Introduction

Macadamia is a member of the family Proteaceae, native to Australia and among only a handful of commercially cultivated endemic Australian plants; it is grown for its edible nuts. Australia and Hawaii are the major producing areas with others including California, Central and South America, and eastern and southern Africa (Truman and Turnbull 1994). There are several species of Macadamia that exist in Australia but only two species, *Macadamia integrifolia* and *M. tetraphylla* and their hybrids are grown commercially. These species are indigenous to the subtropical rainforests of the east coast of Australia (Wallace et al. 1996). Production of macadamia nuts in Australia is centred in northern New South Wales and south-eastern Queensland. These areas provide the rich soils and high annual rainfall needed to promote maximum growth.

The nuts themselves grow encased in a hard, woody shell, which is protected by a green-brown fibrous husk. In its natural state a macadamia tree will have flowers, nutlets and mature nuts growing simultaneously, in abundance for much of the year. The nuts fall to the ground between March and September each year and are harvested by pin wheel harvesters at regular intervals (AMS 2009).

Macadamia production in Australia

There are approximately 850 macadamia growers operating in Australia. The majority of the plantings are in northern New South Wales and south-eastern Queensland with fewer plantings on the New South Wales mid-north coast as well as central and northern Queensland (Table 1). In 2008 Australian macadamia production was about 35,000 tonnes (Table 2). Most of the plantings are on the coastal plains east of the Great Dividing Range with some pockets on tablelands in north Queensland. There are also minor plantings in Western Australia (Figure 1). Current estimates are that the Australian industry has about six million trees covering an area of 17,000 hectares varying in age from newly planted to trees that are over 40 years old (AMS 2009). Of these, 98% of trees are the commercially preferred *Macadamia integrifolia* species. Of the total trees planted, it is estimated that 45% are mature (15-years plus) 30% in the early bearing stage and 25% not yet bearing (AMS 2009).
Macadamia flowers are protandrous (have bisexual flowers) and are partially self-compatible. However, the initial nut set of many commercial cultivars is reduced when self-pollination is compared with cross-pollination. Heard (1993) suggests that given the small size of the stigma, the sticky pollen and the absence of wind-borne pollen, insect pollination must be a significant factor to pollination. Several studies in Hawaii cited by Wallace et al. (1996) have claimed that pollination by the honey bee *Apis mellifera* was responsible for increases in yield when honey bees were placed in an orchard (Shigeura Lee and Silva 1970, as cited in Wallace et al. 1996) and better yield and nut quality with cross-pollination in mixed block planting and honey bee introduction (Ito and Hamilton 1980, as cited in Wallace et al. 1996).

In Australia, the major pollinators in commercial macadamia plantations are from two genera of social bees: the introduced honey bee, *Apis mellifera*, and native bees of the genus *Trigona* (Vithanage and Ironside 1986). The behaviour of these species of bees influences their effectiveness as pollinators. Pollen collectors of both genera consistently make contact with the stigma of macadamia since pollen is presented on the swollen tip of the style adjacent to the stigma (Heard and Exley 1994). Nectar-collecting honey bees only occasionally make contact with the stigma and nectar-collecting *Trigona* never make contact with the stigma. Since contact with the stigma is necessary for effective pollination, the presence of honey bees is crucial for successful pollination in macadamia plantations.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>NSW</th>
<th>NT</th>
<th>QLD</th>
<th>WA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production per state (‘000 tonnes)</td>
<td>21,473</td>
<td>21</td>
<td>11,272</td>
<td>19</td>
</tr>
<tr>
<td>Percentage production per state (%)</td>
<td>65.49</td>
<td>0.06</td>
<td>34</td>
<td>0.05</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production NIS (nut in shell) in tonnes at 10% MC (moisture content)</td>
<td>35,000</td>
<td>43,900</td>
<td>41,800</td>
<td>35,000</td>
</tr>
<tr>
<td>NIS prices $/kg at 10% MC</td>
<td>3.6</td>
<td>2.6</td>
<td>1.5</td>
<td>1.6</td>
</tr>
</tbody>
</table>
There are a number of factors within the orchard which have a direct bearing on the pollination efficiency of honey bees:

### Orchard layout

- **Tree and blossom density**: Orchard design usually favours long rows to maximise land use and machinery operation. Planting distance can vary from high density (6 x 3m) to lower density (10 x 4m) depending on tree variety, soil conditions and topography. Staggered planting within rows to form equilateral triangles is favoured by some, but, in the main, trees usually form long hedgerows. High-density crops will have a greater blossom density and as such would require a greater amount of hives to ensure best possible pollination (AMS 2009).

- **Access**: From a beekeeper’s point of view, all-weather truck access is highly desirable. Limited access may lead to an increased workload for the beekeeper, uneven placement of hives and thus inefficient pollination. Ensuring the beekeeper has good access will aid in placement of hives and be mutually beneficial to the grower (increased pollination efficiency) and the beekeeper (decreased labour effort).

### Pollinisers

Macadamia flowers are largely self-compatible and protandrous with anthers opening several days before the stigma is receptive. Initial and final nut set are positively correlated with insect visitation rates and orchard yields may be increased by interplanting varieties. Because macadamia trees flower heavily, large numbers of insects are attracted which results in higher levels of cross-pollination than would be achieved if fewer flowers were presented (Heard and Exley 1994).

### Density of bees

Macadamia flowers are borne on long narrow racemes arising from the axils of leaves. The racemes are pendent, 10–20cm long, with 100 to 300 white flowers. Each flower is perfect with both male and female parts, and is about 12mm long (Heard and Exley 1994). A study conducted by Heard (1993) found that approximately 50 bee visits were made per day to each raceme. The individual flowers remain attractive to insects for three days and so approximately 150 visits per raceme are required to ensure adequate pollination. The optimal number of bee hives per hectare of 5–8 is based on research from both in Australia and overseas (DAF 2005).

### Table 3

<table>
<thead>
<tr>
<th>Pollinator treatment</th>
<th>Initial nut set (number of nuts)</th>
<th>Final nut set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagged</td>
<td>4.6</td>
<td>0</td>
</tr>
<tr>
<td>Exposed</td>
<td>16.1</td>
<td>0.23</td>
</tr>
</tbody>
</table>

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Macadamia since pollen is presented on the swollen tip of the style adjacent to the stigma (Heard and Exley 1994). Nectar-collecting honey bees only occasionally make contact with the stigma and nectar-collecting *Trigona* never make contact with the stigma. Since contact with the stigma is necessary for effective pollination, the type of floral resource gathered is important in determining the effectiveness of pollination.

A study by Heard (1993) in southern Queensland found that initial and final nut set on racemes significantly increased with increasing insect visitation (Table 3). Racemes exposed to six hours of bee visitation per day had similar final nut set to racemes constantly exposed (ten hours). Honey bees and *Trigona* spp. bees visited the racemes in approximately equal numbers at the site.

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Pollination management for macadamias in Australia

There are a number of factors within the orchard which have a direct bearing on the pollination efficiency of honey bees:
Arrangement of hives
The placement of hives within an orchard is very important to maximise pollination of a crop. While there is limited literature specific to macadamia in the placement of hives, suggestions made by Gary et al. (1972) recommend that if an orchard is surrounded by forest, hives could be placed near the central orchard area. This basic strategy would minimise bees targeting other sources of nectar and pollen such as that from eucalyptus trees. Other important measures that should be taken to ensure greater bee hive productivity when pollinating include having hives facing the sun to encourage bees to get out early and come back late, ensuring that the afternoon is shady, avoid low lying, damp and windy areas and place hives near a water source.

Timing
Macadamia flowers on an individual raceme open over a period of 6-12 days. The peak of flower opening is variable from as early as two days from the beginning of flowering to as late as six days and so flowers on some racemes open synchronously while those on other racemes open gradually. For racemes opening over a long period there are more opportunities for cross-pollination. The duration of attractiveness, from anthesis to withering of the perianth, is the period corresponding to visitation by insects. It is the period in which cross-pollen will arrive and hence its duration will partly determine the chances of cross-pollination. Anthesis results in the presentation of pollen to flower visitors. As such, it is an important factor influencing the behaviour of the flower visitors (Heard 1993). In Australia, macadamia will start flowering in August and September (Quinlan and Wilk 2005).

Preparation of bees/attractiveness, nutritional value of pollen and nectar
Honey bees pollinate macadamia flowers primarily whilst foraging for pollen. The quality of macadamia pollen may be variable. It ranges from 16% to 22% crude protein and the amino acid iso-leucine appears in two analyses to be a major limiting nutritional factor for bees (DAF 2005). This low nutritional value for rapidly breeding bees means that hives would need to be primed to collect pollen by feeding them sugar syrup or other supplements (DAF 2005).

Availability of bees for pollination
The macadamia flowering season occurs when beekeepers would be looking to build up the conditions of their hives for the spring and summer flows. Because macadamia nectar and pollen do not provide nutrition suitable for a hive build-up means that the beekeeper and orchardist would have interests which would probably be competitive.

Feral bees
Orchardists relying on feral bees should also be aware that relying on feral bees could be risky given that feral colonies are unlikely to be at full strength by the time the macadamia trees come into flower. If they were strong enough it is unlikely that pollination by these bees would be sufficiently intense to achieve optimal production especially if there are alternative floral resources in the vicinity.

Risks
Pesticides: One of the biggest drawbacks of placing bees near any agricultural crop is the possibility of colonies or field bees being affected by pesticides. Pesticides should be kept to a minimum while hives remain on the property. Most poisoning occurs when pesticides are applied to flowering crops, pastures and weeds.

It is strongly recommended that growers take the following steps to prevent or reduce bee losses:

- follow the warnings on pesticide container labels.
- select the least harmful insecticide for bees and spray late in the afternoon or at night.
- do not spray in conditions where spray might drift onto adjacent fields supporting foraging bees
- dispose of waste chemical or used containers correctly.
- always warn nearby beekeepers of your intention to spray in time for steps to be taken to protect the bees; give at least two days’ notice
- always advise nearby farmers.
Weather
Temperature and rainfall have a marked effect on honey bee activity. Bee activity is very limited below temperatures of 13°C, with activity increasing up to around 19°C, above which activity tends to remain at a relatively high level. Decreases in both numbers of bees visiting blossoms and the distance from the hive at which bees forage occur with a decrease in temperature.

Opportunities for improvement
Awareness: Improved awareness of the technicalities of pollination will allow management decisions to be implemented on an informed basis. This awareness should be directed to everyone involved in the implementation of management decisions in the production of macadamias including the orchardist, the beekeeper and their employees.

Potential pollination service requirement for macadamias in Australia
Optimal use of managed pollination services in all macadamia orchards in Australia would require a service capacity as indicated in Table 4 below.

<table>
<thead>
<tr>
<th>State</th>
<th>Peak month</th>
<th>Area (ha)</th>
<th>Average hive density (h/ha)</th>
<th>Estimated number of hives required</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>August</td>
<td>8,378</td>
<td>7</td>
<td>58,646</td>
</tr>
<tr>
<td>QLD</td>
<td>August</td>
<td>6,470</td>
<td>7</td>
<td>45,290</td>
</tr>
<tr>
<td>WA</td>
<td>September</td>
<td>16</td>
<td>7</td>
<td>112</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>14,864</td>
<td>7</td>
<td>104,048</td>
</tr>
</tbody>
</table>

Notes: Area sourced from ABS 2008 Agricultural Commodities Small Area Data, Australia 2005-06, flowering times from Quinlan and Wilk (2005) and average hive density from DAF (2005).
References


DAF 2005. *Honey bee pollination benefits for crops and orchards in Western Australia*. Department of Agriculture and Food, Western Australia.


This case study was prepared as part of *Pollination Aware – The Real Value of Pollination in Australia*, by RC Keogh, APW Robinson and IJ Mullins, which consolidates the available information on pollination in Australia at a number of different levels: commodity/industry; regional/state; and national. Pollination Aware and the accompanying case studies provide a base for more detailed decision making on the management of pollination across a broad range of commodities.

The full report and 35 individual case studies are available at www.rirdc.gov.au.
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.

RIRDC funds for the program are provided by the Honeybee Research and Development Program, with industry levies matched by funds provided by the Australian Government. Funding from HAL for the program is from the apple and pear, almond, avocado, cherry, vegetable and summerfruit levies and voluntary contributions from the dried prune and melon industries, with matched funds from the Australian Government.