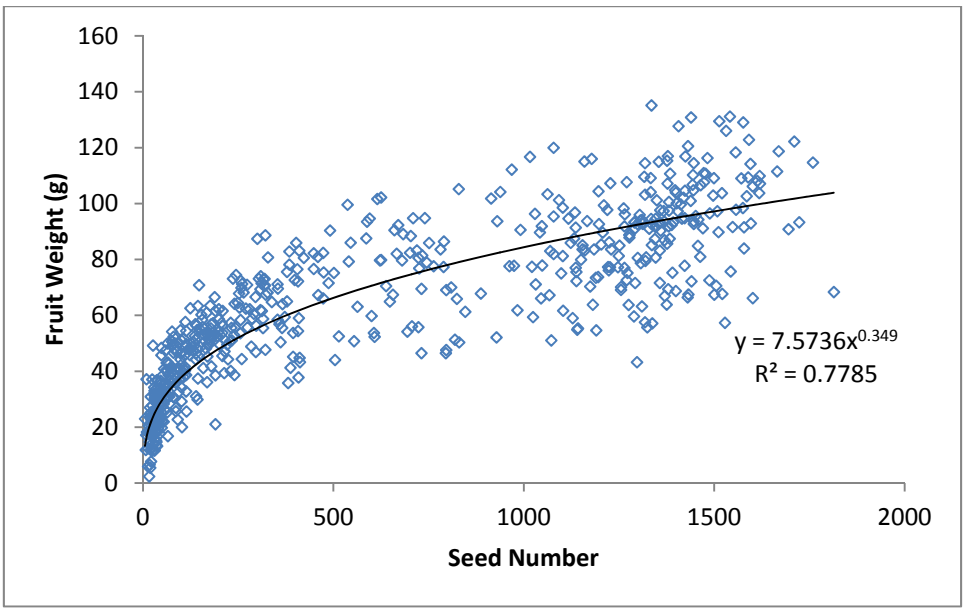


Figure 15. Relationship between seed number and fruit weight in the 'Hayward' kiwifruit pollination trial, 2012-13.

The hand pollinated flowers had 90% fruit set (95% C.I. = 85 – 93.8%). The average seed numbers were consistently high (Figure 16).

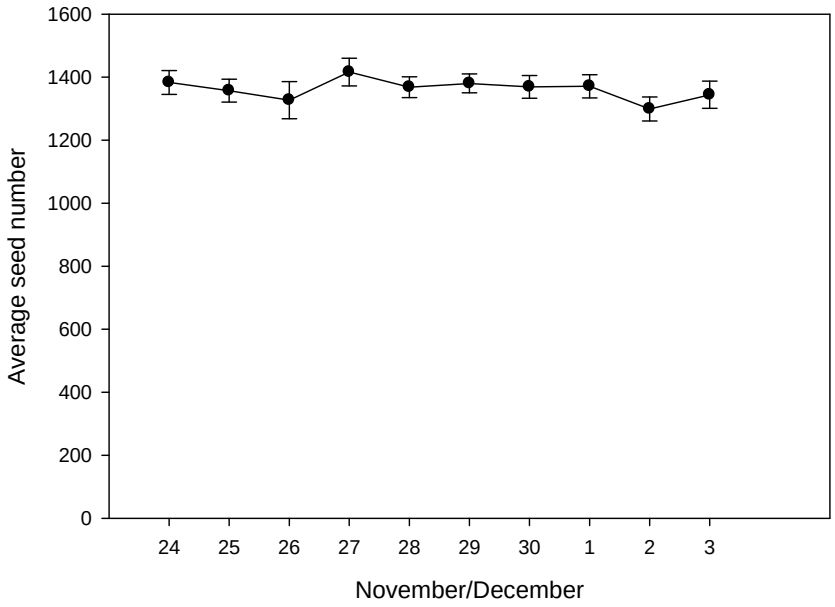


Figure 16. Average seed number of fruit produced by flowers that were pollinated on different days in the 'Hayward' kiwifruit pollination trial, 2012-13.

The fruit produced by flowers exposed to 16 g pollen/hive for a single day had significantly more seeds (P= 0.01) than the fruit produced by flowers exposed to 4 g pollen/hive for a single day (Figure 17). There were, however, large day-to-day variations. The seed number in fruit exposed for a day at 16 g pollen/hive decreased with each day.

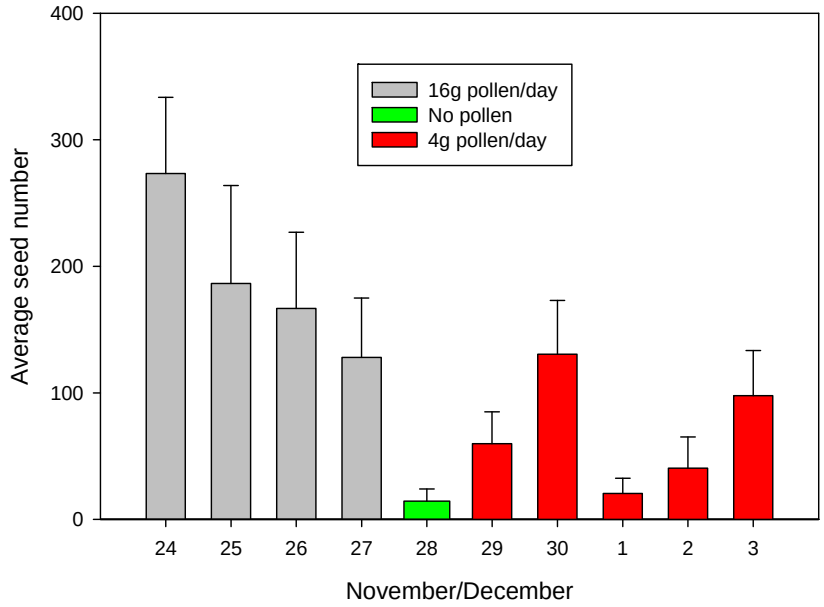


Figure 17. Average number of seeds produced by flowers exposed to honey bees for a single day with 16 g pollen/day, no pollen and 4 g pollen/day in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars.

When flowers were exposed for the four of the five days on which pistillate 'Hayward' flowers were attractive to bees, both average seed numbers with and without including zero values for missing fruit increased for the 16 g pollen per hive (P<0.05) treatment but not for the 4 g/hive treatment. The 16 g/day fruit produced by flowers exposed for five days had significantly higher fruit set (89% 95% C.I. = 81.2-94.4%) than the fruit produced by flowers receiving 4 g/day (65% C.I. 54.8-74.3%) and significantly more seeds (t-test P<0.001) (Figure 18a and b). The fruit set of the flowers exposed to 16 g/day for five days was not significantly different (P<0.05) from that of the hand-pollinated fruit.

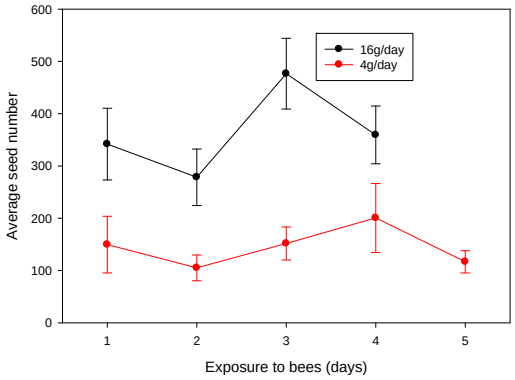


Figure 18a. Average number of seeds per fruit produced by flowers exposed to bees from pollen dispensers for different numbers of days, excluding missing fruit, in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars.

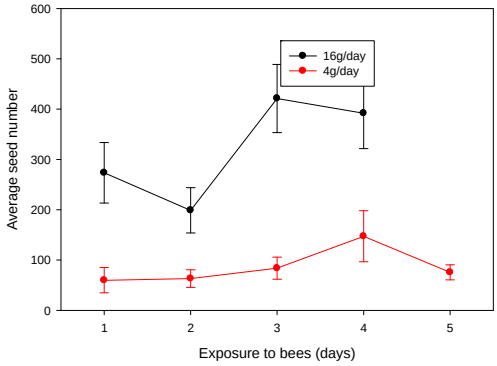


Figure 18b. Average number of seeds per fruit produced by flowers exposed to bees from pollen dispensers for different numbers of days, including the missing fruit as zero values, in the 'Hayward' kiwifruit pollination trial, 2012-13. The vertical lines are standard error bars.

Adding the seed counts from the flowers that were exposed for just one day together, they predict higher seed sets on day five than were found in this study (Figure 19).

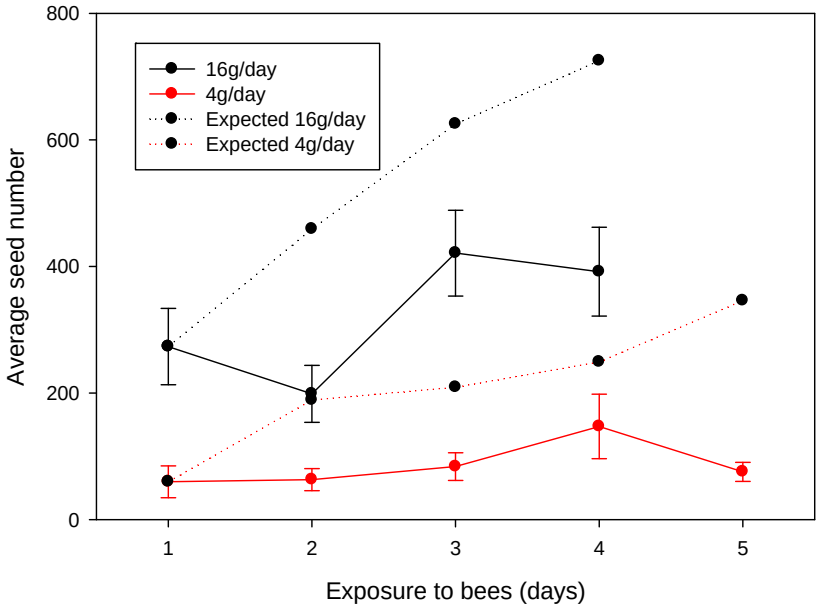


Figure 19. Average number of seeds per fruit produced by flowers exposed to bees from pollen dispensers for different numbers of days, excluding missing fruit, in the 'Hayward' kiwifruit pollination trial, 2012-13. The predicted values from adding the seed numbers together of the flowers that were exposed for one day are also shown. The vertical lines are standard error bars.

4 Discussion

4.1 Dry pollen redistribution and rates trials

Increasing the rate of pollen blown onto the flowers did not increase the average fruit weights or seed numbers. This is a similar result to that achieved when the rates were increased by repeated applications of blown pollen, which produced a very shallow rate response curve in trials carried out in 2010 (Appendix 1) (Goodwin 2011). It does, however, indicate that the 2010 shallow rate response curve was not necessarily a function of increasing the rates by repeated pollen applications. The lack of a rate response with the honey bee transfer-pollinated fruit also suggests that the blower was unsuccessful at putting increasing amounts of pollen on the flowers with higher application rates.

This is the opposite to what has been found with dry pollen applied with hand guns that pollinate one flower at a time (Appendix 2), where increasing rates of pollen significantly increased seed set (Goodwin 2008). In 2010, the leaf blower produced a 1.2x increase in seed number for a 3.4x increase in the rate of pollen applied. In this trial there was no increase in seed number. The hand held blower gave a 3.5x increase in seed number for a 3.1x increase in pollen rate.

One possibility is there was a problem with the blower or the way it was used. This is unlikely, as the pollen could not be seen in the airstream at low rates but could be seen at high rates and the movement of the flowers demonstrated that the device was pointed at the flowers. The differences in weight of the equipment pre- and post-pollen application indicate the pollen was liberated into the airstream. Also, in total the blower had 82.5% fruit set (95% C.I. = 74.5 - 88.8), which indicates that most of the flowers had pollen blown on them.

Another possible reason for the flat rate response curve is the ability of the pollen grains to be carried over large distances decreasing with increasing concentrations of pollen in the airstream. The modified leaf blowers are typically held about 1 m away from the flowers and the hand guns 10 – 20 cm. This explanation is supported by the results of the Italian blower, which had a steeper rate response (only two rates tested) in the 2010 trial. Like the handguns, this device is held very close to the flowers (Appendices 1 and 3). Without a clear understanding for the reasons for the flat rate response curve, it is not possible to give a recommendation on the optimum pollen rates that should be used with the leaf blower technology.

Honey bees transferred enough pollen to produce 156.6 seeds (S.E. = 23.8). This is lower than the number of seeds produced by bee transfer in 2010 (233 S.E. = 38) and probably reflects the lower rate of pollen that was blown onto the flowers. The trial does, however, support the 2010 observation that honey bees redistributing pollen significantly increase the effectiveness of dry pollen applications.

4.2 Pollen Dispensers

Using a small kiwifruit block has the advantage that it is economic to remove all the male vines for trial purposes. However, it has the disadvantage that because a small number of hives are introduced, it can be difficult to achieve sufficient numbers of bees visiting flowers because of competing flowers, and alternatively there may be bees visiting the flowers from hives other than those introduced for pollination.

Both these problems occurred in this trial. Because of competing flowers, only very small numbers of bees from the hives were visiting kiwifruit. Half way through the trial, no bees were observed returning to the hives with pollen dispensers in a 10-min count, so the dispensers were moved to new hives. Even then at the end of the trial when there was still significant numbers of kiwifruit flowers present, only 35 bees could be caught returning to the four hives with dispensers when they were blocked for 30 min.

The pollen dispensers were able to place staminate pollen on to honey bees leaving the hives. The design appeared to be very good at separating outgoing bees from incoming bees; however, it appeared to waste pollen. When 4 g of pollen was placed in the dispenser at the same time, pollen could be seen being blown out of the hives and it caused a short (approx. 5 min) reduction in foraging until the bees got used to the presence of the pollen. It was less of a problem when only 1 g was used per hour. It would be reasonably simple to produce a device that would drop pollen slowly into the dispenser over time.

The maximum number of bees was lower than would be expected in kiwifruit orchards in the Bay of Plenty, which typically have a peak in excess 20 bees/thousand flowers. The average bee count in the Ruakura orchard only reached 20 bees/thousand flowers on one of three days that it was measured. The low bee counts would have had a negative effect on pollination and therefore further underestimated the effectuiveness of the dispensers.

The lack of any staminate pollen on bumble bees caught on rows 3 and 4 indicates that any honey bees coming from beehives other than those with dispensers should not have had any staminate pollen. As only 3% of the bees caught returning to the hives fitted with pollen dispensers and carrying kiwifruit pollen were not carrying staminate pollen, while 37% of those caught on flowers were not, this suggested that at about 34% of the bees visiting kiwifruit flowers were coming from hives without pollen dispensers.

The lack of an increase in seeds per fruit with increasing length of exposure to the 4 g pollen per hive treatment, and the lower than expected increase with 16 g pollen per hive day, are difficult to explain. In a normal orchard, exposing flowers to bee visits for increasing numbers of days uniformly increases the seed number (Goodwin 1987). The lower than expected increases are not due to environmental conditions affecting the ability of the flowers to set seed, as the hand pollinations at the same time gave consistent results. One possible explination for this result is changes in stigma receptivity. Stigma receptivity of Hayward pistillate flowers has been tested on several occasions and have produced the same results(Goodwin 1987; Goodwin et al. 2008). These trials have, however, all been conducted with single hand pollinations that have fully pollinated the flowers. It is possible that appling smaller of amounts of pollen over several days may affect the length of stigma receptivity

The 16 g of pollen/hive per day produced fruit with significantly more seeds than the 4 g/hive per day. The flowers had an average seed count of 515 seeds (S.E. = 41.4). Assuming eight hives per ha and a 5-day peak flowering period, this would require 640 g of pollen. This is more seeds that produced by the blower using similar rates of pollen (Appendix 1), and suggests that pollen dispensers might be a useful addition to the tools available for kiwifruit pollination.

In this trial, approximately 30% of the bees were coming from hives without pollen dispensers. It would be expected that in a commercial block there would be more hives and a smaller edge effect, so most of the bees foraging in the orchard would be coming from the hives in the orchard. The seed count could therefore conceivably be 25% higher, or 616 seeds per fruit. Considering the large amount of pollen that was wasted, dispensers with some small modifications might achieve these results while using much less pollen.

4.3 Further research

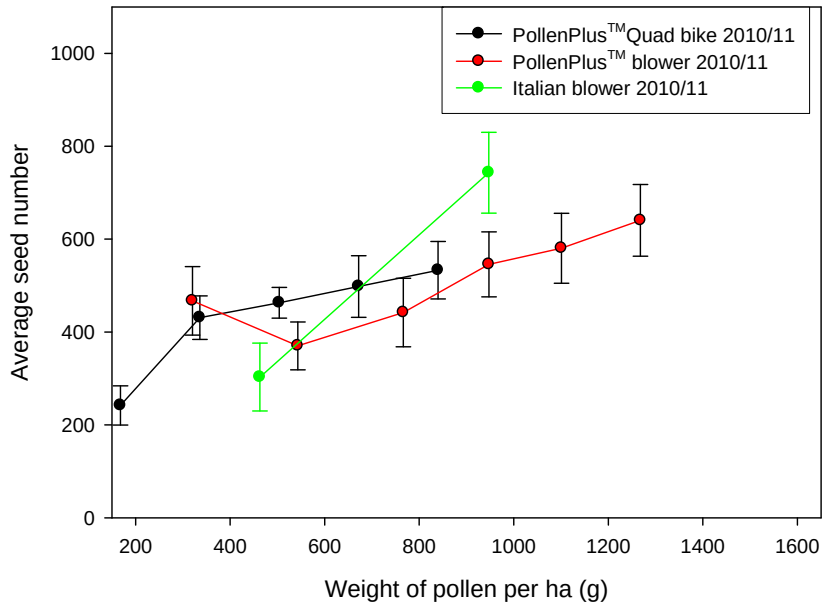
1. Establish the cause of the shallow rate response curve for the modified leaf blower technology.

2. Establish the reason for the lower than predicted cumulative effect of repeated days of using the pollen inserts

3. Redesign pollen dispensers to reduce pollen wastage and to automatically refill.

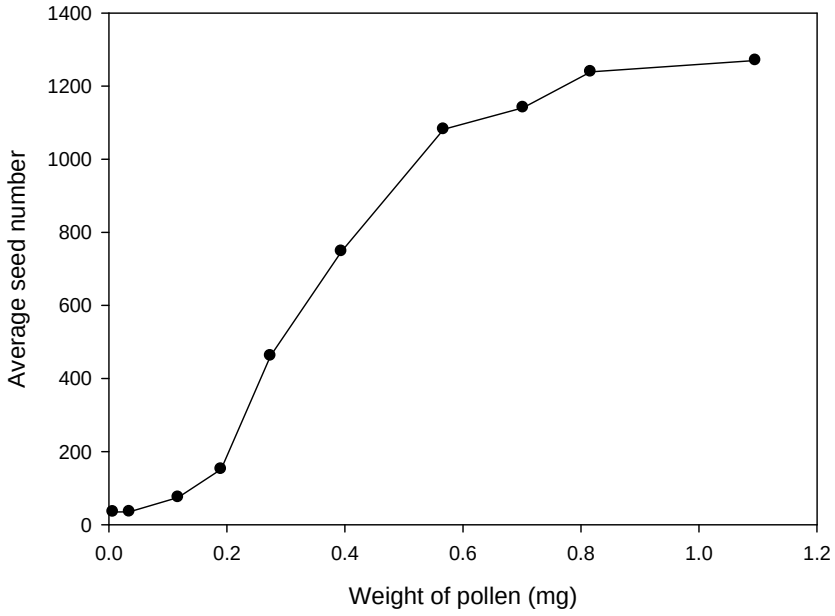
4. Repeat the pollen dispenser trial on a larger scale.

5 Appendix 1



Number of seeds produced by the 'Hayward' kiwifruit pollen applicators tested at the rates of pollen used. The vertical lines are standard error bars (Goodwin 2011).

6 Appendix 2



Relationship between the amount of pollen applied with a hand gun used with 10 cm of pistillate 'Hayward' kiwifruit flower and the number of seeds set (Goodwin 2008).

7 Appendix 3

Leafblower blower held approx. 1 m from the 'Hayward' kiwifruit flowers.

Hand blower held approx. 10 cm from the 'Hayward' kiwifruit flowers.

Italian blower held about 20 cm from the 'Hayward' kiwifruit flowers.

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