Pollination of Crops in Australia and New Zealand

by Mark Goodwin

Protecting Australia's pollination

The Pollination Program

HAL

Horticulture Australia

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Pollination of Crops in Australia and New Zealand

HAL Project HG09058

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Foreword

Compared with the other growing practices required to produce a crop, pollination is often the most poorly managed. For many crops this places limitations on production. This Pollination Manual provides growers with a range of tools that can be used to assess the levels of pollination their crops receive. It also provides growers and beekeepers with methods that can be used to better manage, and optimize, pollination. It also discusses how to protect pollinators introduced to orchards.

This project is part of the Pollination Program – a jointly funded partnership with the Rural Industries Research and Development Corporation (RIRDC), Horticulture Australia Limited (HAL) and the Australian Government Department of Agriculture, Fisheries and Forestry. The Pollination Program is managed by RIRDC and aims to secure the pollination of Australia's horticultural and agricultural crops into the future on a sustainable and profitable basis. Research and development in this program is conducted to raise awareness that will help protect pollination in Australia.

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Chapter 1
Introduction

Pollination is the movement of pollen from the anthers of a flower to the stigma of the same or a different flower. It is one of the most important parts of the economic production of many crops. However, it is often the most poorly understood and least likely to be optimized. In some cases, it is not managed at all and growers just hope there will be enough bees or other insects in the vicinity of the crop to ensure that pollination happens. Even if beehives are introduced for pollination, their performance may not be optimized and the levels of pollination may not be measured. For many crops, obtaining optimized and reliable pollination may be one of the best ways of improving the economics of the production of the crop.

The aim of this manual is to provide growers, beekeepers, and pollination specialists in Australia and New Zealand with the information necessary to optimize the pollination of insect-pollinated commercial crops. The manual begins with a description of the process of pollination, including a summary of the insect species involved and information on how to assess pollination. Honey bee biology and behaviour are described and how to manage them for pollination. Orchard management strategies to protect honey bees are outlined as well as specific issues related to pollination of a range of crops.

Pollination practices in Australia and New Zealand differ in many aspects. In New Zealand almost all crops needing insect pollination have honey bees introduced, with the occasional exception of some very attractive crops like white clover. In New Zealand bumble bees are also managed for pollination, and artificial pollination is common practice. Although many Australian growers use managed hives in the same way New Zealand growers do, some depend in part, or fully, on the large number of feral colonies present in Australia.

The process of pollination

Flower parts

To gain the best understanding of the information provided in this manual, it is necessary to have an understanding of the names of different parts of flowers, their appearance and function.

The flower parts are (Figure 1):

- Sepals enclose the flower buds. They usually open and fold back so the petals can open.
- Petals enclose the reproductive structures. In insect-pollinated flowers, these are usually coloured and conspicuous to attract insect visitors. As some of the colours are in the ultraviolet region, which we cannot see but insects can, many flowers look different to insects than they do to us. The petals usually have to open before pollination can occur.
- Anthers produce the pollen and are usually at the end of a filament. An anther and its filament are referred to as a stamen. The anthers must open or split to release the pollen. A flower may have hundreds of anthers contains many million pollen grains.

- → Pollen grains contain the male genetic material that must be moved to the female reproductive structures.
- → Stigmas, which are at the end of a style (collectively called the pistil), are the female structures on which the pollen must be deposited. Depending on the plant species, a flower may have a single stigma or many.
- → The ovary is normally at the base of a flower and connects directly with the style. Ovaries can contain from one to more than 1000 ovules.
- → Ovules are the female structures that must be fertilized to produce seeds.
- → Nectaries produce nectar to attract animal flower visitors. These are usually situated at the base of the petals.

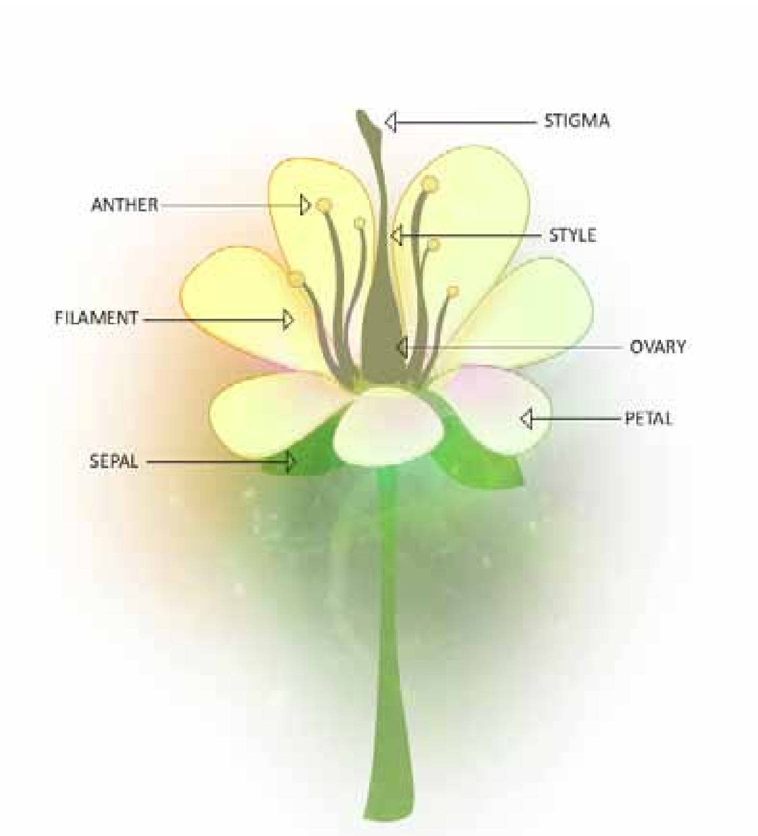

Figure 1. Diagram of a generic insect-pollinated flower.

Pollination

Seeds and fruit are expensive for a plant to produce, while few resources are required to produce a pollen grain. For this reason, plants usually produce relatively few ovules and many pollen grains. There may be millions of pollen grains produced for each ovule.

To produce a seed, pollen must be moved from an anther to the stigma of a compatible flower that is capable of setting seed. To start the process, the anthers must open or split to expose the pollen (dehiscence), and the pollen must be transported to a stigma while it is still alive and receptive. Depending on the plant species, pollen grains and stigma may lose viability in less than a day or remain viable for more than a week.

The pollen may have to be moved a few millimetres or many metres. Once on the stigma the pollen grain must germinate and the resulting pollen tube must break through the pollen grain wall (germination), grow through the stigmatic tissue, and down through the style to reach the ovule. The genetic material in the pollen tube then combines with an ovule to create a seed (fertilization).

For pollination to occur, all these things must happen. For the production of a commercial crop, they need to happen reliably and often.

Over millions of years, plants have evolved complex relationships with the agents that move the pollen to their stigma. For most plants, these systems work sufficiently well to ensure enough seeds are produced for the survival of the species. However, the pollination of plants grown commercially can be much more difficult. Often, humans have produced new plant varieties without reference to their pollination systems. This can be seen in hybrid seed production in radishes. For a normal radish flower, pollen has to be moved only a few millimetres to reach a stigma in the same flower. However, to produce hybrid radish seed, the pollen may have to be moved several metres to another plant. Plants are also often now grown in places where the pollinators with which they have evolved are not present. To complicate matters further, plants are also now forced to grow in a different manner from how they would grow in their natural environments. For example, kiwifruit is a vine that climbs trees in its natural environment in forests in China; however, commercially it is grown on structures that are less than 2 m tall.

In their natural environment plants often grow in relatively small patches or as isolated plants. There are usually sufficient pollinators in these natural ecosystems to ensure they are pollinated. However, commercial crops are usually grown in large monocultures, sometimes kilometres in extent. In such situations there are usually too few natural pollinators in the vicinity of the crop to ensure that the very large numbers of flowers that are present at the same time are pollinated. Other crops are grown under netting or in glasshouses, which may exclude pollinators.

In their natural ecosystems, the plants may not need to have every ovule fertilized to produce enough seeds to ensure survival of the species. However, we often now require these plants to have much higher seed set to produce a commercially viable crop.

For these reasons, pollination of plants grown commercially can be much more difficult than pollinating the same plants when they are part of their native ecosystems.

Self and cross pollination

Plant breeding systems form two basic patterns, out-crossing and self pollination.

1. Self pollination is where a flower produces pollen and fertilizes itself or other flowers on the same plant. An example of this can be seen in the garden pea which is completely self fertile. The pollen is placed on the stigma before the flower opens. Some self-fertile plants may still need an agent to move pollen from the anthers to the stigma, e.g. tomatoes.

   Self pollination is often the aim of breeding programs, as it reduces pollination problems.

2. Out-crossing is the opposite of self pollination. The plant has a mechanism to prevent or decrease the chance that self pollination will occur and to increase the chance that pollen will come from another plant. There are a number of mechanisms plants use to achieve this:
   - Male and female flowers on different parts of a plant, e.g. chestnuts
   - Male and female flowers on different plants e.g. kiwifruit
   - Flowers that are female at one time and male at a different time e.g. avocado
   - Flowers that are male and female at the same time but the pollen is unable to pollinate flowers on the same plant e.g. white clover
   - Flowers that are male and female at the same time but the pollen is unable to pollinate flowers on the same variety e.g. nashi.

Natural selection of plants has favoured the transfer of genetic material between different plants (out-crossing) to maximize the genetic variation within a plant species. This increases a species' ability to cope with variations in its environment. Although plants requiring out-crossing are the most common, many plants are completely self fertile.

As well as plants that are completely self fertile and plants that require out-crossing, some plants are partly self fertile. They can produce seeds by themselves but will produce more if they are cross pollinated, e.g. strawberries.

Vectors for pollen movement

There are a large variety of vectors in natural ecosystems that carry pollen between flowers, including wind, water, insects, birds, bats, small marsupials, and reptiles. However, the following discussion only deals with the common vectors that are significant for commercial crops in New Zealand and Australia. These are wind, gravity, birds, flies, bees and humans.

Wind

Many plants have evolved to use wind to carry their pollen from an anther to a stigma. The most well-known wind-pollinated plants are the grasses, which include wheat, barley, maize and rice. Gymnosperms (cone-bearing trees, conifers) are also wind pollinated. Allergies to the pollen of wind-pollinated plants are the cause of hay fever in many people. Pine trees produce so much pollen that it can look like smoke in pine plantations and can be seen accumulating along the sides of roads.

Wind-pollinated plants typically share a range of basic characteristics. These are:

- → Light pollen that can be blown large distances
- → Anthers that are held higher than the stigma so the pollen can be blown further
- → Large stigma to catch pollen out of an airstream
- → Inconspicuous flowers
- → Flowers that are unscented
- → Flowers that do not produce nectar.

Maize plants (Figure 2) are good examples of wind-pollinated plants. The male flowers are produced at the top of the plant where the pollen produced has the greatest chance of being blown by the wind. The petals are unscented and inconspicuous because they do not need to attract insects. The female flowers, attached to what will later be the corn cob, are lower down and have inconspicuous petals without scent or nectar.

The anthers produce copious amounts of pollen because few of the pollen grains will reach a stigma. The pollen can be usually seen if the male flowers are knocked (Figure 3).

The large number of stigma of the female flowers are very long and have small branches (Figure 4) on them so they have a large surface area to maximize the chance they will intercept a pollen grain floating past.

Wind-pollinated plants will occasionally be visited by insects collecting pollen. Honey bees collect pollen from maize flowers and accumulations of pine pollen when they cannot obtain pollen from other sources. However, this does not aid pollination of these plants.

Figure 2. Maize, showing male flowers at the top of the plant and long stigma attached to what will develop into a corn cob.

Figure 3. Anthers on a maize flower liberating pollen.

Figure 4. Stigmas on a maize flower.

Gravity

Some self-fertile flowers have anthers that protrude above the stigma so that pollen can fall off the anthers and land on the stigma. Tomatoes use this system. The flowers need to be shaken by the wind or an insect for the pollen to fall onto the stigma.

Animals

Animal-pollinated flowers are usually conspicuous and often large. They are usually scented, produce nectar, and produce pollen grains that are heavy and at times sticky so they will stick to animal flower visitors.

Although many commercial crops are completely wind pollinated and others animal pollinated, some appear to be both wind pollinated and insect pollinated. Kiwifruit are an example of this.

Kiwifruit have large conspicuously coloured flowers that produce scent. Female flowers also produce non viable pollen to attract insects to visit them. These are characteristics of insect-pollinated flowers. However, the flowers have many of the attributes of a wind-pollinated flower as well. The male vines produce large numbers of flowers with copious amounts of pollen. The flowers hang downwards to allow the pollen to fall out of the flower. In their natural environment, the vines climb trees so when the pollen is released into the air it can travel large distances. The pollen is dry and carried in the air to such an extent that much of the pollination carried out in Italy is by orchardists blowing pollen from male to female flowers with large fans. The stigma of the female flowers are large and fleshy, which increases their ability to collect pollen out of the airstream.

Birds

Birds visit flowers of a range of commercial crops to collect nectar and hence carry out some pollination (Figure 5). They tend to be less efficient than bees because although they carry pollen on their bodies they do not actively collect pollen. They will usually move pollen over much larger distances than insects do.

Some flowers are, however, designed to be pollinated by birds, e.g. feijoas. Feijoa flowers have sepals with a high sugar content. Birds pull off the petals and in doing so shake pollen onto the stigma and also transfer it to other flowers.

Figure 5. A silvereye drinking nectar from a peach flower.

Flies

Flies (Figure 6) are important pollinators of some commercial crops such as onions, and contribute to the pollination of many crops as they are attracted to the same flower rewards to which bees are attracted. Nashi (Asian pears) appear to have evolved to use flies. Although they have similar flowers to European pears, nashi flowers smell like rotten meat, which attracts flies.

Some species of hover flies (Syrphid flies) (Figure 7) look very much like honey bees and are often mistaken for them. They visit flowers to collect both nectar and pollen. They can be distinguished from honey bees by the number of wings they have. Flies have two wings and bees have four. Hoverflies also do not have long antennae like honey bees. They forage differently as well. Honey bees only stay for short periods of time on each flower, usually only a few seconds, whereas hoverflies will sit on flowers for relatively long periods of time.

Bees

Many bee species contribute to pollination worldwide. Of these only honey bees, leaf cutter bees, alkali bees, and bumble bees are managed to any extent for pollination. Most managed insect pollination is carried out by honey bees (Figure 8), while the other bees are usually used only for specific crops such as tomatoes (bumble bees) and alfalfa (alkali bees and leaf cutter bees), where they are more efficient pollinators than honey bees. In Australia, particularly in the northern areas, stingless bees (Meliponini) are used on a commercial to semi-commercial basis for the pollination of crops such as macadamia.

Figure 6. A fly collecting nectar from an almond flower.

Figure 7. A hover fly, which looks like a honey bee, visiting a plum flower.

Figure 8. Bee on a cherry flower.

Other animals

There are a range of other animals that visit flowers and help with pollination, including moths, reptiles and bats. They are usually not in numbers high enough to contribute significantly to the pollination commercial crops. Thrips are frequently seen on flowers but they do not usually contribute much to the pollination of commercial crops and may be detrimental at times, as they can damage flowers and feed on the pollen.

Free and managed pollinators

Pollinators fall into two categories; those that can be managed and those that cannot. Those that cannot be managed, e.g. feral honey bees, native solitary bee species, stingless bees (in Australia), birds and flies, often contribute to the pollination of commercial crops and in some case may make major contributions. Their value is limited because their presence cannot usually be guaranteed.

If growers do not know whether this free pollination service is going to happen, or to what extent, before flowering starts they will probably have to still introduce enough managed pollinators to pollinate their crop fully, if they do not want to risk pollination losses. The presence of the free pollination service often therefore cannot be exploited to any extent.

Pollination and weather

Adverse weather can have a major effect on pollination. Insects are usually less active in cold weather and in strong winds, and may stop foraging entirely during rain. Different species respond differently to adverse weather, e.g. bumble bees will fly at lower temperatures than honey bees but honey bees are better able to cope with very hot temperatures than bumble bees.

Breaks in foraging caused by poor weather are a particular problem for pollination. Even a single day of rain stopping insects flying can adversely affect pollination and production of plants that need high fruit set. Flowers that are open only for a single day, e.g. radish, are particularly susceptible to a break in foraging.

Low temperatures can negatively affect flowers as well. They can reduce nectar production, e.g. clover[1], delay flower opening and pollen liberation e.g. kiwifruit, and the synchrony between male and female flowers, e.g. avocado[2]. Low temperatures during flower development can reduce pollen viability, e.g. kiwifruit[3] and decrease the length that pollen tubes grow down the stigma[4].

High temperatures can also affect pollination. They can reduce the length of stigma viability e.g. sweet cherries, and reduce self fertility, e.g. apricot[5].

Unfortunately, little can be done to overcome problems with weather other than to grow crops within their normal climatic range, or grow them under cover, ensure pollination is optimized when conditions are suitable, and for some crops, carry out artificial pollination.

Chapter 2
Assessing pollination

Assessing the amount of pollination a crop is receiving can be a very valuable management tool to indicate whether pollination is optimized or can be improved. It is common for growers to know the production they receive from their crop in terms of kg, trays, or boxes per hectare. Although this will be related to the amount of pollination, it is also heavily influenced by the numbers of plants, flowers, and the numbers of fruit or seeds lost through thinning, damage or disease.

Pollination problems include reduced production and small or misshapen fruit. Assessing the degree of pollination and identifying problems can be difficult because other factors can also cause these symptoms. For example, lower than expected yield can be due to low flower numbers, disease, nutrition, or water. Likewise, misshapen fruit might be a sign of poor pollination or of a disease affecting the ovary. Coming to the wrong conclusion about a pollination problem can be both expensive and frustrating.

It is very expensive and frustrating to try to fix a pollination problem that does not exist.

The most accurate way to assess pollination is by determining the percentage of flowers that set seed and/or the number of seeds produced by a flower. There are some simple methods of doing this.

The first step is to mark flowers. They need to be marked in such a way that the fruit or seed heads they produce can be found close to harvest time.

Coloured wool can be used for large flowers like kiwifruit (Figure 9). The wool needs to be tied with a double knot, as birds like to collect wool for their nests. The wool around the stem should be loose enough so that it doesn't restrict any enlargement of the stem as the fruit or seeds develop and tight enough so that it doesn't fall off with the petals. The wool needs to be brightly coloured so that it can be easily located at harvest. Brightly coloured acrylic wool works well. Black, brown and green need to be avoided for most crops as they are too difficult to find again.

Figure 9. Kiwifruit flowers with short pieces of coloured wool tied around their stems.

Sections of coloured drinking straws can be used for smaller flowers like apple and clover flowers (Figure 10). Take a drinking straw and with a small pair of scissors cut up its length. It can then be cut into short sections, which can then be opened

Figure 10. Apple flowers marked with a section of drinking straw.

and clipped around the stem of a flower. The sections will hold firmly and expand as the stem of the flower expands.

Alternatively, small flowers can be marked with jewellers' tags and very small flowers (e.g. radish flowers) with cotton.

The plant and row will probably need to be marked in some way as well so the tags can be found again.

Use brightly coloured tags so they can be found at harvest.

The number of flowers that need to be marked will depend on the percentage of flowers that normally set seed and the number of seeds normally produced per flower. Where there is normally greater than 60% seed or fruit set (e.g. blueberries or kiwifruit), probably only 50 flowers will need to be marked. However, if fruit set is very low (e.g. 0.2% in the case of avocados), several thousand flowers will need to be marked.

The fruit/seed head set can be described as a percentage.

$$\text{Percentage fruit/seed set} = \frac{\text{number of flowers setting fruit/seeds}}{\text{number of flowers marked}} \times 100$$

Where a flower, or flower head, produces more than one seed (e.g. clover, apples, blueberries), more information on pollination can be derived by extracting and counting the seeds.

There are several methods of removing seeds from fruit to count them. Some fruit can be peeled, cooked or processed in a food processor with blunt blades and sieved to extract the seeds. Another possibility is to allow the fruit to ripen and become soft so the flesh of the fruit can be sorted through and the seeds counted. Fruit can also be peeled and placed in a container covered with water with a few drops of pectianase. If the containers are then placed in a warm location the pectianase may dissolve the flesh so it can be washed through a sieve to extract the seeds. The method chosen will probably be a matter of trial and error.

Potential pollination rates

When assessing the rate of pollination in a crop, it is useful to know the maximum potential fruit or seed set if the crop was fully pollinated. This can be determined by hand pollinating flowers. Using hand pollination to measure fruit set can be problematic for some plant species. If the plant is capable of having a high fruit set, e.g. kiwifruit, berries and clover, hand pollination will provide a reliable measure of maximum potential fruit/seed set (Figure 11). It is less reliable in assessing potential fruit set in plants that normally have low set e.g. avocado. Normal fruit set on avocado trees is around 0.1%. However when a few avocado flowers are hand pollinated, it is possible to achieve higher than 5% fruit set6. It is unlikely that if all the flowers on an avocado tree were hand pollinated, the fruit set would be that high.

Hand pollination may provide useful information on potential seed number in fruit that have more than one seed, as this is much less likely to be affected by the total crop load than fruit set.

Most crops can be hand pollinated using a fine paintbrush to brush anthers to collect pollen and then brushing the pollen on to a stigma. It is important to check that the anthers are liberating pollen when the hand pollination is carried out. This can be done in several ways. Perhaps the easiest method is to observe any honey bees visiting flowers to see if they are collecting pollen. Honey bees collecting pollen can be recognized by the balls of pollen they are carrying in their pollen baskets (Figure 12).

A second method is to use a hand lens to observe the anthers. Individual pollen grains cannot usually be seen with a hand lens; however, accumulations of pollen can be seen in many plant species.

As many species are not self fertile, the pollen needs to come from another plant or in some cases a particular plant. Hand pollination needs to occur while the stigma is still viable, and this timing will vary between different plant species.

Another method of carrying out hand pollination is to pick flowers producing pollen and rub the anther onto the stigma of the flower to be pollinated. It is better to use a new flower for each hand pollination.

Figure 11. Hand pollinating a kiwifruit flower.

Figure 12. Honey bee carrying pollen in its pollen baskets.

Where and when to assess pollination

Before carrying out pollination assessments, it is important to have a clear idea of the questions they will try to answer. The type of questions that can be answered with pollination assessments are:

- The overall rate of pollination
- The pollination rates at different times during the flowering season
- Pollination rates at different places in the crop
- The effect of pollinizer distributions
- The effect of beehive placements on pollination
- The effect of any artificial pollination carried out
- Variations in pollination between seasons
- The effect of adverse weather
- The effect of any spray applications that may adversely affect pollination.

Assessing pollination during the flowering season

There are several pollination assessments that can be carried out during the flowering season when there is still time to make changes to pollination systems to avoid crop losses.

Counting pollinators

A method of assessing pollination during flowering is to estimate the number of bees visiting flowers on the crop. There are published recommendations on the number of bees that should be seen visiting some crops to ensure good pollination. e.g. 25 bees per 10,000 white clover flowers is reported to give 85% seed set[7], 6–7 bees per tree for pears[8], 12–14 bees per tree for apples[8], and 10 bees per avocado tree[9].

These recommendations need to be treated with considerable caution, as any bee count must include the number of flowers on the tree or crop e.g. the recommendation for white clover.

It is difficult, however, to collect meaningful bee counts because there is a wide range of factors that influence how many honey bees are observed visiting flowers, including the time of day the counts are made. For example, a count of bees visiting a kiwifruit block might not find any bees at 8 am, 30 bees per 1000 flowers at 11 am, and only 2 bees per 1000 flowers at 1 pm.

The first step in counting flowers is to mark an area of the crop with about 1000 flowers. Walk slowly through the area on a sunny day and count the number of bees visiting flowers. If this is done hourly, the time of peak honey bee foraging can be determined.

Bee activity can then be checked throughout the season. When this was carried out with radishes, it was found that the density of bees on flowers decreased throughout the flowering season. As soon as the decline was observed, the grower could have introduced more colonies.

A count of bee densities on flowers at the same time of day but in different parts of a crop may indicate whether pollination will be even throughout the crop, or whether more hives need to be introduced in specific locations.

An alternative method of counting bees is to use areas of a crop or trees that have similar flower numbers without actually counting the flowers. Although actual density of bees per flowers cannot be determined, it will be possible to compare densities in these areas.

Counting pollen grains

A very effective method of assessing pollination during the flowering period is to cut stigma of flowers with very fine scissors or a scalpel and mount them on a microscope slide. The number of pollen grains on the stigma can then be counted.

Chapter 3

Managed bee species

Various bee species in Australia and New Zealand contribute to pollination. Some of these bees are managed, such as honey bees, bumble bees, leafcutter bees, and alkali bees and several species of stingless bees. Other bee species also contribute to pollination, but are not currently managed to any extent. This includes a small group of native solitary bee species in New Zealand, a very much larger group in Australia, stingless bees in Australia, feral bumble bees in New Zealand and feral honey bees in both Australia and New Zealand.

Although unmanaged bees will at times make a significant contribution to pollination, their value is limited because their presence cannot usually be guaranteed. Because their pollination cannot be guaranteed, or in most cases even measured, growers usually need to introduce honey bees at the same stocking rates that they would have done if the unmanaged bees were not present.

Honey bees

Honey bees are the most important insect pollinators of cultivated crops worldwide. There are a number of species. The Western honey bee (*Apis mellifera*) is the most commonly managed bee for pollination and honey production in temperate countries including Australia and New Zealand. The Asian bee (*Apis cerana*) is managed in some tropical countries but they usually produce smaller colonies and they are generally more difficult to manage, depending on the subspecies. The Asian bee is not present in New Zealand but was found in Cairns, Australia in 2007. Through aggressive swarming it has spread from its site of introduction. They are likely to spread to much of the wetter areas of Queensland and into New South Wales. How far south they will be able to survive is unknown. They are likely to develop into a significant feral (wild) population. It is not possible to determine the likely impact of the Asian bee incursion on pollination in Australia at this stage.

While some insects visit the flowers of only a small number of plant species, honey bees are generalist foragers. They will visit almost any flower from which they can harvest nectar or pollen. Honey bees can be delivered to a crop when required, will start foraging almost immediately and can be removed when required (Figure 13).

Because they produce large colonies that are present throughout the year, honey bees can usually be sourced irrespective of when a crop flowers. There are also various management options available to influence their flower visiting behaviour to improve their pollinating activities.

Figure 13. Honey bee colonies introduced for carrot pollination.

Unlike the other managed insect pollinators, honey bees have uses other than the pollination services they provide. Beekeepers can harvest and sell honey, pollen, wax, royal jelly, venom and propolis. The bees themselves can also be harvested and sold. A hive may be used for the pollination of more than one crop. In New Zealand, a beehive might be used to pollinate apples, then avocados and finally kiwifruit. After that, it will collect a honey crop. In the autumn, a kilogram of bees might be removed from the hive and exported. Beekeepers therefore do not usually have to recoup the complete yearly costs of managing honey bee colonies from the return they receive from supplying them for pollination of a single crop. This makes honey bee colonies more economic to use for pollination than other managed pollinators, where the pollination fee must cover the complete yearly cost of managing them.

Bumble bees

Four species of bumble bee were brought to New Zealand from England, in 1885 and 1906[10] (Figure 14).

The species are:

- The large earth bumble bee (*Bombus terrestris*)
- The large garden bumble bee (*Bombus ruderatus*)
- The small garden bumble bees (*Bombus hortorum*)
- The short haired bumble bee (*Bombus subterraneous*).

Figure 14. A queen bumble bee (*Bombus terrestris*) visiting an almond flower.

The large earth bumble bee (*Bombus terrestris*) was accidently introduced into Tasmania in 1992. Bumble bees have not been reported to have established on mainland Australia.
Several of the bumble bee species have become very common in New Zealand and can be observed in most gardens during the summer. They are frequent visitors to many flowering crops in New Zealand.

Lifecycle

New bumble bee queens are produced and mated in the autumn. They overwinter alone and start nests in the spring. The nests are usually built in the ground, often in abandoned mouse and rat nests. The queen builds the first wax cells, forages, lays eggs, feeds the developing larvae, and keeps the nest warm. As the queen has to do all the work initially, the first workers produced are small and poorly fed. When there are enough workers, the queen stays in the nest while the workers forage and look after the developing larvae. When mature, a colony may have up to 200 bees. New queens and male bees are produced in the autumn, and the colony, workers and male bees then die leaving the new queens to over winter.

Because of their life cycle, feral (unmanaged) colonies are not present in the winter. In the spring, they only have a single queen and do not reach their maximum population and foraging force until early summer after many commercial crops have finished flowering.

Figure 15. Commercially reared bumble bee colony.

Bumble bees forage for both nectar and pollen as do honey bees. They will visit most of the flowers that honey bees visit. Because the colonies are much smaller than honey bee colonies, they collect much less pollen. They collect even less nectar because, unlike honey bees, they do not store it during the winter. A strong bumble bee colony will therefore visit only a small number of flowers compared with a strong honey bee colony.

Bombus terrestris colonies are produced commercially in many countries including New Zealand (Figure 15). This allows colonies to be produced through the year and to be moved into a crop when needed.

Advantages/disadvantages

Bumble bees have several attributes that make them better pollinators than honey bees:

- They will forage in more marginal conditions than honey bees so are less affected by adverse weather.
- Bumble bees, particularly the larger ones like *B. terrestris*, are more likely to touch the stigma of flowers.
- They have a behavioural trait called buzz pollination. Bumble bees vibrate their wing muscles while visiting flowers, which increases the amount of pollen they can extract from some plant species.
- They more easily adapt to foraging in glasshouses and tunnel houses.
- Some bumble bee species have long tongues and can reach the nectar of flowers that honey bees cannot easily reach e.g. red clover.
- They are less aggressive than honey bees.

Bumble bees also have disadvantages compared with honey bees:

- Their colonies are small, often fewer than 200 bumble bees, compared with up to 60,000 honey bee workers in a colony.

- → They are relatively expensive. This is because honey bees are generally easier to manage than bumble bees, and will collect a crop of honey, which in part subsidises the cost of providing them for pollination.

Large numbers of artificially reared bumble bee colonies are used for pollination in New Zealand. They are almost exclusively used for glasshouse pollination, mainly for tomatoes. They are not often used for other crops because, despite being better pollinators than honey bees, they are usually too expensive.

Although bumble bees have been shown to be efficient pollinators of a range of crops, their use is generally restricted to the pollination of high value crops like glasshouse tomatoes, because of their high cost.

Purchasing bumble bee colonies

Bumble bee colonies can be purchased in New Zealand. Once ordered they are delivered by courier, with instructions for their care. The nests contain a queen and about 200 workers. They will survive for up to 3 months and can be sourced at any time of the year.

Feral bumble bee colonies

It is possible to encourage feral bumble bee queens to establish nests near crops. Bumble bees will occupy artificial hives that are placed in appropriate locations near a crop. These usually consist of wooden or concrete boxes placed on the surface of the ground or slightly below ground, depending on the bumble species of interest. However, only a proportion of nesting boxes will be occupied each year[11].

Because bumble bees store only relatively small amounts of nectar compared with honey bees, they must forage on most days. In many parts of New Zealand there are a large enough number of species of flowering plants to ensure that they can find food throughout the spring, summer and autumn. If there is not a good supply of flowers throughout this time, planting species that flower at the appropriate times may increase the success of feral colonies.

Leafcutter bees

Leafcutter bees (Figure 16) are managed in North America for lucerne pollination, as they are better pollinators of lucerne than honey bees. They were introduced into New Zealand in 1971 and into Australia in 1987. They did not prove successful in New Zealand, possibly because the weather was not suitable. In 1984, the population of leafcutter bees was estimated to be about 5 million. In 2009 it was estimated that there were fewer than 100,000[10]. Their success in Australia has been limited, although weather conditions in Australia are more suitable than in New Zealand.

Figure 16. A leafcutter bee.

Lifecycle

Leafcutter bees overwinter as pupae inside their cells. As temperatures rise in the spring, they emerge and mate. The females then build tunnels which they line with cut pieces of leaf — thus their name. They lay eggs in these cells and supply the developing larvae with nectar and pollen. The larva pupates and then either emerges as an adult, if it is early in the season, or stays as a pupa and overwinters if it is late in the season.

A full description of how to manage leafcutter bees can be found in "Leafcutting bee life history allocation details and management techniques"[12].

Alkali bees

Like the leafcutter bee, the alkali bee is important for lucerne pollination. Alkali bees were introduced to New Zealand in 1971 but they are not present in Australia. They are a ground-nesting bee that prefer soil with a high salt concentration. They are of similar size to honey bees. They emerge from the nesting site in early summer, mate and form new tunnels in which they rear new bees. They collect pollen and nectar to feed the developing larvae. The bees forage from December to March, so are unavailable to crops that flower early in the spring, but their life cycle does coincide with lucerne flowering.

Alkali bees will inhabit man-made nest sites although the nest site may need to be protected with a roof in high rainfall areas, as rain can drown nests.

There have not been any recent surveys of the alkali bee populations in New Zealand so their current distribution, numbers and importance for pollination are unknown. Alkali bees have been observed in Canterbury, Central Otago, Marlborough in the South Island and Manunui in the North Island. There is a viable population in a man-made site in the Wairau Valley[13].

A full description on how to establish alkali bees at a site and manage them can be found in "Alkali bee establish and maintenance for lucerne pollination"[14].

Native New Zealand bees

There are many native solitary bee species in New Zealand (Figure 17). Although each female bee builds a separate nest, which consists of a hole in a bank or the ground, there are usually a large number of other individuals nesting at the same site so it looks like a colony. However, none of the nesting holes joins together and the females all act as individuals. The bees overwinter as pupa in the nesting holes and emerge in the spring to mate. The females excavate new holes in which they lay eggs. They then forage for pollen and nectar to provision the cells. Their life cycle ends in late summer when the adult females die.

Solitary bees may contribute to the pollination of a crop because of the proximity of their nesting sites. There is the potential for developing some of the bee species as managed pollinators in the future.

Figure 17. A New Zealand native solitary bee (*Leioproctus* species) on an onion flower.

Native Australian bees

There are estimated to be around 3000 species of Australian native bees in five families. There are many different social forms, from fully social bees (about 20 species of stingless bees) through to solitary bees (Figure 18). The stingless bees are found throughout the northern parts of Australia in the desert areas (above a line from about Perth to southern Queensland) and coastal areas to a little south of Sydney. They live in nests made of wax, bitumen and propolis and have a social structure similar to honey bee colonies, consisting of a queen, workers and drones. Their nests persist for many years. The life histories of all the species are not well-known; however, it is known that they mass provision their young rather than progressively feed them. The vast bulk of Australian species are solitary, with a life history similar to that outlined above for New Zealand solitary bees. In New Zealand the predominant genus of native bees is *Leioproctus*, with about

Figure 18. Male Lasioglossum (Chilalictus) species on a sweet pea flower.

20 species. In Australia there are about 300 species in this genus. Other Australia native bees groups include leaf cutter bees, carpenter bees, cuckoo bees, sugar bag bees, stingless bees, sweat bees and polyester bees.

Stingless bees (sugar bag bees) are generalist pollinators. They gather pollen and pack it into pollen-baskets on their hind legs like European honey bees. They visit a broad range of flowering plants, including crops, and are known to be useful in pollination of various crops, including macadamias, cucurbits, mangos, nuts and cashews as well benefiting a wide range of crops. There are two species that are managed in hives and are used for commercial and semi-commercial pollination services (particularly in Queensland).

Blue banded bees have proven effective pollinators of tomatoes in glasshouses and work is currently being undertaken to enable commercial use of these bees in glasshouses.

Chapter 4

Honey bee biology and behaviour

Western honey bees are managed in almost all countries. They are kept in areas where their hives are covered by snow in the winter and in high temperatures in the tropics. This ability to survive extremes of temperature is a function of the way the bees manage the internal temperature of their hive and their food reserves, rather than because of human assistance. Because of this, they can be imported and used for pollination almost anywhere a crop is grown. Most honey bee colonies are managed, but they also live as feral colonies.

Feral honey bee colonies

Feral honey bee colonies live in cavities in trees, caves, buildings, and other man-made structures. They are usually smaller than managed colonies, swarm more often, and are often more aggressive. Parts of Australia have very high densities of feral honey bee colonies[15]. Even before the varroa bee mite killed most of the feral colonies in other countries, including New Zealand, Australia had one of the highest concentrations of feral colonies in the world. Feral colonies can be long lived, but the presence of the varroa bee mite in New Zealand has meant that feral colonies survive for only one or two years. The small hive beetle, which is present in Australia, also kills feral colonies; however, its effects are less than those of varroa.

Feral colonies can add significantly to pollination if there are enough of them present but there are problems associated with relying on them for pollination. It is difficult to assess whether there are enough feral colonies in the vicinity to pollinate a crop until after the crop has started flowering. At that stage, it may be too late to introduce managed colonies if there are too few feral colonies. Feral colonies also cannot be manipulated to improve their pollination in the way that managed colonies can. Better and more reliable pollination can usually be achieved by introducing managed colonies.

Better and more reliable pollination can usually be achieved by introducing managed honey bee colonies rather than relying on feral honey bee colonies.

Beehives

A beehive (Figure 19a) is the man-made structure in which a managed honey bee colony lives. It usually consists of a floorboard that the boxes sit on, one or more boxes and a hive lid. There are usually between six and 11 frames (Figure 19b) inside each box. The frames carry the honey comb, developing larvae, pollen, and honey stores. Beehives will also often contain a feeder so that the beekeeper can feed the colony sugar syrup if they do not have enough stored honey.

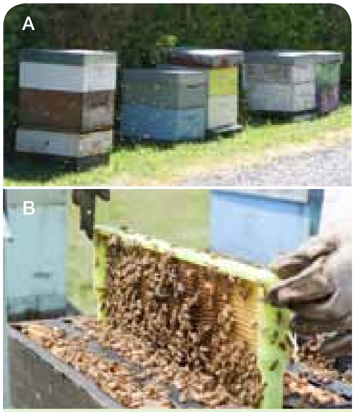

Figure 19. (a) Beehives; (b) Removing a frame from a beehive.

Honey bee castes

A honey bee colony usually consists of three castes of bees — a queen (Figure 20), drones (Figure 22) and many thousands of workers (Figure 23).

Queen

Queen bees are reproductive females. There is usually only one queen in a hive. She will often live for two or three years, although many beekeepers replace queens yearly. The queen lays all the eggs needed to produce the other castes of bees. She can lay over 1000 eggs in a day. The queen will usually only leave the hive on her mating flight, if the colony swarms, and then finally when she dies. If a queen dies and the colony or beekeeper cannot replace her, the colony will also eventually die.

Figure 20. Honey bee queen. She looks like a worker bee but has a much longer abdomen.

Beekeepers replace queens by removing or killing the old queen and either releasing a new queen from a cage or installing a queen cell containing a queen that is about to emerge. The new queen will start laying soon after she is released. If the old queen is replaced with a new queen, there should be little interruption with egg laying. However, if the old queen is replaced with a queen cell, it may take several weeks for the queen to emerge, mate and start laying, which will slow down the development of the hive. In this case there may be a period of time when there are no larvae in the colony, which will reduce the amount of pollen the colony collects.

For this reason, beekeepers should not replace queens with queen cells when the hives are introduced to a crop for pollination, as it may cause an interruption in brood rearing and reduce pollen collection.

Beekeepers should not re-queen colonies with cells while the hives are being used for pollination of crops requiring pollen collectors, as there will be a break in the brood cycle.

Drones

A drone is a male bee (Figure 21). The drone's only function is to mate with a queen when it goes on its mating flight. They are only present in the hive in the spring, summer and autumn. The workers evict the drones in the autumn. As they do not visit flowers and cannot feed themselves, the evicted drones starve. They play no role in pollination.

Figure 21. A drone honey bee (with large eyes) between two much smaller worker bees.

Workers

Worker bees are non reproductive females. There may be more than 60,000 workers in a very large honey bee colony. Everything done in and outside the beehive, except laying eggs, is done by the worker bees. This includes making wax, building comb, feeding larvae, keeping the hive clean and warm, defending the hive and foraging. The jobs they do depend in part on their age. They start carrying out tasks inside their hive and are referred to as house bees. They then graduate to being guard bees that defend the colony, and lastly to being foragers. A worker may live for only 6 weeks in the summer when it is very active, or 6 months during the winter.

When the queen lays a worker egg (Figure 22a), it takes 3 days to hatch into a larva. The larva (Figure 22b) is fed by the workers for the next 4 days. The cell is capped over and the larva spins a cocoon. The larva turns into a pupa under the capping (Figure 22c). This cannot be seen unless the cell capping is removed. The fully formed worker bee emerges from its cell 21 days after the egg is laid (Figure 22d).

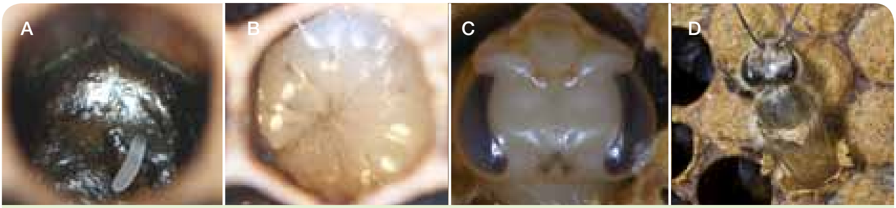

Figure 22. Development of a honey bee showing (a) egg; (b) larva; (c) pupa with the cell capping removed; (d) bee emerging from its cell.

In the spring, summer and autumn, a colony will normally consist of all three castes of bees and all stages of developing bees including eggs, larvae, pupae and fully formed bees. In temperate countries, they are normally at their maximum population in the late summer. However, they can be managed to have large population sizes at other times of the year.

Workers forage for water, propolis, pollen and nectar.

Water

Water is collected to cool the hive and to dilute the honey that is fed to larvae. Bees prefer to collect water (Figure 23) that has an odour. For that reason, they are often attracted to chlorinated swimming pools and muddy puddles. A honey bee colony will die if there is no water available. Lack of water can be a problem in some parts of Australia and beekeepers often supply water for bees. In some Australian states beekeepers are legally required to provide water for their bees.

If introducing hives for pollination in Australia, growers should ask their beekeeper if they need to provide water. Lack of water is usually not a problem in New Zealand and beekeepers do not usually have to provide it for their bees. Because bees like contaminated water, care needs to be taken when spray tanks are washed out, as honey bees may be attracted to the washings.

Figure 23. A honey bee collecting water.

Ask whether water needs to be supplied.

Propolis

Propolis is sap that is collected from trees (Figure 24). Workers use it to fill any gaps in the outside of the beehive that the bees do not want to use as an entrance. They also use it to block any gaps inside the hive that are too small for the bees to move through. Propolis is harvested from many beehives and sold as a human health product.

Nectar

Nectar is collected from flowers and provides the carbohydrate that the colony needs. Bees will usually collect as much nectar as they can. What they don't use, they convert into honey and store for times when there is no nectar available. The nectar and honey are eaten by adult bees and fed to larvae. If there is no nectar available and a colony runs out of honey, it will die within a few days.

A nectar forager can be identified because it probes flowers with its tongue (Figure 25).

Pollen

Pollen is collected by worker bees to provide the minerals, vitamins and protein needed by a larva to develop into an adult bee. A colony can survive for months without pollen but they will stop producing brood. Bees collect pollen by scrabbling across the anthers of a flower (Figure 26). Their bodies become coated with pollen, which they then brush off and pack into the pollen baskets on their back legs.

While some bees visit flowers to collect only nectar or only pollen, many bees will collect both pollen and nectar on the same foraging trip.

Figure 24. Propolis in a beehive. The propolis is the orange material at the end of the black plastic frames.

Figure 25. A nectar forager sampling a flower with its tongue.

Figure 26. A pollen forager scrabbling across the top of the anthers.

Stinging

It must always be remembered that honey bees are not domesticated. All we do is provide them with a suitable nesting site and encourage them to stay. If they consider a person or other animal a threat to their colony, they may attack them. When they sting, it is generally in defence of their colony.

Their propensity to sting depends on a number of factors, one of which is their race. The least aggressive strains may only consider a person to be a threat if they disturb their hive, but other strains may attack anybody within 20 m.

Beekeepers often select strains of bees with reduced aggression. However, colonies placed in crops for pollination may range from very docile to very aggressive, so all colonies should be treated with caution. Even the more docile bees can be provoked to attack by loud noises, bumping hives, or opening hives without a smoker. Honey bees are also very sensitive to weather. On a pleasant sunny afternoon when the colony is collecting nectar, it may be quite docile. However, the same colony may be aggressive in the early morning, or evening, or during bad weather when its bees cannot forage.

All honey bee colonies should be treated with caution.

Bees are very aggressive at night. Although the bees will not usually fly at night unless you shine a light on the hive, they will crawl. Even the most docile colony in daylight will only have one response at night, which is to sting whoever is disturbing them. Bees will also usually be more aggressive on the day they are moved into a crop.

Bees will also sting if they become caught in clothing, or hair, which may happen if you are standing in their flight path. If caught in hair, the bee needs to be killed and removed as quickly as possible.

To minimize the chance of being stung:

→ Don't stand in a colony's flight path.
→ Don't open, knock or interfere with a beehive.
→ Avoid mowing close to hives.
→ If you need to work close to hives, talk to the beekeeper first.

The aggressiveness of a colony can be temporarily reduced using the same method that a beekeeper uses. This is by blowing smoke into the hive entrance (Figure 27). As the colony has to be approached closely before doing this, the beekeeper should be consulted beforehand. The beekeeper might also be able to provide protective clothing and a smoker.

Figure 27. Blowing smoke into the front of a hive.

People's reactions to stings (Figure 28) vary considerably. The sting should be removed as soon as possible. This is best done by scraping the sting out with a fingernail. Squeezing the sack on the bee sting will not increase the amount of venom injected. For most people, the only effect of a sting is a sharp pain and possibly some localized swelling. Localized swelling is usually not a life-threatening problem unless you are stung on the throat or tongue. However, more generalized symptoms can be more serious.

Figure 28. A bee sting.

The symptoms generally appear within a few minutes, but in some cases may be delayed for as long as 24 hours.

The following are the symptoms of a serious reaction:

- Severe rapid swelling around the sting site but extending to other areas (e.g. around eyes, lips and general puffiness of face)
- General rash or hives, which itch
- Breathing difficulty, choking sensation, asthma, lips turning blue
- Vomiting
- Collapse and loss of consciousness.

As these symptoms can lead to death, administer oral antihistamines if possible and get the person medical assistance as soon as possible. When summoning assistance, it is important to stress the urgency of the situation.

It is good practice to check with staff and anyone else working in the crop during the time the hives are there for pollination, to see if they are allergic to bee venom. If they are allergic, they should seek medical advice as there is a chance that they may be stung.

Swarming

Honey bees swarm as a normal part of their colony's reproductive cycle (Figure 29). The bees produce a new queen to head the colony while the old queen leaves with half the bees to form a new colony. This usually happens in spring when the colony is collecting small amounts of nectar. A colony may also swarm if it runs out of space in its hive. A colony can swarm several times in a season.

Figure 29. Honey bee swarm.

The swarm will usually hang from a tree or other object within 100 m of the parent colony and stay there while bees from the swarm hunt for a suitable cavity. The swarm may stay in the same place for a few hours through to several weeks. If a swarm cannot find a suitable cavity to occupy, it may set up home where it is hanging, build comb and rear larvae. In warm climates, these colonies may survive the winter.

When a swarm leaves its parent hive, the workers gorge themselves with honey; hence for the first few days they are usually docile and unlikely to sting people. However, the swarm can become aggressive if it has been present for a longer time and has begun to build a nest to defend.

Bees from a swarm will visit flowers for nectar. However, as they have nowhere to store the nectar they will collect much less nectar than a similarly sized established colony. They do not normally collect pollen as they have no larvae to feed. Because of this, swarming is usually detrimental for pollination. The beekeeper should be asked to replace any hive that swarms while it is used for pollination.

Beekeepers can usually minimize swarming by ensuring colonies have spare room in their hive and that the queen is less than one year old. Some strains of bees are more likely than to swarm than others.

Colonies that swarm while being used for pollination should be replaced.

If a swarm has landed in an inconvenient location, a beekeeper will be needed to remove it. If they are not causing problems, they can be left alone and will usually fly away after a few days.

Honey bee pests and diseases

The long-term outlook for the Western honey bee and the pollination services they provide appears rather bleak at times. Over the last 70 years there has been increasing pest and disease pressure on honey bees. A large number of pests and diseases have unexpectedly turned to attack the Western honey bee. These have included the varroa bee mite jumping species, Africanized honey bees, small hive beetle, the microsporidian Nosema ceranae jumping species and colony collapse disorder. It seems that not a year goes by without a new problem affecting honey bees.

The net result of this is that over time there is likely to be a steady increase in the cost of providing honey bees for pollination as it becomes increasingly difficult to keep colonies alive.

There are several honey bee pests and diseases that currently affect honey bees in Australia and New Zealand, which can affect pollination. The most important of these are varroa, American foulbrood and European foulbrood, and the small hive beetle.

Varroa

Unfortunately, any discussion of honey bee biology would not be complete without including varroa (Figure 30). Varroa is a mite that evolved on Apis cerana, where it infests drone brood. Some time before 1940, varroa jumped species onto the Western honey bee that had been introduced into Asia. It has spread since then to almost all countries, and can be found in all beehives in New Zealand. When this manual was written, varroa had not been found in Australia; however, it is expected to reach Australia in the near future.

Figure 30. A varroa mite.

If colonies with varroa are not treated with miticides at least twice a year, varroa will usually kill them. This has added significantly to the cost of keeping bees, and much of this cost has been added onto the cost of providing hives for pollination. In most countries, varroa have developed increasing resistance to the chemicals used to control them, which has resulted in higher hive losses and increasing costs in maintaining hive numbers and providing pollination services. Resistance to two of the main varroa control chemicals has been reported in New Zealand.

When varroa reaches Australia, it is expected that it will kill most feral colonies and eliminate the free pollination service that they provide. It will also probably increase the cost of providing managed colonies as it has in New Zealand.

American foulbrood

American foulbrood (AFB) is a bacterial disease of honey bees that is present in both Australia and New Zealand (figure 31). AFB will often kill colonies and quickly spread throughout a beekeeping operation. Infected colonies in New Zealand and mainland Australia must be destroyed. Infected colonies in Tasmania can be treated with antibiotics. The disease adds to the cost of providing colonies for pollination and decreases the effectiveness of colonies used for pollination, as there are fewer larvae and worker bees in badly affected colonies.

Figure 31. A honey bee pupae with AFB.

European foulbrood

European foulbrood (EFB) is another disease of honey bee larvae. It is present in Tasmania and the Eastern states of Australia. It had not been reported in Western Australia or New Zealand when this manual was written. The disease is usually controlled through the application of antibiotics. Uncontrolled, infected colonies have reduced worker numbers and less brood and are less effective as pollination hives.

Small hive beetle

The small hive beetle (Figure 32) was discovered in Australia in 2002 but is not present in New Zealand as yet. Currently it is present in the eastern states of Australia but is not found in Western Australia or Tasmania. It lives in beehives and the larvae tunnel through the comb killing larvae and damaging honey. They can kill colonies and have been reported to kill feral colonies.

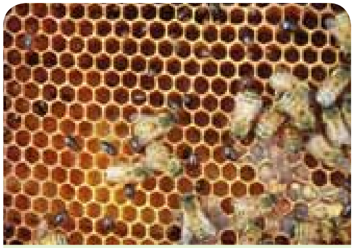

Figure 32. Small hive beetles on a honey bee comb.

Honey bee foraging

Flower utilization by colonies

Honey bees are very efficient at exploiting the flowers surrounding their hive. Most bees forage within a 1-km radius of their hive but they will fly in excess of 5 km to exploit a very rich patch of flowers. A colony may therefore have a foraging range of more than 70 square kilometres.

The workers from a colony are consistently sampling the flowers within the colony’s foraging range and moving the colony’s foraging effort to the most attractive flowers. When a colony is moved to a crop, its bees usually forage on flowers from the crop, as these are the closest and therefore the first ones found. However, if the colony can find more rewarding flowers, it may move its foragers from the crop onto these new flowers.

The attractiveness of a group of flowers depends on a number of factors. These include the distance the bees have to fly to reach it, the number and density of flowers, the amount and attractiveness of pollen, the amount and sugar concentration of the nectar, and the colony’s requirements.

Competing flowers can be a major problem for some crops. Honey bee colonies may be introduced to the crop in very high densities but if the flowers are not very attractive, and there are large numbers of more attractive flowers surrounding the crop, the bees may desert the crop completely.

Foragers deserting a crop to forage on more attractive flowers elsewhere is one of the largest problems with using honey bees for pollination.

Many of the methods used to manage colonies are designed to try to overcome this problem.

Timing of foraging

If you check flowers of a crop at different times of the day, you'll often find large variations in the number of honey bees visiting flowers. This is because of variations in the time of day that pollen and nectar are produced by the flowers. If honey bees are not foraging, it is usually because there is no pollen or nectar available, rather than that the bees are ignoring the reward the flowers are offering.

If bees are not visiting a crop at a particular time of day, this is most likely to be because the flowers are not offering a reward at that time.

Weather and foraging

Honey bees will not usually readily forage at low temperatures. However, for many plants, cold weather will stop flowers producing pollen and nectar before it will stop bees from flying to visit flowers. Honey bees do not forage in heavy rain.

Effect of colony size

For a colony to survive, its workers must look after the larvae in the hive and also forage for nectar, pollen and water. Up to a certain size, the colony has to manage these competing demands on the worker bees. The more larvae they have to feed, the more pollen and nectar they need to collect. However, as the number of bees in a colony increases, there will be more worker bees than required for the colony to care for the brood and meet its daily demand for nectar and pollen. These surplus bees will devote their time to collecting nectar, which will be turned into honey to be stored for the winter. For this reason, beekeepers normally want their colonies to have as many workers as possible when they are using them to collect a honey crop. In practical terms, a very large colony will have more foraging bees than two colonies half the size.

The makeup of a colony therefore has a large effect on what the worker bees collect. The more brood in a colony, the more pollen the bees will collect. However, as the ratio of bees to brood increases, the amount of nectar a colony will collect increases.

Floral constancy

Individual honey bees normally exhibit floral constancy while foraging. In a paddock of clover and dandelions, some bees will visit all clover flowers while other bees will visit all dandelion flowers. Very few will visit flowers of two different species during the same foraging trip. According to the famous naturalist Charles Darwin, this behaviour enhances pollination, as it reduces the chance of pollen being carried to the wrong flower species. However, the behaviour can have a negative effect on crop pollination. Artificial selection to develop a plant species into a commercial crop often produces male flowers that look significantly different (in the eyes of a honey bee), from the female flowers to which the pollen needs to be moved. This may limit the amount of movement between the flowers if bees start to treat the different sexes of flowers as though they are different species; this is an issue in some hybrid carrot and radish varieties and in kiwifruit.

Foraging areas

Rather than foraging randomly over a patch of flowers, individual honey bees tend to have foraging areas. These are groups of flowers from the same plant species to which a bee will come back on successive foraging trips. The size of these foraging areas depends on the density of flowers and the amounts of nectar and pollen per flower. These foraging areas are reached by the bees flying over the crop rather than by visiting flowers on the way. Foraging areas are an important consideration because they affect the movement of bees in a crop and the likelihood that a bee will encounter an appropriate pollen donor.

Chapter 5

Obtaining and managing honey bee colonies for pollination

There are three methods of obtaining managed honey bee colonies for pollination: growers who own their own hives, hives placed for free because a beekeeper wants to harvest honey from the site; and hives that are hired from a commercial beekeeper.

Grower-owned hives

Some growers are also beekeepers who use their own hives to pollinate their crop, often to reduce costs or ensure availability. This can work well, as long as care is taken to ensure that the colonies are large enough when the crop flowers. It is usually important to move colonies into the crop when it flowers, rather than having them permanently sited next to the crop. There are, however, many examples where the decision of growers to buy hives and manage them has ended in failure. This is because the skills required for growing crops and keeping bees are very different. The hives are often neglected in favour of growing the crop, from which the grower's income is derived. Because of this, most growers who take up beekeeping to provide hives for pollination do not continue with it.

Where this has worked, it is usually because the growers were already beekeepers or because they engaged a beekeeper to manage the colonies for them.

Free hives

Some beekeepers place hives in a crop for free to collect a honey crop, e.g. white clover. Although the grower has no direct costs, there are significant risks in using free pollination services, as the grower will have little or no control over the size of the colonies that are introduced, how many are introduced, or how they are managed.

Feral colonies, or managed colonies on permanent sites in the surrounding area, are also occasionally relied on to provide a free pollination service. The risk with this approach is that their numbers may vary from year to year. They are also likely to be at a distance from the crop, which will decrease the number of bees from the hives visiting the crop, unless it is particularly attractive. As they are permanently situated, fewer of their bees will visit the crop than from colonies that are introduced for pollination. This is because at the time the crop flowers the bees from permanently sited hives will already be foraging on flowers elsewhere. These bees will usually not move onto the newly foraging crop unless it is very attractive.

Varroa has all but eliminated feral colonies in New Zealand, so reliance on feral colonies alone is no longer a viable option.

Hiring hives

Hiring hives is the most common solution for obtaining managed hives needed for pollination. Hives are usually hired directly from beekeepers or from agents working for beekeepers or growers. This approach has the advantage that the growers can specify exactly what they require.

It may take a beekeeper a large amount of time to prepare colonies suitable for pollination, especially if they are required early in spring. In many cases, some of the preparation work carried out by beekeepers has to occur during the previous autumn. It is therefore usually important to order hives early to ensure supply.

When hiring honey bee colonies, many beekeepers and growers find it preferable to use a pollination contract that specifies the responsibilities of both parties. Contracts are useful as there is no confusion over what the grower thinks they are hiring and what the beekeeper thinks they need to supply. They become very important if there are any problems with what is supplied or what happens to the hives once they are in the crop. A typical contract may specify:

- Names and addresses of the parties concerned and the date of the agreement
- Location of the crop
- Number of colonies hired
- Strength of colonies (number of frames of brood and bees)
- Distribution of hives throughout the crop
- Length of notice to be given before shifting bees in and out of the crop
- Rental fees and terms of payment
- Any special management practices such as sugar syrup feeding
- An arbitrator in the event of a dispute
- Permission for an independent audit of the strength of the colonies
- Action to be taken if an audit is failed
- Remedial action to be taken if problems occur
- Protection from pesticide damage
- Witness to the agreement.

An example of a generic pollination contract is presented in Appendix 1.

Rental fees

The cost of hiring a honey bee colony will depend on a number of factors. The most significant of these are the opportunity costs. This relates to the amount of money the beekeeper could make from the hives if they were not used for pollination. If the hives can collect as much honey while they are used for pollination as they could anywhere else, there may be no opportunity cost. A good example of this is clover seed crops, where beekeepers put hives near the crop, often free of charge, because of the honey crop they can collect. However, for kiwifruit, most beekeepers have to forgo a honey crop when they introduce hives; this is reflected in the cost of renting colonies. If honey prices increase, the average cost of renting colonies for kiwifruit pollination is likely to rise accordingly.

Also affecting the rental prices is any hive management needed to bring colonies to a particular strength, the distance they need to be transported, any special management required while the hives are in the crop, and any damage that they suffer through pesticide use.

Factors that affect the cost of managing colonies outside pollination time may also affect prices. When varroa was found in New Zealand, beekeepers' costs increased significantly because of varroa treatment costs and colony losses. As a result of this, the cost of hiring hives for kiwifruit pollination almost doubled.

As with any product or service, supply and demand is also a significant driver for hive rental prices.

Finding beekeepers

If using honey bees for the first time, growers will need to contact a beekeeper. The easiest way is to talk to other growers in the area who are renting hives. Alternatively, the internet will provide contact information on beekeeper organizations that can provide details of local beekeepers that may be willing to provide pollination services.

Pollination associations and agents

Beekeepers sometimes establish pollination associations, which may take up a wide range of functions. Some meet only to discuss issues of common interest. Others work together to educate members, provide quality assurance programs for their members' hives, co-ordinate advertising and some also act as agents for the placement of hives in crops and the collection of pollination fees.

In some larger growing industries, there are people or companies who act as agents or brokers for pollination hives. They organize the rental of hives for growers and often have some arrangements with beekeepers to guarantee quality. The beekeeper may deliver the hives into a single location (dump site) and the agent will then arrange their delivery to the crop, collect the pollination fee and pay the beekeeper.

Agents provide several advantages for beekeepers and growers. Committing large numbers of hives to a particular crop is a complicated logistical issue for beekeepers who have to deal with a large number of growers, pick up hives from widely distributed sites, and position them in crops at night. They also need to check colonies for strength before moving them and carrying out any management required while the hives are in the crop. Using an agent means that the beekeeper just has to check colony strengths and deliver the hives to a dump site.

Agents can be of use to growers as well. Discussing the strength of colonies and colony management requirements with a beekeeper often develops into a very technical discussion on honey bees in which growers may soon find themselves out of their depth. These discussions can be left for an agent, who usually has beekeeping experience as well as experience with the crop.

Colony strengths

This is one of the most important issues; however, it is often neglected. It is tempting to think of beehives as the wooden boxes in which the colonies are housed. A great deal of thought is usually given to the number of these wooden boxes that will be hired, as this is what pollination fees are calculated on, and they are easy to count. Less thought is given by growers to the strength of the colonies (amount of brood and the number of bees). However, the strength of the colonies is usually much more important than the number. A large colony may collect more than 100 times more pollen and nectar than a small colony. There is therefore little point in talking about hive numbers without also specifying the size of the colonies.

The strength of a colony is influenced by a number of factors. In temperate climates, colonies are usually at their smallest during winter. They grow in strength through the spring and summer and are at their peak size in late summer and early autumn. In tropical climates colonies are usually not as populous and tend to have more even numbers of bees throughout the year.

Honey bee colonies can sometimes have large numbers of bees but no brood (larvae and pupae), if there is no queen or there is a new queen that has yet to start laying. However, brood cannot survive without worker bees to feed it and keep it warm. Because worker honey bees collect pollen to feed their larvae, colonies without brood will collect little pollen. Colonies will not naturally have large amounts of brood and few bees.

It is possible for a beekeeper to produce large colonies outside this annual cycle by feeding pollen and sugar to the bees. Beekeepers can also influence the size of colonies by adding or removing frames of bees and brood.

When introducing hives for pollination, it is important to specify the size of the colonies as well as the number of hives.

The size of colonies used for pollination is often described as the number of frames covered with bees and brood. This is complicated by the variation that occurs in the sizes of frames. The most common frame size is the 'Langstroth' full-depth frame. However, there are also frames used that are ¾ and ½ this size.

The following discussion assumes that Langstroth full-depth frames are being used, as these are the most common. The measurements will need to be converted if a beekeeper is supplying hives with different frame measurements.

When discussing the size of colonies, it is worthwhile to specify the following:

Amount of brood

Even if bees are only needed to collect nectar from a crop, colonies should still have brood. The presence of brood ensures colonies will function normally, and that new bees will be emerging to replace those that die. The amount of brood (eggs, larvae and capped cells containing pupae) is usually measured as the number of frames of brood present in a hive. In most cases, frames will not be completely full of brood (Figure 33). For this reason, the number of frames of brood in a hive is usually discussed as full-frame equivalents, i.e. the number of frames that would be completely full if the areas of brood on each frame were added together. For instance, a colony of six frames that are 60% full of brood will have 3.6 full-frame equivalents.

When the brood area is being checked, the beekeeper or auditor will normally count the number of frames with brood and estimate the proportion of each frame that is covered with brood. The proportions are added together to determine the total amount of brood.

Age of brood

The age of brood can also be specified if it is important that the colony collects large amounts of pollen. The more unsealed cells with larvae that are still being fed, the more pollen a colony will collect. A typical specification is that the colony should have at least 25% of the brood as unsealed larvae (Figure 34).

Position of brood

If it is important that bees collect pollen, then most of the brood should be as close to the hive entrance as possible, as this encourages the foraging bees to collect more pollen. If the colony is housed in two boxes, this can be achieved by having the brood in the bottom box.

Bee numbers

It is usual to specify the number of frames completely covered with bees. In a normal functioning colony, there will be a greater number of frames of bees than brood. A colony may have between 1 and 20 or more frames of bees. A full depth frame completely covered with bees (as

Figure 33. A honey bee frame 60% covered with brood (the area of brown cells on the bottom half of the frame). The area above the brood is capped honey.

Figure 34. A frame with an area of white c-shaped larvae in the bottom of the cells.

Figure 35. A frame covered with bees.

shown in Figure 35) would have about 3,000 adult bees. There should be enough bees on the frames so that the comb below the bees cannot be easily seen.

Empty comb

It is common to specify the amount of empty comb, especially if the colonies are going to be in the crop for more than two weeks. If there is not enough empty comb for the queen to lay in, the area of brood will reduce. This will limit the amount of pollen collected and eventually reduce the number of bees in the hive. This is particularly a problem if a colony is collecting large amounts of nectar or is being fed sugar syrup, as the workers will fill up the cells that the queen needs to lay in if they have no other room. Enough empty comb should be available to allow the queen to continue laying while the colonies are in the crop and to store the nectar the colony collects.

Enough empty comb should be present to store any nectar or sugar syrup.

Honey stores

Colonies should have enough stored honey so they do not starve while in the crop if there is little nectar available. In most situations, hives should have at least two full-depth frame equivalents of honey.

Queens

Each colony needs to have a queen. It may be useful to specify the age of the queen, as young queens tend to lay more eggs than older ones. A colony with a queen that is less than one year old will normally grow faster and have a larger demand for pollen than a colony headed by an older queen. Older queens are also more likely to swarm.

Swarming

Hives should not be overcrowded with workers, as they may swarm. Beekeepers should manage their colonies so they do not swarm while they are being used for pollination. This may consist of adding an extra box of empty comb, ensuring the colony is headed by a young queen or removing queen cells regularly.

Identifying problems with colonies — auditing

Having specified a particular standard for the hives that are being hired, it is often important to check the hives to ensure that they meet the required standard.

It is usually not possible to determine the strength of colonies by observing the number of bees entering and leaving hives as this is affected by factors in addition to the size of the colony. If there is little nectar or pollen for the colonies to collect or the weather is not suitable for foraging, there may be few bees flying. Even standing close to the hives may confuse the bees and reduce the number entering the hive. However, if some hives have large numbers of bees entering and leaving and others do not, this may indicate a problem.

The best way of determining if the colonies supplied meet the required standard is to have a beekeeper open and inspect them. If there is a written contract or a verbal agreement with a beekeeper that specifies a colony standard, it is possible to have the hives audited by an independent person to ensure they fulfil the requirements. It is usual to gain permission from the beekeeper before having the hives audited. An audit may consist of checking some or all of the hives or just the hives that are causing concern.

If you think there is a problem with the hives, have them audited.

In some instances, a beekeeper will open and go through any hives with a grower. Alternatively, with sufficient training and the appropriate permission from the beekeeper, growers can do their own auditing. The most common arrangement is for an independent beekeeper to carry out the audit. In some industries, hive auditors advertise their services or work for groups of beekeepers, pack-houses or seed companies.

Any audit should take place as soon as possible after the hives are placed in an orchard, so remedial action can be taken before any problems start to affect pollination. Alternatively, it may be possible to have the hives audited before they are introduced to the crop.

Audits should occur as soon as possible after the hives are introduced to the crop.

Audits may take a variety of forms, depending on why the audit is being carried out.

Auditing to a standard

This consists of determining whether colonies meet a specified standard. The results are usually reported as the percentage of hives that meet or fail the standard. No credit is given in the audit to colonies that are significantly over the standard. The method has the advantage that it is easy to carry out and for everyone to understand.

Average colony strengths

In this method the average number of frames of bees, brood and empty comb in each hive is determined. The approach has the advantage that it more clearly reflects the pollinating potential of the colonies and that the beekeeper is credited for any strong colonies provided, which may compensate for any weak colonies.

Problem hives

This is where colonies that do not have as much activity at their entrance are audited to determine if there is a problem with them.

Managing colonies

Moving colonies

Colonies are normally closed up when the bees are not flying at night or early in the morning to ensure that all the foraging bees are in their hives when they are moved. If hives are closed up and moved to the crop during the daytime, many of the foraging bees may be left behind. This will reduce the pollination performance of the colonies for several days until they have converted more of their house bees into foragers.

Bees have good memories, so they can find their way back to their hive. For this reason, if a hive is going to be moved it must be moved more than 3 km. If a hive is moved a shorter distance, the foragers may recognize where they are and return to the location from where the hive has been moved. Colonies should therefore not be moved within a crop once the bees have started to forage. If colonies need to be moved within a crop, they should be removed completely from the crop and new colonies brought in and placed in the new location.

Colonies should not be moved within a crop once they have begun foraging.

When hives are moved from a crop, some bees are likely to be left behind, even if the hives are moved in the middle of the night. These bees will usually settle in small bunches that look like very small swarms. If they are not in the way, they can be left and will eventually die. If they are a problem, the beekeeper should be asked to remove them or to provide advice on how they can be removed.

Situating colonies within a crop

Distance from the crop

Although bees can fly large distances (>5 km) if the need arises, they usually fly only as far as required to collect the pollen and nectar they need. The number of bees from a hive visiting a crop often decreases with increasing distance to the crop[16]. This trend is more pronounced during bad weather, when bees are even more likely to forage close to their hive. Colonies therefore should be as close (< 20 m) to the crop as possible. If the crop is very large, hives may need to be placed amongst the crop (Figure 36).

Figure 36. Honey bees placed in a carrot crop.

Place the hives close to (within 20 m) the crop if possible.

Distribution within the crop

The distribution of colonies within a crop is often a controversial issue between growers and beekeepers. This is because it is easiest for the beekeeper to drop off all the hives in a single or several large groups (Figure 37). However, many growers want the hives spread evenly throughout the crop, in the hope that there will be an even distribution of bees through the crop.

Figure 37. A large group of beehives in a kiwifruit orchard.

There is no simple answer to whether hives should be placed in large groups or spread evenly through the crop. If hives are spread evenly throughout a crop, foraging bees will tend to spread themselves evenly throughout the crop. The same may not occur if hives are placed in large groups. If the density of hives is high enough that there is pressure on the supply of pollen and nectar available in the crop, bees from large groups of hives should spread themselves evenly over the crop. However, if there is more pollen or nectar than the bees can collect, they will tend to forage close to their hives, as this requires the least energy. In this situation, there will be a high density of bees close to a large group of hives and the bee density on flowers will decrease with increasing distance from the hives.

This was seen in a kiwifruit orchard where hives were introduced into a 10-ha orchard in three large groups of 30 hives. A large decline in the number of bees visiting flowers was observed with increasing distance from these hives (Figure 38).

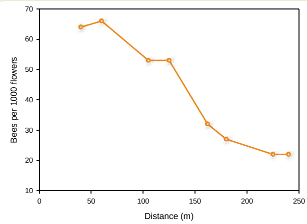

Figure 38. Number of bees on kiwifruit flowers with increasing distance from a group of beehives.

Another example of this is where the pollination of squash was reported to decrease from a group of 20 beehives at the end of a field[17].

In summary, for some crops and in some years, large groups of beehives will produce an even distribution of bees over the crop. Bees are less likely to distribute themselves over a crop if too few hives are being used. However, irrespective of the crop or the year, single or small groups of hives distributed throughout or around the crop are <u>more likely</u> to result in an even distribution of bees on the crop.

Because of this, hives should not be placed in large groups unless research or experience has shown that large groups give suitable pollination for the crop.

Put a maximum of 8 hives in each group unless it has been demonstrated that larger group sizes will also give an even distribution of bees.

It is important to remember that the beekeeper will have to drive around the crop in the dark to find the proposed hive sites. It is usually a good idea to provide the beekeeper with a map of the proposed hive locations with ditches, low wires or other hazards clearly marked on it.

Position

It is good practice to place colonies in as warm a situation as possible. This will encourage the bees to forage in marginal conditions. The placement of the hives in front of a windbreak, where the colonies will receive early sun, is best. Avoid windy locations.

There is no need to take this to its extremes. For example, it was noted that bees were not visiting kiwifruit flowers till 9 or 10 am. Growers tried to encourage bees to forage earlier by placing hives on packing crates so they were a metre above the ground where it was warmer. This made no difference, however, because the delay in foraging on kiwifruit was because kiwifruit flowers do not normally produce pollen till after 9 am.

Place colonies in a warm, sunny situation.

Pollen versus nectar foragers

Nectar foragers are likely to forage from the side of flowers to collect nectar (side working; Figure 39a) while pollen foragers approach from the top of the flower (top working Figure 39b). Nectar foragers are thus less likely than pollen foragers to touch the stigma. This is mainly a problem with flowers that have a bowl or plate shape, e.g. apples and almonds. For many crops it is useful to try to increase the number of pollen foragers. This can be done by increasing the brood to adult bee ratios, feeding sugar syrup, trapping pollen and stripping pollen from hives.

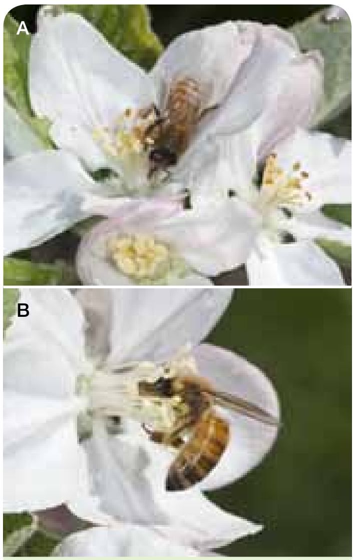

Figure 39. (a) A side-working honey bee visiting an apple flower; (b) A top-working honey bee visiting an apple flower.

Sugar syrup feeding

Feeding sugar syrup to colonies (Figure 40) is a simple way of increasing the amount of pollen collected by a colony. This is usually done for crops that have flowers that produce only pollen, e.g. kiwifruit, or for crops where pollen foragers are better pollinators than nectar foragers, e.g. apples, pears and almonds.

The results of syrup feeding can be dramatic. Colonies fed sugar syrup typically collect 2 to 3 times as much kiwifruit pollen as unfed colonies, making them 2–3 times more valuable as pollinators[18].

Why syrup feeding should increase pollen collection is not entirely clear. It has been suggested that it causes bees that have been collecting nectar to change to gathering pollen. When a nectar-collecting bee returns with its load, it passes it to the house bees waiting just inside the hive entrance (Figure 41). The house bees then store the nectar in cells to make honey.

When sugar syrup is fed to a colony, the house bees consume the sugar syrup instead of waiting at the hive entrance. As there are fewer house bees available to accept nectar loads, the nectar collectors have to wait longer to get rid of their load. This is thought to discourage them from collecting nectar, so they collect pollen instead.

Because syrup feeding works by changing honey bee behaviour rather than simply by increasing the food supplies, it works regardless of how much honey the colony has stored. Sugar syrup feeding has been shown to increase pollen collection from almonds, sweet cherry, field beans, red clover and kiwifruit[19].

Figure 40. Feeding a colony sugar syrup.

Figure 41. A nectar forager (right) feeding a house bee (left).

It has been suggested that feeding sugar syrup scented with flowers of the target crop can be beneficial. However, there is insufficient evidence that this practice is any better than feeding unscented syrup to be able to recommend it.

Although dramatic increases in pollen collection have been observed, the effect of syrup feeding on pollination is unknown because of the difficulty in collecting this type of data. It has been assumed that in order to collect more pollen, the bees from a colony must either visit more flowers, or visit them to collect pollen instead of nectar, both of which should increase pollination for most plants.

Feeding colonies

The feeding of honey bee colonies needs to be organized with the beekeeper, usually well before the hives are introduced, as the beekeeper will need to ensure that the colonies have sugar feeders fitted (see below). The beekeeper will also need to ensure that the colonies have sufficient empty comb to store the sugar that is being fed. If there is not enough room, the bees will fill the combs with sugar that the queen needs for egg laying. This will cause the colony to stop growing, which may reduce their pollination efficiency.

The beekeeper should be involved in any decision to feed sugar syrup to honey bee colonies.

Where hives are fed sugar syrup by growers or their staff, it is important that they are protected from bee stings with appropriate clothing and show no major allergic reaction to being stung. This should be arranged with the beekeeper.

Wear protective clothing when feeding sugar syrup to avoid being stung.

The sugar syrup must be fed inside the hive rather than outside. The method is unlikely to work if the syrup is fed outside and it may provoke robbing (see below).

Only feed sugar syrup to bees inside their hive.

Types of feeders

Both division board feeders (Figure 42) and top feeders (Figure 43) work equally well[20]. Top feeders sit on top of a hive, while a division board feeder sits inside a hive replacing one or two frames. Top feeders have the advantage that there is less disturbance of the colonies when the feeders are filled so there is less chance of being stung.

With both division board feeders and top feeders, large numbers of bees can feed on the syrup at the same time. Feeders that work on a drip feed principle, delivering small quantities of syrup over a long period, may not be effective or in some instances may not work at all and are therefore not recommended. Feeders generally need pieces of wood, bracken or other items floating on or in the syrup to stop bees drowning.

Only use feeders that permit a large number of bees to access the syrup at the same time.

Figure 42. Division board feeder positioned at the outside edge of a box.

Figure 43. Hive with lid removed to show a top feeder.

Concentration of the sugar syrup

In many countries, beekeepers feed sugar syrup to colonies to keep them alive (usually 60–65% sugar) or lower concentrations to encourage the colonies to increase in size.

Both 30% sugar syrup (30 g of sugar in 70 ml of water) and 60% (60 g in 40 ml) have been tested on kiwifruit and both were found to be equally effective[20]. The choice of concentration may therefore depend on factors other than enhancing pollination. Lower concentrations have the advantage that they are cheaper and easier to make up, but they ferment much faster. Bees will not consume syrup if fermentation is too advanced. Concentrated syrup is very slow to ferment but is more expensive. Feeding dry sugar does not appear to have any effect on pollen collection.

Feed sugar syrup that is between 30% and 65% sugar.

Feeding sugar syrup can be beneficial for beekeepers as well. Because hives are often introduced to crops at high densities, there may be little nectar and pollen available for each hive. Feeding sugar syrup may encourage the colonies to expand in size so they are more able to collect honey after they are removed from the crop.

While sucrose (white sugar) solutions have been tested and shown to work, it is not reported whether other sugars like glucose and fructose will be equally effective. For this reason, only sucrose is recommended at this stage.

Timing of feeding

Honey bee colonies can become aggressive when they are first moved to a new location so it is best to avoid doing anything with them on the first morning they are in a crop. A syrup feeding program should start on the second day the hives are in the crop and continue until the end of flowering.

Although trials with kiwifruit have demonstrated that feeding at any time between 9 am and 5 pm will increase pollen collection, it is probably best to feed sugar syrup about the same time as the crop of interest is starting to produce pollen.

Amount and frequency of feeding

The amount of syrup required depends in part on the number of bees in the colony. All the syrup fed should have been consumed by the bees before the feeder is refilled. Quite often the bees will not have consumed all the syrup given on the first few days, but will do so later as they learn to take the syrup from the feeder.

Feeding 1, 2 and 3 litres per hive every three days has been tested in colonies with about 30,000 bees (12 frames covered with bees) in kiwifruit orchards. The amount of kiwifruit pollen collected increased with increasing volumes of syrup fed. In New Zealand, hives are usually fed 1 litre every day or 2 litres ever second day over one to two weeks. It may be necessary to feed less than this if the colonies have fewer than 30,000 bees.

Feed 1 L of syrup daily or 2 L every second day.

Adverse weather

It is often assumed that it is not worth feeding colonies while it is raining. This has not been researched but it is probably worth continuing with feeding programs irrespective of the weather, unless bad weather is likely to stop all honey bee activity for three or more days.

Robbing

Robbing is where a honey bee colony attempts to steal honey from another colony (Figure 44). Many of the flowers honey bees visit are present only for a short period so they have evolved to take the maximum advantage of any available food sources. They are quick to find new food sources, and because they are able to communicate the distance, direction and taste of the food to other bees, they can very quickly recruit large numbers of their hive mates to visit a food source. It may take several hours for the first bee to find a new food source, but very quickly there will be hundreds or thousands of bees. Although this is fascinating to watch, the results can be drastic.

Figure 44. A colony being robbed by other bees.

Honey bees from one colony usually leave other colonies alone. Foragers can, however, become confused when returning from a foraging trip and enter the wrong hive when these are placed in straight rows and painted the same colour. When this happens by accident, the bees are usually accepted by the new colony. However, a bee that decides that taking honey from a neighbouring colony is much easier than visiting flowers, gets a very different reception. The bees whose job it is to guard the hive appear to be able to differentiate between those bees entering by mistake and those bees that attempt to steal honey. The robbers are usually set upon by the guard bees and either ejected from the hive, or killed. Because of this, usually few bees attempt to steal honey.

Feeding sugar syrup or honey can change all this. As long as the syrup is placed inside the hive it seldom causes problems. The house bees consume the syrup and its presence is treated in the same way that the colony treats its own food reserves. Other than increasing pollen collection and stimulating the queen to lay, it seldom has any side effects. However, feeding sugar syrup outside a hive, either on purpose or accidentally, can cause large problems. In this case it is the experienced foragers that take the syrup instead of the house bees. The foragers, and the thousands of other bees that they recruit to the food, become conditioned to collecting large volumes of high quality food outside their hive. When the food is finished, they start to search elsewhere for it. The only other source of this type of food is usually the honey reserves of the neighbouring colonies.

A single robber bee causes few problems, but thousands of them can cause major problems. If the robbers are in sufficient numbers, they can kill other colonies and remove all the honey, which is detrimental to pollination. Robbing causes the colonies under attack to become very defensive. While hives can usually be approached safely if care is taken, you are liable to receive a very hot reception if robbing is occurring, even if you happen to be the innocent party. This defensive behaviour may also extend for quite large distances around the hive, causing all sorts of other problems. The robbing bees usually concentrate on the weaker colonies. If these colonies are weak because of disease, robbing can result in the spread of disease to healthy colonies. Colonies that are spending their time attacking other colonies or defending themselves from attack are usually not interested in visiting flowers.

By following a few simple rules, it is possible to eliminate robbing problems. The most important things to remember are not to feed bees outside the hive, and to avoid spilling syrup while feeding without cleaning it up. This includes not letting it run down the outside of the hives or through the frames and out through the hive entrance. Also, always store the syrup in closed containers, even if it is inside a garage or packing shed. When the containers are empty, wash them out or seal them again rather than letting the bees clean them out. As long as care is taken, robbing should not be a problem.

Be careful not to cause robbing.

Summary:

- Only feed syrup if more pollen foragers are needed.
- Feed 1 L /day or 2 L of syrup every second day if the colonies can consume this amount.
- Feed at the time the crop is producing pollen.
- The syrup should have between 30 and 65% sugar by weight.
- Use a top or division board feeder.
- Don't feed dry sugar, fructose or glucose.
- Don't feed bees outside their hive.
- Be careful not to initiate robbing.

Pollen trapping and feeding

It is possible to influence the amount of pollen a colony collects by removing pollen from a hive or by feeding pollen. Pollen can be removed using one of two methods, either pollen trapping or stripping frames of pollen.

Pollen trapping

A pollen trap fits is fitted underneath a colony, replacing the floorboard, or at the entrance of the colony. The entrance traps are usually faster and easier to fit to beehives.

The traps work by scraping some of the pollen pellets off the legs of the bees as they enter the trap (Figure 45). Once dislodged, the pollen pellets fall through another screen and are collected in a tray. Bees do not seem to notice when their pollen pellets have been removed and still do everything they would normally do in the hive as if they still had their pellets.

Figure 45. Honey bees walking through the grid of a pollen trap, which scrapes some of the pollen pellets off their legs.

Beekeepers in some countries use pollen traps to collect pollen for human consumption or to feed back to bees. The proportion of pollen pellets removed from incoming bees depends on the size of the pollen pellets, which vary considerably between crops. Their efficiency also varies with the size and the shape of the holes in the grid. Star-shaped grids usually remove more pollen pellets than grids with square holes.

If high efficiency pollen traps are used for a long time (months), they can have a negative effect on the colonies, as they become starved of pollen. Care should be taken to ensure that the pollen trap grid is large enough not to slow down the movement of bees into and out of the hive. The traps should also be checked frequently to ensure they do not become blocked with dead bees.

It has been demonstrated that pollen trapping can result in an increase in pollen collection[21]. The effects are, however, usually smaller than those achieved with sugar syrup feeding.

Pollen traps are also a very useful way of determining how much pollen a colony is collecting from a crop, as pollen pellets from different flowers often are uniquely coloured (Figure 46).

To determine the colour of the pollen pellets collected from the crop of interest, catch several bees while they are collecting pollen. This can

Figure 46. Pollen pellets in the drawer of a pollen trap.

be done by placing a plastic bag over the bees while they are visiting flowers. They can then be killed in a freezer and the pellets removed, which can then be compared with the pollen pellets in the pollen trap. This is best done under natural light conditions.

Ensure the pollen traps are not restricting the movement of bees into and out of their hives.

Stripping frames of pollen

When bees bring pollen into a hive, they store it in specific areas of cells in the honey comb until the colony needs to use it. It is sometimes possible to remove full frames of pollen (Figure 47), which has been shown to stimulate pollen collection[22]. The size of the increase that could be expected is, however, unknown. If frames of pollen are going to be removed, this will need to be done by a beekeeper.

Figure 47. A frame with pollen in its centre that could be removed.

Feeding pollen

Many beekeepers feed pollen or pollen substitutes to beehives to promote colony growth. Feeding pollen has been reported, however, to decrease the amount of pollen a colony collects[23]. This effect does not happen in all cases[24]. This may be worthwhile doing in crops in which only nectar collectors are important pollinators e.g. hybrid radishes and avocados, as it may decrease the number of pollen foragers, allowing the colony to concentrate on nectar foraging.

Experienced versus inexperienced foragers

Honey bees quickly learn the easiest way to visit the flowers their colony is exploiting. Unfortunately, they often learn behaviours that are unhelpful for pollination For some flower species (e.g. apples) they learn to collect nectar from flowers without touching the stigma (side working); they learn to avoid flowers where they are hit by the staminal column e.g. lucerne; they learn to collect nectar from the holes bitten in red clover flowers by short tongued bumble bees; and they often learn that there are more attractive flowers than the crop they are “supposed” to be pollinating.

For this reason, it often advantageous to introduce new colonies throughout the flowering season or to exchange colonies, to ensure there is a high proportion of inexperienced foragers.

For many crops, it may be useful to introduce new colonies throughout the flowering season or to ensure there are large numbers of naïve bees.

Attracting honey bees to flowers

Growers have long been sold compounds to spray on flowers to attract honey bees. The earliest attempt involved sugar syrup. More recently, a number of other materials have been sold, including a range of products using honey bee pheromones.

Sugar syrup

Spraying sugar syrup onto flowers has been shown to increase the number of bees visiting plums[25], European pears[26], apples and nashi[27] (Figures 48 and 49). Increases in fruit set have also been recorded after spraying sugar syrup[26]. However, other studies have reported increases in the number of bees visiting leaves and branches but fewer bees visiting flowers. The reduction in the number of bees visiting flowers may be due to there being insufficient honey bees in the area.

When spraying sugar syrup was tested on nashi, it increased the number of bees visiting leaves and branches. However, it also increased the number of bees visiting flowers. The effect lasted into the second day. On apples, the number of bees visiting flowers increased with the concentration of syrup applied (Figure 50)[27].

The evidence is sufficient to indicate that spraying crops with sugar syrup will probably increase the number of bees visiting the flowers and increase pollination. If syrup is being applied, concentrations between 30 and 40% are probably the most appropriate. It needs to be noted, however, that there are still many unknowns with this method and its effects. The best recommendation we can give is to try it on a small area of the crop before treating everything.

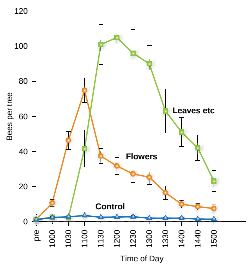

Figure 48. Average number of bees per tree visiting nashi flowers (flowers), leaves or branches (leaves etc.) on trees sprayed with 33% sugar syrup or visiting flowers on unsprayed trees (control) on the day the treatment was applied (0900 h). The vertical lines are standard error bars[27].

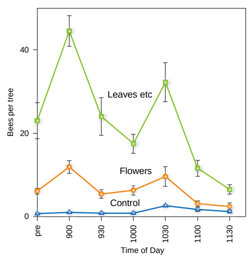

Figure 49. Average number of bees per tree visiting nashi flowers (flowers), leaves or branches (leaves etc.) on trees sprayed with 33% sugar syrup or visiting flowers on unsprayed trees (control) on the day after the treatment was applied (0900 h)[27].

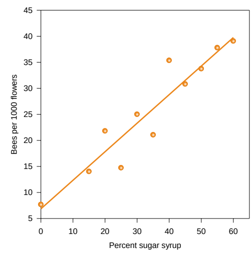

Figure 50. Relationship between the number of bees visiting apple flowers and the concentration of sugar syrup applied.

Commercial bee attractants

A number of bee attractant sprays have been marketed over the last 30 years. The reported results are variable however, especially considering that positive results are more likely to be published than negative results. These products include:

Bee-Q®: It has been reported to increase the pollination of onions[28,29], gourds[30] , cotton[31] and Sesamum[32]. Bee-Q® failed to increase the pollination of sunflowers[33].

Fruit Boost®: This contains queen mandibular pheromone, which is produced by queen honey bees. It has been reported to increase the pollination of gourds[30], pears[34,35], cranberries and blueberries[36]. It did not increase the pollination of cherries[34] or apples[35].

Bee-Here®: It has been reported to increase pollination of Sesamum[32].

Bee Scent®: It is a liquid formulation containing 9% pheromone and 40% other natural attractants. It has been reported to increase the number of bees visiting apples[37] and the pollination of pears, cherries, apples[38]. It failed to increase the pollination of cucumber or watermelons[39,40 41].

Beeline®: This is a wettable powder food supplement[42]. It was reported not to increase the pollination of cucumbers or watermelons[39], carrots[43] nor to increase the activity of honey bees on fruit trees[42].

Bee Lure®: This contains sugars and strawberry flavouring[44]. It was reported not to increase pollination of apples[44,45].

Several of these bee attractants appear to have enough published information to suggest that they may be beneficial in some situations; however, there are no guarantees. If there is a problem with too few bees visiting a crop, it may worth trying some, although only treat a portion of the crop at first and check results. Then you will know whether they are worth continuing.

Honey bee stocking rates

Providing recommendations for how many honey bee colonies should be introduced to a crop is probably one of the most important things to do, but it is usually impossible to do reliably. For most crops there are published recommendations on the number of colonies that should be introduced for pollination. However, the recommendations vary considerably even for the same crop. For example, there are recommendations for hive stocking rates for blueberries that range between 1 and 10 hives per hectare.

Various factors can affect the number of colonies that are required to be present to pollinate a particular crop.

Colony strengths

Colony stocking rates cannot be discussed without also discussing the number of bees in a colony. One very populous honey bee colony may have as many foragers as 10 or 20 small colonies combined. Unfortunately, most published recommendations for stocking.

Recommendations on colony stocking rates need to include the number of bees and the amount of brood in the hives.

Competing flowers

Probably the largest complicating factor when discussing colony stocking rates is the number of competing flowers around a crop and how attractive these other flowers are relative to the crop of interest. In one study, a crop had the same number of colonies that were all prepared to the same strength, on two consecutive years. In the first year there were few competing flowers outside the crop to draw bees away. However, in the second year white clover in the fields surrounding the crop flowered earlier than usual and caused the bees to desert the crop in favour of the white clover. In hindsight, the grower should have used four hives per ha the first season and possibly more than 20 hives per ha the second season.

It is usually not possible to assess with any degree of accuracy the importance of competing flowers and how far colony numbers should be adjusted to compensate for them. This is because honey bees have such a large potential foraging area that it is very difficult to assess the area of competing flowers that are within the bees' foraging range. Even if the size of the area of competing flowers is known, the amount of nectar and pollen produced by these flowers will probably vary between years and depend on the temperature and soil moisture.

Attractiveness of the crop

If a crop is very attractive to bees, e.g. white clover and citrus, it may not be necessary to introduce many hives, as most of the bees in the colonies introduced will forage from the crop. We have recorded bees flying 5 km to reach a white clover field. If a crop is less attractive, many hives may need to be introduced to ensure that at least some of the bees visit the crop.

Area of the crop

The larger the area of the crop, the fewer the number of colonies that will be needed per hectare. If there is a large area of the crop, there will be a relatively large number of hives introduced at a standard stocking rate. The effect of any competing flowers outside the cropping area will be much less. An example of this is kiwifruit where, in some parts of New Zealand, this crop is almost a monoculture. At eight hives per ha, there may be more than 800 hives per km^2. In those cases there are so many bees that the effect of competition around the edges will always be minimal compared with a single hectare of a crop surrounded by competing flowers.

Perhaps the only exception to this is where the crop is particularly attractive or there is a large number of feral honey bees surrounding a crop.

Number of flowers in the crop

The number of flowers affects the number of bees needed and hence the number of hives. If there were no competing flowers, there would be a simple relationship in which doubling the number of flowers per hectare in the crop would require doubling the number of bees. However, often many of the hives are introduced to ensure that at least some of the bees visit the crop, because others are visiting the flowers outside the crop. In such cases, doubling the number of flowers in the crop will usually require a smaller increase in the number of hives required.

Deciding on hive numbers

Past experience

If you have grown the crop previously you will have a good indication of how many hives to use the following year, assuming the strength of the hives and the number of hives in the surrounding area are the same. If the degree of pollination the crop received last year was adequate, consideration should be given to using the same number of hives next season. You could reduce hive numbers, although it would be risky as pollination might suffer. If pollination was insufficient, it would be worth increasing hive numbers.

Likewise if there appears to be more or fewer competing flowers nearby than in previous years, consideration should be given to changing hive numbers.

Others' experience

If it is a new crop, it is worth discussing the number of hives used by others in the area growing the same crop. The beekeeper supplying the hives may also be able to provide information on how many hives other people are using. However, the further away these other crops are, the less reliable the information will be.

Trial and error

This may consist of introducing hives and monitoring the results by assessing the number of bees on the crop and the rate of pollination.

As a general principle, the cost of hives is usually small compared with the value of a crop, so it is better to overestimate the number of hives than to underestimate.

It is better to overestimate hive numbers needed for pollination than to underestimate them.

Chapter 6

Crop management to enhance pollination

Conditions within the orchard

Landmarks

Bees use landmarks for their orientation when flying, which can result in problems in some crops. The bees can become confused when blocks look similar. In such situations, groups of bees can often be seen flying in circles looking for their hives, which may be in the next block. It has been suggested that coloured markers, flags or any other thing to break up the monotony of blocks may assist bee orientation, but this has not been tested. The disorientation usually looks worse than it actually is. Many of the confused bees are probably house bees going on orientation flights, or bees visiting other flowers outside the crop, and hence of little importance for pollination. The disorientation appears to be short lived, as the number of disorientated bees does not appear to continue to increase during the flowering season. Disorientation is, therefore, a problem that can usually be safely ignored.

Water

Like other animals, bees need water. If there is no water easily available to bees, it may be useful to provide it. A dripping tap or a sack hanging over the edge of a bucket of water may be sufficient. This will help to reduce the number of bees visiting the neighbour's swimming pool.

In arid conditions, larger amounts of water may need to be provided and this should be discussed with the beekeeper. In some states of Australia it is a legal requirement for beekeepers to supply water for their bees.

Wind

Bees do not like flying in strong winds. Wind in excess of 15 km/h will reduce bee activity, and few bees will leave their hives when wind velocities are in excess of 20–25 km/h[46]. It is therefore important to place colonies in a location that is protected from strong winds.

Mowing orchards

It is sometimes suggested that the weeds in or under a crop should be left to encourage bees to stay in the crop. This is, however, unlikely to improve pollination, as the bees visiting the weeds will not generally also visit the flowers of the crop. It is therefore, useful to keep the weeds mown while the crop is flowering. As a general practice, it is useful to remove as many competing flowering plants as possible.

It is good practice to remove competing flowers growing around or under a crop.

Pesticides

In many northern hemisphere countries, there are reports of large numbers of colonies dying. One of the popular theories blames the pesticides that are used in and around crops. Although it is still unclear to what degree pesticides are the cause of the bee losses, honey bee poisonings due to pest control chemicals do occur in most countries, including New Zealand and Australia.

Bee poisonings initially affect the beekeepers who are trying to derive their income from the bees. This may either reduce their willingness to supply hives for pollination or increase the fees that they charge. If the poisoning occurs when the crop is flowering, it may also reduce the of pollination, as foraging bees will be killed.

Bee poisonings have several common symptoms, such as large numbers of dead bees at the entrance of the hive (Figure 51). It is common to see a few dead bees at the hive entrance but thousands suggest they have been poisoned. Another symptom is live bees outside the entrance that have a very jerky motion.

It is good practice to remove competing flowers growing around or under a crop.

Pest control has changed over time. Historically most pest control chemicals were 'broad spectrum' so that they would kill a wide range of invertebrates. However, with advances in chemistry, there has been a move to pesticides that are increasingly species specific. Although this has resulted in many chemicals being safer for honey bees, it has made the issue more complicated, as some pest control chemicals can safely be applied to flowers without killing bees while others cannot. Even with these safer chemicals being available, many of the older broad-spectrum chemicals are still being used.

Poisoning of hives introduced to a crop can occur because the grower has applied a bee-toxic chemical to flowers in the crop. However, even if growers are very careful about the pest control chemicals they use, poisoning can still occur. Honey bee colonies have large flight ranges, so the bees from the colonies introduced to an orchard may be foraging on flowers up to 5 km away and be poisoned there. It can therefore be useful to remind neighbours that hives are being brought in for pollination and ask them not to put toxic sprays on flowers.

Figure 51. Dead bees outside their hive.

In some crops where sprays can cause significant bee deaths, growers, beekeeper organizations and chemical companies work together to put in place education programs designed to prevent bee poisonings. These programs may include seminars, mail drops, published articles and even erection of roadside signs.

There is a large variety of chemicals used to control insect pests that are also toxic to honey bees. The list (Appendix 2) does not include everything that is toxic to honey bees and new chemicals continue to become available to pose a threat to honey bees. The chemicals vary in their toxicity and under what conditions they are toxic. Some are very toxic and are used to eradicate bees from an area when there is an exotic bee pest to eliminated. Some lose their toxicity very quickly, while others are not toxic when they are dry, and some are only mildly toxic.

Faced with this bewildering array of chemicals, the simplest way not to poison bees is that if a chemical is toxic to bees, it should not be applied to flowers that are being visited by bees or are likely to be. In New Zealand and Australia, the pest control chemicals come with instructions that will describe whether they can be safely applied to flowers.

Tell your neighbours you are introducing hives so they do not inadvertently poison them.

The wording on warning labels on pesticide container might say:

- Don't apply to flowers that are, or are likely to be, visited by bees.
- Don't apply to flowers that are, or are likely to be, visited by bees, except in the evening.
- The spray must be dry before it makes contact with bees.
- Do not spray on flowers that are being visited by bees.
- Can be applied while bees are foraging.
- Dangerous to bees. Avoid direct application or drift of the spray mix onto beehives.
- Dangerous to bees. Do not apply to any areas where the crop, weeds, or cover crops are in flower at the time of spraying, or are expected to flower within 28 days of spraying (7 days for pastures or sorghum).
- Dangerous to bees. Do not spray any plants while bees are foraging. Ensure beehives are removed from the area to be treated and from adjacent paddocks.

Sprays that are non toxic to bees can be used during the flowering season. It is, however, important to wash the tank out first.

If applying bee-safe chemicals to flowers, ensure the spray tank is washed thoroughly beforehand.

Spray drift

One of the most common causes of bee poisoning is spray drift. This is where a pesticide has been applied to a crop that is not in flower but has drifted onto flowers of other plant species. This problem can often be eliminated by mowing underneath the canopy of horticultural crops before spraying. It is much more difficult with flowering weeds growing amongst a crop. In this case, only non bee-toxic chemicals should be used.

Fungicides

It had been assumed that most fungicides are not toxic to adult honey bees. Although this is probably correct, a recent study has demonstrated that the pollen collected by bees from flowers sprayed with fungicides becomes contaminated with fungicides. Some of these fungicides are toxic to honey bee larvae when fed at the same concentration[47].

The effect of fungicides on honey bee larvae has not been extensively researched, so that a complete list of fungicides that are likely to be toxic to larvae is not reported. Also, fungicide warning labels do not normally include warnings about honey bee larvae.

It is therefore good practice not to apply fungicides to flowers unless it is essential for disease control. If the safety of the fungicide to honey bee larvae is not known, the issue should be discussed with the beekeeper before it is applied to flowers.

Some fungicides can also affect pollination by affecting the pollen grains' ability to germinate on the stigma[48], which may adversely affect pollination. Unfortunately, there have been few investigations on how frequently this will be a problem.

Where possible, avoid spraying fungicides onto flowers.

Surfactants

Surfactants are used to improve the effectiveness of chemicals, to decrease the droplet size or to increase the penetration of chemicals on a plant or insect. Some surfactants used with insecticide and fungicide sprays are toxic to bees. When water is sprayed onto bees it usually forms discrete droplets on the surface and does not damage the bees (Figure 52). However, surfactants allow the water to penetrate the body hairs, which will kill bees (Figure 52)[49]. Unfortunately, the toxicity of most surfactants has not been tested and they do not carry bee warning labels. Unless it has been demonstrated

Figure 52. A honey bee sprayed with water (top) and a surfactant (bottom).

that a surfactant will not kill bees, it should not be applied to bees even if the pesticide with which it is mixed is non-toxic to bees.

Don't spray surfactants onto honey bees unless they have been shown to be bee-safe.

Water itself can be a problem if it is cold or if it is applied at high pressure or high volume (Figure 53). The effect is similar to when surfactants are used (Figure 54).

To avoid killing bees and adversely affecting pollination, it is good practice to avoid applying even bee-safe chemicals while bees are visiting the crop. Care should also be taken to avoid applying sprays directly onto beehives.

Do not apply sprays or water directly on bees or beehives.

Figure 53. A clover field being irrigated.

Figure 54. A bee affected by irrigation.

Removing beehives before spraying

Growers sometimes have their beehives removed if they have to apply an insecticide and the crop is still flowering. This eliminates bee deaths but great care is needed to ensure that there are no other colonies in the area. It is important to remember that the bees may be flying up to 5 km to visit the crop if it is particularly attractive.

Mowing grass sward

Although it is important to mow the grass sward before spraying bee-toxic pest control chemicals to avoid killing bees, the mowing itself may kill bees. Some mowers are reported to kill over 60% of the bees visiting flowers in the sward when it is mown[50]. The best way to avoid killing bees is to mow early in the morning or late in the evening when the bees are no longer foraging .

Mow grass in the evening or morning when bees are not foraging, to avoid killing them.

Beekeeper/grower co-operation

A good practice when supplying or hiring hives for pollination is for the beekeeper and grower to discuss the spray program that will occur when the hives are in the crop. This will allow a plan to be developed to minimize any negative effects on honey bees or pollination.

Further information on protecting bees from pesticides can be found in the book 'Honeybee Pesticide Poisoning – A risk management tool for Australian farmers and beekeepers' published by the Australian Rural Industries Development Cooperation.

Problems with poor pollinizer distribution or no pollinizers

Orchardists sometimes find themselves with areas planted without the appropriate pollinizers, either because they were not planted or because they are flowering too early or late for the plants they need to pollinate. The obvious solution to this is to plant new pollinizers; however, this takes time and growers may want a temporary solution. A number of different solutions are available if this problem arises.

Importing flowering branches

Sometimes growers cut flowering branches off pollinizers and move them to areas where pollinizers are not present to improve pollination. The ends of the branches are placed in water to increase the longevity of the flowers. The branches are then either placed on the ground underneath the trees, or hung in the trees so the flowers on the branches are close to the flowers they need to pollinate. Placing them in the tree is preferable to being on the ground, as it is a shorter distance for the bees to move the pollen[51]. They will probably need to be replaced every 2 to 3 days. While this method will almost certainly aid pollination, it is questionable whether the benefits will be large enough to justify the effort. How many branches are required and how far apart they should be is not known and will depend on the crop. In a trial with plums, the bouquet only increased the fruit set on the side of the tree containing the bouquet[52], which suggests that their effect may be quite local. Apple trees with flowering branches from pollinizers produced four times as many fruit as trees without them[51]. Bouquets increased the fruit set in plums by about three times[52].

Bouquets may be worth considering if there are problems with insufficient compatible pollen in particular locations in a crop.

Hand pollination

Hand pollination can be carried out by picking flowers from the pollinizer and rubbing them on the flowers to be pollinated. This is usually successful as long as care is taken to check that the anthers on the flowers being picked are liberating pollen and the stigma on the flower being pollinated is still viable. Pollen from some species is produced commercially and can be brushed, blown or sprayed on to flowers (Figure 55). It is however, often both expensive to collect

Figure 55. Blowing pollen onto a kiwifruit flower.

and apply. Even so, there are well-developed artificial pollination systems. New Zealand harvests approximately 300 tonnes of male kiwifruit flowers each year to extract about 3 tonnes of pollen, which is then reapplied to kiwifruit flowers.

It may not be necessary to put pollen on every flower. It has been demonstrated for kiwifruit that, if you put pollen on a flower, bees will pick up some of it and move it to nearby flowers[53].

Pollen from a range of plant species can be purchased from companies overseas. However, it is very important that if pollen is going to be imported, an appropriate import permit is first applied for, as pollen has been implicated in the spread of both plant and honey bee diseases.

Pollen dispensers

Pollen dispensers are devices that sit at the hive entrances and dust bees exiting the hive with pollen (Figure 56). Hopefully, the bees will then take the pollen to the flowers of interest and pollinate them. This system has the advantage that the process involves relatively low labour; however, the pollen must be purchased or collected in some way. For some plant species, this it is not possible, either because the flowers do not produce enough pollen, the pollen does not survive long enough, or the pollen is produced on flowers that are needed to produce the crop and therefore cannot be picked.

Figure 56. A pollen dispenser fitted to the front of a beehive.

Some of the pollen ends up being deposited on bees entering the hive rather than those leaving, some may get packed into the bees' pollen baskets rather than being placed on the stigma, and some pollen may be placed on bees that are visiting other flower species.

Pollen dispensers have been demonstrated to increase fruit set in trees in cages[54] and in almonds in the field[55]. There are also examples where they have been tested but were unsuccessful at increasing fruit set (e.g. apricots)[56].

As long as the pollen in the dispenser is viable, and the bees walk through it before visiting the flowers needing pollination, they will almost certainly pollinate flowers. The only question is whether this increase in the amount of pollination occurring is enough to result in a significant increase in the crop. If there is a pollination problem related to insufficient compatible pollen in a crop and a source of compatible pollen is available, it would be worth considering using pollen dispensers.

If there is a pollination problem, and pollen is available, it is worth considering using a pollen dispenser.

Chapter 7

Pollination under nets, glass and plastic

It is becoming increasingly common to grow crops under cover, either for commercial production or for research purposes. The crops may be a few square metres or many hectares in extent, as occurs with some large blueberry cages. Achieving pollination of crops grown under nets, glass or plastic does, however, provide a set of particular challenges. Any cover changes the temperature, light intensity and wavelengths, humidity and wind speed. These not only affect flowers, but also insects introduced for pollination. Because of the complications that often occur when pollinating covered crops, it is important to assess the rate of pollination the crop is receiving, to ensure it is optimized.

Both bumble bees and honey bees are used for pollination of covered crops (bumble bees are commercially available only in New Zealand). Bumble bees appear to be the most unaffected by being placed in a glasshouse or mesh cage and will forage normally in most situations (Figure 57). For this reason they are used extensively for glasshouse tomato pollination in New Zealand and in many other countries. Honey bees are also used extensively to pollinated covered crops, but there can be complications with their use.

Figure 57. Bumble bees being used in a mesh enclosure to pollinate onions in New Zealand.

The discussion on how to get the best out of honey bees under covered crops is complicated because of the large number of different designs and different materials that are available, many of which affect honey bee behaviour in different ways.

Plant protection

Plant protection chemicals can be more of a problem when used on covered crops than when used outside, as their evaporation and drying are very different. Depending on the chemicals to be used, it might be appropriate to remove the hives while the chemical is being applied and until dried.. If there are no bees inside the enclosure and they cannot fly in through open windows, it is possible to apply pest control chemicals directly to flowers without risking poisoning bees, which may happen if they were applied outside.

Effect on light conditions

Of particular importance is the amount of ultraviolet light excluded. Bees become confused and may not forage at all under material that absorbs large amounts of ultraviolet. Hail nets can also be an issue if they reduce light intensity too greatly. I have seen examples where the combination of the hail cloth and the foliage of the crop make it very dark, which reduces bee activity.

Wind

Covering a crop reduces or even eliminates wind, which reduces the rates of wind pollination. This needs to be taken into account before a crop is planted so appropriate decisions can be made on how pollination will occur. In many cases it will make insect pollination more crucial.

Temperature and humidity

High temperatures and humidities can be a problem. High humidity will dilute the nectar in the flowers and make the crop less attractive to bees, while high temperatures cause stress for foraging bees. Honey bees are able to cope with higher temperatures than bumble bees, which are adapted to operate in colder conditions. These problems can be minimized though adequate ventilation.

Distance between the crop and the cover

Bees usually fly over a crop to reach the flowers they are visiting. There may be problems if there is insufficient space between the crop and the cover for them to do this, which will make it difficult to achieve an even distribution throughout the crop. This situation can be improved by ensuring there is an even distribution of hives in the crop.

Open tunnel houses

Tunnel houses are usually covered with some type of plastic or similar material but may be open at each end (Figure 58). The hives are often situated outside the tunnel house and the bees fly into it to visit the crop. This approach appears to work well with little obvious disorientation of bees, especially if the crop is very attractive to bees (e.g. raspberries), the tunnel house is not too long, and it is not built of ultraviolet-absorbent materials. The bee numbers on the crop should be checked, however, to ensure that the bees are spreading evenly through the tunnel house. This may be a problem if the tunnel house is very long.

Figure 58. Open tunnel houses growing raspberries.

I have seen this system work well for raspberries, strawberries and cucumbers. If the crop is not very attractive to bees or the tunnel house is very long, hives should be spread throughout the crop, as bees often will not fly large distances in a tunnel house or glasshouse. It is important to check that there is an even distribution of bees across the crop.

Monitor the crop to determine that there is an even distribution of bees throughout the tunnel house.

If wet weather is a problem, it might be worth considering putting the hives under the edge of the plastic cover so bees do not need to fly through the rain to reach the tunnel house. If this approach is to be taken, it might be necessary to position the hives so that people who have to work on the crop during flowering do not need to be too close to the hives where they might get stung.

Fully enclosed glasshouses and mesh cages

Fully enclosed structures like glasshouses or net cages are much better suited for bumble bees than honey bees. Bumble bees do not appear to be disconcerted when confined and seem to have little problem finding their way to and from their hive to forage. However, bumble bees are often too expensive to use except for very high value crops and are not currently commercially available in Australia.

Honey bees

When honey bee hives are placed in a fully enclosed glasshouse, or a net cage, large numbers of bees appear confused. They will often be seen to bang their heads on the roof and accumulate in bunches in the corners of the glasshouse. They tend to stay in these bunches without foraging until they die. Large numbers may be found dead or dying on the floor of the enclosure.

The reason for the disoriented bees is at least partly because these are often the older bees that were flying large distances to forage before their hives were moved into the glasshouse. The bees try to fly the same distance and direction once they are in the glasshouse and become confused by the new unseen barriers. Although these dying bees can be disturbing and the loss of bees a problem for the beekeepers, they are not necessarily a problem for pollination. While this is happening there will probably be other bees behaving normally and foraging on the crop, although these are not usually as obvious as the disoriented bees. The crop should, however, be checked regularly to determine if enough bees are visiting the flowers.

The number of disoriented bees can be reduced in several ways:

1. Move the hives into the enclosure in the middle of the day, instead of the usual practice of moving hives at night. Most of the older foraging bees will be left behind and will move into any colonies left at the apiary. Leaving older bees behind will not negatively affect pollination as they were probably only going to be accumulating in bunches in the glasshouse and not visiting flowers. The younger, inexperienced bees in the hive will quickly start foraging and learn the boundaries of their enclosure.

2. Using smaller colonies may also reduce the number of disoriented bees. Often hives introduced into glasshouses or net cages have many times more bees in them than are required for pollination. In such situations it is not surprising that bees will want to try to leave the enclosure to forage elsewhere.

Even if the problem of disorientated bees is managed, a honey bee colony will usually be adversely affected if enclosed in a glasshouse or net cage. Along with the death of disorientated bees, there will also often be insufficient nectar and pollen for the colony. This will reduce the number of new bees being produced and the number of bees and amount of brood (developing larvae and pupae) will slowly decline, reducing the pollination performance of the hive. This can be rectified in several ways:

1. If the colonies are needed for more than two weeks, it may be worthwhile to swap them with others that are outside every week or so, to allow them to recover.
2. It is possible to add more brood or bees to a colony to increase its strength. Some beekeepers routinely do this in early spring to prepare hives for honey collection.
3. It is possible to keep honey bee hives in enclosures for longer periods of time if they are provided with an appropriate protein source and they have sufficient honey and water. In Israel they keep honey bee colonies in glasshouses for as long as three months. This feeding will need to be discussed with the beekeeper.

An artificial diet used successfully in Israel[57] consisted of:

- 20% sugar
- 20% honey
- 20% soy flour (toasted to prevent the activity of the trypsin inhibitor)
- 20% deactivated yeast
- 20% bee-collected pollen pellets. The pollen should be irradiated so that it will not spread bee diseases.

When mixed, the resulting diet should have the consistency of baker's dough. It is normally fed by flattening about 250 g of the diet and placing it on the frames above the brood nest, which is usually directly under the hive lid. More should be fed as soon as it is consumed. It may have to be replaced sooner if it starts to dry out.

Bumble bees

Depending on how the bumble bee colonies are set up, these may also need to be replaced if the crop is flowering for a long time. The company providing the bees will usually provide advice on how often this should occur and what feeding is required. Even with this advice it is good practice to check the activity of the bumble bee colonies regularly at the time of day they are usually the most active, to make sure the numbers foraging are not decreasing. The best way of doing this is to count the number of bees entering a hive over a set period of time, e.g. 2 minutes. The count should be done while standing behind the hive so returning bees can easily find their hive entrance.

Nets

Nets are most frequently used over crops to protect them from hail or birds. Bird netting is usually used to form a cage. If the hole sizes are large, the bees will pass through them relatively easily. However, bird net cages are sometimes made with mesh with holes smaller than they need to be, which will either trap the bees inside or make it very difficult for them to leave. Hail netting usually has small holes that bees cannot pass through easily; however, the sides are usually open, which allows bees to fly out from under the hail cloth.

In bird netting cages, and under hail cloth, there may be better visitation to the crop if the bees are placed inside the cage or under the edge of the cloth rather than outside. However, problems can sometimes occur if there is insufficient space for bees to fly between the net and the crop.

If problems occur, they will usually consist of bunches of bees on top of a hail net above where the hive is. The bees will have flown out from under the net to forage elsewhere and then flown back over the top of the net to try and reach their hive again, but have not been able to get through the net. Where this occurs, it usually looks worse than it is. A few hundred bees on top of a net will not usually be a significant loss to a colony containing 30,000 honey bees. The bees on top of the net will also usually not have been visiting the crop, so the loss will usually not have a negative impact on pollination.

Disposable colonies

In many situations the plants to be pollinated may not require large numbers of bees. In such cases, disposal colonies can be useful. This may consist of one or more frames of bees and brood with honey and pollen stores but no queen. Although they will not forage as heavily as a colony with a queen, they will forage and pollinate smaller areas for short lengths of time.

Providing food for bees

When honey bee and bumble bee colonies are used in glasshouses and cages for long periods of time, the bees will probably need to be fed. Most purchased bumble bee colonies will come with instructions on how to look after them; however, discussion will be needed with the beekeeper about feeding honey bee hives. Because they may be aggressive, a bee suit is required if a honey bee colony is to be opened and fed. The beekeeper supplying the hives will usually organize any feeding required, although beekeepers sometimes provide everything necessary for a grower to do it.

Bees will normally need to be provided with water if they cannot forage outside. The normal irrigation that occurs may be sufficient, or containers of water may need to be provided. If water is being provided, place something floating in the water to stop bees drowning on it. A sack hanging in a container of water is often a good solution.

Even with careful attention and feeding, honey bee colonies usually decline with extended time in a glasshouse or cage. Because of this it is important to monitor the number of bees visiting the flowers over time.

Monitor the number of bees foraging on the crop over the flowering season.

Chapter 8
Crops

This chapter discusses the pollination of a range of crops. It also discusses recommended honey bee stocking rates for some of the crops. These recommendations should be treated with caution as they depend heavily on the strength of the colonies, the area of the crop and the amount of competing flowers surrounding the crop.

Almonds

Pollination of almonds (*Prunus dulcis*) is very important. They need 30–60% fruit set to produce a commercial crop.

Almonds are one of the earliest crops to flower in the spring. The flowers have five petals, and a single stigma surrounded by a ring of anthers (Figure 59). They open before the tree produces leaves. The flowers produce both nectar and pollen. While the ovary contains two ovules, only one ovule normally develops into a seed and produces a fruit. The stigmas are usually receptive as soon as the flowers open. Almonds are not self fertile and pollinizers must be planted. Pollination has been reported as the most significant factor affecting crop yield[58].

Figure 59. Almond flower.

A wide range of insects visit almond flowers to collect pollen and nectar including flies, bumble bees (not present on mainland Australia) and honey bees. Honey bees are usually the most important pollinators because they can be managed and introduced to a crop.

Because almonds flower early in the spring, in many situations they may be the only crop flowering in an area. Although this has the advantage that there are fewer flowers surrounding the crop that may draw bees away from the almonds, it also means that almonds are often open in cooler conditions, which may reduce honey bee activity. Anything that can be done to site honey bee colonies in warm sheltered positions may encourage them to forage in colder conditions.

For many crops it is recommended that hives are not introduced until about 10% flowering; however, colonies can be introduced earlier to almonds when there are few competing flowers around the orchard. Even if there is competition, a few hives should be introduced at the start of flowering to ensure the early flowers are pollinated.

With the relatively high fruit set required and the large numbers of flowers on the trees, fruit set often declines quickly as with increasing distance from a pollinizer. Honey bees will mainly forage on a single tree and if they leave this they are most likely to move to the next tree in the same row[59]. It used to be common for pollinizer rows to be every third row; however, it is now more common to plant them every second row.

It has been recommended that between 2.5[60] and 10 hives per ha[61] are used.

Because of the flower shape, pollen gatherers are likely to be better pollinators than nectar foragers. Many nectar foragers collect nectar from almond flowers without touching the stigma (Figure 60). Pollen gathers have a greater chance of contacting the stigma, as they scramble over the anthers to collect pollen, so there is a high frequency of contact with the stigma. Managing colonies so that they have a high demand for pollen may assist pollination. Feeding sugar syrup[62] and pollen trapping have both been reported to increase the number of foragers collecting pollen from almond flowers[63].

Figure 60. A bee collecting pollen from an almond flower

Apples

Apple (*Malus domestica*) flowers have five stigma surrounded by anthers. The ovary has five carpals, each with two to four ovules. An apple may therefore have between 10 and 20 seeds depending on the variety.

Each group of flowers has a main flower called the king bloom which opens first and usually produces the best fruit if pollinated.

Most varieties of apples are not self fertile and need pollen from another variety. Flowers that are not pollinated are soon shed by the plant. If apples are not adequately pollinated, especially if only the ovules on one side of the flower have been pollinated, the resulting fruit may be misshapen.

Apple pollen can be carried in the wind; however, trials suggest that this is usually not significant for pollination[64]. Apple flowers are mainly pollinated by insects. Although a large number of insects visit apple flowers, honey bees are usually the most important pollinators and should be introduced to orchards (Figure 61). Studies have shown that the more bees recorded on flowers, the higher the fruit set[65].

Figure 61. Apple flowers.

The flowers of most varieties of apples are attractive to bees. They flower early in the spring, so there is often little competition from the flowers in the vicinity of the orchard.

As most varieties are not self fertile, they must be planted with a pollinizer. Good advice should be sort when choosing a pollinizer as it has to flower at the same time and not be too closely related to the trees being pollinated. The best distribution would be to have a pollinizer in every row, as bees are more likely to move up and down rows than between rows. This is usually excessive, however, as too much area has to be devoted to pollinizers. A good compromise between pollination and the area devoted to pollinizers would be to have the pollinizer as the third tree in every third row. In this arrangement every pollinizer is surrounded by fruiting trees and every fruiting tree is next to a pollinizer tree in the same or next row. To achieve the best pollination, the pollinizer should be offset so they are not in the same position in every third row.

P = POLLINIZER F = FRUITING VARIETY

P	F	F	F	F	F	F
F	F	F	F	F	F	**P**
F	F	F	**P**	F	F	F
P	F	F	F	F	F	F
F	F	F	F	F	F	**P**
F	F	F	**P**	F	F	F
P	F	F	F	F	F	F
F	F	F	F	F	F	**P**

As it is not usually necessary that every apple flower is pollinated, hives are not usually introduced until after 10% flowering, to ensure there are enough flowers to encourage the hives to forage in the orchard. Pollen-collecting bees are better pollinators than nectar-collecting bees, as they have greater stigma contact. It may therefore be worth managing hives to promote pollen collection, by ensuring they have a lot of brood and are fed sugar syrup or have pollen traps fitted.

Stocking rates between one[66] and 1267 hives per ha have been recommended. Four hives per ha is common. It has been reported that the optimum bee number that should be seen on trees is 12–145 bees/tree/minute[8].

Apricots

Apricot flowers (*Prunus armeniaca*) have about 30 stamens and one pistil. The blooming period usually lasts for one or two weeks. Some varieties are self compatible, while others are not. 'Sundrop', a cultivar planted widely in New Zealand, needs cross pollination[68]. Apricots will therefore usually need to be inter-planted with an appropriate pollinizer.

Honey bees are important pollinators of apricots[69]. They visit flowers to collect both nectar and pollen. However, because apricots flower early in the spring (mid August)[70], the weather is often cool and rainy and will often not be suitable for honey bee foraging and pollination can be difficult. The flowers are also often not very attractive to honey bees, as their nectar has very low concentrations of sugar[71], which will cause bees to move onto more attractive crops if they are available in the vicinity.

Pollen foragers are reported to visit apricot flowers faster than nectar foragers[70] and are also more likely to touch the stigma while foraging and are therefore better pollinators.

It has been suggested that for adequate pollination, a minimum of two bees need to be seen in a 30-s search of a tree[72]. It is recommended that five hives each containing at least 22,500 bees are used per ha[70]. Using colonies with a high demand for pollen will increase pollen collecting, as will trapping pollen and feeding sugar syrup.

Pollen dispensers have been tested with apricots but have proved unsuccessful[73].

Avocado

Avocado (*Persea americana*) trees can reach 18m high, but they are usually between five and nine metres in height. Trees can appear completely covered with flowers (Figure 62). In New Zealand and Australia flowering is typically spread over six to eight weeks. The flowers are small and inconspicuous (10 mm diameter) and contain a single stigma surrounded by six anthers. The stigma becomes receptive when the flowers open. The flowers are usually open for 2–6 hours, then close and open again for 2–6 hours on the second day. When a flower opens for a second time, it produces pollen and the stigma is not receptive. The flowers then close and remain closed. Flowers in their female phase can be recognized by the anthers, which lie flat along the petals (Figure 63). When the flowers are in their male phase, the anthers stand upright and flaps open at their tips to expose the pollen (Figure 64).

Figure 62. 'Hass' avocado tree

Flowers will usually be one sex in the morning, closed in the middle of the day and the opposite sex in the afternoon. The timing of the sex phases can be quite defined, but environmental conditions will affect the timing and duration of the male and female phases.

Avocado cultivars are classified in two groups (A or B) based upon their flowering behaviour[74]. In the type 'A' cultivars, the female organs are receptive to pollen in the morning and the pollen is released in the afternoon. In the type 'B' cultivars, the pollen is released in the morning, while the female organs are receptive in the afternoon. Type 'A' cultivars include: 'Hass', 'Gwen', 'Lamb Hass', 'Pinkerton', 'Reed', 'Gem', and 'Harvest'. Type 'B' cultivars include: 'Bacon', 'Ettinger', 'Fuerte', 'Sharwill', 'Sir Prize', 'Walter Hole', 'Zutano', 'Marvel' and 'Nobel'. Both type 'A' and 'B' cultivars are often planted in orchards to allow cross pollination. In New Zealand, some orchards are planted solely with the fruiting variety 'Hass'. How these are pollinated is unclear. It is likely that there is sufficient overlap in the opening times of male and female phase o allow pollen transfer between flowers on the same tree.

Figure 63. Avocado flowers in their female phase with anthers lying flat along the petals.

Figure 64. Avocado flowers in their male phase. Notice the upright anthers with the flaps open at the tip of the anthers to expose the pollen.

Studies in New Zealand[6] and Spain have shown that hand pollinating flowers can significantly increase fruit set. Typically, fruit set can be increased from less than 0.3% to more than 5%. This suggests that the fruit set in some orchards may be limited by inadequate pollination. The reasons of this sub-optimal pollination have yet to be established. They may be in part due to orchard design.

Although there is only one seed in an avocado fruit, more than 20 pollen grains need to be deposited on the stigma before a flower will produce a fruit.

The trees are normally planted with large gaps between trees when they are young. However, pollinators such as honey bees tend to move from a flower to the next closest flower so they will probably not readily move between trees. As the trees grow larger, the gap between trees decreases. Although this will probably increase the movement of pollinators between trees, the pollinators are less likely to move completely around a tree.

Pollination usually requires an insect vector. In Central America the avocado is pollinated by social bees (*Meliponinae*) and wasps (*Vespidae*). In other regions of the world, honey bees (*Apis mellifera*) are the main pollinators. In parts of Australia, large numbers of hover flies visit avocado flowers. Their importance as pollinators has not been measured.

The timing of colony introduction is important because avocado flowers are not highly attractive to honey bees. Hives should be placed in the orchard when flowering is at 5–10%. This will encourage honey bees to exhibit fidelity to the avocado bloom.

Flowers in both their female and male phases produce nectar. However, as insects can collect pollen only from male flowers, only nectar foraging bees usually visit both female and male stage flowers and contribute to pollination (Figures 65, 66). Honey bees only collect small pollen loads but may collect enough nectar to produce a honey crop for the beekeepers if there are sufficient trees.

As only nectar foragers pollinate avocado flowers, colonies should be prepared that have a high demand for nectar.

Two[75] , eight[76] and 10[77] hives per ha have been recommended. Rates between five and eight hives per ha are common. It has been reported that the for optimum pollination, 40[77] bees should be seen on a 5–6 m high tree.

Figure 65. Honey bee probing an avocado flower with its tongue to collect nectar.

Figure 66. A honey bee collecting avocado pollen with a small pollen pellet on its leg.

Blackberries

Blackberry (*Rubus* sp.) flowers are usually white with four petals (Figure 67). The stigma are surrounded by 50 to 100 anthers. Nectar is produced in a cup at the base of the petals. They start producing nectar as soon as the flowers open and continue until after the petals have fallen[78].

Figure 67. A honey bee visiting a blackberry flower.

There are a large number of varieties of blackberry with different degrees of self fertility. It has been suggested that several different cultivars should be planted to ensure cross pollination[79]. Certainly, if planting blackberries, advice should be sought as to whether the variety being considered needs cross pollination. They probably all benefit from bee visits to spread pollen to the stigma. As an example of this, the cultivar 'Thornless Evergreen' is self fertile but honey bee pollination results in better yields. The stigma are receptive for the first three days the flowers are open[75] . Honey bees visit blackberries to collect both pollen and nectar.

The flowers are usually attractive to bees and beekeepers can at times collect a honey crop from wild and cultivated blackberries.

Because blackberries are very attractive, there may be sufficient insects visiting flowers without introducing beehives. However, for commercial production the low risk approach is to introduce beehives unless it has been shown that they are not needed. It has been suggested two hives of 30,000 bees per hectare are sufficient for pollination[80]. Because the flowers are usually very attractive to bees, they can be introduced at the start of flowering.

Blackcurrants

Blackcurrants (Genus species) have a small bell-shaped flower with white petals that are attached to a raceme (Figure 68). The flowers hang downwards. The size of the berry is related to the seed number and the rate of pollination[81]. A well-pollinated blackcurrant will have about 30 seeds. Different varieties have different rates of self pollination. This appears to be dependent on the relative lengths of the anthers and stigma[82].

Figure 68. Blackcurrant flower

Flowers on the same plant may have stigma above, at the same height, or below that of the anthers. Cultivars with a high percentage of flowers with stigma at the same height or below the anthers have a higher rate of self pollination. They are able to set fruit when bagged to prevent insects visiting flowers and shaken by hand or by the wind[83].

Flowers at the base of the raceme tend to have larger stigma and are more likely to be self pollinating. Because of this, fruit set and fruit size both increase toward the base of the raceme.

Fruit abortion occurs because of both poor pollination and nutritional problems. The degree with which blackcurrants benefit from out-crossing is unclear. Some trials report increases in fruit set when varieties are planted together[84]. Other trials were unable to find increases[83]. It is common practice now not to interplant varieties for pollination.

Fruit set and the number of seeds are improved with honey bee pollination[85]. Beehives should therefore be introduced for blackcurrant pollination. Most bees (>90%) visit blackcurrant flowers to collect nectar (Figure 69), so colonies with large numbers of foragers should be introduced, so they should have a high demand for nectar.

Stocking rates between three[85] and eight colonies per ha have been recommended. Considering the high sensitivity to pollination, at least eight hives should be used per ha.

Figure 69. A honey bee collecting nectar from a blackcurrant flower.

Blueberries

There are two main types of blueberry (*Vaccinium* sp.) grown in New Zealand and Australia. These are highbush, and rabbiteye blueberries.

Blueberry flowers are bell-shaped and hang facing the ground (Figure 70). There is a central stigma surrounded by 10 shorter anthers. The sigma often extends out of the flower. Blueberry flowers produce both pollen and nectar. Pollen is produced for up to 5 days.

Figure 70. Blueberry flower.

A blueberry flower is capable of producing up to 50 seeds. Berry weight increases with seed number. There are, however, factors other than seed number that also affect blueberry weights.

Blueberries are insect pollinated. The most significant pollinators are honey bees that visit flowers to collect nectar and or pollen (Figure 71). In a study in Australia, honey bees comprised 95% of all insect visitors[86] In New Zealand, bumble bees are also frequent visitors (Figure 72).

Figure 71. A honey bee collecting nectar from a blueberry flower.

Bumble bees are not suitable for the pollination of all blueberry varieties. Bombus terrestris, which is produced commercially, has a short tongue and cannot reach the nectar of some cultivars. They will sometimes bite holes in the side of the flowers to reach the nectar without touching the stigma, and honey bees will also use these holes to collect nectar. Short-tongued bumble bees could therefore potentially reduce the rates of pollination of some varieties.

Figure 72. A bumble bee collecting pollen from a blueberry flower.

Highbush

The degree of self fertility of highbush flowers appears to vary with variety and location. Most, however, appear capable of setting fruit without cross pollination and self pollination frequently produces a similar fruit set. The number of seeds and fruit weight will usually be increased with cross pollination. It is also reported that that cross pollination may cause fruit to ripen up to a week earlier[87].

If planting highbush blueberries, it is important ask whether the cultivar would benefit from inter-planting with a second variety to ensure cross pollination. Even if a block of a single variety is already planted and producing, it may still be worth checking if better production could be achieved with inter-planting with another cultivar to ensure cross pollination.

Rabbiteye

Rabbiteye blueberry varieties are mostly self infertile and cross pollination is required.

Planting designs to facilitate cross pollination

When planting a second variety for cross pollination, the different varieties need to be in different rows if the fruit from each variety need to be kept separate. The best design would be to have alternate rows of each variety. Not quite as good for pollination, but possibly easier to manage, would be to have every third row planted with a second variety.

Honey bee stocking rates

Stocking rates between one and 10 hives per hectare have been recommended; however, eight or more hives per hectare would seem appropriate for most blueberry crops.

Assessing pollination

As a management tool it is good practice to mark and count flowers and then count the number of fruit produced to determine if pollination rates are optimized. Counting the seed number in fruit on a regular basis is also worthwhile.

Buckwheat

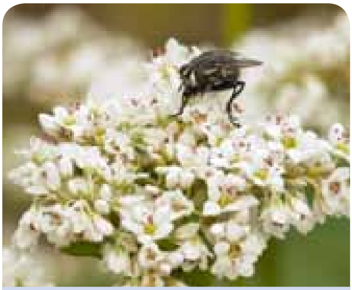

Figure 73. A fly visiting buckwheat flowers.

Buckwheat (*Fagopyrum esculentum*) (Figure 73) flowers occur in clusters, mostly at the top of the plant. The flowers have eight stamens surrounding a central style, which has three stigma. The stigma are receptive only for one day.

There are two forms of flowers. One form has long stamens and a short style and the other form has short stamens and a long style that projects above the anthers. A single plant usually only has one form of flowers. Although a small degree of self pollination is possible (i.e. pollen from the same flower type), pollination is most effective with pollen from the opposite type[88]. Self pollination is reported to only give 0.5% seed set compared with 44% set with insect visitation[89]. Varieties with higher rates of self fertility have been developed.

The flowers have eight nectaries spread around the base of the ovary, which secrete large amounts of nectar in the morning[90]. The amount of nectar produced and its concentration varies with cultivar and the year[83]. A plant may have up to 2000 flowers and flowering may take up to 30 days.

The flowers are visited by insects to collect both pollen and nectar. Honey bees are the most common visitors of buckwheat and can be most easily managed. In sufficient densities, each flower will receive more than 40 visits; however, seed set is usually not improved with more than two visits[91].

It has been recommended that between five and eight honey bee hives per ha should be introduced for buckwheat pollination[83].

Carrots

Figure 74. A male fertile carrot umbel.

Pollination of carrots (*Daucus carota*) is important for commercial seed production. Carrot flowers are in the form of an umbel (Figure 74). There is usually a primary umbel, which is produced first, and then a series of increasingly smaller lower order umbels. The primary umbel is the most important for seed production. The plants will flower for between 4 and 6 weeks.

The umbel is made up of groups of individual florets. The florets are presented in a number of discrete groups of flowers. The flowers around the outside of the group open first and those in the centre last. It takes about 7 days for all the florets on an umbel to open. The anthers dehisce during the first and second day after the flowers open[83]. The stigma remains viable for about a week[83].

Although carrot flowers have both male and female parts, much seed production has shifted to hybrid seed production. To achieve this, lines that are male sterile (Figure 75) or male fertile are produced. A male-sterile line produces the seed and has non functional male parts. The pollen must be moved from a male-fertile line to a male-sterile line, producing hybrid seed. As only the male-fertile lines produce pollen, pollen-foraging insects will not normally visit both male-fertile and male-sterile lines except by accident. Usually only nectar foragers visit both lines and pollinate the crop.

Hybrid carrot crops are usually planted with five or six male-sterile lines interspersed with three male-fertile lines.

Some lines appear to be very attractive to insects (Figure 76). The difference in attractiveness was probably due to the amount of nectar being produced.

Although a number of insects visit carrot flowers and pollinate them, some species of flies may be better pollinators than honey bees. Honey bees tend to stand high enough so their bodies do not have good stigma contact, which reduces their effectiveness (Figure 77). They may, however, transfer some pollen with their feet. Currently, honey bees are the only insects that can be managed in sufficient numbers to provide the necessary pollination services.

Large numbers of honey bees need to be introduced to pollinate carrots. They need to be prepared so they have a high demand for nectar. As the crop flowers for 6 weeks, it is worthwhile considering introducing further hives as flowering progresses to replace any foragers that have deserted the crop. Because some hybrids appear not to be particularly attractive to bees, it is

Figure 75. A male sterile carrot floret.

Figure 76. A carrot flower with three species of insects visiting it.

Figure 77. A honey bee collecting nectar from a carrot umbel.

important there are sufficient bees visiting the crop. We do not currently have enough information to be able to recommend a particular density of honey bees that should be observed, but it is possible to check for differences in the number of bees visiting flowers throughout the season. With this approach the counts should be done at the time there is the peak honey bee activity for the day. This may necessitate carrying out several counts during a day. If the number of bees counted starts to decline through the flowering season, more colonies should be introduced.

Bees are mostly visiting carrot flowers for a nectar reward. Colonies should therefore have large numbers of bees. Sugar syrup should not be fed and pollen traps should not be used, as both of these measures increase the number of pollen foragers.

Feijoas

Feijoa (*Feijoa sellowiana*) are evergreen plants that grow up to 6 m in height. The fruit are green and contain 20–30 seeds (Figure 78).

Feijoa flowers are about 4 cm in diameter and have four fleshy petals that hang down when the flower is open (Figure 79). The flowers have more than 60 white anthers at the end of long red filaments. There is a single red style that projects several cm above the anthers.

Some feijoa cultivars are self fertile and others self sterile. Even those that are self fertile benefit from cross pollination[83]. They typically suffer from high rates of flower and fruit abortion, which are thought to be due to poor pollination[92].

Flowers are visited by a number of insects and birds. The petals of feijoa flowers have a high sugar content and are collected by birds: blackbirds, mynas and silvereyes in New Zealand[92]. Silvereyes were less effective pollinators than mynas and blackbirds because of their small size. Honey bees visit feijoa flowers to collect pollen, but are reported to be less efficient pollinators than birds when making a single visit to a flower[92]. This is probably because of the relatively large distance between the anthers and the stigma.

It has been suggested that honey bees should not be placed in feijoa blocks and that birds should be encouraged by positioning nesting boxes[92].

Figure 78. Feijoa fruit.

Figure 79. Feijoa flower.

However, honey bees do visit the flowers and add pollen to the stigma, although smaller amounts than are deposited on the stigma by birds. Honey bees are likely to visit an individual flower more often than birds, which is likely to improve their effectiveness. It is clear that the presence of birds in feijoa orchards should be encouraged; however, it may also be worthwhile introducing honey bees.

If honey bees are being introduced to feijoa orchards, they should be managed to increase their demand for pollen by maximizing the brood to bee ratios in the hives, feeding sugar syrup and/or using pollen traps.

Field beans and Broad beans

Field beans

Field bean flowers have a standard petal, two wing petals and two lower petals joined along one edge to form a keel. There are 10 stamens, nine of which are enclosed along most of their length in a sheath. The 10th (upper) stamen is usually exposed along its complete length. There is a single ovary with 2–4 ovules. The flowers reopen each day for about a week.

When the flower is tripped, the style, which has long hairs, brushes the pollen out of the keel and places it on the visiting insect. The rates of self fertility often vary between plants in a crop. Some may set seed without being visited by an insect, while others need an insect visit to set seed[83].

Trials with plants in cages with or without honey bees have demonstrated field bean pollination benefits from honey bee pollination[93].

Broad beans

Broad bean (*Vicia faba*) flowers (Figure 80) are similar to field bean flowers. Honey bee pollination does, however, appear to be more important in broad beans.

The main insects visiting bean flowers are honey bees and bumble bees. Honey bees and short-tongued bumble bees can usually collect only pollen from the flowers and not nectar. Short-tongued bumble bees (present in New Zealand and Tasmania) will, however chew holes in the base of the flower to reach the nectar, without pollinating the flowers. Honey bees will then use the holes to reach the nectar. It is possible, therefore, that short-tongued bumble bees may be detrimental for pollination of broad beans.

Figure 80. A honey bee visiting a broad bean flower

Kiwifruit

Kiwifruit (*Actinidia* sp.) are fruiting vines. When grown commercially they are usually grown on T-Bars or pergola trellis (Figure 81) about 2 m off the ground.

Female (Figure 82) and male (Figure 83) flowers are borne on separate vines. Neither male or female flowers produce nectar; however, both produce pollen. The pollen produced by the female flowers is not viable but is still collected by insects. The female pollen has little nutritional value for the insects that collect it[94].

Female *A. deliciosa* 'Hayward' flowers usually liberate pollen for five days after they open. The stigma are viable and the flowers can set a full size fruit for up to 7 days after the flowers open[95], even though the petals may have fallen and the stigma may have dried and shrivelled by this time. Female *A. chinensis* 'Hort16A' flowers produce pollen for 2 days. The stigma viability is at its highest the first two days after opening, after which time it starts to decline.

Greater than 90% fruit set is usually required for a commercial crop. Since fruit size increases with the number of seeds, pollination is very important. A fully pollinated 'Hayward' fruit will normally have more than 1200 seeds, while a fully pollinated 'Hort16A' fruit will have approximately 700 seeds.

In commercial orchards, male vines are inter planted with female vines with distributions of between 1:5 and 1:8 male:female vines[96]. Male vines are also at times planted in rows across the rows of female vines when they are trained on t-bars, or at the same height as the canopy when they are trained on pergola trellis (strip males).

A large number of insect species visit kiwifruit flowers; however, most flowers are pollinated by honey bees that are introduced to orchards for this purpose (especially in New Zealand, Australia and Chile).

Figure 81. Kiwifruit trained on pergola trellis.

Figure 82. Female kiwifruit flower.

Figure 83. Male kiwifruit flower.

Male kiwifruit pollen is dry and can be blown from flowers, so there is often a small amount of wind pollination. When there are few bees present, large amounts of pollen accumulate on male flowers[97], which can be blown towards female flowers with a fan. Much of the pollination of 'Hayward' flowers in Italy occurs by growers using fans to assist wind pollination (Figure 84). There is probably little value in using fans in orchards were there are high bee densities.

Figure 84. Blowing kiwifruit pollen in Italy with a fan.

Honey bee pollination

Honey bee colonies are usually introduced to orchards at 10–15% flowering. If high rates of fruit set are required, it may be useful to introduce a small number of colonies earlier.

If there are large numbers of competing flowers, bees may be drawn away from this crop. This effect can be minimized by not introducing all hives at the same time but introducing half at the beginning of flowering and the remainder at about 50% flowering (split introductions).

Colonies are usually introduced at stocking rates of between eight and 12 hives per ha. In New Zealand these are prepared to meet a minimum standard of four full-depth Langstroth frames completely covered with brood and 12 frames covered with bees.

The colonies are managed so they have a high demand for pollen. In New Zealand, all hives used for kiwifruit pollination are fed 2 litres of sugar syrup every second day they are in the orchards to increase the amount of pollen they collect[18,20]. Some beekeepers also use pollen traps or remove frames of pollen from hives to increase pollen collection.

Artificial pollination

Kiwifruit can be artificially pollinated. Approximately 13,000 pollen grains need to reach the stigma to produce a full sized fruit. Pollen can be applied by brushing the anthers of a male flower across the stigma of a female flower, by blowing pollen on to flowers (Figure 85), or by spraying pollen suspended in a liquid. There are a number of devices that can be purchased to carry out artificial pollination. Pollen can also be purchased in many countries. Dry pollen applications have the advantage that some of the pollen is deposited on other flower parts and can be redistributed by bees. However, pollination with dry pollen cannot

Figure 85. Blowing pollen onto kiwifruit flowers.

usually be used on wet flowers or in the rain. Pollen applied in solutions designed to maintain its viability can be applied in the rain.

Those marketing pollen, pollination devices and solutions can also provide advice on application rates.

Timing of artificial pollination

For the most efficient use of pollen, it should be applied to 'Hort16A' every 3 days and every 6 days for 'Hayward' flowers if it is being used to supplement honey bee pollination.

Artificial pollination is used on kiwifruit to either replace honey bee pollination or to assist honey bee pollination. The reasons for using artificial pollination will usually dictate a particular approach to artificial pollination.

Rain

If artificial pollination is being used during rain, the best approach is to use pollen suspended in an appropriate liquid. Dry pollen applications will generally not work well in rain.

Replacing bees with artificial pollination

Wet or dry applications can be used to replace bees; however, the artificial pollination needs to ensure that significant numbers of pollen grains reach the stigma to pollinate flowers fully. With the high cost of pollen, the most economic approach is to apply pollen to individual flowers rather than using general broadcast devices that waste large amounts of pollen that never reach a flower.

Linseed

Linseed (*Linum usitatissimum*) flowers have five petals, five stigma, five anthers, and an ovary with five locules. Each locule contains two ovules. Under good conditions, the flowers open in the early morning, followed closely by anther dehiscence. As the flowers open the anthers touch the stigma and deposit pollen.

The flowers are visited by insects including honey bees but trials on cultivar 'Antares' were unable to find any evidence that these visits increased seed production[98]. Linseed therefore appears to be completely self fertile and will not benefit from the introduction of honey bees or other efforts to increase pollination. Other cultivars may, however, be developed in the future that are not completely self fertile.

Despite the reported lack of self sterility[98], when growing linseed it is probably good practice to check with the supplier of the seed to determine whether the variety is completely self fertile.

Lotus, Birdsfoot trefoil

Birdsfoot trefoil (*Lotus corriculatus*) flowers have wing petals and keel petals. The flowers are mostly self incompatible, although some self-compatible clones exist[99]. In a trial, untouched flowers produced two seeds per flower, tripped flowers produced 340 seeds per flower and cross pollinated flowers produced 481 seeds[100]. The main pollinators are honey bees and bumble bees, which are large enough to trip the flowers.

Bees visit lotus flowers to collect both pollen and nectar. Twelve to 25 honey bee visits are needed for full pollination[101]. Pollen foragers produce more seeds per visit than nectar foragers[102]. Managing bees to promote pollen collection may therefore be of value. Five to six hives per hectare have been recommended for pollination[103].

Lucerne (alfalfa)

Figure 86. Lucerne flowers.

The lucerne (*Medicago sativa*) flower (Figure 86) is made up of five petals: the large standard petal, two smaller wing petals, and two petals that are fused and called the keel. The keel encloses the stigma and 10 anthers. Nectar is produced at the base of the petals. Depending on the variety, pods may have between 3 and 8 seeds.

The stigma and anthers are under tension. When this tension is released, the 'tripped' stigma and anthers snap against the standard petal and remain in that position[83]. A flower must be tripped to produce seed. Some flowers self trip under a range of environmental conditions, but self tripping results in self pollination. Because there is a range of self sterility in lucerne plants, only 17–46% of self pollinated flowers produce seeds[83]. Cross pollination is required for good seed yields from lucerne crops.

Cross pollination occurs when the flower is tripped by a bee looking for pollen or nectar. The force of the tripping usually traps the head of the bee that is visiting the flower. It must struggle to free itself and so becomes coated with pollen and deposits pollen it may have carried from another flower.

Because of the forces required to trip the flowers, only heavier insects like bees can usually trip lucerne flowers. These are usually honey bees, bumble bees, and in some countries leafcutter and alkali bees. In New Zealand, most lucerne pollination is carried out by honey bees because they are the easiest to manage and can be introduced to crops in large numbers.

Pollen gatherers normally trip the flowers when collecting pollen. Inexperienced nectar gatherers usually trip flowers while foraging as well, but soon learn to collect nectar from the side of the flower, which does not usually trip it. In 16 studies[83], an average of only about 1% of nectar foragers tripped the flower they visited.

Numerous methods can be used to increase the percentage of flowers that are tripped.

Increasing the number of pollen foragers

Because of their high rate of tripping flowers, increasing the number of pollen foragers visiting lucerne is likely to have the largest effect on pollination rates. Using colonies with a high demand for pollen, stripping pollen from colonies or feeding sugar syrup should increase the number of bees collecting pollen from lucerne and hence the number of flowers tripped. These methods have, however, not been adequately investigated in lucerne to know how effective they will be.

Increasing the number of nectar foragers

If only 1% of nectar foragers trip flowers, increasing the total number of nectar foragers visiting the crop by introducing more colonies should increase the number of flowers tripped. There are limits, however, on how far the number of nectar foragers can be increased. When there are enough nectar foragers to deplete the nectar available in the lucerne flowers, any additional nectar foragers introduced may forage elsewhere. The number of nectar foragers can be increased by increasing the number of hives and, perhaps more importantly, the number of bees in each hive.

Native foragers

When colonies are first introduced, a relatively high percentage of nectar foragers trip flowers before they learn that there are easier ways to collect nectar from lucerne flowers. Thus increasing the number of naïve foragers should increase the percentage of lucerne flowers tripped. It has been reported that bringing in new colonies at frequent intervals almost doubled the percentage of tripped flowers[104].

Other bees

Although honey bees are the most important pollinators of lucerne because of the numbers introduced to crops, there are other bee species that are more efficient at tripping flowers and pollinating lucerne.

Long-tongued bumble bees are reported to trip more flowers than short-tongued bumble bees, which feed from the side of the flowers[104,105]. Bumble bees can be hired but they are likely to be too expensive to use for lucerne pollination. It may be possible to increase the number of feral bumble bee colonies in the vicinity of a crop.

Leaf cutter bees are reported to be better pollinators of lucerne than honey bees. They are an option if they can be acquired in sufficient numbers for a suitable price.

Assessing pollination

Because of the difficulties associated with lucerne pollination, it is recommended that the rate of pollination be assessed. This can be done by measuring the weight of seed per ha but more accurately by picking seed heads and counting the number of seeds produced. It is probably good practice to assess seed set in areas close to and distant from any introduced hives.

Macadamia

Macadamia trees *Macadamia intergrifolia* and *M. tetraphylla* are tall evergreen trees growing to 20 m (Figure 87). The flowers are 5–10 mm long and are born on racemes with 100–150 flowers. There are about 2,500 flowers on a tree. Each flower has 20 ovules, four anthers attached to the petals, and a long stigma (Figure 88). It takes about a week for all the flowers on a raceme to open, with most opening over 2 days[106]. Most cultivars are partly or completely self incompatible so inter-planted with compatible cultivars is usually necessary. Cross pollination has been reported to increase nut weight as well as the number of nuts[107]. Nut set is usually only about 15%[108]. Nut set in New Zealand is reported to be less than 0.3%[109]. A three-year study of macadamia pollination in Queensland, Australia found pollination to be limiting[107].

The flowers produce both pollen and nectar. The anthers dehisce several days before the flower opens and the sigma only becomes viable after the flower opens.

Flowers are visited by a range of insects including honey bees (Figure 89). Most honey bees collect nectar in the morning and a few collect pollen in the afternoon[110]. The flowers are attractive to bees for 3 days[106]. Each flower produces relatively small amounts of nectar. The pollen gatherers are reported to be better pollinators than nectar foragers as they are more likely to contact the stigma[111]. The flowers are also visited by stingless bee and native solitary bees in Australia[112]. However, as stingless bees are only managed on a small scale, honey bees and unmanaged stingless bees are probably the most important pollinators of macadamia. It has been estimated that about 150

Figure 87. Macadamia fruit.

Figure 88. Macadamia flowers.

Figure 89. A honey bee visiting a macadamia raceme.

bee visits to a racemes are needed for full pollination in Australia[106]. There has been little research on the value of introducing honey bee colonies; however, it is probably worth doing so.

As pollen collectors are more effective pollinators than nectar foragers, colonies should be managed to promote pollen collection; e.g. high brood to bee ratios, sugar syrup feeding and pollen trapping or stripping.

Nashi (Asian pear)

Nashi pears (*Pyrus pyrifolia*) have white flowers with five petals. Most varieties are self infertile, and a compatible pollen donor needs to be inter-planted. European pear pollen will also successfully pollinate nashi flowers if they flower at the same time. When the flower opens, the anthers are pink and folded inwards towards the five stigma in the centre of the flower (Figure 90). They then open out and the outside ring of anthers dehisces on the first day (Figure 91). The inside ring of anthers dehisces on the second day. The dehisced anthers turn black.

Figure 90. Newly opened nashi flower.

The flowers are visited by honey bees to collect both nectar and pollen. The flowers smell like rotting fish and also attract flies that probably assist with pollination. Pollination can be difficult because the trees flower early in the spring and the flowers are not particularly attractive to honey bees.

Figure 91. One-day-old nashi flower.

The fruit usually have four to eight carpels, with each carpel being able to produce two seeds[114]. Increasing seed numbers usually results in larger fruit (Figure 92). Poor pollination and an uneven distribution of seeds around the fruit result in misshapen fruit[114].

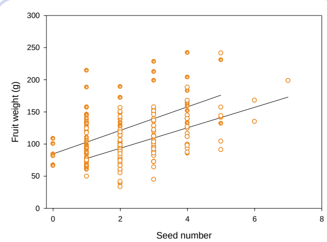

Figure 92.

Two to five hives per hectare are recommended for pollination[115]. Eight hives per hectare are usually used in New Zealand. Pollen foragers are likely to be better pollinators than nectar foragers, so colonies should have a high brood/bee ratio and possibly be fed sugar syrup.

Oil seed rape (Canola)

The flowers are in racemes of canola (*Brassica napus*) at the top of the plants. They usually have four petals, six stamens and a style. Four of the stamens are longer than the style and two are shorter. The flowers have nectaries at the base of the stamens. Although the flowers are self fertile, seed set is improved with cross pollination. This can occur through wind pollination but seed set is generally accepted to be improved with insect pollination. The importance of honey bee pollination does, however, appear to vary with variety. In trials on cultivar 'Midas', using caging plants to exclude bees, plants did not suffer decreased seed set[116]. On 'Karoo', at a stocking rate of 1.28 hives/ha it was demonstrated that seed set decreased with distance from hives[117], indicating that honey bee pollination was important for that cultivar and that too few honey bee colonies had been introduced.

It is probably best practice to introduce honey bees for the pollination of all canola varieties, unless it has been shown that the variety does not benefit from honey bee pollination.

Onions

Figure 93. A male-fertile onion flower.

Onion (*Allium cepa*) flowers consist of a spherical umbel made of florets that are less than 5 mm in length. The florets have six stamens, a single style and an ovary with two ovules (Figure 93). It takes about two weeks for all the florets on an umbel to open completely. Most of the pollen is made available on the first day and the remainder on the second day. The pollen is shed before the stigma becomes receptive. Pollen viability declines quickly after the floret opens[118]. The stigma of a flower may still be viable for up to 6 days after it opens[119]. The flowers are self fertile so pollen from one floret can pollinate another floret on the same umbel. Where male-sterile lines are used for seed production, pollen must be moved between umbels for pollination.

The flowers are visited by a range of insects that collect pollen and nectar. They produce enough nectar that beekeepers can occasionally collect a honey crop if large enough areas are planted.

Flies have been used for pollination of onions in breeding trials but for commercial production of onions, honey bees are usually the only option. Honey bees will visit onion flowers to collect both nectar and pollen, but only nectar foragers will visit both male-sterile and male-fertile lines in hybrid onion production.

The onion nectar is not particular attractive to honey bees. The sugar concentration of the nectar has been reported to increase if potassium fertilizer is added. However, high amounts of potassium in nectar have been suggested to be the reason why onion nectar is not particularly attractive to honey bees[120].

Bees have a tendency to move up and down rows instead of crossing between male-fertile and male-sterile varieties[121], which probably reduces pollination. They also tend to find male-fertile lines more attractive than male-sterile lines[122].

Because only bees foraging for nectar will visit both male-fertile and male-sterile lines, colonies introduced to onion fields should have large numbers of adult bees and should not be fitted with pollen traps or be fed with sugar syrup, as both these methods promote pollen collection at the expense of nectar foraging.

Usually bees do not find onions very attractive and they can be easily drawn away from them to other surrounding crops. For this reason, high colony stocking rates are recommended. Rates in excess of 30 hives per hectare have been suggested[123].

Peaches and nectarines

Peaches and nectarines (*Prunus persica*) have white, pink or red flowers (Figure 94). They have five oval petals, more than 20 anthers surrounding a single pistil, and ovary that has two ovules, only one of which usually develops. The flowers produce nectar and pollen. The flowers are usually attractive to both nectar and pollen-foraging insects.

Figure 94. A peach (Golden Queen) flower.

Most varieties are self fertile. Because of their attractiveness to pollinators, the self fertility of most cultivars and the relatively small number of pollen grains that need to be transferred to the stigma, peaches and nectarines are much easier to pollinate than many other plant species.

Honey bees are usually the most important pollinators of peaches but, as with many fruit trees, pollen collectors are more likely to contact the stigma as they scramble across the anthers (Figure 95). Some bees visiting peaches climb down through the anthers to reach the nectar (Figure 96) and have good stigma contact, while others collect nectar from the side (Figure 97), and are thus less likely to touch the stigma.

Figure 95. A pollen-collecting honey bee visiting a peach flower.

Bees visiting nectarines will also at times collect nectar from the side of the flowers, not touching the stigma (Figure 98). For this reason,

Figure 96. A nectar-collecting bee climbing through the anthers.

Figure 97. A nectar-collecting bee approaching the nectar from the side of a flower.

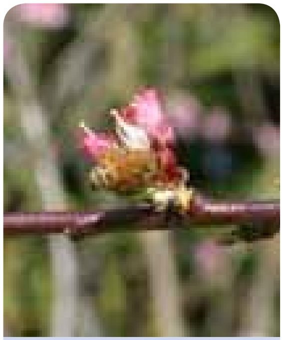

Figure 98. Side-working bee visiting a nectarine flower.

colonies managed for pollen collection are likely to be better pollinators of peaches and nectarines. However, because of the flowers' self fertility, the difference between the efficiency of pollen and nectar gatherers may not be as large as for other fruit trees.

Pears (European)

Most varieties of European pears (Figure 99a) (*Pyrus communis*) are not self fertile. The flowers have five stigma and ten ovules. If few of these ovules are pollinated, the fruit may be misshapen.

Honey bees are the most important pollinators of pears (Figure 99b), but they do not find the flowers very attractive. Pear flowers produce relatively large amounts of pollen but little nectar. The sugar concentration is low and hence not very attractive to bees. For this reason, pear pollination with honey bees can be difficult.

Because of the low amounts of weak nectar, bees introduced for pollination are readily attracted to flowers surrounding the crop. There are a number of tools that can be used to maximize the number of bees visiting the crop.

Colony numbers and strengths: The most obvious technique is to use large numbers of strong bee hives. Recommended stocking rates range between 1.2 and five colonies per ha[75,67,61].

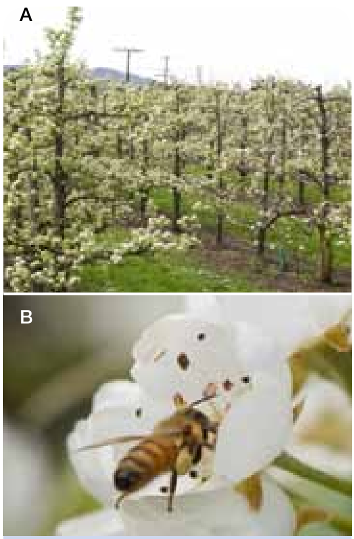

Figure 99. (a) A pear orchard; (b) A honey bee visiting a pear flower to collect pollen and nectar.

Multiple hive introductions: On the first day hives are introduced to pear orchards, the bees will probably forage on the pear flowers, as they have not yet found the more attractive flowers nearby. When they find the other flowers, they will probably desert the crop. It can therefore be useful to introduce the colonies in two or more introductions, with one or two days between introductions. The bees from the hives introduced in the later introductions will replace the bees from the earlier introductions that have deserted the crop, until they too find the flowers outside the orchard.

Distribution of colonies: If honey bee densities on the pear flowers are low, it is important to ensure hives are distributed evenly so that the bee densities in the orchard will be as even as possible.

Pollen collection: As bees will collect pollen from pear trees, managing colonies to increase pollen collection may be beneficial, e.g. using colonies with large amount of brood, colonies on pollen traps or feeding sugar syrup.

Bee attractants: Both Bee Scent® and Fruitboost® have been reported to increase pear pollination and might be worth trying if there are problems with too few bees visiting the crop. Bee Scent® is reported to have increased fruit set in 'Bartlett' pears by 27%, and 44% in 'Anjou' pears.

It has been reported that the optimum bee number that should be seen on trees is 7–8 bees/tree/minute[8].

Plums

The most important plums (*Prunus* sp.) grown commercially are the European and Japanese plums. They produce clusters of white flowers that have five petals, one style and a ring of anthers (Figure 100).

Figure 100. Plum flowers.

Species range from those that are self fertile through to those that are completely self infertile. When planting plums it is therefore important to find out if the variety needs cross pollination and if so, also to plant the variety required for pollination. Plums are commonly planted in a 1:8 distribution. Many problems with plum pollination occur because the necessary pollinizers are absent at flowering.

Honey bees (Figure 101) are the most important pollinators of plums because they can be introduced for pollination. In a study on Japanese plums in the Goulburn Valley area of Victoria, Australia, 19% of insect visitors were honey bees[124]. The study concluded that other insect visitors lacked the behavioural traits to be effective pollinators.

Honey bees visit flowers to collect both pollen and nectar. The flowers are more attractive to honey bees in the morning but they will visit them throughout the day[75]. Sequential introductions of colonies (split introductions) are reported to improve pollination[125].

It has been reported that the optimum bee number that should be seen on trees is 12–14 bees/tree/minute[8].

Figure 101. A honey bee collecting pollen and nectar from a plum flower.

Pumpkin and Squash

Pumpkin and squash (*Cucurbita* sp.) have male and female flowers. The male flowers have five anthers and are usually more numerous than female flowers[126]. The male flowers (Figure 102) have anthers fused into a central column. The female flowers (Figure 103) are easily recognized by the large circular ovary at the base of the flower. Inside the female flower is a three-lobed stigma The female flowers produce more nectar than male flowers; however, nectar from male flowers has a higher sugar content[127]. The proportion of male and female flowers is affected by temperature, day length, the proportion of fruit already set and the season[128].

The flowers of most varieties open in the morning and close again in or by the early afternoon. The timing of opening and closing can, however, be affected by weather conditions.

The pollen grains are large and sticky and are transferred by insects rather than wind. Bees visit pumpkin and squash to collect both pollen and nectar. As the nectaries surround the base of the flower, bees have to climb completely to the base of the flowers, and past the stigma or anthers to collect nectar.

Figure 102. A male pumpkin flower with a petal removed.

Figure 103. A female flower with a petal removed.

The flowers are visited by both honey bees and bumble bees, along with a variety of other insects. Bumble bees in the USA are reported to be better pollinators than honey bees, presumably because of the larger size, which increases their propensity to make contact with the stigma[127].

Pollination is usually the result of a number of bee visits. Fruit set in *Cucurbita moschate* was 6.5% after one honey bee visit, and increased to a maximum after 12 visits[129]. The seed number of fruit also increased with increasing numbers of bee visits.

Some varieties will cross pollinate each other and should be kept separate if the seeds are to be harvested.

Recommendations for honey bee stocking rates vary between one and eight hives per ha[66].

It is probably worth keeping records of the percentage of female flowers that set fruit in different parts of a field, so it can be determined if enough beehives are being used.

Figure 104. A honey bee visiting a squash flower.

Radishes

There is relatively little published information on radish (*Raphanus sativus*) pollination, particularly on hybrid radish pollination.

Figure 105. A radish flower.

Radishes have small white flowers with four petals (Figure 105), anthers and a single stigma and style. They have a pod that, when fully pollinated may produce six seeds. The flowers produce pollen and nectar. In hybrid radishes, male-sterile plants produce only nectar, while male-fertile flowers produce both pollen and nectar. The flowers open only for a single day and then usually wither.

Hybrid radishes are usually planted with three rows of male-fertile flowers and six to eight rows of male-sterile flowers. Bees are reported, however, to be able to differentiate between some male-fertile and male-sterile lines, and restrict their movement between them. Only 1.3% of bees

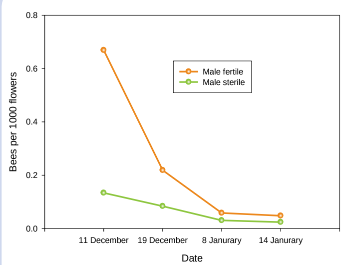

Figure 106. Number of bees counted on male-fertile and male-sterile radish flowers on four dates.

were recorded changing between the two types of flower they visited when moving between flowers.

Radishes are visited by a range of insects, but honey bees are the main pollinators because they can be managed and introduced in sufficient numbers. In a study carried out at four sites in New Zealand, all sites had less than 50% of the potential seed crop, indicating that there was insufficient pollination. It has been estimated that 6.5 bees per 1000 flowers are needed for full pollination[130]. The number of bees recorded per flower decreased during the flowering season, suggesting that the bees were moving onto more attractive food sources (Figure 106).

Figure 107. A honey bee coated in pollen collecting nectar from a radish flower.

In hybrid radishes, only nectar foragers visit both male-sterile and male-fertile flowers (Figure 107). For this reason, colonies introduced for pollination should have large numbers of bees and a high demand for nectar. It has been recommended that more than four strong hives should be introduced per hectare.

It is worthwhile assessing the number of bees on the crop at the time of peak activity to determine if there are enough hives present.

Raspberries

Raspberry (*Rubus* sp.) flowers have five petals and a ring of anthers. The flowers have many ovules, each with its own stigma. The fertilized ovules are called drupelets.

The flowers are partially self fertile. They will produce some fruit when caged to exclude bees, but will produce more and much larger berries if bees have access to the flowers (Figure 108).

Figure 108. A honey bee visiting a raspberry flower.

The stigmas are receptive before pollen is liberated by the anthers. Because of this, the first pollen to reach the stigma is likely to be from other flowers on the same or other plants. Once the anthers start to release pollen, it may be transferred directly to the stigma and thus self pollination will occur. The flowers can still set seed 4 days after they open. When pollen was applied each day for 4 days after the flowers opened, the seed number increased after each pollen application[131]. This suggests that not all the stigma may be receptive on the first day.

The degree of pollination affects not only the number of fruit but also the fruit size and shape. There is usually an increase in berry size with increasing number of drupelets. Increasing pollination will also decrease the number of malformed fruit. Fruit size, shape and number are good measures of the degree of pollination.

It has been suggested that some crosses between different varieties may result in larger drupelet size[132] .

Figure 109. A bee collecting raspberry pollen.

The flowers produce relatively large amounts of nectar. They have been reported to produce an average of 17 µl per day[83], which is between two and 10 times the amount reported to be produced by apples. Because of this, raspberry flowers are usually very attractive to bees. Honey bees will also collect small loads of pollen from the flowers (Figure 109). Pollen is not particularly attractive to bees and they will discard it at times. The attractiveness of the crop will usually mean that fewer colonies will need to be introduced. It is suggested in the literature that between 0.5 and 2.5[123] hives should be introduced per hectare.

Because the flowers produce relatively large amounts of nectar, bees may need to visit fewer flowers to collect a nectar load and may not spread evenly through a field. If an uneven distribution of bees is noted, more hives should be introduced and spread around the crop.

Red clover

Tetraploid red clover (*Trifolium pratense*) is grown for seed production in New Zealand and Australia (Figure 110). The red clover flower head has up to 200 florets, which open starting at the base of the flower head and fold downwards afterwards. In the middle of flowering, a flower head will typically have a ring of flowers that have opened and have folded down, a ring of open flowers in the middle and a ring of unopened florets at the top of the flower-head. It takes about a week for all the florets on a flower head to open.

Figure 110. Red clover field.

Red clover florets are self sterile, so pollen needs to be transported from another plant. Because of the need to pull down part of the flower (keel) to gain access to the pollen and nectar, only heavier insects can pollinate red clover. For this reason, honey bees (Figure 111) and bumble bees (Figure 112) are the main pollinators of red clover. Long-tongued bumble bees were introduced into New Zealand for the purpose of pollinating red clover.

Long-tongued bumble bee species are reported to be better pollinators of red clover than honey bees and short-tongued bumble bees because the florets are longer than those of white clover, so these bees have difficulty in reaching the nectar. Short-tongued bumble bees (B. terrestris) will sometimes bite holes in the base of the flowers to access the nectar, and therefore are less efficient pollinators than the other bumble bee species. Honey bees will occasionally use these holes as well.

Although not as efficient as bumble bees, honey bees can pollinate red clover as they visit flowers to collect nectar and pollen. They will collect pollen from red clover flowers even if they cannot collect nectar[133].

It is generally too expensive to hire bumble bee colonies for red clover pollination in New Zealand and the only species of bumble bee that is commercially available is the short-tongued *B. terrestris*, which is less efficient than the long-tongued bumble bees. Bumble bees can be encouraged to establish nests in the area of a crop by placing bumble bee nest boxes close by.

Most red clover is pollinated by honey bees, so they should be introduced to optimize pollination. Feeding honey bees colonies sugar syrup has been shown to increase the amount of red clover pollen colonies collect[134] and presumably the number of flowers visited, and hence probably also increases pollination. Ensuring colonies have a high brood to bee ratio will be important, as these colonies will have a high demand for pollen.

Figure 111. A honey bee foraging on a red clover flower.

Figure 112. A bumble bee foraging on a red clover flower.

As the pollination of red clover is difficult, it is worth assessing seed set. This can be easily done by removing seed pods and rubbing them between the thumb and forefinger to determine the number of seeds. If fully pollinated, there should be six seeds per seed pod.

Strawberry

Strawberry (*Fragaria* sp.) flowers (Figure 113) are hermaphrodite. They have five white petals, a ring of 20–25 yellow anthers and 50–200 stigma and ovules[135]. The flowers produce nectar at the base of the stamens. The flowers are self fertile and they can pollinate themselves. However, the stigmas are usually viable before the anthers liberate pollen, which increases the chance of cross pollination happening with pollen from a neighbouring plant. When the anthers dehisce, some of the pollen is forcefully ejected from the anther so that it lands on the stigma of the same flower. Pollen is shed for 1–3 days[135]. The stigma are receptive for seven[136] to 10[135] days after opening.

Figure 113. A strawberry flower.

The anther heights vary with different cultivars. It has been found that the shorter the anther, the less likely a flower is to be self pollinated[137]; presumably pollen grains from the long anthers are more likely to fall onto the stigma of the same flower.

The flowers are borne in clusters and the first flower in the cluster is the most likely to set and will usually produce the largest fruit, because they have more ovules[138].

Poor pollination can result in poor fruit set, and small or misshapen fruit[139]. Strawberries benefit from insect pollination. Cages without honey bees only produced 55% fruit set compared with 65.5% in cages with honey bees They also had smaller berries (6.7 g), and a higher percentage of deformed berries (48.6%) than the cages with bees (8.3–8.4 g and 20.7%)[140].

Figure 114. A honey bee collecting nectar from a strawberry flower.

Bees visit strawberry flowers to collect pollen and or nectar (Figure 114). However, they do not find them particularly attractive[123]. Between six[141] and 15[135] bee visits are reported to be needed to pollinate a strawberry fruit fully.

Honey bee colonies should therefore be introduced for strawberry production. There are recommendations for between two[66] and 22 hives per ha[123].

Sweet Cherries

Cherry (*Prunus avium*) flowers have a single pistil surrounded by about 30 stamen and five petals. The ovary contains two ovules (Figure 115). Flowers that are not pollinated soon fall off the tree.

Although the flowers may stay open for up to 5 days, the stigma receptivity of some flowers begins to decline as the flower opens. It has been reported that the earliest flowers that open will produce the highest quality fruit[142].

Most cherry cultivars are self incompatible[143]. Pollination occurs by insects, with honey bees the most important.

Honey bees visit cherry flowers to collect pollen and nectar. Pollen foragers are likely to be the better foragers as they usually have more pollen on their bodies[144]. They normally enter cherry flowers by climbing though the anthers and so even nectar gatherers have good stigma contact (Figure 116). Whether the extra pollen carried will increase pollination significantly is unknown. Feeding sugar syrup to colonies has been shown to increase cherry pollen collection[134] and may increase pollination, as it should increase the total number of bees visiting the crop, as it does for kiwifruit.

It is recommended that up to 10 honey bee colonies per hectare be introduced for pollination[75].

Figure 115. A sweet cherry flower.

Figure 116. A honey bee collecting nectar by climbing past the anthers and pistil.

Tomato

Tomato (*Solanum lycopersicum*) flowers have six yellow petals that fold backwards when the flower is open (Figure 117). There are six anthers that are fused with the six stamens to form a tube. The flowers are self fertile and so can be pollinated with their own pollen. However, the stigma is usually viable for several days before the pollen is released by the anthers to facilitate cross pollination. The stigma remains viable for up to 7 days[145], so self fertilization can occur. The pollen is released into the tube formed by the anthers and stigma. The flower must, however, be shaken for the pollen to land on the stigma. The flowers have little or no nectar and are only visited by insects collecting pollen.

Figure 117. Tomato flower.

There is usually enough wind and insects visiting field-grown tomatoes to ensure pollination, but this is not the case when tomatoes are grown inside glasshouses. The flowers need to be either vibrated mechanically or by an insect to cause pollen to fall on to the stigma. If not using insects, growers often use vibrators that are placed on the trusses to cause the flowers to vibrate. Because not all flowers are open at the same time, a vibrator needs to be used every two or three days.

Bumble bees are used to pollinate tomatoes in New Zealand as they have the advantage that they carry out buzz pollination. To do this they hold on to a flower and vibrate their muscles, emitting a buzzing sound. This vibrates the tomato flowers, causing the pollen to fall on to the stigma. Bumble bees are not used in Australia, as they are not present in mainland Australia and a bumble bee production industry has not been permitted to develop in Tasmania where bumble bees are present.

Honey bees can also be used to pollinate tomatoes[146 147,148], although they do not usually perform as well as bumble bees. Because they do not buzz-pollinate flowers, honey bees find it more difficult to extract pollen. In a trial, honey bees provided better pollination than vibrators and vibrators and honey bees were better than vibrators alone146. Others have had less success with honey bees, which may be because of the tomato variety or the way in which the honey bees were managed.

Because honey bees only collect pollen from tomato flowers, colonies should have large amounts of brood, so they have a high demand for pollen. It might also be worthwhile feeding colonies sugar syrup.

Because there is little pollen and no nectar available, tomato glasshouses with honey bee colonies do not fare well[146]. As tomatoes flower for relatively long periods of time, honey bee colonies should be exchanged with colonies outside the glasshouse so that they can recover. Honey bees can also be used to supplement bumble bee pollination[147].

There are no recommendations for the number of honey bees colonies that should be used for glasshouse tomatoes.

White clover

White clover (*Trifolium repens* L.) has been introduced throughout the world as a pasture crop. It is also grown as a seed crop in New Zealand and Australia (Figure 118).

Figure 118. A white clover seed crop in Canterbury, New Zealand.

White clover is a low-growing, herbaceous perennial plant that bears white flower heads ('inflorescences'), made up of small florets. There are a large number of different varieties. The varieties are classified by the size of their leaf: large, medium-large, medium, and small leaved.

White clover flowers have between 21 and 104 florets per flower head (Figure 119). The florets on a flower-head open successively over a week, beginning with those at the base and ending with those at the crown of the flower head. Once the florets are open, they will stay open for five to eight days if they are not pollinated. However, seed set can be reduced by 60% after five days. Based on the number of ovules present, each floret should be able to produce six seeds. In commercial seed crops in New Zealand, florets produce between zero and seven seeds, with an average of approximately three seeds.

Figure 120. A honey bee visiting a white clover flower.

The florets on a flower head are hermaphroditic (have both male and female organs), but all varieties are self incompatible. A floret cannot produce seeds with pollen from the same florets, with pollen from other florets on the same flower head, or with pollen from other flower heads on the same plant. The pollen has to come from other plants.

For pollination to occur, an insect vector is needed. The anthers liberate pollen before the florets open and deposit it onto the stigma. Insect visitors pick up this pollen and replace it with pollen from other clover plants.

To be able to gain entrance to a white clover flower, the insect must have sufficient weight to pull the flower downwards (Figure 20). For this reason, only larger insects can gain access to white clover florets and pollinate them.

Honey bees are the most important pollinators of white clover. Honey bees visit clover flowers to collect nectar and/or pollen. Both types of foragers are thought to be equally efficient at pollinating clover, as they both contact the stigma. White clover flowers can be very attractive to honey bees, which have been recorded to fly 5 km to reach a clover crop. Good rates of pollination can be achieved by feral bees or managed bees placed in other crops that are still within flight range. But to optimize the reliability and effectiveness of pollination, it is best to introduce bees.

Based on the average number of seeds produced by a single bee visit to a clover floret (1.24), the length of a bee's foraging trip and foraging day, and the number of open florets at any particular time, 19,420 bees are required per hectare for the maximum number seeds to be set per floret[149].

Although some growers rely on managed colonies that are already in the vicinity of the crop, the best results will be achieved by introducing colonies a rate of eight per ha.

Appendix 1 Draft pollination contract

This agreement is made on the ____ (date)

BETWEEN ____
(grower's name) hereinafter called the "grower"

AND ____
(beekeeper's name) hereinafter called the "beekeeper"

TERM OF AGREEMENT

The term of this agreement shall be for the 20___ growing season, covering flowering until 48 hours after the grower requests hive removal, but not beyond _____________ of that year. (Other agreed provisions should be added or deleted if required at the time of signing, and initialled by both parties.)

SECTION A: RESPONSIBILITIES OF THE BEEKEEPER

Beekeeper Agrees:

1. To supply the grower with hives of honey bees as stipulated in the following table:
   HIVE DELIVERY TABLE

Hive number	Description of the delivery location	Timing of introduction
		At _____% flowering
		At _____% flowering
		At _____% flowering

(Grower to advise beekeeper of delivery dates as per clause 3)

2. To supply hives each containing a minimum of (higher standards may be negotiated, especially on isolated or problem crops):

   a. four full standard frames of brood in all stages (7000 cm^2 of brood, 7 frames 60% full).
   b. twelve standard frames well-covered with bees (approximately 30,000 bees)
   c. at least three full-depth frames of honey
   d. a high quality laying queen
   e. sufficient room for colony expansion

such hives to

f. be free of American FoulBrood and EFB (currently only in Australia) and
g. have been treated for Varroa for at least four weeks prior to being introduced to the property (currently only in New Zealand).

3. To deliver each instalment of hives to the property within 24 hours of final notice from the grower under Section B, clause 10.
4. To place hives in positions decided in previous consultation with the grower in group sizes of no more than _____ hives.
5. To feed each colony _____ litres of _____% sugar syrup solution every second morning starting on the second day colonies are in the orchard.
6. To not place/spill sugar syrup outside the hives where it can be collected by foraging bees.
7. a. Within 24 hours of notice from the grower to open and demonstrate bee colony strength of any hives specified by the grower.
   b. To lend the grower and/or auditor effective protective clothing if requested where they wish to accompany the beekeeper under 7 a), or under 7 c).
   c. To allow an auditor nominated by the grower to audit the strength of the colonies if requested by the grower (such request not to be made unreasonably).
8. To supply within 24 hours an additional hive(s) to compensate for any hive found to be below the minimum standard, at no extra cost to the grower.
9. To remove the hives within 48 hours of being notified by the grower that they are no longer required.
10. To take all reasonable measures to reduce the number of field bees left behind in the grower's property when hives are removed.
11. To collect any bee swarms in the property during the flowering period within 48 hours of request by the grower.
12. Replace any hives that swarm within 24 hours.
13. To carry public liability insurance.
14. To inspect the property and any hazards identified by the grower under Section B, clause 8, such inspection to be in daylight before delivery of hives.
15. Carry out any sanitation of vehicles as required by the growers.

SECTION B: GROWER RESPONSIBILITIES

Grower Agrees:

1. To pay a rental sum of $______ per hive for a total of _____ hives. GST is to be added to all payments.
2. The total rental is $_________ . This is payable as to $________ on or by ____________ (date) and a final payment of $__________ by the 20th of the month following removal of hives from the property.
3. To pay 1.5% per month (or part thereof) interest on amounts unpaid after due dates.
4. To liaise with the beekeeper well in advance of hive delivery and allow beekeeper prior inspection of the property in daylight.
5. To provide a suitable place to locate hives. This site must be readily accessible to a truck and other vehicles used in handling and servicing the colonies and be in a sheltered, sunny position.
6. To provide the beekeeper with a map of the property well before delivery of hives showing the positions in which hives are to be placed, and the number of hives to be placed at each location. The positions will be as agreed under Section A, clause 4.
7. To be present, or nominate an appropriate person to be present, when the beekeeper inspects under Section A, clause 14, and when hives are delivered and removed (to assist with locating sites).
8. To advise the beekeeper in writing of any property hazards including drains, orchard wires, fences, ditches, irrigation pipes, and any other hazard, and to clearly identify the location and nature of such hazards.
9. To allow the beekeeper entry onto the property at a reasonable time whenever necessary to service the bees.
10. To give the beekeeper at least 48 hours first notice and 24 hours final notice that hives are required to be placed in the property.
11. Not to shift, examine, or disrupt bee access to or from hives without the beekeeper's approval.
12. To give the beekeeper at least 48 hours notice to remove hives from the property.
13. To abide by the appropriate country and/or state pesticide legislation.
14. To comply with bee toxicity warnings on agrichemical labels.

15. Not to spray any bee-toxic chemical while the hives are on the property, and in so far as is reasonably practicable, to avoid spraying any insecticide in the ten days prior to hives being shifted into the property.

16. To avoid spraying any agrichemicals between 08:00 and 17:00 hours when large numbers of bees are foraging, in so far as is reasonably practicable.

17. To provide the beekeeper with at least 24 hours notice if anything is to be sprayed on the property while hives are present and to flush any insecticide or other bee-toxic chemical from tanks and spraying equipment before spraying while hives are on the property.

18. To dispose of any insecticide-contaminated liquid or other bee-toxic material so that bees cannot contact or drink it.

19. To give adjoining land owners notice of intent to bring in hives at least ten days before the hives are moved into the property and notice of the full period that the hives may be present.

20. To advise the beekeeper within 12 hours if a significant number (one cup or more) of dead bees are seen near the entrance of any hive.

21. To avoid irrigating flowering crops while bees are foraging and to ensure irrigators will not overrun and drench hives.

PERFORMANCE

Neither party shall be responsible for failure to comply with the terms of this agreement where such failure to comply results from causes beyond the reasonable control of that party, provided however that this shall not relieve the grower from liability to make payment for services performed.

ARBITRATION

If the grower is dissatisfied with the quality of hives supplied his/her first recourse shall be to the beekeeper. Such complaints shall be lodged as soon as possible and in no case after the hives are removed from the property.

In the event of any unsettled dispute between the beekeeper and grower both parties agree to abide by the decision of a mutually agreed upon independent arbitrator.

ASSIGNMENT OR TRANSFER

This agreement is not assignable or transferable by either party, except that the terms hereof shall be binding upon a successor by operation of law to the interest of either party.

IN WITNESS THEREOF, the parties hereto have executed this agreement the day and year above.

Grower: ____

Address: ____

____

Contact details: _________________________ (Home) _________________________ (Mobile)

Beekeeper: ____

Address: ____

____

Contact details: _________________________ (Home) _________________________ (Mobile)

(One signed copy each to be retained by the grower and by the beekeeper)

Appendix 2

List of the active ingredients found in horticultural and broadacre pesticides in Australia and New Zealand known to be toxic to honey bees.

Active Ingredient	Active Ingredient
Abamectin	Fipronil
Acephate	Gamma-cyhalothrin
Alpha-cypermethrin	Imidacloprid
Azinphos-methyl	Indoxacarb
Bendiocarb	Lambda—cyhalothrin
Beta-cyfluthrin	*M. anisopliae* var. *acridum*
Beta-cypermethrin	Maldison
Bifenazate	Methamidophos
Bifenthrin	Methomyl
Bioresmethrin+pip.but.	Methidathion
Carbaryl	Methiocarb
Chlorfenapyr	Mevinphos
Chlorpyrifos	Milbemectin
Clothianidin	Omethoate
Cyanamide	Omethoate
Cyfluthrin	Permethrin 40:60
Cypermethrin	Phosmet
Deltamethrin	Pyrethrins
Diafenthiuron	Pyrethrins+pip.but.
Diazinon	Pyridaben
Dimethenamid-P	Spinetoram
Dimethoate	Spinosad
Emamectin as benzoate	Tebufenpyrad
Esfenvalerate	Thiamethoxam
Ethion+zeta-cypermethrin	Thiodicarb
Fenthion	Trichlorfon
Fenitrothion	Zeta-cypermethrin

Glossary

American foulbrood – A bacterial disease of honey bee larvae

Anther – The flower structure producing pollen

Bisexual flowers – Flowers from male vines that produce viable flowers and have functioning ovules so that they are able to produce fruit

Brood – Developing larvae and pupae in a honey bee colony

Buzz pollination – Where a bumble bee grasps a flower and vibrates its wing muscles to increase the amount of pollen it can extract from a flower

Carpel – The structures containing the ovules

Cross pollination – Where pollen is transferred between flowers on different plants

Dehiscence – The breakdown of the anther wall to expose the pollen

Division board feeder – A steel or plastic trough that replaces one or two frames in a super and can be filled with sugar syrup

Drone – A male honey bee

Dump site – A location where hives are delivered to prior to their being moved into a crop

European foulbrood – A bacterial disease of honey bee larvae

Feral honey bee colony – A honey bees living somewhere other than a man-made bee hive

Fertilization – The fusion of a sperm cell from a pollen grain with the ovule of a female flower

Filament – The flower structures that holds up the anthers

Floral constancy – The behaviour where a honey bee will usually only forage from on a single plant species during a foraging trip

Floret – A small flower that usually is part of a larger flower head umbel, e.g. clover

Forager – A bee that is collecting nectar and/or pollen, water or propolis

Foraging area – The area over which a honey bee will forage during a foraging trip

Frame – The wood or plastic surrounding the sheets of honey comb

Germination – The rupture of the pollen grain wall by the pollen tube

Hive – The wooden structure produced to house bees

Honey – The sugar-based material that honey bees make from nectar

Honey bee brood – Honey bee eggs, larvae and pupae

House bees – The bees that do all the work inside the hive

Incompatible – Where the pollen from a flower cannot fertilize the ovules from the same flower or ovules in other flowers on the same plant

Inflorescence – A group of flowers arranged on a stem

Locule – A chamber within an ovary

Nectar – The sweet substance produced by flowers to attract animals to visit the flowers

Nectaries – The flower structures that produce nectar

Out-crossing – Where a flower needs pollen from a different plant to be able to produce seed

Ovary – The part of a the female flowers containing ovules

Ovule – The part of the female flower that fuses with the pollen sperm cell

Petals – The structures that enclose the reproductive structures; they are often coloured

Pistils – The flower structures that hold up the stigma and the style

Pollen dispenser – A device fitted into the entrance of beehives and dusts outgoing bees with pollen

Pollen germination – The growth of the pollen tube through the wall of the pollen grain

Pollen grains – Structures that contain the male genetic material for movement to the female reproduction organs

Pollen pellets – The balls of pollen carried on the hind legs of worker bees

Pollen trap – A device for removing the pollen pellets from the legs of bees

Pollen tube – The portion of the pollen grain that grows through the stigma to reach the ovules

Pollen viability – The ability of pollen to germinate under optimal conditions; usually expressed as a percentage

Pollinizer – The plant that is producing the pollen

Pollination – Transfer of viable pollen from male flowers to the stigma of female flowers

Pollinator – The animal that transfers pollen

Propolis – Sap or resin that bees collect from trees to fill gaps in their hives

Queen – A female bee with developed ovaries that is capable of laying fertilized eggs

Queen cell – A honey bee wax cell containing a developing queen bee

Queenless colony – A colony without a queen

Raceme – A flower structure with flowers attached along a central stem.

Self compatible – Where pollen from a flower can fertilize the ovules from the same flower

Self fertility – The ability of a flower to pollinate itself

Self pollination – Where a flower produces pollen and fertilizes itself

Sepals – The structures that enclose the flower buds

Side working – Where an insect collects nectar from the side of a flower without touching the stigma

Smoker – A device made of a steel cylinder and bellows, used to blow smoke over bees to pacify them

Split introductions – Moving hives into a crop at different times as flowering progresses

Spray drift – Where a chemical spray application drifts onto non target plants

Stigma – The structure on which the pollen grains land and through which the pollen tubes grow to reach the ovaries

Style – The structure between the stigma and ovary through which the pollen tube grows

Super – The box that holds the frames in a beehive

Swarm – A part of a honey bee colony, including the queen, that has left the parent colony to establish a new colony

Top feeder – A box that sits on top of a hive that can be filled with sugar syrup

Top working – Where an insect collects nectar by reaching through from the top of the anthers

Umbel – An inflorescence that consists of a number of short flower stalks which are equal in length and form a structure like an umbrella

Varroa – A honey bee mite

Worker – Female honey bee that does all the work inside and outside a beehive

References

[1] Jakobsen, H. & Jansson, K. Influence of temperature and floret age on nectar secretion in *Trifolium repens* L. Ann. Bot. 74, 327-334 (1994).

[2] Sedgley, M. & Grant, W. J. R. Effect of Low-Temperatures during Flowering on Floral Cycle and Pollen-Tube Growth in 9 Avocado Cultivars. Scientia Horticulturae 18, 207-213, (1983).

[3] Jansson, D. M. & Warrington, I. J. The influence of temperature during floral development and germination *in vitro* on the germinability of kiwifruit pollen. New Zealand Journal of Experimental Agriculture 16, 225-230 (1998).

[4] Jakobsen, H. & Martens, H. Inflluence of temperature and aging of ovules and pollen on reproductive success in *Trifolium repens* L. Ann. Bot. 74, 493-501 (1994).

[5] Austin, P. T., Hewett, E. W., Noiton, D. & Plummer, J. A. Self incompatibility and temperature affect pollen tube growth in 'Sundrop" apricot (*Prunus armeniaca*). J. Horticult. Sci. Biotechnol. 73, 375-386 (1998).

[6] Evans, L. J., Goodwin, R. M. & McBrydie, H. M. Factors affecting 'Hass' avocado (*Persea americana*) fruit set in New Zealand. New Zealand Plant Protection 63, 214-218 (2010).

[7] Palmer-Jones, T., Forster, I. W. & Jefferies, C. J. Observations on the role of the honey bee and bumble bee as pollinators of white clover (*Trifolium repens* Linn) in the Timaru district of the Mackenzie country. N. Z. J. Agric. Res. 5, 318-325 (1962).

[8] Stern, R. A., Sapir, G., Shafir, S., Dag, A. & Goldway, M. The appropriate management of honey bee colonies for pollination of *Rosaceae* fruit trees in warm climates. Middle Eastern Russian Journal of Plant Science and Biotechnology 1, 13-19 (2007).

[9] Ish-Am, G. & Lahav, E. Evidence for a major role of honeybees (*Apis mellifera*) rather than wind during avocado (*Persea americana* Mill.) pollination. J. Horticult. Sci. Biotechnol. 86, 589-594 (2011).

[10] Howlett, B. G. & Donovan, B. J. A review of New Zealand's deliberately introduced bee fauna: current status and potential impacts. N. Z. Entomol. 33, 92-101 (2010).

[11] Lye, G. C., Park, K. J., Holland, J. M. & Goulson, D. Assessing the efficacy of artificial domiciles for bumblebees. J. Nat. Conserv. 19, 154-160, (2011).

[12] Reid, P. E. & Donovan, B. J. Leafcutting bee life history, allocation details and management techniques., 24 (Entomology Division, Department of Scientific and Industrial Research, Lincoln., 1980).

[13] Donovan, B. J. Apoidea (Insecta: Hymenoptera). Fauna N. Z. (2007).

[14] Donovan, B. J. & Read, P. C. E. Alkali bee establishment and maintenance for lucerne pollination., 11 (Entomology Division, Department of Scientific and Industrial Research, Lincoln, 1983).

15 Oldroyd, B. P., Thexton, E. G., Lawler, S. H. & Crozier, R. H. Population demography of Australian feral bees (*Apis mellifera*). Oecologia 111, 381-387, (1997).

16 Free, J. B. & Williams, I. H. Influence of the location of honeybee colonies on their choice of pollen sources. . J. Appl. Ecol. 11, 925-935 (1974).

17 Wolfenbarger, D. O. Honey bees increase squash yields. Fla. Agr. Expt. Sta. Sunshine State Agr. Res. Rpt. 7(1), 15,19. 310 (1962).

18 Goodwin, R. M. T. H., A. Feeding sugar syrup to honey bee (*Apis mellifera* L.) colonies to increase kiwifruit pollen collection: Effect of frequency, quantity and time of day. Journal of Apicultural Reserach 30, 41-48 (1991).

19 Goodwin, R. M. Feeding sugar syrup to honey bee colonies to improve pollination:a review. Bee World 78, 56-62 (1997).

20 Goodwin, R. M., Tenhouten, A. & Perry, J. H. Effect of Variations in Sugar Presentation to Honey-Bees (*Apis-Mellifera*) on Their Collection of Kiwifruit (*Actinidia-Deliciosa*) Pollen. N. Z. J. Crop Hortic. Sci. 19, 259-262 (1991).

21 Levin, M. D. & Loper, G. M. Factors Affecting Pollen Trap Efficiency. American Bee Journal 124, 721-723 (1984).

22 Tsirakoglou, V., Thrasyvoulou, A. & Hatjina, F. in Third International Symposium on Kiwifruit, Vols 1 and 2 Acta Horticulturae (ed E. Porlingis J. Sfakiotakis) 439-443 (1997).

23 Free, J. B. & Williams, H. I. The effect of giving pollen and pollen suppliments to honey bee colonies on the amount of pollen collected. J. Apic. Res. 10, 87 - 90 (1971).

24 Goodwin, R. M., Tenhouten, A. & Perry, J. H. Effect of Feeding Pollen Substitutes to Honey-Bee Colonies Used for Kiwifruit Pollination and Honey Production. N. Z. J. Crop Hortic. Sci. 22, 459-462 (1994).

25 Roberts, D. Sugar sprays aid fertilization of plums by bees. New Zealand Journal of Agriculture 93 (1956).

26 Zyl, H. L. & van Strydom, D. K. The problem of poof fruit set of Packham's Triumph pear trees. The Decious Fruit Grower 18, 121 – 123 (1968).

27 Goodwin, R. M. H., H. . Attracting bees by spraying crop with sugar syrup. The New Zealand Beekeeper December 11, 10-11 (1998).

28 Patil, J. S., Mokat, R. B., Mupade, R. V. & Kamate, G. S. Role of bee attractants in pollination and productivity of onion (*Allium cepa* L.). J. Entomol. Res. 35, 127-131 (2011).

29 Kalmath, B. S. & Sattigi, H. N. Effect of bee pollination by using attractants on the qualitative parameters of onion seed. Pest Management and Economic Zoology 12, 97-99 (2004).

[30] Jayaramappa, K. V., Pattabhiramaiah, M. & Bhargava, H. R. Influence of bee-attractants on yield paramaters of ridge gourd (*Luffa acutangula* L.) (Cucurbitaceae). World Applied Science Journal 15, 457 - 462 (2011).

[31] Ganapathi, K., Shashidhar, V. & Viraktamath, S. Effect of bee attractants on bee visits and yield parameters of MECH-184 BT hybrid cotton. (2007).

[32] Patil, B. S., Shashidhar, V. & Viraktamath, S. Influence of bee attractants on pollinator visitation and yield parameters in sesamum. (2005).

[33] Singh, P. B. & Sinha, S. N. Effect of Bee-Q on honeybee visit and seed yield of hybrid sunflower. Seed Research 24, 151-153 (1997).

[34] Naumann, K., Winston, M. L., Slessor, K. N. & Smirle, M. J. Synthetic Honey-Bee (Hymenoptera, Apidae) Queen Mandibular Gland Pheromone Applications Affect Pear and Sweet Cherry Pollination. J. Econ. Entomol. 87, 1595-1599 (1994).

[35] Currie, R. W., Winston, M. L., Slessor, K. N. & Mayer, D. F. Effect of Synthetic Queen Mandibular Pheromone Sprays on Pollination of Fruit Crops by Honey-Bees (Hymenoptera, Apidae). J. Econ. Entomol. 85, 1293-1299 (1992).

[36] Currie, R. W., Winston, M. L. & Slessor, K. N. Effect of Synthetic Queen Mandibular Pheromone Sprays on Honey-Bee (Hymenoptera, Apidae) Pollination of Berry Crops. J. Econ. Entomol. 85, 1300-1306 (1992).

[37] Tew, J. E. & Ferree, D. C. The influence of a synthetic foraging attractant, Bee-Scent, on the number of honey bees visiting apple blossoms and on subsequent fruit production. Research Circular - Ohio Agricultural Research and Development Center, 14-23 (1999).

[38] Mayer, D. F., Britt, R. L. & Lunden, J. D. An evaluation of BeeScent as a honeybee attractant. Good Fruit Grower 40, 40 (1989).

[39] Ambrose, J. T., Schultheis, J. R., Bambara, S. B. & Mangum, W. An Evaluation of Selected Commercial Bee Attractants in the Pollination of Cucumbers and Watermelons. American Bee Journal 135, 267-272 (1995).

[40] Schultheis, J. R., Ambrose, J. T., Bambara, S. B. & Mangum, W. A. Selective Bee Attractants Did Not Improve Cucumber and Watermelon Yield. HortScience 29, 155-158 (1994).

[41] Loper, G. M. & Roselle, R. M. Experimental use of BeeScent to influence honey bee visitation and yields of watermelon. American Bee Journal 131, 777 (1991).

[42] Mayer, D. F. & Johansen, C. A. Field evaluation of chemical pollinator attractants on tree fruits. American Bee Journal 122, 287-289 (1982).

[43] Belletti, A. & Zani, A. A bee attractant for carrots grown for seed. Sementi Elette 27, 23-27 (1981).

[44] Tew, J. E. & Ferree, D. C. The effects of Bee Lure on honey bee (Apis mellifera) pollination of apples. Research Circular, Ohio State University, Agricultural Research and Development Center, 31-32 (1984).

[45] Rajotte, E. G. & Fell, R. D. A commercial bee attractant ineffective in enhancing apple pollination. HortScience 17, 230-231 (1982).

[46] Graham, J. The Hive and the Honey-Bee . (Dadant & Sons, 1992).

[47] Mussen, E. C., Julio, L.; Lopez, E.; Peng, C.V. S Effects of selected fungicides on growth and development of larval Honey bees, Apis mellifera l. (Hymenoptera: Apidae). Environ. Entomol. 33 (2004).

[48] Manandhar, D. N. L., G S Blossom sprays and their effect on fruit set. The Orchardist of New Zealand. 53, 269,271-272 (1980).

[49] Goodwin, R. M. & McBrydie, H. Effect of surfactants on honey bees. New Zealand Kiwifruit Journal 135: (1999).

[50] Fluri P.; Frick, R. Honey bee losses during mowing of flowering fields. Bee World 83, 109-118 (2002).

[51] MacDaniels, L. H. Practical aspects of the pollination problems. Proceedings of the New York State Horticultural Society 75, 195-202 (1930).

[52] Free, J. B. The effect of distance from pollinizer varieties on the fruit set on trees in plum and apple trees. J. Hortic. Sci. 37, 262-271 (1962).

[53] Goodwin, R. M. Honey bees aid artificial pollination. New Zealand Kiwifruit Journal September/October, 59-61 (2010).

[54] Johansen, C. A. Pollination of tree fruits in Eastern Washington. . Proccedings of the Washington State Horticultural Association. 56, 17-19 (1960).

[55] Dag, A., Weinbaum, S. A., Thorp, R. W. & Elisikowitch, D. Pollen dispensers (inserts) increase fruit set and yield in almonds under some commercial conditions. J. Apic. Res. 39, 117-123 (2000).

[56] Vaissaire, B. E., Morison, N. & Subirana, M. Ineffectiveness of pollen dispensers to improve apricot pollination. Acta Hort 701, 635-641 (2006).

[57] Kalev, H., Dag, A. & Shafir, S. Feeding pollen supplements to honey bees colonies during pollination of sweet pepper in enclosures. American Bee Journal 142, 675 - 679 (2003).

[58] Hill, S. J., Stephenson, D. W. & Taylor, B. K. Almond Pollination Studies - Pollen Production and Viability, Flower Emergence and Cross-Pollination Tests. Australian Journal of Experimental Agriculture 25, 697-704, doi:10.1071/ea9850697 (1985).

[59] Degrandihoffman, G., Thorp, R., Loper, G. & Eisikowitch, D. Identification and Distribution of Cross-Pollinating Honeybees on Almonds. J. Appl. Ecol. 29, 238-246, (1992).

[60] Thorp, R. W. & Mussen, E. Honey bees in almond pollination. University of California Cooperative Extension Service Leaflet 2465 (1979).

[61] Levin, M. D. Using honey bees to pollinate crops. (US Department of Agriculture Leaflet 549, 1986).

[62] Thorp, R. W. Honeybees in almond pollination. Almond Facts 49, 30-32 (1984).

[63] Webster, T. C., Thorp, R. W., Briggs, D., Skinner, J. & Parisian, T. Effects of Pollen Traps on Honey-Bee (Hymenoptera, Apidae) Foraging and Brood Rearing during Almond and Prune Pollination. Environ. Entomol. 14, 683-686 (1985).

[64] Pornbacher, H. Wind pollination of apple Windbestaubung beim Apfel. Imkerfreund 46, 23-24 (1991).

[65] Ponomariova, E. G. Efficiency of bee pollination when applying advanced agricultural techniques. Honey plants - basis of apiculture. International symposium on melliferous flora, Budapest, 1976., 158-162 (1977).

[66] Kevan, P. G. Pollination: crops and bees. . Vol. Publication 72 (Ontario Ministry of Agriculture and Food, 1988).

[67] Scott-Dupree, C. D. et al. A guide to managing bees for crop pollination. (Canadian Association of professional Apiculturalists, 1995).

[68] Wood, D. E. S. Apricot cv. Sundrop - pollination study. Orchardist of New Zealand 56, 451 (1983).

[69] Langridge, D. F. & Goodman, R. D. Honeybee pollination of the apricot cv. Trevatt. Australian Journal of Experimental Agriculture and Animal Husbandry 21, 241-244, doi:10.1071/ea9810241 (1981).

[70] Austin, P. T., Hewett, E. W., Noiton, D. A. & Plummer, J. A. Cross pollination of 'Sundrop' apricot (*Prunus armeniaca* L) by honeybees. N. Z. J. Crop Hortic. Sci. 24, 287-294 (1996).

[71] Meheriuk, M., Lane, W. D. & Hall, J. W. Influence of Cultivar on Nectar Sugar Content in Several Species of Tree Fruits. HortScience 22, 448-450 (1987).

[72] McLaren, G. F., Fraser, J. A. & Grant, J. E. Pollination of apricots. Orchardist of New Zealand 65, 22-23 (1992).

[73] Vaissiere, B. E., Morison, N. & Subirana, M. in Proceedings of the XIIth ISHS Symposium on Apricot Culture and Decline, Vols 1 and 2 Acta Horticulturae (ed J. M. Audergon) 637-642 (2006).

[74] Alcaraz, M. L. & Hormaza, J. I. Reproductive biology of avocado (*Persea americana* Mill.) in Southern Spain. Acta Horticulturae 814, 387-390 (2009).

[75] McGregor, S. E. Insect pollination of cultivated crop plants. Agriculture Handbook, United States Department of Agriculture, viii + 411 pp. (1976).

[76] Williams, I. H. The dependence of crop production within the European Union on pollination by honey bees. . Agricultural Zoology reviews 6, 229-257 (1994).

[77] Dixon, J. Avocado Pollination, Best practice guidelines. 13 (Avocado Industry Council Ltd, 2006).

[78] Percival, M. S. Observations on the flowering and nectar secretion of *Rubus fructicosus*. New Phytol. 45, 111-123 (1946).

[79] Anderson, C. P. & Crocker, T. E. Blackberry and rasberry. University of Florida IAFS Extension HS807 (2001).

[80] Botero Garces, N. & Morales Soto, G. Flower visitation patterns of *Apis mellifera* on the Andean blackberry. Revista Colombiana de Entomologia 21, 153-157 (1995).

[81] Denisow, B. The influence of the degree of pollination of black currant (*Ribes nigrum* L.) flowers on the number of seeds in fruits and its size. Annals Universitatis Mariae Curie-Skodowska. 11, 11-18 (2002).

[82] Denisoe, B. Self pollination and self fertilisation in eight cultivars of black currants (Ribes nigrum L.). Acta Biologica Cracoviensia, Series Botanica 45, 111-114 (2003).

[83] Free, J. B. Insect Pollination of crops. (ACADEMIC PRESS INC., 1993).

[84] Zakharov, G. A. Role of supplimentary pollination with pollen of a different species in increasing the yield of black currants. Agrobiologiya, 461 - 462 (1960).

[85] Dijkstra, J., Smeekens, C., Ruijter, A. d. & Hermanns, G. J. F. M. Honeybees and black currants, an assurance of yield? Erwerbsobstbau 29, 118-121 (1987).

[86] Goodman, R. D. & Clayton Green, K. A. Honeybee Pollination of Highbush Blueberries (*Vaccinium-Corymbosum*). Australian Journal of Experimental Agriculture 28, 287-290, doi:10.1071/ea9880287 (1988).

[87] Brevis, P. A., NeSmith, D. S., Seymour, L. & Hausman, D. B. A novel method to quantify transport of self- and cross-pollen by bees in blueberry plantings. HortScience 40, 2002-2006 (2005).

[88] Darwin, C. the effects of cross and self fertilisation in the vegetable kingdom. London, Murray (1876).

[89] Puausheva, Z. P. in Pollination of Entomophilous Agricultural Crops by bees (ed R.B. Koxin) 334-338 (Amerind Publishing Co., 1976).

[90] Phillips, E. F. & Demuth, G. S. Beekeeping in the Buckwheat region. U.S. Department of Agriculture Farmers Bulletin 1216, 22pp (1922).

[91] Bjorkman, T. Role of honey bees (*Hymenoptera*: *Apidae*) in the pollination of Buckwheat in Eastern North America. J. Econ. Entomol. 88, 1739-1745 (1995).

92 Stewart, A. M. & Craig, J. L. Factors affecting pollinator effectiveness in feijoa sellowiana. N. Z. J. Crop Hortic. Sci. 17, 145-154 (1989).

93 Free, J. B. The pollination requirements of broad beans and field beans. Agric. Sci. 66, 395-397 (1966).

94 Jay, S. C. & Jay, D. H. The Effect of Kiwifruit (*Actinidia-Deliciosa*-a Chev) and Yellow Flowered Broom (*Cytisus-Scoparius* Link) Pollen on the Ovary Development of Worker Honey-Bees (*Apis-Mellifera* L). Apidologie 24, 557-563, (1993).

95 Goodwin, R. M. Ecology of honey bee pollination of kiwifruit PhD thesis, Auckland University, (1987).

96 Goodwin, R. M., Ten Houten, A. & Perry, J. H. Effect of staminate kiwifruit vine distribution and flower number on kiwifruit pollination. N. Z. J. Crop Hortic. Sci. 27, 63-67 (1999).

97 Goodwin, R. M. Afternoon Decline in Kiwifruit Pollen Collection. N. Z. J. Crop Hortic. Sci. 23, 163-171 (1995).

98 Williams, I. H., Martin, A. P. & Clarke, S. J. Pollination requirements of linseed (*Linum usitatissimum*). The Journal of Agricultural Science 115, 347-352 (1990).

99 Spiss, L. & Hittle, C. N. Effect of geitonogamic pollinations on self-incompatibility in birdsfoot trefoil (*Lotus corniculatus* L.). Acta Agraria et Silvestria, Agraria 18, 257-265 (1979).

100 Silow, R. A. Self fertility of *Lotus* spp. Bulletin of the Welsh Plant Breeding Station 12, 234-240 (1931).

101 Morse, R. S. The pollination of Birds-foot trefoil. Proceedings of the 10th international Congress of Entomology 4, 951-953 (1958).

102 Badger, K. L. & Anderson, S. R. Effect of pollen and nectar collecting honey bees on the seed yield of birdsfoot trefoil, *Lotus corniculatus*. Crop Sci. 2, 148-149 (1962).

103 Kubisova-Kropacova, S. & Nedbalova, V. A study of the relationship between the honeybee and birdsfoot trefoil. Pol'nohospodarstvo 21, 560-567 (1975).

104 Palmer-Jones, T. & Forster, I. W. Measures to increase the pollination of lucerne (*Medicago sativa* Linn.). N. Z. J. Agric. Res. 15, 186 - 193 (1972).

105 Gurr, L. The role of bumblebees as pollinators of red clover and lucerne in New Zealand: a review and prospect. Proceedings of the New Zealand Grassland Association 36, 111-122 (1974).

106 Heard, T. A. Pollinator requirements and flowering patterns of *Macadamia integrifolia*. Aust. J. Bot. 41, 491-497 (1993).

107 Wallace, H. M., Vithanage, V. & Exley, E. M. The effect of supplementary pollination on nut set of Macadamia (*Proteaceae*). Ann. Bot. 78, 765-773 (1996).

[108] Heard, T. A. The requirement for insect pollination by macadamia and the pollinator efficiency of Trigona bees. Proceedings of the Fourth Australasian Conference on Tree and Nut Crops, Lismore, NSW, Australia, 14-20 August 1988., 219-223 (1988).

[109] Richardson, A. & Dawson, T. New Zealand macadamias: the industry and its research needs. Orchardist of New Zealand 64, 30-33 (1991).

[110] Stace, P. Observations on the behaviour of honey bees in flowering macadamia orchards. Australasian Beekeeper 88, 36-41 (1986).

[111] Vithanage, V. & Ironside, D. A. The insect pollinators of macadamia and their relative importance. Journal of the Australian Institute of Agricultural Science 52, 155-160 (1986).

[112] Heard, T. A. Behavior and pollinator efficiency of stingless bees and honey-bees on macadamia flowers. J. Apic. Res. 33, 191-198 (1994).

[113] Rohitha, B. H. Pollination compatability between commercial nashi (*Pyrus serotina Rehder* var *Culta Rehder*) Cultivars in New Zealand. N. Z. J. Crop Hortic. Sci. 17, 109-111 (1989).

[114] Rohitha, B. H. & Klinac, D. J. Relationships between seed set and fruit weight and shape of nashi *Pyrus serotina Rehder* var *culta Rehder*). N. Z. J. Crop Hortic. Sci. 18, 133-136 (1990).

[115] Manning, R. Honey Bee Pollination. Technical data for potential honey-bee pollinated crops and orchards in Western Australia. Western Australian Department of Agriculture Bulletin 428 (2006).

[116] Langridge, D. F. & Goodman, R. D. Honeybee pollination of oilseed rape, cultivar Midas. Australian Journal of Experimental Agriculture and Animal Husbandry 22, 124-126, doi:10.1071/ea9820124 (1982).

[117] Manning, R. & Boland, J. A preliminary investigation into honey bee (*Apis mellifera*) pollination of canola (*Brassica napus* cv. Karoo) in Western Australia. Australian Journal of Experimental Agriculture 40, 439-442, doi:10.1071/ea98148 (2000).

[118] Mann, L. K. & Woodbury, G. W. The effect of flower age, time of day and variety on pollen germination of onion, *Allium cepa* L. American Society of Horticulture Science Proceedings 94, 102-104 (1969).

[119] Moll, R. H. Receptivity of individual onion flowers and some factors affecting its duration. American Society of Horticulture Science Proceedings 64, 399-404 (1954).

[120] Waller, G. D., Carpenter, E. W. & Ziehl, O. A. Potassium in onion nectar and its probable effect on attractiveness of onion flowers to honey bees. American Society of Horticulture Science Proceedings 97, 535-539 (1972).

[121] Lederhouse, R. C., Caron, D. M. & Morse, R. A. Distribution and behavior of honey bees on onion. Environ. Entomol. 1, 127-129 (1972).

[122] Waters, N. D. in Proceedings of the Fourth International Symposium on Pollination, Maryland, 1978. 65-72.

[123] McGregor, S. E. Insect Pollination of Cultivated Plants. Vol. no 496 (US Department of Agriculture, 1976).

[124] Langridge, D. F. & Goodman, R. D. Honeybee Pollination of Japanese Plums (*Prunus-Salicina* Lindl Cv Satsuma) in the Goulburn Valley, Victoria. Australian Journal of Experimental Agriculture 25, 227-230, (1985).

[125] Sapir, G., Goldway, M., Shafir, S. & Stern, R. A. Multiple introduction of honeybee colonies increases cross-pollination, fruit-set and yield of 'Black Diamond' Japanese plum (*Prunus salicina* Lindl.). J. Horticult. Sci. Biotechnol. 82, 590-596 (2007).

[126] Robbins, W. W. The Botany of Crop Plants. (McGraw-Hill, 1931).

[127] Skinner, J. A. & Lovett, G. Is one visit enough? Squash pollination Tennessee. American Bee Journal 132, 815 (1992).

[128] Nitsch, J. P., Kurtz, E. B., Liverman, J. L. & Went, F. W. The development of sex expression in Curcurbit flowers. Am. J. Bot. 39, 32-43 (1952).

[129] Jaycox, E. R., Guynn, G., Rhodes, A. M. & Vandemark, J. S. Observations on pumpkin pollination in illinois USA. American Bee Journal 115, 139-140 (1975).

[130] Page-Weir, N. E. M., Goodwin, R. M., McBrydie, H. M. & Cox, H. M. Honey bee pollination efficiency of carrot and radish seed crops. (HortResearch Client Report No. 25933, Ruakura, 2008).

[131] Eaton, G. W., Daubeny, H. A. & Norman, R. C. Pollination techniques for red raspberry breeding programs. Canadian Journal of Plant Science 48, 342-344 (1968).

[132] Colbert, S. & de Oliveira. Influence of Pollen viability on Raspberry (*Rubus idaeus* L.) development. J. Hered. 81, 434-437 (1990).

[133] Free, J. B. The ability of bumble bees and honeybees to pollinate red clover. J. Appl. Ecol. 2, 289-294 (1965).

[134] Free, J. B. The effect on pollen collection of feeding honey-bee colonies with sugar syrup. J. Agric. Sci. 64, 167-168 (1965).

[135] Jaycox, E. R. Pollination of Strawberries. American Bee Journal 110, 176-177 (1970).

[136] Darrow, G. M. The Strawberry, History, Breeding and Physiology. (1966).

[137] Connor, L. J. & Martin, E. C. Components of pollination of commercial strawberries in Michigan. HortScience 8, 304-306 (1973).

[138] Darrow, G. M. Sterility and fertility in the strawberry. Journal of Agricultural Research 34, 394-411 (1927).

[139] Hughes, H. M. Preliminary studies on the insect pollination of soft fruits. Experimental Horticulture 6, 44 (1961).

[140] Free, J. B. The pollination of strawberries by honeybees. J. Hortic. Sci. 43, 107-111 (1968).

[141] Chagnon, M., Gingras, J. & Oliveira, D. d. Effect of honey bee (Hymenoptera: Apidae) visits on the pollination rate of strawberries. J. Econ. Entomol. 82, 1350-1353 (1989).

[142] Mayer, D., Rathbone, L. & Miliczky, E. M. New ideas in cherry pollination. Proceedings of the Annual Meeting, Washington State Horticultural Association, 1987., 228-229 (1988).

[143] Asghary, H. & Arzani, K. A study on the compatibility and incompatibility of some sweet cherry (*Prunus avium* L.) cultivars with cv. Haj-Yosefy. Agricultural Sciences and Technology 20, Pe13-Pe19 (2006).

[144] Free, J. B. & Wiilliams, I. H. The transport of pollen on the body hair of honey bees. J. Appl. Ecol. 89, 609-615 (1972).

[145] Auerswald, H. Methods of improving pollination of greenhouse tomatoes. Gartenbau 25, 299-300 (1978).

[146] Cribb, D. M., Hand, D. W. & Edmondson, R. N. A comparative study of the effects of using the honeybee as a pollinating agent of glasshouse tomato. J. Hortic. Sci. 68, 79-88 (1993).

[147] Higo, H. A., Rice, N. D., Winston, M. L. & Lewis, B. Honey bee (*Hymenoptera*: *Apidae*) distribution and potential for supplementary pollination in commercial tomato greenhouses during winter. J. Econ. Entomol. 97, 163-170 (2004).

[148] Houbaert, D. & Jacobs, F. J. in Bees for pollination. Proceedings of an EC workshop, Brussels, Belgium, 2-3 March 1992. 207-218.

[149] Goodwin, R. M., Cox, H. M., Taylor, M. A., Evans, L. J. & McBrydie, H. M. Number of honey bee visits required to fully pollinate white clover (*Trifolium repens*) seed crops in Canterbury, New Zealand. N. Z. J. Crop Hortic. Sci. 39, 7-19, (2011).

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