



OPTIMISING POLLINATION IN PROTECTED CROPPING ENVIRONMENTS

**Case studies from Australia
and New Zealand**



Australian Government
Department of Agriculture,
Fisheries and Forestry

Collaborating organisations



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Booklet by Applied Horticultural Research



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01.

Introduction

The case studies presented in this booklet are the result of a five-year collaborative research project which explored the relationship between protected cropping practices, Honey bee health and pollination success. Funded through the Australian Government's R&D for Profit scheme, and managed by Hort Innovation, researchers from the Universities of Adelaide, Tasmania and New England, the NSW Department of Primary Industries, and Plant & Food Research, conducted studies aimed at understanding how Honey bees are affected by protective coverings, and how this in turn impacts crop yield and quality.

BACKGROUND

Australian horticultural industries are increasingly turning to protected cropping to mitigate the impacts of extreme weather, pests and diseases. Protected cropping systems offer many benefits. They shelter crops from extremes of wind, sun and, in some cases, rain and hail. Such systems help growers adapt to a hotter, drier and more changeable climate, supporting farm viability and maintaining food security. As a result, the area under protected cropping is expanding by at least four to six percent annually.

However, these benefits do not come without cost. The altered environmental conditions within protective environments do not necessarily suit the needs of pollinators. It is vital to understand the impact of such systems on the insects growers rely on to pollinate their crops.

Inadequate pollination reduces both yield and quality. Growers and apiarists are therefore grappling with the challenges of balancing the needs of crop and pollinator.

This collaborative project had several aims:

- Increase insect pollinator efficacy and pollination by improving the performance of Honey bees under covers.
- Manipulate plant floral and reproductive traits to improve fruit production and quality.
- Study Honey bee foraging behaviour in netted apples in order to optimise the configurations of pollinisers.
- Improve and advance innovative methods of mechanical pollination.
- Investigate non-crop floral resources

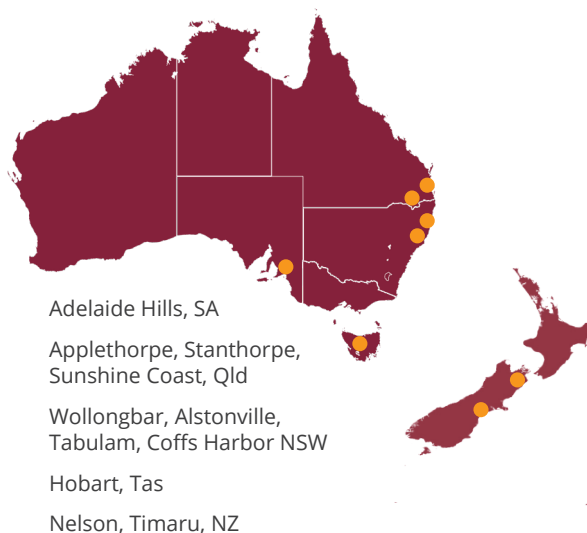
The case studies in this booklet summarise some of the key outcomes of this research, providing insights into strategies that can mitigate risks and improve pollination in protected cropping systems.

The full findings of this research have been compiled in a detailed research report submitted to the Department of Agriculture, Forestry and Fisheries.

STUDY SITES

Studies were conducted in several locations in Australia and New Zealand, across multiple seasons and years.

Geographic and climate variability therefore need to be considered when interpreting these results.



Dr Lisa Evans and colleagues on an apple orchard in New Zealand

KEY OUTCOMES

Honey bee performance and vigour was improved by allowing Honey bees to forage outside and by raising covers high above the crop.

Placing hives in the centre of blocks, and providing gaps in netting, increased the distance Honey bees travelled while mitigating Honey bee losses.

The position of blueberry flowers was more important than floral morphology in attracting Honey bees.

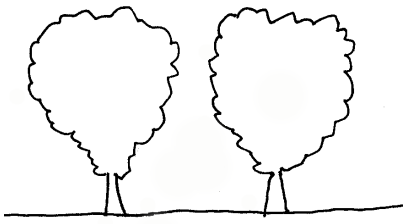
Although Honey bees visit fewer flowers in plastic tunnels, pollination may still be acceptable, especially if tunnel length is optimal.

Mechanical pollination shows some promise but application methods need further work to maximise yield.



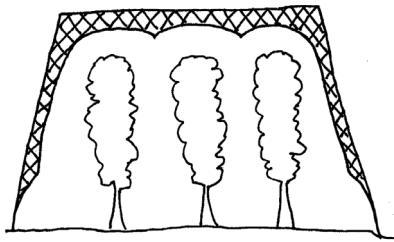
GLOSSARY

Protective covers can include any structures that protect crops from adverse conditions. The glossary summarises the key covers used in the studies summarised in this booklet.



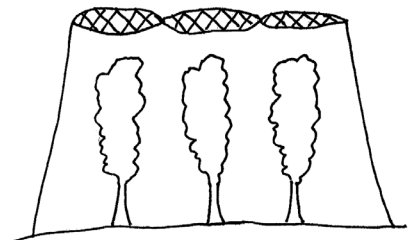
OPEN ORCHARD

No covers installed during the pollination period.



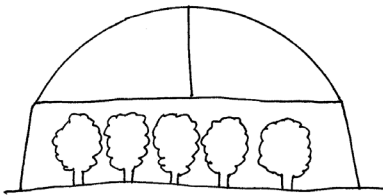
FULLY COVERED

Orchard is fully enclosed with netting covers both top and sides of crop.



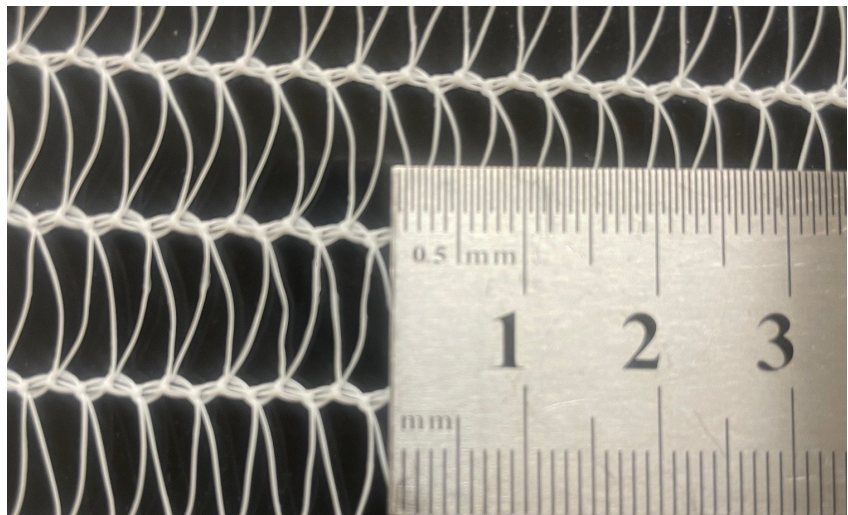
PARTIALLY COVERED

A roof or partial roof and some or all sides left open during the pollination period.



TUNNEL HOUSE

Open at ends, sides may be open or closed, solid structure covered with plastic or shade netting. Typical use – blueberries.



HAIL NET

A type of netting that is typically used to protect crops from hail damage. Hail netting is usually made from a sturdy, hail-resistant material, such as high-density polyethylene. The weave design and colour is variable.



RICE NET

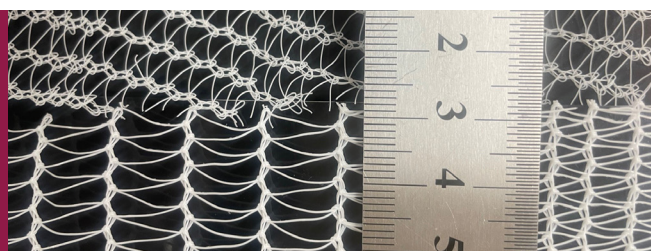
A fine weave, flexible, apex/gable style net that allows hail to collect above and drop through into the interrow. Not permeable for Honey bees, but can be opened above the interrow, as it is connected with bungees.



BIRD NET

Low (1-2m) and relatively floppy, lightweight material, mesh size 16mm x 16mm, commonly black or white.

RICE NET V
HAIL NET
Rice net
weave is
much finer
than hail net.



(Title page photo: checking Honey bees in an apple orchard in New Zealand; photo credit: Dr Lisa Evans; above, photos supplied by JA Grigson Trading)



02.

Managing the pollinators



CASE STUDY 1: Hive health, colony performance and Honey bee behaviour in apple orchards

Dr Katja Hogendoorn, Jay Iwasaki, Scott Groom, Michael McLeish, Elisabeth Williamson

In the apple orchards of the Adelaide Hills, researchers from the University of Adelaide examined why Honey bee health declines under some protected cropping environments.

Studies were carried out to measure and understand the 'status of the Honey bees' in this altered environment.



WHAT WAS INVESTIGATED

1. **Honey bee losses:** Honey bees stuck in hail net and open and closed rice net were counted at the end of the flowering period. Results under hail net were related to net height.
2. **Hive health:** The number/volume of adult workers, open brood, capped brood, and honey and pollen stores were measured.
3. **Hive health in relation to hive placement:** Hives with easy access to outside (under gaps, in the open or under light bird net) were compared to hives placed in the centre of an area of closed net. Differences between hives under closed hail and rice net were also explored.
4. **Pollen diversity in hives:** Pollen was collected under different conditions including open air, under nets, and under closed roofs. Pollen weight, plant species diversity, and proportion of apple pollen was compared across hive positions.
5. **Honey bee behaviour:** Marked Honey bees were observed in a defined area on two consecutive days to determine the number returning to the same spot.

RESULTS

Honey bee losses - Honey bees stuck in nets

Many Honey bees flew out of the netted area through the open sides.

- Placing the hive in the centre under the net, where Honey bees had to travel a relatively long distance (50 – 100m) to exit, likely resulted in many foragers not finding their way back, especially shortly after placement of the hive under the net.
- This is because, on their return flight, the Honey bees fly in a straight line to the hive, inadvertently ending up above the hive, on top of the net. They may then attempt to find an opening or to crawl through the mesh that is too small.

Losses were reduced under higher hail net and opened rice net.

- Increasing the height of hail net from 5m to 6m or 8m reduced the number of dead Honey bees found.
- The higher hail net provides space between the trees and the roof, which may help Honey bee orientation back under the net.
- Approximately 3x more dead Honey bees were found stuck in closed rice net than closed hail net.
- Birds were observed landing on the top of hail nets and removing dead Honey bees; this was not observed in the folds of the floppy rice net. Consequently, loss under the hail net may be underestimated.

BEST PRACTICE TIP

In the Adelaide Hills, some nets had lower overhangs along the sides compared to the roof.

This made it difficult for Honey bees to leave from under the net, especially in the late afternoon. Many Honey bees were seen struggling to exit from these corners.

While not measured, this aspect should be considered in net design, as there seems to be no clear reason for this overhang.

(Title page photo: checking Honey bees in an apple orchard in New Zealand; photo credit: Dr Lisa Evans)

Hive and colony health - changes in workers and brood

Hive health was better when Honey bees could easily access areas outside the orchard.

- There was considerable variation between hives.
- Hives with easy outdoor access increased by an average 1,955 workers over a three week period.
- Worker populations in hives that could not easily access outside decreased by an average of 44 workers.
- Capped brood in hives with easy outside access increased by an average of 2,300 cells, with similar increases in open brood cells.
- In contrast, capped brood in hives that could not easily access outside declined by an average of 4,620 cells.
- The number of open brood cells was less affected.

Hive health was negatively impacted under closed rice nets compared to closed hail nets.

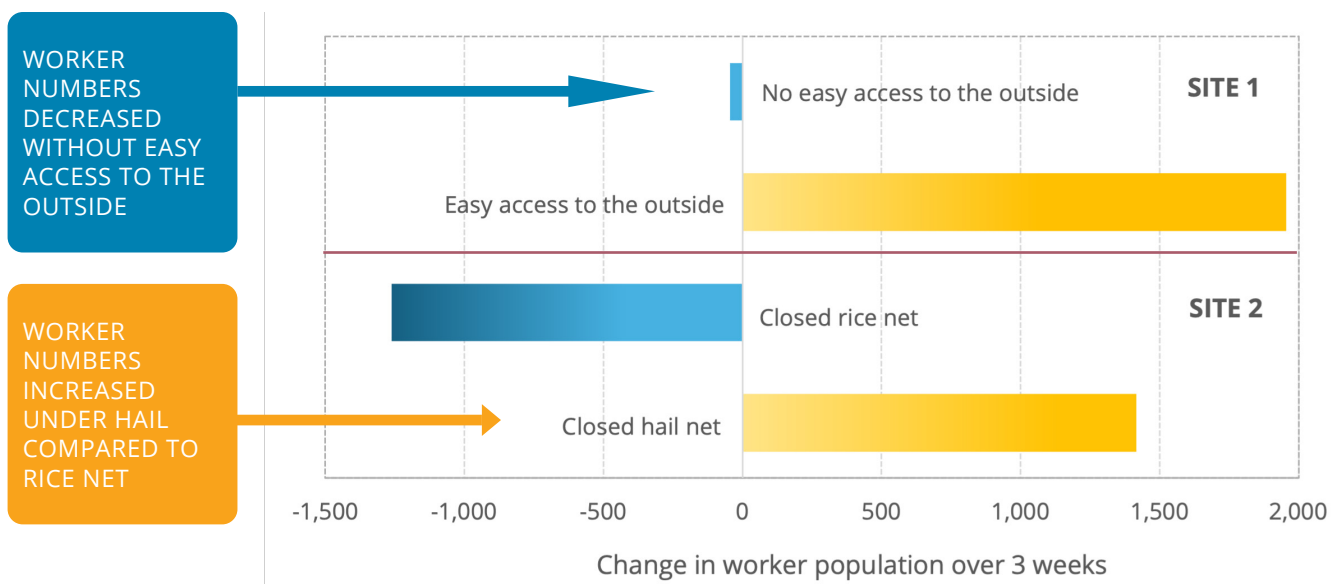
- Populations in hives under closed hail nets increased by an average 1,417 workers.
- Populations in hives centrally located under closed rice nets declined by an average of 1,261 workers.
- The greater decrease in workers under rice nets is likely due to navigation challenges in those conditions.
- Although capped brood decreased more under rice nets compared to hail nets, this difference was not statistically significant.

- The decline in capped brood cells aligns with the decrease in worker numbers under rice nets.
- The type of net (rice or hail) had less effect on the amount of open brood.

Honey bee behaviour, pollen collection and impact on hive decline

Honey bees forage more in open orchards and under hail nets than under closed rice nets.

- Honey bees find it more difficult to orient under rice netting.
- Pollen and honey storage declined most in the hives which had easy access outside orchards or were under closed hail netting.
 - ➔ The number of open brood cells also increased at these hive locations.
 - ➔ Outside access did not significantly affect nectar storage.
- There was no significant difference in pollen collecting behaviour between hives placed under open edges or bird netting and those placed outside orchards.
- Pollen collection was slightly lower under closed roofs, but not significantly.
- Honey bees with access to outside areas collected pollen from a wider range of plant species than those from hives located under closed netting
- Although Honey bees collected less pollen overall when outside access was difficult, they collected nearly three times as much pollen from apple flowers, potentially improving pollination services.



IN SUMMARY

- Hive health decreased substantially when hives were placed under closed roofs constructed with rice net. This was likely due to many foragers not being able to find their way back to the hive, as evidenced by:
 - The large number of workers stuck in nets
 - Reduction in the numbers of active Honey bees
 - Reductions in closed brood
 - Lack of the ability of foragers to return to the spot where they were foraging earlier
- Low netting likely impairs Honey bees' ability to orient themselves relative to the hive. Differences in light quality and quantity may also have effects (see Case Study 6 on page 15).
- Total pollen collection decreased in both quantity and diversity in hives without easy access to the outside.

Honey bees mainly collected pollen from apple flowers under closed rice and hail nets, potentially benefiting pollination and offsetting the effects of reduced foraging activity. Although this appears to be efficient in the short term, the evidence suggests that it will have long term effects on hive health.

KEY RESULTS

- Hive health declines when hives are placed centrally under closed rice net, with decreases in both worker populations and brood reared.
- Hive health, based on the number of capped brood, declined when access to the outside of the crop was difficult.
- The amount of stored food declined in all hives, even those with easy access to the outside, with the greatest changes in hives that had the most brood cells.
- Under hail net, there was less attrition (Honey bees stuck in the nets) when nets were >5 m high than under nets that were lower. Under rice net with cross bungees, the attrition was significantly lower when the roof was opened every fourth row.
- Honey bees can easily become trapped in the corners if nets have an overhang on the sides, compared to presenting a clean exit with no side panels
- Honey bees find it difficult to orient under closed rice net, likely due to interruption of the light and lack of height above the trees
- Honey bees from hives without easy access to the outside mostly focus on collecting apple pollen. Increased visits to apple flowers may partly compensate for the negative effects on the number of foragers, foraging activity, and hive size.
- Other factors being equal, the presence of high hail net more than halved Honey bee activity on apples compared to Honey bees foraging in the open. It is likely that this is related to changes in the quality and quantity of light under the net.

CASE STUDY 2: Effect of protective covers on Honey bee colony development and access to resources in blueberry orchards



Dr Romina Rader, Dr Karen Santos, Carolyn Sonter, Jeremy Jones

To determine the impact of protective cropping structures on Honey bee brood production and resource storage in blueberry orchards, 14 Honey bee colonies were placed inside and outside of protective covers on four blueberry (*Vaccinium corymbosum* and *V. virgatum*) farms of northern NSW, Australia.

WHAT WAS INVESTIGATED

The researchers measured the following factors each fortnight for 12 weeks:

1. Changes in brood production
2. Pollen and honey storage
3. Hive weight
4. Ambient hive temperature

RESULTS

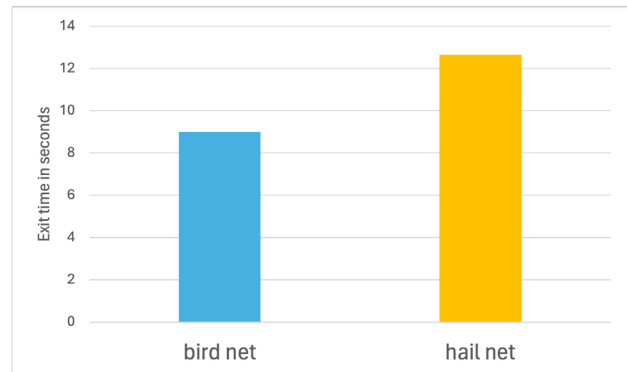
- Brood production, pollen and honey storage, and hive weight all decreased within four weeks of placement under net cover.
- Although brood and honey measurements gradually increased in all hives during the 12-week monitoring period, hives located under protective netting had relatively smaller gains in brood production and pollen storage when compared to hives located outside the protective covering.
- Hives under protective netting that were in the shade and/or whose entrances were facing south were most impacted.
- Bees took significantly less time to exit (just over 9 seconds) and had greater success in exiting, when the area was covered by bird net, compared to an average 12.6 seconds, from under hail net.
- Bees contacted and rebounded off hail netting more frequently than bird netting during individual flight observations.

KEY RESULT

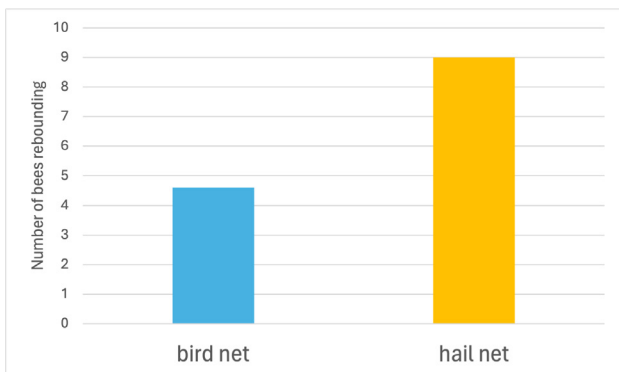
Hive health can be negatively affected by placement under hail netting, especially if the hives are south facing and shaded.

FURTHER READING

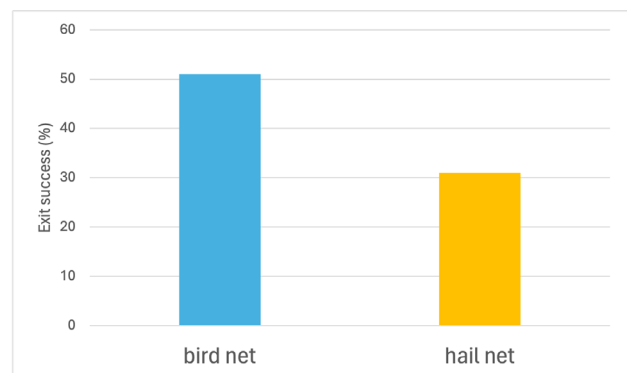
Carolyn A. Sonter, Jeremy Jones, Blake M. Dawson, Jared N. Reid, Karen C.B.S. Santos, Steve Fuller, Matthew Tighe, Susan C. Wilson, Romina Rader (2024). *Protective covers impact honey bee colony performance and access to outside resources*. Agriculture, Ecosystems & Environment, Volume 368, 109028.



HONEY BEES TOOK LONGER TO EXIT FROM HAIL NETS (12.6s) THAN FROM UNDER BIRD NETS (9s)



TWICE AS MANY HONEY BEES REBOUNDED FROM HAIL NET COMPARED TO BIRD NET



HONEY BEES COULD EXIT BIRD NET MORE EASILY THAN HAIL NET

CASE STUDY 3: Position of hive and its impact on pollination in apple orchards

Dr Katja Hogendoorn, Jay Iwasaki, Scott Groom, Michael McLeish, Elisabeth Williamson

Initial studies indicated that Honey bees find conditions challenging under closed rice net, with declines in hive health and Honey bee activity (see Case Study 1). The next step was to investigate how this environment affected pollination and, therefore, fruit set and quality. The study was undertaken in a single large orchard block of Pink Lady apples (25 x 200m long rows) in the Adelaide Hills. The orchard was fully covered using rice net supported by posts approximately 15m apart. The distance between two posts is referred to as a 'panel'.

WHAT WAS INVESTIGATED

1. The effect of polliniser proximity on fruit set was assessed over two seasons by counting applets per flower cluster, choosing one high and one low branch on two trees per panel.
2. The distance to the nearest possible pollinator was assessed by examining microsatellite markers in 170 individual apple seeds.

RESULTS

Polliniser proximity to seeds

For nearly 75% of the examined seeds, the closest potential pollen donor was within 10m. In contrast, less than 8% of seeds were fathered by pollen sources more than 50m away.

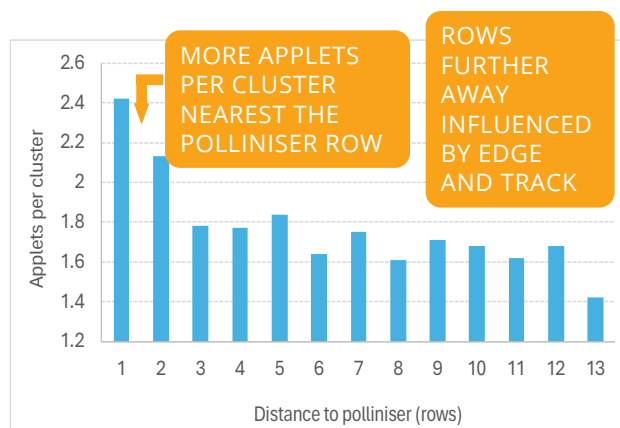
The pollen may or may not have been supplied by the nearest potential source. However, the result is consistent with other observations of Honey bee behaviour, which all indicate that Honey bees rarely forage further than 50m in the crop.

MORE THAN 90% OF SEEDS FORMED WITHIN LESS THAN 50M OF THE NEAREST POSSIBLE POLLEN DONOR

DISTANCE (M) TO CLOSEST POSSIBLE POLLEN DONOR	PERCENT OF SEEDS FATHERED
5	71.38
10	73.5
30	80.6
40	81.8
50	93.5
60	94.1
100	98.8
130	99.4
170	100

Polliniser proximity and fruit set

- The numbers of applets per cluster varied depending on the position in the orchard.
- The number of applets per cluster was higher for the two rows nearest to a polliniser row.
- Pink Lady fruit set was higher next to 'Galaxy' than 'Kanzi', but this may be due to closer proximity to the outside rather than favouring a variety.
- For rows further from the polliniser blocks, fruit set was increased near the internal access track and the outside edge of the orchard; both areas with higher Honey bee activity.

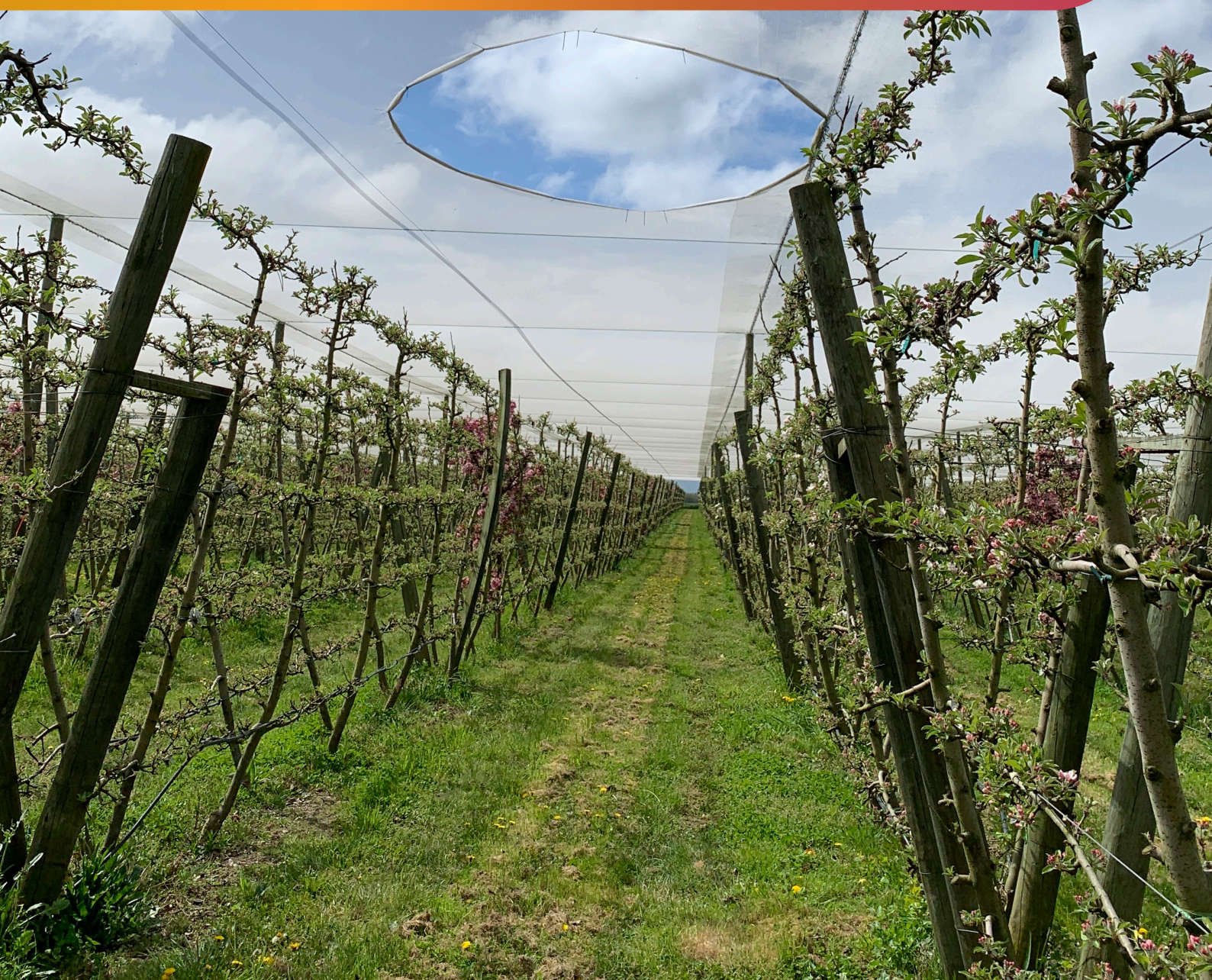


BEST PRACTICE TIPS

- ✓ If placing hives on the outside areas of net, avoid rows longer than 100m; most Honey bees will not venture further than 50m under net
- ✓ Ensure that one or more rows of pollinisers are present every six rows under net
- ✓ High hail net is better for hive health and encourages Honey bees to forage more on the crop than low rice net
- ✓ Placing hives centrally under the net, rather than on the edge, forces the Honey bees to forage on apples, potentially improving pollination despite negative impacts on foraging activity

03.

Managing the protected cropping environment



CASE STUDY 4: Does creating gaps in netting improve pollination in covered apple orchards in the Adelaide Hills?

Dr Katja Hogendoorn, Jay Iwasaki, Scott Groom, Michael McLeish, Elisabeth Williamson

This study measured the impact of opening nets on apple yield and quality.

WHAT WAS INVESTIGATED:

- The impact of opening rice net every third (orchard A) or fourth (orchard B) row above the inter-row during pollination on Honey bee activity and, therefore, apple yield and quality.

→ Fruit set was assessed by recording applets per cluster on 120 trees, while fruit symmetry was recorded for 120 apples per orchard.

THE RESULTS

- There was significantly more Honey bee activity under opened rows than under closed rows.
- Although average fruit set was slightly higher under open rows compared to closed ones, this difference was not significant.
- The number of seeds per fruit and, therefore, apple symmetry, were not affected by whether the rows were opened or left closed.

In this study, leaving nets closed decreased Honey bee foraging activity, but there was no effect on fruit yield or quality.

Opening and closing nets requires special machinery and potentially risks extra wear and tear on nets. It also leaves the crop vulnerable to hail damage.

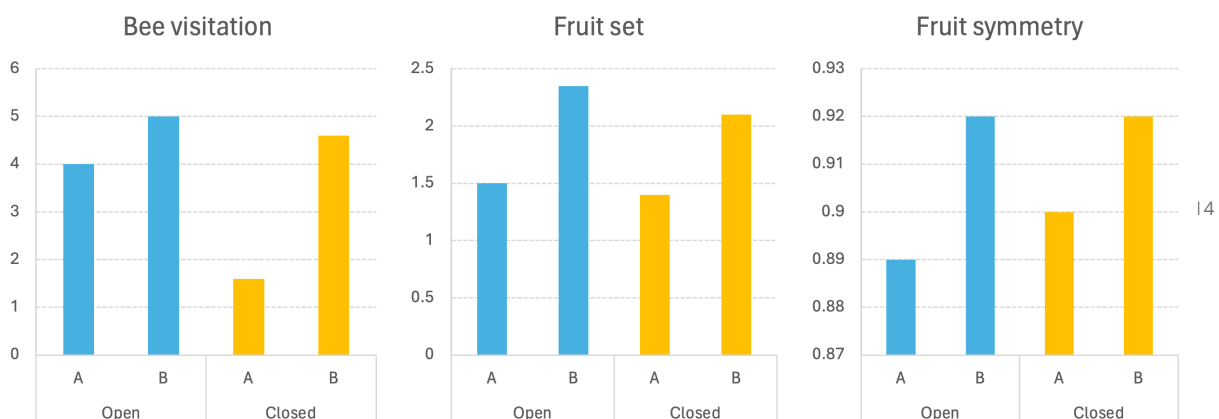
These results suggest that it is better to leave nets closed so long as hive health is managed.

KEY RESULTS

- Although opening the net over every 3 – 4 rows increased Honey bee activity on the crop, it did not lead to higher fruit set or better apple symmetry.
- These results suggest that the cost and additional risks incurred by opening nets is not justified by improved pollination.
- As hive health tends to deteriorate under closed rice net, beekeepers need to manage hive resources and limit time spent under these conditions.



ALTHOUGH HONEY BEE ACTIVITY INCREASED UNDER NET OPENINGS, FRUIT YIELD AND QUALITY WERE UNAFFECTED

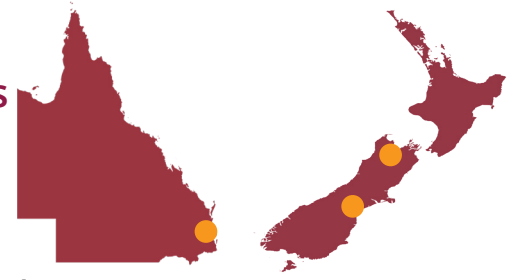


Honey bee visitation, fruit set and apple symmetry under rice net in two orchards (A and B), measured under rows where the net had been opened or kept closed. The roof was open over every third (A) or fourth (B) row.

(Title page photo: apple orchard in New Zealand; photo credit Dr Lisa Evans)

CASE STUDY 5: Do gaps in netting or open sides impact bee movement in covered apple (New Zealand) and lychee (Queensland) orchards?

Dr Lisa Evans, Brian Cutting, Dr Melissa Broussard, and Dr Mateusz Jochym



This study investigated the effect of cover structure on Honey bee health and overall colony performance, and whether the position of the hive in the orchard also had an impact.

WHAT WAS INVESTIGATED

- To determine whether cover structure can be modified to reduce adult bee losses from colonies deployed for apple pollination:
 - Blocks fully covered with white hail netting
 - Partially covered (roof only or a roof and partial sides)
 - Uncovered (control) blocks
 - Fully netted blocks with a gap in the roof
 - Partially netted blocks with a gap in the roof
- Assessments were also undertaken to determine whether cover structure can be modified to reduce adult bee losses from colonies deployed for lychee pollination, including:
 - Adult Honey bee numbers in fully covered blocks with black hail netting
 - Adult Honey bee numbers five partially covered blocks (a roof and some sides) with black hail netting

All hives were moved into the blocks at night at approximately 20% flowering.

Colony strength was assessed on their first day in the orchard and then re-assessed prior to hive removal from the blocks. All assessments were conducted starting at first light, before the Honey bees began to forage.

- In addition to cover structure, the effect of colony position was assessed in terms of colony health and bee foraging distance. Colonies were categorised as being:
 - Open/uncovered (no netting)
 - At edge of partially covered block (roof only)
 - In the middle of a partially covered block
 - Under gaps in roof netting of partially covered blocks
 - On the edge of fully covered blocks

- In the middle of fully covered blocks, and
- Under gaps in roof netting of a fully covered block
- To assess Honey bee activity on apple flowers relative to hive position a fluorescent powder was used to mark Honey bees as they left their hives.
 - Transects were conducted along rows of the orchard every 25m to assess visitation from marked and unmarked bees

RESULTS (APPLE)

Colony strength:

- Colonies in the partially covered blocks performed similarly well compared with the open/uncovered blocks and maintained their strength over the course of flowering regardless of their position within the block.
- Conversely, colonies in the middle of fully covered blocks declined significantly compared to colonies in the open/uncovered blocks.
- In fully covered blocks, creating a gap in the netting above the colonies significantly reduced Honey bee losses over the flowering period.

Honey bees foraging on flowers:

- The number of Honey bees on apple flowers declined more rapidly with distance from the hives when the hives were located at one end of a covered block.
- Overall, Honey bees foraged the furthest from their colony when their hive was located in the middle of the block.
- Colonies placed on the edge of netted blocks foraged the shortest distance, and were rarely seen in the orchard.

RESULTS (LYCHEE)

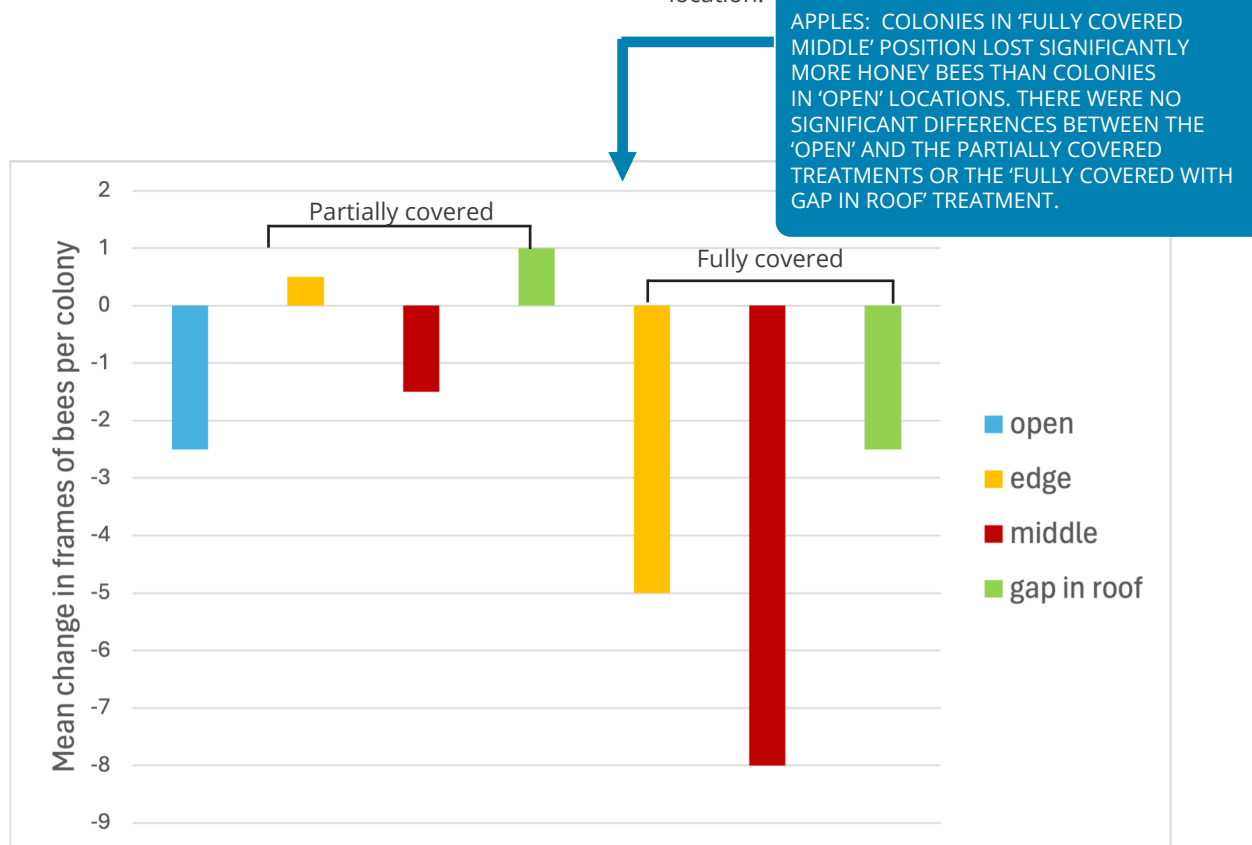
Colony performance:

Hives were assessed across fully covered blocks and blocks with one to two open sides.

- The number of adult Honey bees in colonies remained similar in the fully covered and partially covered (one side rolled up) blocks.

Honey bees foraging on flowers:

- Across all hives/blocks, Honey bee activity (Honey bees per 1000 flowers) was not significantly affected by cover treatment but was affected by location within the block, with fewer Honey bees being found in the centre of blocks. However, this pattern of activity was not influenced by hive location.



Notes: 1. A cold snap in year 3 of the study likely had a negative effect on colony strength in the open orchard.; 2. There was significant variability among observed hives

KEY RESULTS

- Partially covered apple blocks:** The strength of honey bee colonies at the end of flowering was similar to those in open blocks, regardless of their location within the block.
- Fully covered apple blocks:** Colonies lost fewer bees when placed under gaps in the netting cover.
- Hive placement in covered apple orchards:** Placing hives in the middle of the orchard encouraged bees to forage further from their hives.
- Partially covered lychee orchards:** Adult bee numbers in colonies increased when at least one side of the covered block was opened up.

BEST PRACTICE TIPS

- ✓ **Open netting sides:** Opening one or more sides of hail netting-covered apple and lychee blocks can help mitigate adult bee losses from hives during the pollination period.
- ✓ **Roof gaps:** If opening the sides is not possible or undesirable, including a gap in the roof of the netting above honey bee hives can help reduce adult bee losses.
- ✓ **Central hive placement:** Deploying bee hives in the middle of covered apple blocks improves their spread across flowers in the block. In a highly modified pastoral/apple growing landscape, including a gap in the roof of the netting above honey bee hives (to mitigate bee losses) does not significantly reduce their foraging activity/ spread over flowers in the covered block.

CASE STUDY 6: Impact of different types of covers and netting on light transmittance and Honey bee orientation in apple orchards in NZ and Australia

Dr Lisa Evans, Brian Cutting, Dr Melissa Broussard, and Dr Paul Martinsen

This study measured a number of light parameters through different coloured nets to determine whether colour impacted Honey bee behaviour.

WHAT WAS INVESTIGATED

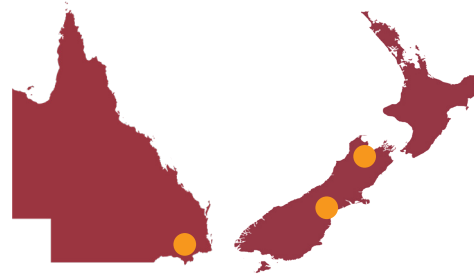
When light passes through the atmosphere, some of it is blocked or scattered – the light that passes through is said to be **polarised**. Polarised light has a predictable orientation which is invisible to humans but is used by bees to help them orient themselves in the landscape. Subsequent passage of light through clouds, windows, or crop covers can change both the polarisation and the intensity of light, potentially affecting bees' ability to navigate.

1. To assess **light transmittance through nets**: Sensors were used to quantify polarised light under various colours and weave patterns of hail netting typically used in horticulture. Measurements were taken during the period of apple bloom over two different years in Nelson, New Zealand and Stanthorpe, Australia. Both the degree of polarisation (how much of the light was filtered in a polarising way) and the angle of polarisation (the directional orientation of the light) was quantified for the entire visible sky under these different netting types.

The results were analysed for the light spectra most likely to affect bees (blue and ultraviolet light). The light intensity in these environments was also assessed – netting can change how much light passes through to the environment below, which may also affect bee behaviour independently of polarisation.

2. To determine **how netting types affect honey bee navigation while foraging**: Hives were observed under two different types of hail netting (black and white), as well as in an uncovered (control) apple orchard at Stanthorpe, QLD.

The dance behaviour of returning foragers communicating their direction of flight was recorded using infrared video cameras inside the hive. The information in these bee dances was decoded, providing the direction that the bees were communicating to other foragers. The average direction communicated, and the variability between dances, was assessed and compared to the actual direction where bees were known to be foraging.



RESULTS

Light Transmittance

- Bees are highly sensitive to polarised light in the blue-to-ultraviolet band, needing only 5-10% polarisation in a patch of sky to successfully navigate (Wehner 1984). All netting types measured exceeded this threshold in sunny conditions.
- Darker materials tended to absorb light rather than scattering it, resulting in linear polarisation levels similar to an uncovered sky.
- Linear polarisation of light was reduced under lighter materials, with only approximately 20% linear polarisation under white quad netting.
- Orientation of the covering, whether parallel to the ground or pitched, affected light polarisation, particularly in the lighter coloured coverings.
- Light scattering may be affected by the microstructure of the covering material, and the way it is stretched, so the effect is still apparent in flat coverings.
- Clouds also scatter light. Heavy cloud can reduce polarisation to <5%, and the combination of light cloud and netting can do the same, producing a biologically meaningful reduction in polarised light

Forager navigation

- Difference between actual honey bee dance direction and the true direction of foraging:
 - There was no significant difference between the uncovered control and the white netting treatments. Bees in these treatments exhibited dances that closely aligned with the actual direction of flight.
- The direction of bee dances under black netting differed significantly from the actual feeder direction, suggesting that these environments may pose greater challenges for bee orientation.

- It is not clear whether polarised light or light intensity is causing this change in dance accuracy, and the effect may be caused by other factors (e.g., the low-apparency of black netting against a blue sky). This is a new area of research that has focused on a small number of different hail nettings in Australian light condition. Further research is needed before clear recommendations on netting type can be made.

HONEY BEES, LIGHT AND THE WAGGLE DANCE

In 1973, Professor Karl von Frisch won the Nobel Prize in Physiology for decoding the dance of the Honey bee, termed the 'waggle dance'.

Honey bees navigate using a map of polarised light. When a worker Honey bee finds flowers that contain nectar, she converts polarised 'light maps' into a dance movement that lets the other worker Honey bees know where the nectar is located.

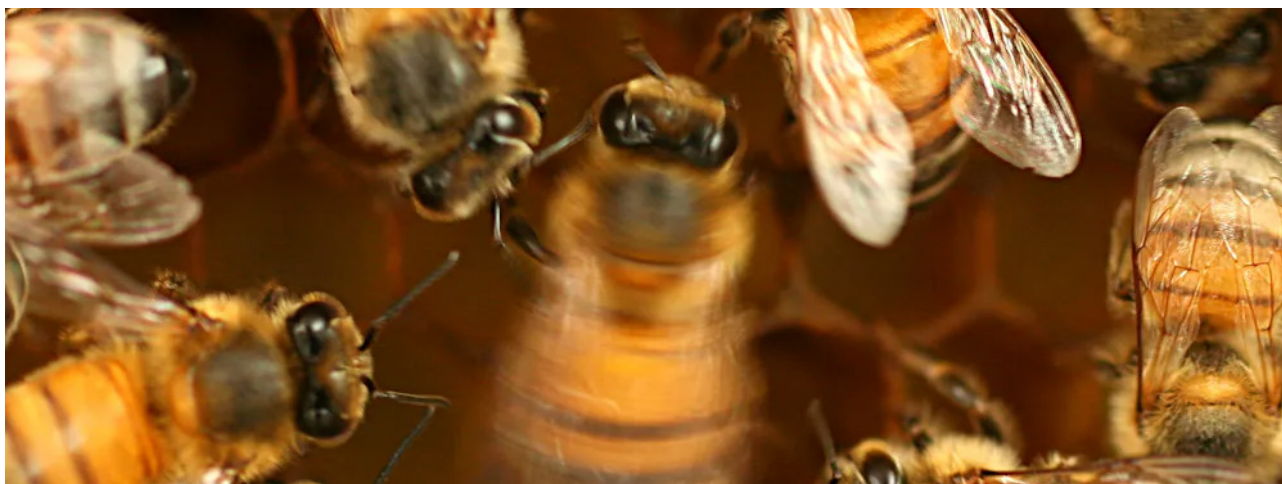
The waggle dance communicates various information about a Honey bee's foraging trip, including the food source's distance and direction from the hive, angle from the sun, and the quality of the resource.

The forager positions herself perpendicular to the sun in the direction of the food source, thereby demonstrating its direction. She also performs a 'vibration' through the centre of a figure eight, which demonstrates how far the source is.

This study sought to understand the impact of protective covers on the Honey bees ability to read these 'light maps' and thus communicate vital information.

KEY RESULTS

- Polarisation was lower in the presence of nets, thick clouds or both, and higher under clear patches.
- Artificial coverings may alter the natural pattern of polarisation insects may 'expect' to observe in the sky, but perhaps no more than variation in cloud cover. However, cloud cover is temporary whereas fixed coverings are more permanent.
- The accuracy of Honey bee waggle dances was compromised by the presence of black netting, leading to incorrect communication of feeding locations to nest mates.
 - This disruption does not appear to stem from a reduction in polarised light caused by the black netting.
 - Instead, it may be attributed to a decrease in the total amount of light entering the growing system.
 - These findings suggest that Honey bees are more likely to become disoriented or lost while foraging under black netting.



Returned foraging worker Honey bee performing the waggle dance (photo source: Heather Broccard Bell, CC BY-NC-S)



CASE STUDY 7: Effect of blueberry cover type, length and height on insect visitation, pollen flow and blueberry yield

Dr Romina Rader, Dr Karen Santos, Carolyn Sonter, Jeremy Jones

To learn how cover types impact blueberries, these studies evaluated the effects of the different cover types on insect visitation and yield using polythene and bird-netting covers over blueberries.

WHAT WAS INVESTIGATED

1. Insect visitation
 - During a 22-hour period, the researchers watched Honey bees visiting Snowchaser (USPP19503P3; AU PBR Grant No.: 3570) and Arana plants (USPP22778P3; AU PBR Grant No.: 3662.)
2. Pollen flow and composition of blueberry stigmas
 - The researchers counted a total of 41,779 pollen grains on 840 blueberry stigma
3. Tunnel length
 - Pollinator numbers were counted to determine the impact of tunnel length.

RESULTS

Insect visitation

Snowchaser mainly attracted Honey bees (94.8%), while Arana was more popular with stingless bees (56.7%).

- Stingless bees visited more often when the plants were covered with bird-netting rather than polythene.
- Overall, more insects visited under bird-netting than polythene, and this was consistent across both types of plants.
- The impact on yield varied. Snowchaser produced 17% more berries under polythene, while Arana had a 39% higher yield under bird-netting.
- For Arana, there was not a significant yield difference between plants with or without pollinators under polythene.
- Both types of plants tended to yield more under polythene than bird-netting when pollinators were absent; while this suggests that polythene can boost yield independently of pollination, the effect likely depends on other factors, including variety.
- Polythene might be most beneficial when pollination rates are already high, whereas if pollination rates are low, bird-netting could lead to higher yields.

Pollen flow and composition on blueberry stigmas

- 31 pollen species from 20 families were identified on blueberry stigmas, with netting significantly affecting pollen diversity.
- While netting impacted pollen deposition, mesh size did not correlate significantly.
- Blocks transitioning to fully netted showed reduced pollen counts.

	UNNETTED	PARTIALLY NETTED	FULLY NETTED
Total pollen counts	Highest	Middle	Lowest
Same pollen type	Highest	Middle	Lowest
Overall pollen diversity	Highest	Middle	Lowest
Edge stigmas v middle stigmas	Edge had more pollen than middle, both in total and in diversity	No difference between edge and middle for total pollen, however significantly higher diversity at the edge	Pollen diversity slightly higher at the edge than in the middle

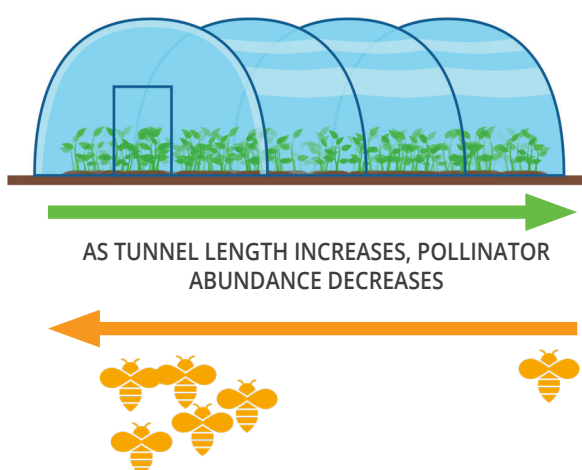
FURTHER READING

Karen C. B. S. Santos, Manu E. Saunders, Ulrika Samnegård, , Maurizio Rocchetti, Jessica Scalzo, Romina Rader (2023) *Protective nets reduce pollen flow in blueberry orchards*. Agriculture, Ecosystems & Environment, Volume 353, 108544.

Tunnel length

More pollinators were found on plants in shorter tunnels.

This suggests that blueberry yields may be increased by using an optimal tunnel length and cover type for a given blueberry cultivar.



KEY RESULTS

- Blueberry yields may be increased by using an optimal tunnel length and cover type for a given blueberry cultivar.
- While polythene reduces Honey bee visitation compared to bird-netting, in some circumstances this lower visitation rate may still be sufficient for optimal yields.
 - Polythene covers may provide a yield advantage over bird-netting, independently of insect visitation, but this effect may depend on cultivar, climate, or other factors.



Experimental setup for the study evaluating the effects of netting on blueberry pollination (photo credit: Jeremy Jones, UNE)



Honey bee foraging on a blueberry flower under bird netting (photo credit: Jeremy Jones, UNE)



04.

Managing the crop and the orchard floor

CASE STUDY 8: Do co-flowering non-crop floral resources influence pollinator visitation to crop flowers?

Dr Katja Hogendoorn, Jay Iwasaki, Scott Groom, Michael McLeish, Elisabeth Williamson



To investigate the significance of non-crop floral resources, this study assessed insect activity on the flowering weeds, and various other mixed plantings in the inter row areas.

WHAT WAS INVESTIGATED

Non-crop floral resources

- In 2021, the presence of native bees on weeds before flowering in the orchard was assessed whenever the weather permitted.
- In 2022 and 2023, flowering weeds were assessed in more detail for the presence of pollinators. Up to 100 flowers of different species were counted and the number of visitors quantified in four categories: Honey bees, hoverflies, other flies, and native bees.
- In 2022 and 2023, native bee visitation was assessed in a trial led by the University of Tasmania and coordinated in South Australia by Fruit Growers SA. This trial investigated the effect of orchard floor treatments on the adjacent apple trees. The inter-row treatments were:
 - Grower's standard inter-row sward (Lenswood orchard mix)
 - Native grass mix
 - Meadow mix

Of these combinations, only the meadow mix contained flowers that were useful for generalist bees; their visitation was quantified.

The trial did not investigate the effects on pollination but rather how the native bees present in the orchard made use of the meadow mix.

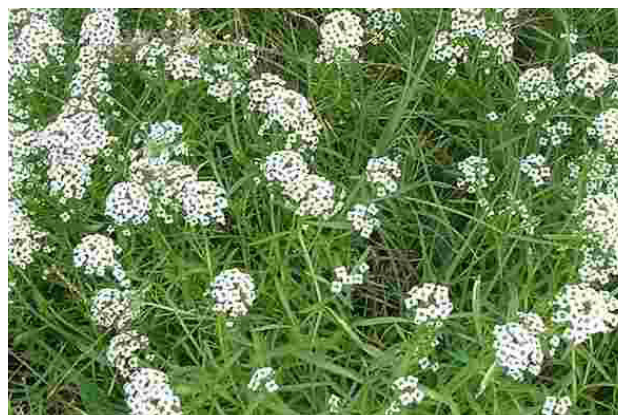
RESULTS

- On the weeds in the orchard, *Lasioglossum* (sweat bees), *Homalictus* bees, and hoverflies were found actively foraging on cape weed (*Arctotheca calendula*), dandelions (*Taraxacum officinale*), and wild mustard (*Sinapis arvensis*).
- After the apple flowering season, the unmown rows mostly had introduced grasses. These were sometimes accompanied by flowering subterranean clover (*Trifolium subterraneum*), plantain (*Plantago lanceolata*), chickweed (*Stellaria media*), and red chickweed (*Anagallis arvensis*), none of which were attractive to native bees.

- *Lasioglossum* and *Homalictus* were often observed when capeweed or other yellow Asteraceae including flatweed (*Hypochaeris radicata*), hairy hawkbit (*Leontodon taraxacoides*) or dandelion were present. These were the main wild bee visitors of apple in this region.

The plants in the meadow mix trial did not grow or flower well in either year and were mown soon after the apples finished flowering, however the number of native bee visitors per flower or plant was established.

- The weeds already present were more attractive than most of the plants in the meadow mix, with cape weed and flat weed standing out.
- However, as cape weed only flowers in spring it will not provide food for bees during summer.
- Cape weed can be maintained in the interrow, or just outside the orchard block by disturbing the soil (e.g., every two years).
- Of the meadow mix flowers, *Nemophila menziesii* seemed the most useful for native bees.
- Of native plants in the Adelaide Hills, *Scaevola* spp. and *Pultenaea pendiculata* are among the most useful plants for generalist bees (Spronk et al, 2023). While these can be planted on the edge of orchard blocks, it is unlikely that they would survive in the interrow, and it is possible that they would cause slipping hazards in steep orchards.






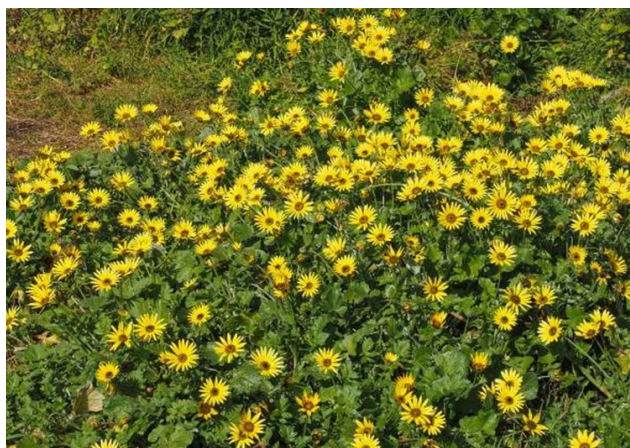
Sweet alyssum is attractive to hoverflies (photo credit: lucidcentral.org)

(Title page photo: Honey bee on a cape weed flower; photo credit Beverly Buckley from Pixabay)

Plants in the meadow mix trial, and other weeds, in apple orchards with bees observed per flower.

Blue: attractive hoverfly plant. Orange: attractive bee plant

	FLOWERING?	N FLOWERS OBSERVED	HONEY BEES	HOVERFLIES	BUTTERFLIES	NATIVE BEES
Meadow mix						
 <i>Alyssum benthamii</i> (Sweet alyssum)	yes	500	0	200	2	1
<i>Ammi majus</i> (Queen Anne's Lace)	no					
<i>Anethum graveolens</i> (Common Dill)	no					
<i>Aubrieta hybrida</i> (Rock Cress)	few	0	0	0	0	0
<i>Nemophila menziesii</i> (Menzies' Baby Blue Eyes)	yes	140	2	0	0	2
Other weeds in orchard						
 <i>Arctotheca</i> (Cape Weed)	yes	2500	127	121	5	67
<i>Veronica persica</i> (Creeping Speedwell)	yes	500	0	7	4	15
<i>Trifolium repens</i>	yes	400	8	9	1	2
<i>Trifolium subterraneum</i>	yes	400	0	0	0	0
<i>Oxalis pes-caprae</i> (Sour sob)	yes	100	2	0	0	1
 <i>Taraxacum officinale</i> (Dandelion)	yes	200	6	1	0	1
<i>Hypochoeris radicata</i> (Flat Weed)	yes	400	20	56	4	16
<i>Anagallis arvensis</i> (Red Chickweed)	yes	150	0	0	0	0



Both cape weed (left) and flat weed (right) are attractive to bees (photo credit: lucidcentral.org)

KEY RESULTS

- Ground nesting bees benefit from access to open soil under the trees or in headlands, which is kept clear of dead leaves and pruned branches.
- Under-tree herbiciding in winter creates accessible soil, allowing establishment of weeds such as yellow Asteraceae; these can provide additional pollen and nectar sources for native bees.

TO MOW OR NOT TO MOW?

Mowing has mixed effects.

Alternate mowing of rows seems to lead to a reduction in flowering weeds and an increase in grass

However, it is possible that seed production, and therefore proliferation of flowering weeds, is influenced by the frequency of mowing.

CASE STUDY 9: Can fertigation modify nectar in blueberry flowers?

Sophie Parks, Melinda Simpson, Dr Madlen Kratz

Floral nectar is the main attractant to blueberry crops for Honey bees.

The covers used to exclude birds and protect blueberry crops can also act as barriers to the Honey bee's flight paths, limiting their access to nectar resources. This study aimed to better understand the attributes of nectar from blueberry flowers with a view to increasing the 'attractiveness' of this crop.

One potential intervention to modify nectar production in blueberry flowers (*Vaccinium corymbosum* '11-11') is through fertigation. Blueberry crops are often fertigated (irrigation water plus fertiliser), and the aim of this study was to determine whether adjusting fertigation strength can modify nectar production and better suit the needs of pollinators.

WHAT WAS INVESTIGATED

To determine whether nectar was modified by fertigation, delivered at different strengths for several months prior to flowering, the following characteristics were measured on two consecutive days:

1. **Nectar weight**
2. **Total sugars** in nectar, including sucrose, glucose and fructose and their concentrations

Following peak flowering, nectar was extracted from blueberry flowers for mineral analysis. Flowers and nectar were limited and only enough nectar was extracted for two samples from the crop. A further two samples were extracted from a different crop of the same cultivar.

THE RESULTS

- The nectar volumes and total sugar concentrations differed between the two days of sampling, despite their similar environmental conditions. On both days the nectar sugars were predominantly fructose and glucose.
- As the fertigation strength increased from the low to high treatments, nectar characteristics did not change.
 - However the number of flowers per plant increased, suggesting that higher fertigation strength is a way of increasing the nectar available for pollinators when the plants have insufficient levels of nutrients.

→ Nutrient deficiencies in plants can be avoided by ensuring crops are growing optimally. For example, analysing leaf mineral content in summer after harvest to evaluate crop nutrient status.

- Nectar volumes were not sufficient to measure nitrogen, but potassium, calcium, manganese, copper, and zinc were detected in these nectars, with the other elements being below levels of detection.
- Although potassium concentrations were low compared with reports for avocado and onion nectar, potassium was higher than those reported in citrus.

KEY RESULT

- **Fertigation modified the nutrient status of plants which affected flower production and therefore total nectar availability**
- **Fertigation did not change nectar characteristics**



Top: A blueberry flower with nectar droplets visible on the stigma and inside the floral tube

Left: Leanne Davis, Technical Officer (NSW DPI) extracting nectar from blueberry flowers for analysis of sugars, and chemical elements in some samples (photo credit: Dr Sophie Parks, NSW DPI)

05.

Managing pollen



CASE STUDY 10: Mechanical harvest, storage and delivery of onion and sweet cherry pollen

Dr Alistair Gracie, Dr Alieta Eyles, Dr Ryan Warren, Dr Cameron Spurr



Can pollen be harvested, stored and mechanically delivered to boost pollination in protected cropping environments? This study investigated the viability of such measures in two contrasting production systems: onion seed and sweet cherry crops.

WHAT WAS INVESTIGATED

1. Pollen collection

- Several methods were tested to determine the best way to harvest pollen for each crop. These were based on milling and separation of pollen from harvested flowers, or use of vacuum devices to collect pollen *in-situ* or from harvested flowers. The most efficient method for each crop was refined to optimise collection of high-quality pollen, accounting for:
 - Differences between cultivars and growing environments
 - Time of day
 - Stage of flower development
 - Repeated harvests for *in-situ* techniques

2. Quality assessment

- Pollen quality (viability) was assessed in the laboratory using germination tests or rapid UV fluorescent microscope methods. These *in-vitro* quality tests were validated against *in-vivo* germination on the stigmas (female part of the flower) of compatible plants.

3. Handling and purification

- Pollen was dried and refined prior to storage. Typically, pollen was dried in a chamber with silica gel (for small batches) or in a large drying

room for at least 24hr at 20°C and then purified by passing the sample through a 300-micron sieve to remove contaminant particles e.g., anther debris and dirt.

- The combined effects of storage temperature (20°C, 4°C, -18°C, -80°C) and duration (multiple assessments between 24hr to 12 months) on dried and non-dried pollen samples were investigated.
- The effect of pollen rehydration on pollen germination was also examined. Desiccated and stored pollen samples were allowed to return to ambient temperature (20°C) and then rehydrated at 20°C above a water bath for different times (0, 15, 30, 60mins) prior to germination.

4. Delivery

- A range of pollen carriers, comprising commercially available products, organic and salt-based solutions and dry powders, were assessed for suitability. Suitability was determined by:
 - Laboratory (*in-vitro*) and/or *in-vivo* germination of pollen suspended in the carrier
 - Pollen delivery rates to the stigma surface in suspension
- Additional studies tested the effects of adding thickening agents to maintain pollen in suspension.



Flower collection, purification and pure pollen ready for delivery (photo credit: Prof Alistair Gracie, UTas)

(Title page photo: Cherry blossom, photo credit Alistair Gracie)

- Liquid pollen suspensions were applied using either hand-held electrostatic sprayer or modeller's airbrush. Powder based pollen suspensions were with a modified venturi gun. Pollen manually applied using a paint brush (dry) or needle (liquid) were used as controls.
- Preliminary trials investigated the effects of different pollen suspension concentrations.
- The efficacy of mechanical pollination was assessed in a series of trials in commercial crops from production seasons 2020/1 to 2023/4.
- Pollen recovered from each plant with the vacuum unit was comparable with hand harvesting (rubbing dried inflorescences on a screen), validating the approach.
- Pollen collected by the vacuum unit had a high level of purity. Purification was completed by passing the harvested pollen through a 300 micron screen.
- It was possible to harvest 25 grams of pollen per hour, per operator, using the vacuum method with an average viability of ca. 30%.

THE RESULTS: ONION SEED CROPS

Collection by vacuum

- A purpose designed, portable vacuum unit fitted with cyclone separators was most effective for pollen collection from harvested inflorescences (umbels) and for *in-situ* harvesting in the crop.
- Optimum vacuum head air velocity was 12 to 16km/hr.
- The best time of day to harvest pollen for yield and quality was midday
- Repeated harvests over a 10-day period at 24 – 48hr intervals optimised pollen yield per umbel(30mg of pure pollen per umbel, or ~0.1g/ plant).



Rapid Assessment of Pollen Quality

- The FCR test and the germination of pollen on agar plates combined with analine blue staining for definition of pollen tubes were effective methods for assessing pollen quality.
- Harvested pollen commenced germination within 2hrs of plating and completed germination within 6hrs.

Optimised pollen handling and storage

- Onion pollen dried over silica gel for 48hours at 20°C to 7% moisture content immediately following harvest was successfully held at -18°C or -80°C for 1 year without a detectable loss in viability.
- Rehydration of stored pollen for 30 minutes over a water bath at 20°C after thawing significantly improved pollen germination rates.

Delivery

- Both mechanical pollination systems (liquid or dry carriers) were effective in setting seed.
- The most effective liquid carriers were aqueous solutions of polyethylene glycol and calcium nitrate and the most effective dry carrier was lycopodium spores.
- Mechanical pollination using liquid carriers increased seed setting rates in field trials with open pollinated parent lines by up to 18% but, in a single trial, did not improve seed setting rates of an inbred male sterile line.
- Pollen delivery rates using mechanical devices were suboptimal to maximise seed set in the field trials and future studies need to focus on improving this component of the system.

THE RESULTS: SWEET CHERRY

Flower collection, drying and milling

- The sticky nature of sweet cherry pollen did not permit harvest using a vacuum method.
- Large-scale purification of raw pollen was achieved by harvesting flowers (by hand at present), drying at 20°C then gentle milling using a custom designed mill to release the pollen. The milling process was best done at low speed as high speed and vigorous milling caused significant damage to pollen rendering it unviable. The mill prototype was modified through iterative processes over two seasons to optimise pollen recovery whilst limiting damage to pollen.
- Pollen was then refined by passing through a series of sieves down to 125µm.
- The optimal stage to harvest flowers was just prior to opening (flowers had to be closed to ensure the pollen remained genetically pure and of high quality).
- Flowers could be harvested at an approximate rate of 6-8 kg per day.

Quality assessment

- The most reliable results for pollen viability assessment were obtained with agarose-sucrose medium using 15% sucrose at 20°C for 24hr. This was based on a range of incubation temperatures, durations, sucrose concentrations and other additives tested.
- Adding the surfactant Tween 80 to the medium reduced pollen clumping making it easier to count the level of germinated pollen. The addition of the surfactant did not reduce pollen viability.
- The robustness of the pollen differed among cultivars. For example, cultivars 'Van' and 'Lapin' were found to have highly robust pollen, whilst 'Tamara' was highly susceptible to milling damage.

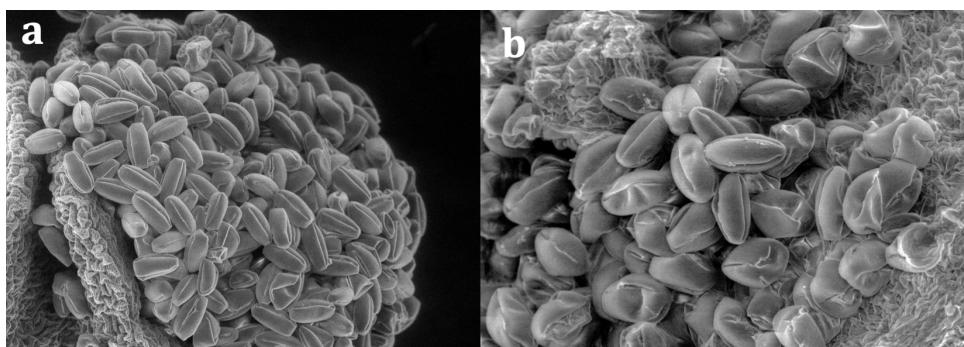
- Assessment of pollen quality across three commercial growing regions, demonstrated that both growing environment and cultivar affected the level of viable pollen and thus the quality of each batch of pollen needed to be assessed.

Handling and storage

- Dried pollen (7% moisture) could be stored at -18°C (standard household freezer) or -80°C for at least 12 months with little loss of viability.

Delivery

- Pollen was added to and suspended in a 15% sucrose carrier (at 100 mg of purified pollen in 100mL) just prior to application to flower.
- Pollen was applied twice during flowering (40-50% and 60-70% flower bloom) using a hand-held positive electro-spray instrument, which produced a fine and even mist in low volumes (i.e. 100 mL, Tpshe 2.5 AH Max 12 V).
- Trials were undertaken in commercial orchards with the goal of increasing fruit set above the standard insect-mediated levels in commercial settings.
- A 40% increase in yield per tree compared to commercial control in a low yielding orchard was recorded in season 2021/2 for supplementary pollination. Evaluation at other sites in the same season showed no yield improvement. Similarly in season 2022/3 no yield improvements were detected at the whole tree level.
- In season 2023/2024, refinements to the pollen:carrier ratios and spray volumes were increased to improve number of pollen grains per stigma and experiments were undertaken at the branch level with high replication (n=20) and individual flowers tagged (100 per branch). The following fruit set increases were recorded:
 - Kordia: 13.5% (orchard control) to 23% (supplemental mechanical pollination). This represents an increase of 70% more fruit.



Under the microscope:
Electron microscope images of A)- pre-mill and B)- 3rd mill pollen of cherry cv. Tamara

- Regina: 30% (orchard control) to 48% (supplemental mechanical pollination). This represents an increase of 60% more fruit.
- These results demonstrate success with the method. However, refinements are needed to optimise pollen delivery system that is underpinned by a greater understanding of the interaction between the pollen, pistil and suspension media used in order to provide a reliable approach.

Cordless hand-held electrostatic sprayer (TPSHKE) used to apply pollen (photo credit: Prof Alistair Gracie, UTas)



KEY RESULTS

- Scalable methods to collect and refine pollen have been developed for both crops:
 - **Onions:** a portable vacuum unit fitted with cyclone separators was constructed that made it possible to harvest 25 grams of pollen per hour, per operator, without a loss in pollen viability (ca. 30%) or pollen yield
 - **Sweet Cherry:** this required harvesting flowers that were then dried at 20°C, milled using a custom-built mill to release the pollen from anthers. Pollen viability mostly ranged from ca. 30 to 50%, depending on the cultivar and orchard.
- Robust, rapid methods to measure pollen viability were developed for both crops. Assessment of each batch of pollen is required as both cultivar and the growing environment influence pollen quality.
- Dried pollen (approx. 7% moisture) can be successfully stored in a standard household freezer (-20°C) for at least 12 months without a detectable loss in viability for both crops.
- Yield improvement from supplemental mechanical pollination delivery in commercial settings were recorded in some contexts:
 - **Onions:** up to 18% increase in seed yield was recorded for trials involving open pollinated lines but not for experiments involving male sterile parent lines for hybrid seed production.
 - **Sweet Cherry:** 60 to 70% increase in fruit set from supplemental mechanical pollination involving two spray applications (approx. 30% full bloom and 60% full bloom) in season 2023/4. This was from detailed, high-replication experiments at the branch level following refinements to the pollen delivery system. Earlier work (seasons 2021/2 and 2022/3) at the tree level found yield increases (up to 40%) in some contexts but was inconsistent.
- This program provided a strong framework for future development of commercial supplemental pollination.
- Greater understanding of the interaction between pollen/pistil and application media is required to develop robust and reliable delivery systems.

06.

Further reading

The outcomes of the research presented in these case studies establish the foundation for future integrated crop pollination methods aimed at improving pollination outcomes in protected cropping systems for various horticultural crops.

The insights gained from the extensive data collected over several seasons from a range of environments highlight the impact of protected covers and may help both growers and beekeepers the resources to make informed decisions about their practices and orchard designs.

FURTHER READING - ACADEMIC PUBLICATIONS

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FURTHER READING - GENERAL

Fat Bees Skinny Bees – a manual on honey bee nutrition for beekeepers

Securing pollination for productive agriculture: guidelines for effective pollinator management and stakeholder adoption

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