Department of Primary Industries
and Regional Development

NSW GOVERNMENT

Hazelnut growers' handbook

NSW PRIMARY INDUSTRIES MANAGEMENT GUIDE

AgriFutures Emerging Industries

HAZELNUT GROWERS OF AUSTRALIA INC

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Hazelnut trees at the Orange Agricultural Research Institute.

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HAZELNUT GROWERS OF AUSTRALIA INC

Contents

Introduction

About this manual

The aim of this manual is to produce an informative resource for hazelnut growers in Australia. As many growers currently process and value-add, sections on postharvest handling and processing are included.

Hazelnut growers in Australia have a reputation for producing hazelnuts of excellent quality that are free from chemical residues and microbial contamination. The addition of this resource to members of the industry will help to maintain and improve this reputation. This updated edition reflects changes in domestic requirements by consumers and processors but still allows scope for producers to use different growing systems. It also reflects best practices from other hazelnut-producing regions around the world and includes information from Australian research programs.

Many hazelnut growers will want to make their own decisions, whereas others might not have the confidence or time to do so. The framework presented in this manual aims to help producers optimise their efficiency so their enterprises can be profitable and sustainable.

The overall aim is to create confidence for the producer, buyer and consumer and that Australian hazelnuts are of high quality.

The manual forms part of a package for new members joining the Hazelnut Growers of Australia Incorporated (HGA, https://www.hazelnutgrowersaustralia.org.au/).

History of hazelnut growing in Australia

Dr Basil Baldwin, Associate Professor, Charles Sturt University, Orange, NSW.

The European hazelnut (*Corylus avellana*) is the main species grown in Australia. It belongs to the birch family, Betulaceae, and originated in north-western Europe.

The European hazelnut was introduced into Australia over 150 years ago. Nursery catalogues from the 1840s show hazelnut planting material for sale in Tasmania and later in Victoria in the 1880s. These were most likely varieties introduced from England.

Records from the 19th century and evidence of small remnant orchards reveal that hazelnuts were grown near Launceston and Hobart in Tasmania, as well as in Bright, Wandiligong and the hills to the east of Melbourne in Victoria.

During the early 1900s, small hazelnut orchards were planted in cool climate areas of Victoria, particularly in the upper Ovens Valley, with Wandiligong being the main production centre (Pescott 1937). Most of these orchards were removed in the 1950s for higher return enterprises such as tobacco (Paskas 1988), which has since been abandoned as a crop. One of the main cultivars grown in this area was 'Wanliss Pride' (Allen 1986), which appears to be a selection from the Turkish cultivar 'Kargalak', also known as 'Imperial de Trebizonde'.

The first recorded experiment to evaluate hazelnut cultivars started in 1937 at the NSW Department of Agriculture, Glen Innes Research Station on the Northern Tablelands of NSW. The source of most of this planting material is unclear. Yields of 7.5 kg were reported from some trees. In 1972, the experiment at Glen Innes was discontinued and suckers from those trees were transferred to the Agricultural Institute at Orange, NSW.

In 1981, Dr Maxine Thompson, a well-known hazelnut researcher from Oregon State University, visited the Orange site, where she inspected the collection of cultivars. She considered they were types of seedlings rather than known varieties.

Through the early part of the 20th century, little development took place in the hazelnut industry, and many small orchards that were based on seedlings went into decline or were removed for more profitable crops.

In 1956, a Hungarian immigrant, Imre Tokolyi, set up a small baking enterprise in Victoria using various types of nuts. He was frustrated by not being able to source Australian-grown hazelnuts. It is purported that he planted thousands of nuts and selected seedlings for yield and suitability for local conditions. From these seedlings, he selected 3 types that he named 'Tokolyi Cosford', 'Turkish Cosford' and 'White American'. His use of the word 'Cosford' is unfortunate as there is an English variety of that name that is very different in nut shape from 'Tokolyi Cosford'. The variety 'Tokolyi Cosford', or 'Tokolyi Brownfield Cosford (TBC)' as it is often known, is now grown widely in Australia.

During the 1970s, there was a renewed interest in hazelnut growing in Australia, particularly in Victoria, where in 1978, enthusiastic growers decided to establish the Victorian Hazelnut Growers Association. This group included growers of walnuts and chestnuts as well as hazelnuts. They produced a very informative quarterly magazine, *The Australian Nutgrower*, from 1987 to 1996. The magazine subsequently continued as a journal of the Australian Nut Industry Council (ANIC).

During the 1970s and 1980s, many hazelnut cultivars of European and North American origin were introduced into Australia through the Australian Quarantine Inspection Service (AQIS) by growers, propagators and the Victorian Department of Agriculture.

During the 1980s, collections of hazelnut cultivars were established by the Victorian Department of Agriculture at the Ovens and Toolangi research centres. Although these were useful collections, there was little systematic evaluation of the material. Milan Paskas developed a significant varietal collection, including varietal types grown in the former orchards in the upper Ovens Valley as well as imported varieties. His collection was a valuable source of material when a varietal evaluation study was started in 1995.

Paul Baxter, John Kenez and Anthony Allen were involved in these trials and grower education programs. In 1986, Anthony Allen published a book, *Growing nuts in Australia*.

In 1988, the Australian Nut Industry Council was formed as a peak nut body, and by 1990–1991, the Victorian and NSW Nutgrowers Association ceased to operate; hazelnuts became a separate nut commodity group within the ANIC.

In 1988, Professor Harry Lagerstedt from Oregon State University came to Australia as a guest speaker at the Australian Nut Growers Association annual conference. He visited several hazelnut farms as well as the research sites at Toolangi and Ovens. He considered the cultivar 'Wanliss Pride' worthy of promotion for both the in-shell market, due to its large size and attractive appearance, and also for the kernel market, due to the good blanching characteristics and sweet flavour of its kernels. He considered that each state should have its own replicated variety trials to assess the material for both the in-shell and kernel markets and to define the most suitable ecological areas for hazelnut growing in Australia.

In 1995, Basil Baldwin of the University of Sydney started a major varietal evaluation program funded by the Rural Industries Research and Development Corporation. Lester Snare of the NSW Department of Agriculture was a key collaborator in the project. With 2 trial sites in NSW, 2 in Victoria and one in Tasmania, the aims of this program were to evaluate the growth and productivity of a range of hazelnut varieties in a range of soil types and climatic conditions to identify the most suitable varieties to grow for the in-shell and kernel markets. The outcomes of this research had a significant effect on varietal selection for orchards planted in subsequent years.

There is very little recorded information on the mechanisation of the hazelnut industry. We do not know how the nuts from the orchards in Myrtleford Valley were harvested in the 1920s; was it by hand-picking or were there some mechanical devices? Anecdotal evidence suggests that by the 1980s, some mechanical harvesting was taking place in a few larger orchards with locally made suction harvesters. These harvesters probably did not incorporate nut cleaners, so cleaning was done as a separate operation. Probably one of the earliest imported harvesters was a Petracci suction harvester with some cleaning capacity. The *Hazelnut growers' handbook*, published in 1990, has a photograph of a Tonutti suction harvester being used in a Victorian orchard, probably Brownfields. That machine is similar to current models of power take off-powered Tonutti and Facma harvesters using suction harvesting combined with debris cleaning. Dennis Bear had an orchard at Beechworth in the 1980s and made a pick-up harvester from parts from potato and grain harvesters. In more recent years, pin-wheel and suction harvesters have been used by many larger-scale growers.

Rotary graders were being used to sort nuts into size grades in the 1970s and probably earlier. Some growers were making their own cracking machines based on a rotating wheel with bars welded to them. There was an anvil plate against which the nuts were cracked. The gap between the rotating wheel and anvil was adjustable for varying nut sizes. Basic air separation machines were made to separate the kernels from the shells. Peter Rinaudo was manufacturing processing equipment in Myrtleford for the nut industries during the 1980s and 1990s. He produced size graders, elevators, cracking machines and airlegs for kernel and shell separation.

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Establishing an orchard

Site selection: soil requirements

Establishing highly productive, sustainable, long-term hazelnut plantings requires individual site analysis followed by careful planning and preparation. Soil structure and depth, clay content, and previous use at each site will potentially vary greatly within a small area. With chemical and physical amendments and additions, the scope of potentially suitable and productive soil types is broadened.

Hazelnuts require well-drained soil, approximately 1.8 m deep and preferably with good organic matter levels. The trees have a mainly fibrous root system, and deeper soil types allow for greater access to soil resources and heavier production in the mature orchard. Alluvial river flats have produced excellent growth in Australian research trials.

In areas with shallow soil types, particularly over rock, trees have initially grown well but then declined. Heavy clays and very sandy soil types should be avoided; a deep loam is preferred. In some areas of NSW on krasnozem soil, acidic conditions combined with high manganese levels can be detrimental to growth. The pH of these soil types can go as low as 4.5. A neutral to slightly acidic soil (pH 5.5–6.5) is suitable.

There are 2 common measurements of soil acidity or alkalinity: pH as measured in water (pH$_{W}$) and pH as measured in calcium chloride (pH$_{Ca}$), both at a soil to solution ratio of 1:5. pH is a logarithmic scale, meaning that pH 4 is 10 times more acidic than pH 5 and 100 times more acidic than pH 6. A simple pH test can also be conducted in the field (Figure 1).

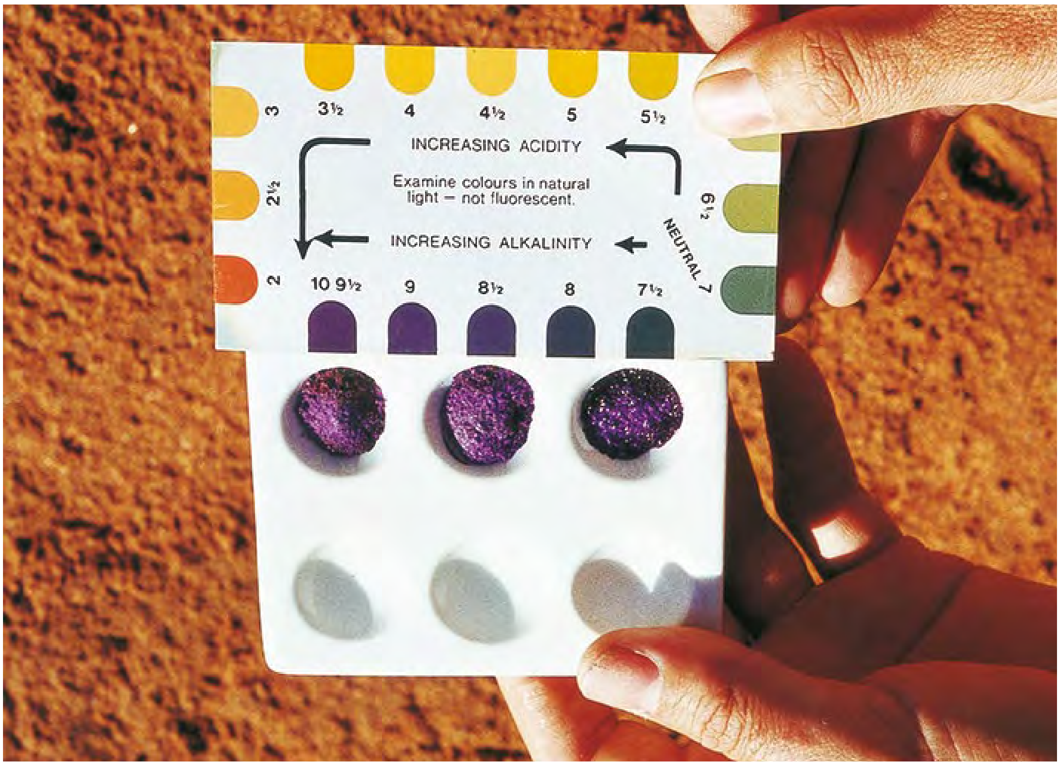

Figure 1. Measuring soil pH in the field.

Soil test reports usually provide pH results measured in both water and calcium chloride (Table 1). Soil tested in calcium chloride registers about 0.5 to 0.8 units lower than the same soil tested in water. The calcium chloride test is more useful for long-term monitoring and is often used for fertiliser and planting recommendations. It is less subject to seasonal variations and is better at estimating field conditions.

Although all the indicators in Table 1 are important, cation exchange capacity (CEC) plays a significant role. Cation exchange capacity is a measure of the soil's ability to hold nutrients for later use by the plants. Soil with a low CEC is often sandy and prone to leaching, while soil with a high CEC is usually more fertile. Organic matter, which eventually decomposes to humus, has a much greater CEC than, for example, clay; hence increasing organic matter in the nut orchard is important for maintaining soil fertility.

Table 1. Typical indicators evaluated in a soil test and desirable levels for hazelnut production.

Indicator	Desirable range
pH_{Ca}	5.5–6.5
Organic carbon % (Walkley-Black method*)	3.5–4.0
Nitrate nitrogen (mg/kg N)	10–20
Phosphorus bray (mg/kg)	30–50
Electrical conductivity (dS/M)	<0.15
Cation exchange capacity (cmol(+)/kg)	>10
Exchangeable cations	**Desirable range**
Calcium (Ca)	65–80% (4–6 meq/100 g)
Magnesium (Mg)	10–20% (1–2 meq/100 g)
Potassium (K)	2–6% (0.3–0.5 meq/100 g)
Sodium (Na)	<2% (0 meq/100 g)
Aluminium (Al)	<5% (0 meq/100 g)
Cation exchange capacity	>10
Calcium:magnesium ratio (Ca:Mg)	3–5:1 (i.e. 3–5 parts Ca to one part Mg)

*Standard operating procedure for soil organic carbon: Walkley-Black method titration and colourimetric method.

If pH falls below 5.5, lime or dolomite should be applied (Table 2), preferably some months before planting. Lime also adds calcium (Ca) to the soil and dolomite adds Ca and Mg. Note that dolomite should not be used regularly, otherwise exchangeable Ca:Mg ratio levels can also become low. A full soil test will provide greater detail on other factors that should be considered. In established plantings, soil should be tested at least every 2 years, and if necessary, top dressed with lime or dolomite before the pH drops too low.

As well as being mobile in plants and components of chlorophyll, Ca and Mg should be kept at sufficient levels in the soil because they are beneficial to the soil's physical state. This relates to their ability to stabilise soil aggregates and their influence on the activity of decay organisms. Stabilising soil aggregates is encouraged by the active decay of organic residues. Alternatively, excess or high levels of Mg can lead to the soil structure collapsing, with soil becoming hard and forming crusts. Infiltration rates of water can also be reduced. Gypsum ($CaSO_4$) can help by loosening the soil but adding gypsum is only part of the solution: increasing organic matter levels will provide improved soil aggregate stability. A ratio of 3–5 parts Ca to one part Mg is desirable.

The relative availability of 12 essential plant nutrients in well-drained mineral soil types in temperate regions in relation to soil pH is shown in Figure 2. A pH_{Ca} range between 5.5 and 6.5 is considered ideal for hazelnuts.

Table 2. Amounts of lime required to reduce pH in soil types of different textures.

To change pH(w) in 0–150 mm topsoil		t/ha of fine agricultural lime				
From	**To**	**Sand**	**Sandy loam**	**Loam**	**Silty loam**	**Clay loam**
4.0	6.5	4.50	6.70	8.00	9.00	11.25
4.5	6.5	3.30	3.50	6.75	7.50	9.00
5.0	6.5	2.25	3.75	5.25	6.00	7.50
5.5	6.5	1.50	3.00	3.75	4.50	5.25
6.0	6.5	0.75	1.50	1.80	2.25	5.25
4.0	6.0	3.30	5.25	6.75	7.50	9.00
4.5	6.0	2.25	3.75	5.25	6.00	7.50
5.0	6.0	1.50	3.00	3.75	4.50	6.00
5.5	6.0	0.75	1.50	1.80	2.25	5.25
4.0	5.5	2.25	3.75	5.25	6.00	7.50
4.5	5.5	1.50	3.00	3.75	4.50	6.00
5.0	5.5	0.75	1.50	1.80	2.25	5.25

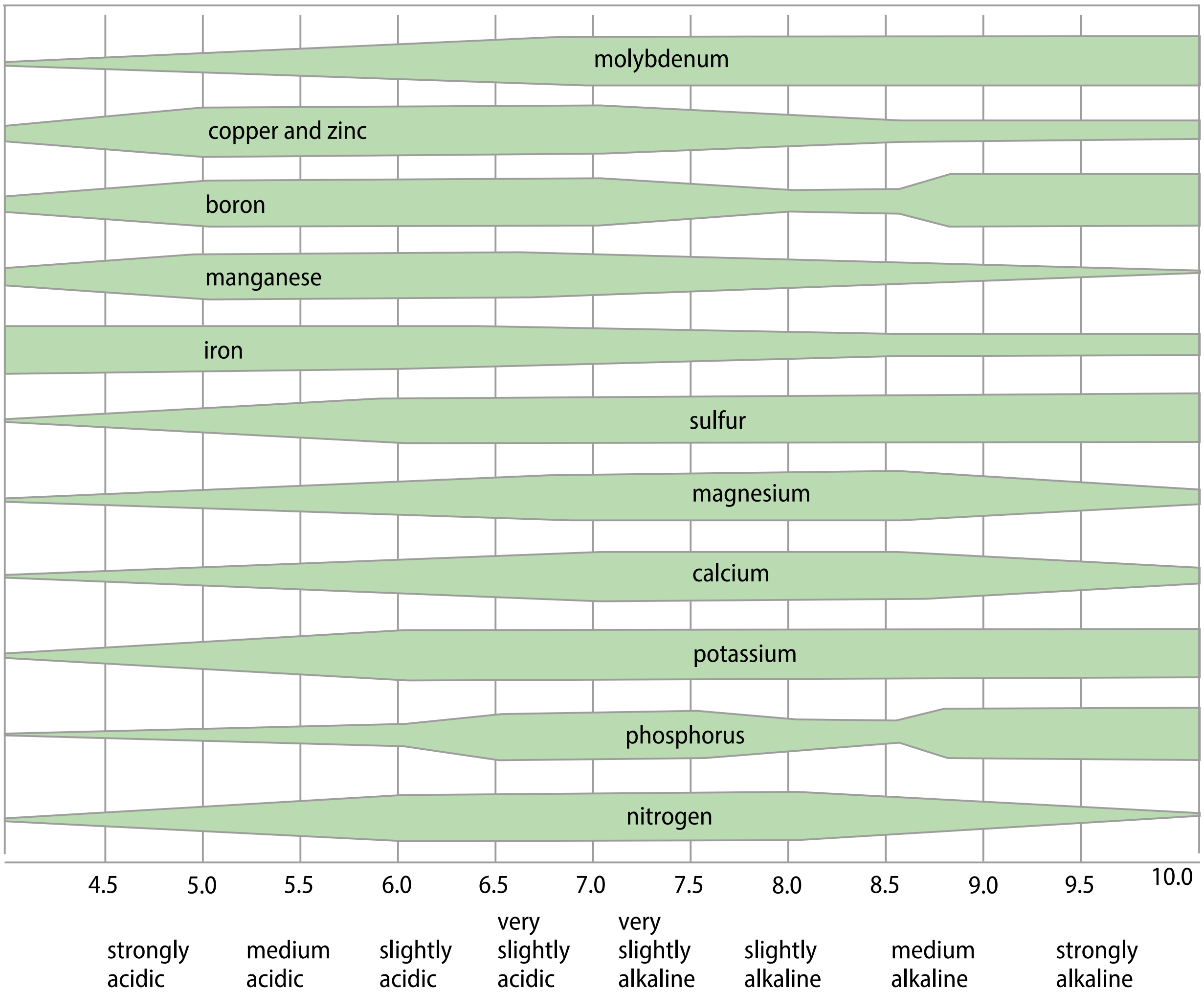

Figure 2. The effect of soil pH on the availability of plant nutrients. The thicker the band, the more soluble the element is at that soil acidity/alkalinity level.

Managing the soil

The hazelnut orchard floor needs to be relatively clear for successful nut collection during harvest. This will be influenced by the type of harvest machinery used.

With a varying climate, summer storms are predicted to become more intense. Orchard floors that are unprotected can be prone to erosion. Typically, in an established bearing orchard, a flail mower is used on the ground cover (Figure 3). This helps to reduce the ground cover height to just above the soil surface, chops up leaves and twigs, and prepares the orchard floor for harvest.

Observing the soil profile can provide information about its advantages and limitations. The soil profile refers to the sequence of horizons down to and including the parent material. The A horizon is the topsoil from where hazelnuts obtain most of their nutrients, and the B horizon or subsoil is the soil profile's moisture storage layer. To determine the soil depth, dig suitable holes with an auger, backhoe or shovel to 2 m deep (Figure 4). A hand auger is portable (Figure 5) and can be used to check irrigation depth as the orchard matures.

Soil structure is the physical arrangement of the soil particles, aggregates and pores. Its greatest influence is on the distribution of moisture and oxygen in the soil, which in turn affects how easily roots can obtain nutrients from the soil. Growers should be wary of soil with sandy silt or loam topsoil over clay subsoil because the fibrous roots of the hazelnut tree can be restricted in these soil types, which can have poor drainage. Lateral drainage at the top of the subsoil can also cause problems for root growth.

The proportion of sand, silt and clay determines soil texture. Organic matter and clay minerals provide the bonds that hold the soil together. In soil comprising over 60% clay particles, the clay minerals will do most of the bonding. As the proportion of clay in the soil decreases, organic matter becomes increasingly important. For example, a loam soil has roughly equal portions of sand, silt and clay, and is generally good topsoil that is suitable for hazelnut production.

Figure 3. A flail mower in a hazelnut orchard. Photo: Filotas (2021).

Figure 4. A soil pit showing root development and soil characteristics.

Figure 5. Soil sampling in Orange (NSW) with a hand auger.

Colour is often the first clue to determining soil type. Red soil is generally more sandy than black soil, whereas red clay soil types have limited ability to swell. These soil types are typically acidic and can become hard-setting. Redness in soil generally indicates good drainage, which can be evidenced by oxidation of the iron content. Yellow or mottling of soil can indicate poor drainage and the possibility of waterlogging.

Growers should maintain sound cultural practices to sustain soil structure, minimise erosion and provide an environment for healthy root development. Soil compaction and low levels of organic matter can reduce root growth and tree performance. Avoid using heavy machinery and harvesters on bare, wet ground, particularly on soil with high clay content. Excess run-off exposes tree roots, which can then be left without protection from herbicides if the tree strip is sprayed.

The basic principles for managing soil are:

- Orchards should be planned so that water flow is managed to minimise soil erosion and nutrient run-off: the topsoil is the most valuable soil and needs to be stable.
- Aim to keep the soil at least 70% covered through the growing season.
- Shorten intermediate slopes with contour banks.
- Contour rip, where necessary, pre-planting; this will increase water entry into the soil and limit run-off.
- On sloping land, plant on the contour if possible.

Site selection: climate requirements

A suitable climate, reliable rainfall or supplementary irrigation are needed for good tree growth and high-quality nut production. The preferred climate is characterised by mild to warm summers and cool winters. Sites exposed to the drying effects of summer winds should be avoided. Hazelnuts have soft leaves and do not tolerate extreme heat, cold or wind.

Major nut production areas in Northern Turkey, Italy and Spain lie in the latitude range of 40 to 45 °N. Many areas of Australia have a similar temperate climate, particularly in Victoria, Tasmania and the NSW Tablelands, as well as some areas of western WA and SA (Table 3).

More than 750 mm of annual rainfall is required for good production. In seasons or areas with low or unreliable rainfall, supplementary irrigation is useful, especially while the trees are establishing.

Long chilling periods are required to ensure fruitfulness and reliable yields. Chilling requirements vary for male flowers (catkins or staminate), female flowers (pistillate) and leaf buds, but 1,200 hours between 0 and 7 °C is considered suitable. Some varieties, such as Tonda di Giffoni, can have lower chilling requirements. Areas with severe frosts and temperatures below −5 °C when the female flowers are opening should be avoided. Low temperatures at pollen shed followed by bursts of substantially warmer weather can cause catkins to dry out, affecting pollen quality.

During dormancy, hazelnuts can tolerate snow and winter frosts down to at least −15 °C, but catkins can be killed at temperatures >21 °C; higher summer temperatures can scorch and burn leaves and prevent satisfactory fruiting. Newly planted trees can be whitewashed or have sarking applied to protect the trunks from sunburn in the early years. Hazelnuts do not tolerate windy conditions combined with high summer temperatures and low humidity.

Slope and aspect should be considered; west-facing slopes should be avoided. These can be prone to strong, hot winds in summer, causing stress in developing trees.

Table 3. The climate of hazelnut production areas overseas compared with Australian localities where hazelnut groves have been successfully established.

	Key production areas							
	Ordu Northern Turkey	Nola Campania Italy	Corvallis Oregon USA	Bega NSW	Kettering Tas	Myrtleford Vic	Narrandera NSW	Orange NSW
Latitude	40.9 °N	40.9 °N	44.5 °N	36.6 °S	43.1 °S	36.5 °S	34.7 °S	33.2 °S
Mean annual rainfall (mm)	990	1,010	1,050	870	700	910	287	940
Hottest month mean max (°C)	25	30	27	27	22	28	33	25
Mean min (°C)	18	18	11	14	10	12	17	12
Mean rain (mm)	68	29	14	89	46	45	23	109
Rain days*	5	4	3	7	9	5	3	9
Coldest month mean max (°C)	10	12	7	16	12	14	16	9
Mean min (°C)	3	5	1	1	2	1	4	0
Mean rain (mm)	95	111	173	53	56	106	25	87
Rain days	10	11	19	6	12	14	5	14
Harvest month mean rain (mm)	72	79	38	98	52	60	20	50
Rain days	6	5	6	8	9	6	3	7

*Rain days refer to the mean number of days with ≥1 mm of rain.

Sources: Salvin et al. (2004); Bureau of Meteorology (http://www.bom.gov.au).

Calculating a region’s chill hours

Different plant parts have different chilling requirements. Catkins generally require fewer chilling hours than either vegetative buds or female flower clusters. Calculating the average temperature in the coldest months (usually June to August) and using the ‘ready reckoner’ (Figure 6) can help determine the number of chill hours at a site. This should be used as a general guide as it does not take into account site-specific considerations. For help obtaining the mean temperature for an area, refer to the Bureau of Meteorology (http://www.bom.gov.au). Climatic data are available online from the bureau’s website. The mean temperature for each month is obtained by adding the daily maximum and daily minimum temperatures and dividing that number by 2. Add the daily mean temperatures for the month and divide by the number of days in the month. This figure can then be used to read from the graph and estimate available chilling hours per month.

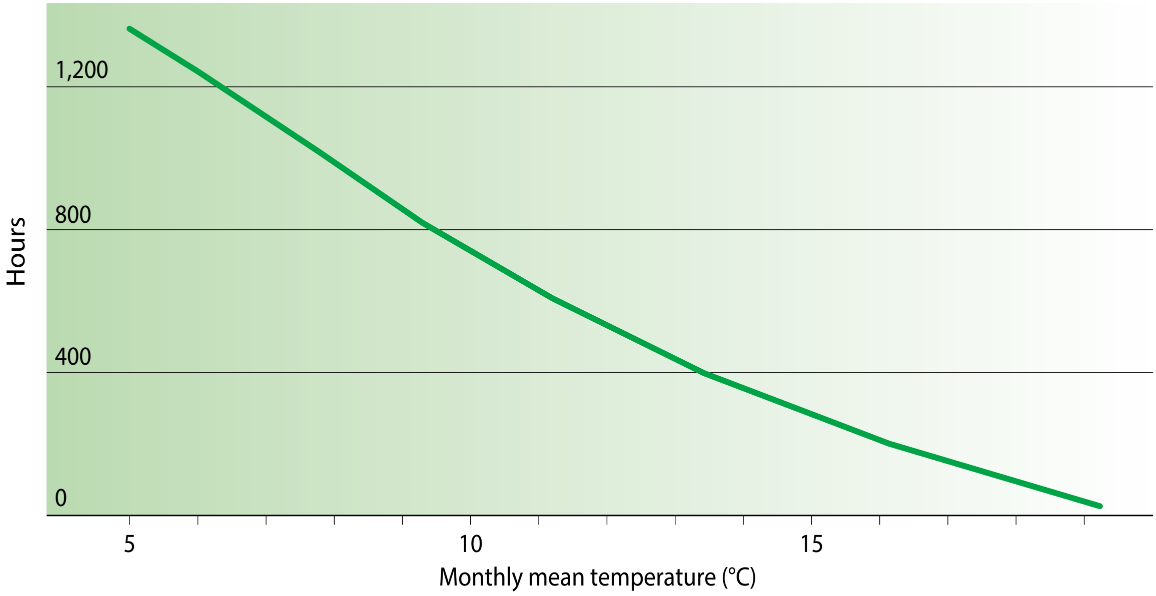

Figure 6. Winter chill ready reckoner.

Site selection: risk factors

Pistillates (female flowers) can be damaged by late spring frosts, which can reduce crop yield. Historical frost-day data can be used to assess region suitability based on the average of annual frost days. Late spring frosts are more likely to occur in regions that have more annual frost days, presenting a risk for hazelnut production.

Further reading

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Variety selection

Selecting the most appropriate hazelnut varieties before planting is a very important decision. The main considerations are:

- intended markets (nuts in-shell or as kernels, after cracking)
- productivity
- pollinisers
- site and climate
- pests
- diseases
- proposed harvesting method.

If inappropriate varieties are chosen, it might not be apparent for several years. Replanting is expensive in terms of replacement trees and loss of potential income.

Several varieties have been imported through the Australian Quarantine Inspection Service and have undergone checks to confirm the absence of pests and diseases. Many of these imported varieties have now been propagated and are available from Australian specialist hazelnut nursery suppliers. Contacts for nurseries are available from the Hazelnut Growers of Australia Incorporated website (https://www.hazelnutgrowersaustralia.org.au/).

Intended markets

The **in-shell** market uses large nuts with attractive shiny shells.

The **kernel** market typically uses nuts that can be either blanched (i.e. the pellicle or skin is removed) or unblanched and they are sold raw or roasted. Ideally, nuts for this market have:

- round shells that are easy to crack
- plump, bright, white kernels
- crisp and crunchy texture when dried, with a nutty flavour
- easily removed pellicle by heat for the blanched or roasted market.

Hazelnut kernels are covered with a pellicle that varies between varieties in thickness, appearance and ease of removal. Kernels suitable for the raw, unblanched trade ideally have thin pellicles. Rough, thick pellicles are considered to be unattractive. The pellicle can be relatively easily removed from varieties such as Tonda di Giffoni, Barcelona, Lewis (Figure 7) and the Australian selection, Tokolyi Brownfield Cosford (TBC). The blanching process involves heating kernels for 10–15 minutes at 135 °C and then rubbing or brushing them to remove the loose pellicle.

Figure 7. Examples of blanched hazelnut kernels. Left to right: Ennis, Barcelona and Lewis, showing little skin removal with Ennis to a high level of skin removal and good blanching with Lewis. Photos: Snare (2010).

Varieties for the in-shell market

Ennis is a very popular variety for the in-shell market due to the large-sized shiny nuts and relative tree vigour. However, kernels are not always well-filled, which might present some disappointment for buyers when the nuts are cracked. Butler is also a vigorous variety that yields well but the nuts are a little smaller, with fewer in the Jumbo (>22 mm) nut category.

Hall's Giant produces large nuts but is low-yielding. It is used as a late polliniser for other varieties including Ennis and Butler.

The Royal variety is not commonly grown. It produces large, attractive nuts, has kernels that are generally well-filled and has a pleasant nutty flavour, especially when roasted. The kernels also blanch well relative to the Ennis and Butler varieties.

Wanliss Pride produces very attractive nuts and kernels that blanch well. It can be grown for either the in-shell or kernel markets. However, it is not very adaptable; it grows well in some environments but very poorly in others, and it has a straggly, weak growth habit.

Table 4 shows the varieties recommended for the in-shell and kernel markets based on extensive field trials in Australia. Nut weight, nut shape and kernel attributes for many varieties are included.

Table 4. Varieties recommended for the in-shell and kernel markets based on field trials in Australia.

Cultivar	Nut weight (g)	Nut shape (length/width)	Kernel weight (g)	Kernel/nut weight (%)	Kernel fibre	Relative blanching
Cultivars with large nuts mainly for the in-shell trade						
Butler	3.4	1.10	1.4	42	2.0	6.3
Ennis	3.9	1.10	1.6	41	1.5	6.6
Halls Giant	3.4	1.10	1.4	41	1.3	3.4
Royal	4.1	1.20	1.6	40	1.7	4.8
Cultivars with kernels 15–17 mm size grade						
Barcelona	3.3	0.97	1.3	40	3.0	3.3
TBC	3.0	1.01	1.3	43	2.5	2.6
Wanliss Pride	3.2	0.85	1.5	45	2.0	2.4
Cultivars with kernels 13–15 mm size grade that blanch						
Lewis	2.4	0.97	1.2	48	1.8	2.6
Montebello	3.0	0.92	1.1	36	2.5	2.7
Negret	1.9	1.15	0.8	49	2.0	1.7
TGDL	2.5	0.97	1.1	45	2.0	2.8
Tonda di Giffoni	2.6	0.94	1.1	43	2.0	3.1
Cultivars with kernels 13–15 mm size grade that do not blanch						
Casina	1.9	1.08	1.0	51	1.5	5.7
Segorbe	2.4	1.04	1.0	40	1.7	4.1

Note: kernel fibre was rated on a 1 (low) to 5 (high) scale. Relative blanching was rated on a 1 (little pellicle remaining or excellent blanching) to 7 (most pellicle remaining, kernels did not blanch) scale.
Source: Baldwin (2015).

Varieties for the kernel market

There are several varieties that are suited to the kernel market (Table 4). Barcelona, TBC and Tonda di Giffoni are commonly grown, vigorous varieties that can produce high yields. Both Barcelona and Tonda di Giffoni fall free from the husk when ripe, whereas some TBC nuts can stick in the husk. Barcelona kernels can appear slightly shrivelled, whereas those of TBC are generally well-filled but prone to black tips, giving them an unpleasant taste.

Lewis nut yields are variable. It has small nuts with thin shells that are prone to predation by cockatoos. Its best role is as a polliniser for TBC as it produces many catkins and sheds pollen during the mid-period of female anthesis of TBC.

Tonda Gentile delle Lange (TGDL) is prized for its kernel quality but did not grow or yield well in Australian field trials. Negret is a widely grown variety in Spain, where it grows as a small tree. The kernels blanch very well, but in Australia, it suffers from low yields.

Casina and Segorbe produce modest yields of small nuts with kernels that do not blanch. Casina has some potential as a polliniser, as it sheds pollen in mid-season and is compatible with many varieties. Its small nuts are relatively easy to separate from the larger nuts of varieties such as Barcelona and TBC.

Varieties grown mainly as pollinisers

Pollinising varieties for the in-shell and kernel markets are listed in Table 5.

Table 5. Varieties grown mainly as pollinisers.

Variety	Alleles	Time of female anthesis	Suggested compatible pollinisers for early, mid and late stages of pollen shed
In-shell varieties			
Butler	2, 3	Late	Casina, J#5 and Halls Giant
Ennis	1, 11	Late	J#5 and Halls Giant
Royal	1, 3	Mid	TBC and Halls Giant
Wanliss Pride	2, 10	Early–mid	Barcelona, Ennis, TBC
Kernel market varieties			
Barcelona	1, 2	Mid	Lewis, TBC, J#5 and Halls Giant
Lewis	3, 8	Mid	Barcelona, TBC and J#5
Tokolyi Cosford	5, 23	Mid–late	Barcelona, Lewis, J#5
Tonda di Giffoni	2, 23	Mid	Barcelona, Lewis, TBC, J#5, Halls Giant

Sources: based on data from Baldwin (2015) and Mehlenbacher (2014).

An allele is a form of a specific gene.

Jemtegaard#5 (J#5) is a vigorous variety that sheds pollen late in the season. It has medium-sized nuts but yields are generally low.

Halls Giant is also a vigorous but low-yielding variety, shedding pollen late in the season. It produces medium-sized nuts that blanch well. It usually produces many catkins, but in some situations, these fall from the tree in autumn. The trunk is subject to sunburn if planted in areas exposed to late afternoon sun.

For the kernel market, TBC is a useful polliniser for both Barcelona and Tonda di Giffoni as well as being a significant nut-bearing variety. It is best used where Lewis and J#5 are also included as pollinisers.

Other factors

Some varieties are more widely adapted than others. If in doubt, plant a few trees of the preferred varieties before embarking on a major planting.

TGDL, Tonda di Giffoni and Lewis leaf out very early in the season. Their new shoots can be damaged by a late frost. If the site is frost-prone, such as a valley floor, this risk needs to be considered.

Varieties differ in their susceptibility to bacterial blight. Young Barcelona trees can be affected by this disease in warm, wet spring weather. Some varieties are susceptible to big bud mites, although this pest seems to be limited to Tasmania.

Sulfur-crested cockatoos predate on nuts of all varieties but seem to prefer those with small nuts and thin shells.

Big nuts are generally easier to harvest and process than small nuts. The husks on TBC can be a nuisance unless the harvester has a de-husker.

Varieties

Barcelona (synonym Fertile de Coutard)

This is an old variety that is widely distributed in Western Europe and has been the basis of the industry in Oregon. In the 1880s, Frenchmen Felix Gillet imported many hazelnut varieties and began distributing these from a nursery he established in California. Australian imports of this variety have mainly come from the USA. Barcelona has vigorous growth, performing well in variety trials in Australia and appears to be well adapted to a range of regions. It can be used in the in-shell and kernel markets and blanches reasonably well (Figure 8). Nuts have a 40% crack-out kernel by weight. Barcelona is productive and mid-season flowering. Suitable pollinisers are Lewis, TBC and Halls Giant.

Figure 8. Barcelona nuts.

Butler

This selection from the USA has been available in Australia for many years. It has been used widely in the USA as a polliniser for Ennis since 1957 and can be used in the in-shell market. The attractive, well-sized nuts come freely from the husk, but the kernels do not blanch well (Figure 9). Butler is productive and matures about 8 days before Barcelona.

Figure 9. Butler nuts.

Casina

Casina (Figure 10) is a Northern Spanish variety with small nuts averaging 1.8–2.0 g that are suitable for the unblanched market. Casina has a high proportion of catkins shedding mid-season and is a suitable polliniser for many varieties, including Barcelona, TBC and Ennis. Casina nuts are enclosed by the husk and have a crack-out of 51% kernel by weight.

Figure 10. Casina nuts.

Ennis

Ennis (Figure 11) is an American cultivar known around the world for its large nut size and reliable high yield. Its size (nut weight up to 4.3 g)and attractive colour make it well suited to the in-shell market, although it can be used in other markets. Ennis does not blanch well, having a similar blanching ability to Daviana. In Australia, Ennis falls freely from the husk and releases its pollen relatively late in the season. Pollinisers include Halls Giant, Casina and Jemtegaard #5.

Figure 11. Ennis nuts.

Lewis

Lewis (Figure 12) is a high-yielding variety for the kernel market; it was released by Oregon State University in 1997. Lewis trees are early bearing and 75–80% of the size of Barcelona trees; they are upright and spreading and might be suited to closer plantings. Nuts are slightly smaller than those of Barcelona, fall free from the husk at maturity, and have a blanching capacity slightly better than Barcelona. Pollinisers for Lewis include Tonda di Giffoni and Halls Giant. Lewis pollinates Ennis and Casina.

Figure 12. Lewis nuts.

Tokolyi Brownfield Cosford

Tokolyi Brownfield Cosford (TBC; Figure 13) is most likely an Australian seedling selected by Imre Tokolyi, who immigrated to Australia in 1956. A large, productive planting existed at the Brownfield orchard at Acheron in Victoria for many years. Some material was distributed from this orchard. TBC is a vigorous, upright tree that is well adapted to many hazelnut-producing areas in Australia. It has good yields and produces kernels that are suited to a range of products. The nut is round, blanches well and has a kernel percentage of 43–45%. A proportion of TBC nuts fall with the husk attached; these are typically removed by harvest equipment or later during processing. TBC produces pollen mid-season and can pollinise many varieties. TBC is pollinised by Barcelona, Lewis and Jemtegaard #5. This is one of the few Australian varieties with known alleles.

Figure 13. Tokolyi Brownfield Cosford nuts.

Tonda di Giffoni

Tonda di Giffoni originates from central Italy and has a kernel much prized by the confectionery market. The nuts are round (Figure 14), blanch extremely well and have a crack-out of 43% kernel by weight. The yield is reliable and similar to those of Barcelona and Ennis. Australian observations show it to be a strong tree with early leaf out and good yields. Both catkins and leaf buds have a low chilling requirement, making them suitable for areas with lower chill hours. Pollinisers for this variety include Barcelona, Lewis and Halls Giant.

Figure 14. Tonda di Giffoni nuts.

Daviana

Daviana originated in England and has been used as a polliniser for Barcelona in the USA. Daviana nuts are medium to large, slightly elongated and do not blanch well. Daviana yields are reported to be low overseas, and this is supported by Australian studies. Observations in Australia also show that Daviana is prone to dropping catkins in late autumn and, compared with other varieties, might be more prone to moisture stress. Daviana matures approximately 10 days before Barcelona.

Halls Giant (synonym: Merveille de Bollwiller)

Halls Giant plays an important role as a late polliniser and is a vigorous, erect tree. It is compatible with a range of varieties, except TBC. Halls Giant nuts are smaller and thicker-shelled than those of Ennis, but can be blanched to some extent. It is a low-yielding variety and resistant to big bud mite.

Jemtegaard #5

Jemtegaard #5 (J#5), a growers' selection from Oregon, is a useful late polliniser in Australia. It is a relatively vigorous variety with good numbers of catkins to ensure ample pollen distribution. J#5 will pollinise Barcelona, Ennis and TBC. J#5 nuts are medium to large.

Tonda Romana

Tonda Romana is an Italian variety of ancient origin and is the main variety in the hazelnut orchards of Viterbo province (north of Rome). The tree has moderate to low vigour, is semi-erect and has many suckers. The husk is slightly longer than the nut and most nuts fall free of the husk. Tonda Romana has moderate to high yields. The nut is medium to small, round, with a dull light brown shell yielding 44–48% kernel. Kernels are round, usually free of fibre and do not blanch. Black tips can be a problem due to splitting along the shell suture.

Tonda Romana is resistant to big bud mite but is susceptible to bacterial blight. Pollen shed and female flowering are mid-season. Suitable pollinisers are Lansing, Tonda di Giffoni and Halls Giant.

Wanliss Pride

Wanliss Pride is a medium-sized tree with a spreading habit. It was grown in north-east Victoria in the 1920s. It could be a selection of the Turkish variety Imperial de Trebizonde. Reported yields of Wanliss Pride are variable, but the tree appears to grow well as a multi-stemmed plant. The nuts are large, with a distinctive broad base. Some growers report a degree of shrivelling following harvest.

Rootstocks

The Turkish tree hazel (*Corylus colurna*) has particular value as a non-suckering rootstock. Its deep taproot results in increased drought tolerance in the drier Australian summers. However, the seeds are difficult to germinate and because of the taproot, seedlings are difficult to transplant. Only vigorous hazelnut varieties should be grafted onto the Turkish tree hazel as the rootstock tends to outgrow all but the most vigorous varieties. More research is required in Australia into the use of *C. colurna* as a rootstock to identify any compatibility problems and eventual tree size. *C. colurna* seedlings are useful as a rootstock for ornamental hazels where nut production is not important.

Newberg and Dundee rootstocks have been imported into Australia, as have several interspecific hybrid 'trazels' that might have potential as rootstocks.

Using vigorous, non-suckering rootstocks could increase orchard cost-effectiveness by reducing the need to prune suckers and potentially facilitating mechanical harvesting.

Yields

Hazelnuts begin to bear at approximately 3 years old, and at 6 years, yields should approach 2–2.5 kg/tree. At the lower limit, this translates to 1,000 kg/ha, assuming 500 trees/ha. Yields of 2.5–3.5 t/ha sustained annually would be an acceptable level of production. Yields of 4.5 kg of in-shell product and greater have been recorded from 8-year-old trees at the Orange Agricultural Institute. Mature trees grown without irrigation or fertilisers can produce 20–25 kg/tree. With intensive management, yields can be up to 40 kg/tree.

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Nutritive value

Table 6 shows the nutritional values of a range of hazelnut varieties.

Table 6. Nutritional properties of hazelnuts.

	Dry matter (%)	Carbohydrate (%)	Protein (g/100 g)	Fat (g/100 g)	Dietary fibre (g/100 g)	Ash (g/100 g)
Barcelona (Orange NSW)[2]	94.7	–	13.0	62.9	–	–
Barcelona (Yanco NSW)[2]	95.2	–	14.0	65.0	–	–
Ennis (Orange NSW)[2]	93.7	–	9.0	65.2	–	–
Ennis (Yanco NSW)[2]	94.8	–	13.9	64.1	–	–
Hall's Giant[1]	96.0	–	18.4	54.1	19.7	2.5
Merveille de Bollweiler[1]	96.2	–	11.7	62.3	15.3	1.9
Lewis (Orange NSW)[2]	95.0	–	16.3	62.1	–	–
Lewis (Yanco NSW)[2]	95.7	–	14.2	54.1	19.5	2.7
Mortarella (Yanco NSW)[2]	95.4	–	12.9	66.0	–	–
Nocchione (Orange NSW)[2]	95.1	–	13.4	65.0	–	–
Nocchione (Yanco NSW)[2]	95.2	–	14.5	66.6	–	–
Tokolyi Brownfield Cosford (Orange NSW)[2]	95.4	–	12.2	68.1	–	–
Tokolyi Brownfield Cosford (Yanco NSW)[2]	95.8	7.8	21.2	60.8	–	2.4
Tonda di Giffoni[1]	96.1	–	16.5	62.7	13.8	2.1
Tonda di Giffoni (Orange NSW)[2]	95.0	–	12.2	64.5	–	–
Tonda di Giffoni (Yanco NSW)[2]	94.9	–	13.2	65.0	–	–
Tonda Gentile delle Langhe (Orange NSW)[2]	94.9	–	15.3	62.7	–	–
Average	95.6	10.0	15.0	60.5	16.4	2.5

[1] Müller et al. (2020).

[2] NSW DPIRD testing.

Ca (mg/100 g)	P (mg/100 g)	K (mg/100 g)	Mg (mg/100 g)	Sulfur (mg/100 g)	Na (mg/100 g)	Cu (mg/100 g)	Zn (mg/100 g)	Mn (mg/100 g)	B (mg/100 g)	Fe (mg/100 g)
140	390	760	180	170	1.5	1.6	2.5	1.8	2.5	3.4
160	380	690	190	190	1.5	1.5	2.6	4.2	2.5	3.9
130	390	860	160	150	1.7	1.4	2.3	1.3	2.2	3.9
170	460	830	190	200	2.0	1.8	2.9	7.1	2.4	4.1
211	–	–	182	–	–	1.7	3.4	1.7	–	3.7
155	–	–	155	–	–	0.9	2.1	1.2	–	2.9
170	440	730	190	210	1.6	1.6	2.1	4.2	2.3	3.4
201	–	–	213	–	–	1.9	2.9	1.8	–	3.7
170	430	620	170	170	1.5	1.6	2.1	4.9	2.4	3.8
120	440	730	190	170	1.5	1.8	2.3	2.0	2.6	3.4
160	450	650	190	190	1.4	1.6	2.3	4.3	2.3	4.2
210	390	710	190	180	1.4	1.3	2.0	5.9	2.3	3.4
234	330	550	159	–	0.5	3.3	3.7	13.2	–	4.9
177	–	–	148	–	–	1.1	2.5	2.8	–	3.0
140	400	740	160	150	1.5	1.6	1.9	1.6	2.1	3.4
160	450	850	170	170	1.8	1.6	2.1	4.8	2.4	3.5
140	410	660	160	160	1.4	1.6	2.0	2.7	2.0	6.4
177	330	468	191	172	1.2	1.7	2.7	4.6	2.3	4.1

Buying and planting nursery stock

Most hazelnut trees in Australia are propagated vegetatively by mound (stool) layering. This process produces a rooted sucker, or 'whip' that is true to type and genetically the same as the parent. Very few nurseries produce grafted trees. Trees are generally sold as bare-rooted, single whips up to 1 m tall. Dormant whips are normally supplied from early July through to August. It is best to order material one year ahead to guarantee supply. Details of propagators are available from the Hazelnut Growers of Australia Inc (https://www.hazelnutgrowersaustralia.org.au/).

The whip

The following points are provided to help growers and nursery operators to select good quality stock.

- Whips should be from stools that are true to type; this means meeting the specifications for the variety.
- The whip should be supplied with a root system that can adequately support it and should be free of residual soil; roots should not be damaged or deformed (Figure 15).

Figure 15. Well-rooted hazelnut whips ready for planting.

- If possible, confirm the whips are fully dormant before they have been cut from the stool, and confirm complete defoliation; ideally, the wood should have hardened all the way to the tip.
- The whip should be free from obvious lesions, pests and diseases. Bacterial blight, mildews and scales are most common; many growers have unwittingly brought in diseases with their plants by not ensuring the whips are free from pests and diseases.
- A calliper-measured size of >10 mm at the base of the whip and about 0.8–0.1 m high is desirable.
- If the whips are packaged in sawdust, avoid putting large pieces of wood in the mix that might carry wood rots.
- Plants should be bundled and transported to ensure minimal damage and tree roots must remain damp.
- Dipping or spraying with a solution of winter oil and copper before shipping will help prevent pests and diseases (especially bacterial blight).

- Nursery operators should comply with any state plant health import regulations when shipping propagation material interstate, especially from regions where big bud mite is known to exist.

If delays are possible between the collection of plants from the nursery and planting, the whips should be 'heeled in' to moist, friable soil or a heap of sawdust. This reduces the chances of roots drying out and planting can then be done over several weeks, as weather and time permits. Caution should also be taken to avoid roots being frozen before planting.

Mound (stool) layering

Mound or stool layering is the most common and successful way of propagating hazelnuts and producing whips (i.e. rooted suckers) for planting in Australia. This involves cutting a dormant plant to ground level and mounding sawdust or other media around the newly developing shoots to encourage root growth (Figure 16).

Typically, mother plants are established in nursery rows and allowed to grow until they can support strong suckers. This can take 2 years. In the second or third year, all plants are cut back to about 25 mm above the ground. Shoots develop from this stump and are mounded with sawdust approximately 3 times through the growing season. The height of the sawdust is about one-third of the total height of the sucker or future whip. Girdling or ringing (when expanding cankers restrict the movement of water and nutrients) the base of the shoot by twisting a short length of copper wire around the stem, causing a restriction that induces root formation, and applying a rooting hormone such as indole-3-butyric acid (IBA) can help roots develop.

Figure 16. Hazelnut whips in the nursery stool bed. Tags provide identification for nursery handling.

At the end of the growing season, shoots should have rooted sufficiently to be separated from the mother plant. The rooted shoots are cut almost to ground level and removed from the stool. The rooted plant, or whip, is now ready for planting out in the orchard or for growing-on in a nursery; the rotation from the mother plant can continue. This process is shown in Figure 17.

Trench layering, where shoots are pinned horizontally to the ground and sawdust is added, is a variation of this technique, but it is a far less common practice in Australia for commercial nursery production. Stool beds can be productive for up to 20 years if maintained in a vigorous condition.

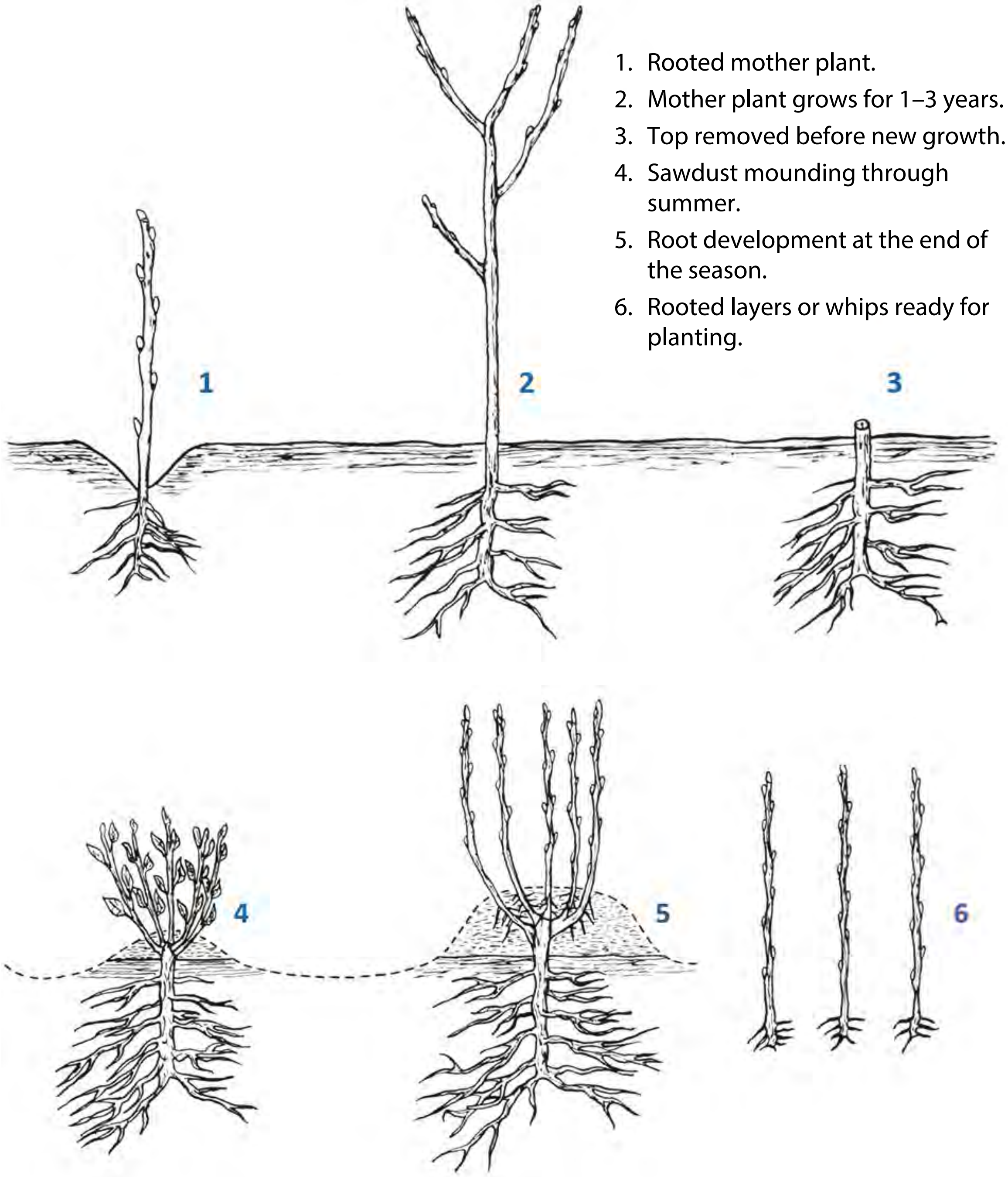

Figure 17. The process of producing whips from mound layering.

Propagation

Several techniques are used to propagate hazelnut plants. Vegetative or asexual reproduction allows for reproduction of all the genetic information of the parent plant. This provides uniformity and potentially consistent performance in the orchard. Seedlings are an unacceptable means of propagating stock for the commercial hazelnut orchard as they are a result of open pollination and will not necessarily reproduce the characteristics of the parent plant.

Producing grafted plants is not common in Australia, nor is micro-propagation commonly practised, although both methods are possible with appropriate equipment. Effective methods for micro-propagating hazelnuts in tissue culture have been developed in the USA. This method is helping breeding programs and commercial laboratories to fast-track new disease-resistant varieties.

As hazelnuts do not reproduce true to type from seed, the main method of propagation is by stool beds to produce trees on their own roots.

Inhibited callus formation has prevented grafting in the past, but using a hot callusing tube has increased grafting success by up to 90%.

Using leafy cuttings with bottom heat in a coarse rooting medium and IBA hormone treatment has had limited success.

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Orchard establishment

A whole-farm plan helps when planning, establishing and managing an orchard. It optimises the use of natural resources and is the basis of successful management. The plan should include a map of the farm and neighbouring areas and a strategic plan for the enterprise.

Generally orchards should be:

- planned so water flow is managed to minimise soil erosion
- designed to reduce the effect of any spray drift on neighbouring properties
- arranged so the processing shed is located away from neighbours and there is access for transporting the crop.

The layout of varieties in an orchard is a compromise between the benefits of cross-pollinising and maximising harvest and orchard efficiency. Good pollinising between varieties increases the number and quality of nuts. Incorporating 3 different polliniser cultivars in the planting that overlap with the female bloom will provide a good nutset. Planting too many varieties can lead to problems with mixing early and late-season varieties and can make labour and machinery operations inefficient.

Planting distances

Several spacings are used to grow hazelnuts. In recent years, more efficient ways of increasing yields and making better use of the available land area have been adopted. The selection of tree planting distances should consider the relative vigour of the variety, the soil type and the width of implements to be used in the orchard. Close plantings might have to be thinned at maturity, but the higher return in the first 10 years could be crucial to the economic survival of a new planting. The spacings in Table 7 are typical examples indicating the number of trees per hectare. The first value is the distance between rows, while the second value is the distance between the trees.

Higher density plantings such as the 6 × 3 m grid are considered more efficient, as yields can be double that of the 6 × 6 m spacing in the first 10 years. The closer planting also allows for better pollinising and nutset. Trees can be thinned in the long term if excessive shading and crowding occur. For example, every second tree down the row can be removed at 11 to 15 years. This allows for greater earlier revenue but will involve greater capital input for planting and removal costs.

Table 7. Tree spacings and density.

Tree spacing (m)	No. of trees/ha
6 × 3	554
6 × 4	416
6 × 6	277

Barcelona and Tokolyi Brownfield Cosford (TBC) varieties are spreading, and therefore, larger spacings might be desirable, whereas Ennis and Tonda di Giffoni are slightly more erect. In Oregon (USA), the recommended spacings include 6 × 6 m and 5.4 × 5.4 m.

The relationship between pollinising trees and the main crop trees needs to be considered when high-density plantings are thinned. Hazelnuts are pollinised by wind moving the air around the trees, so the pollinisers should not be too far from the main trees. Research from the USA into pollen movement indicates that trees up to 18 m away from a polliniser will usually bear a good crop.

If the area of land available to the grower is less of a consideration than the cost of planting material, then it might be prudent to plant at full width spacing initially, as it is always a difficult decision to remove trees. If land is limited and the grower wishes to maximise the returns in the initial years, then closer spacing might be the best option. A closer-spaced orchard might be maintained with appropriate pruning, but this will incur higher maintenance costs.

Layout

Most plantings are laid out in a regular pattern based on a square, rectangle or triangle. These are established by using a straight baseline, usually next to a fence or roadway. Lines at right angles to the base at both ends are established, along with one or 2 markers in the middle of the block. Right angles are established by using rope or wire in lengths of 3:4:5 proportions (Pythagorean theorem). For example, 30, 40 and 50 m lengths are suitable. The 40 m length is placed on the baseline and the 30 m one at an approximate right angle. The 30 m piece is adjusted in either direction to touch the end of the 50 m piece, which is run from the other end of the 40 m length. The 30 m piece is now at a right angle to the baseline. Once these lines are established, upright markers can be placed along the base and right angle lines for sighting. Row and tree spacing can be established with a tape or marked rope. Actual tree position can be marked with small stakes, pressure-pack survey paint or lime. Figure 18 shows the 3:4:5 triangle used to establish right angles from the baseline. Sighting stakes allow the entire orchard to be marked out.

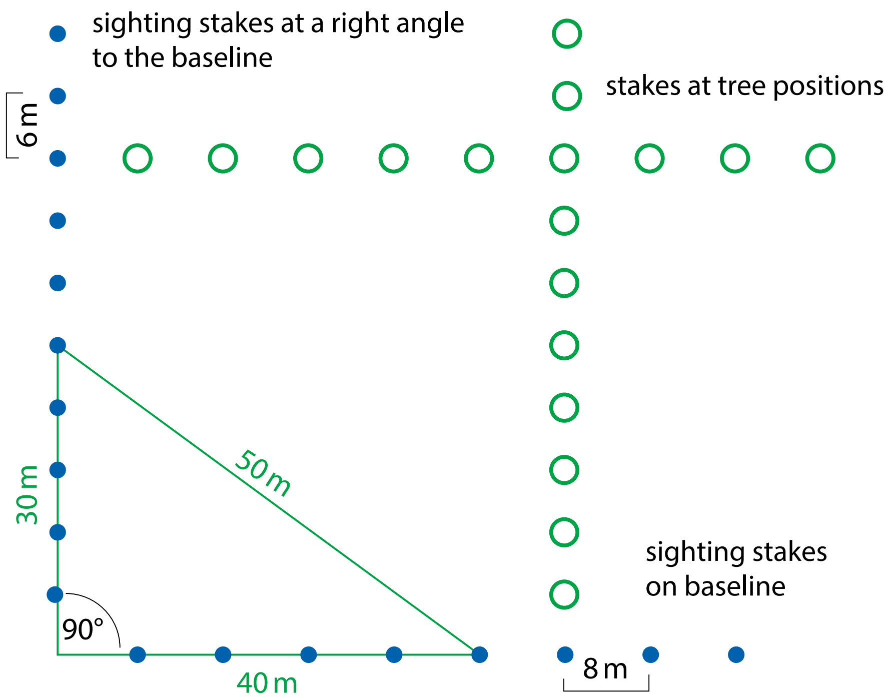

Figure 18. Setting up the right angle.

Aligning trees

A useful device to ensure trees are aligned within the row is a planting board (Figure 19). This is a light board about 1.0 × 0.1 m that has a V notched in the centre and at both ends. When planting, the centre notch is placed at the mark indicating the tree location and dowels or pegs are placed at the end notches. Only the board and the tree peg are removed and the hole is dug. The board is then relocated using the end pegs and the tree is placed at the centre peg. This centres the tree in the hole.

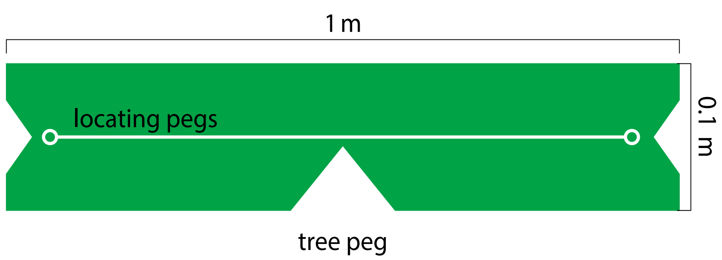

Figure 19. A planting board.

Planting

Hazelnuts, being deciduous trees, are planted in winter when they are dormant. Early winter planting (July to early August) is preferable to allow the root system to develop well enough to cope with spring growth. Trees need to be settled in the ground before soil and air temperatures start to increase. This provides some buffer time for delays or bad weather.

Tree holes should be large enough for the root system to spread out evenly from the trunk. Damaged or long roots can be trimmed, as long roots might form suckers. If small white basal buds are at the root and stem joint, they should be removed by rubbing off with fingers. This can provide some early relief for managing suckers.

Planting can be done mechanically (Figure 20), but the walls of any hole that are glazed by mechanical action need to be sliced with a shovel. Digging holes when the soil is dry or slightly moist will prevent them from being glazed. Typically, nursery whips can be held in the hole and backfilled around the roots with topsoil. The tree is firmed in with the feet. A longer whip can be planted a little deeper, as hazelnuts have a good capacity to develop roots. This is usually not necessary but might be advantageous on exposed sites. Trees should be watered in as soon as possible after planting. The top 6 buds can be left and the lower buds can be rubbed off. This directs growth to where it is required and helps with the tree's structural development. Fertiliser is generally not placed in the hole when planting.

Ground that has been suitably prepared can usually be planted using a shovel with relative ease. Well-prepared ground also allows for a mechanical planter to be used with no ill effects on establishment.

Figure 20. Mechanical hazelnut planting.

Figure 21. A plastic tree guard on a young hazelnut tree. Photo: Barb Yates, Ferrero Canada.

After planting

Young trees are easily sunburned before the bark on the trunk matures. The most vulnerable area is just above the ground. Simple protection can be provided by painting the trunk with a 50:50 mixture of water and white water-based paint. Coverage should go to ground level. Varying types of tree guards (Figure 21) can also provide some protection from the sun. Foil laminate building insulation (silver side out) has proven to be cost effective (Figure 22) and can be stapled snugly around the tree trunk, enabling growers to make guards to suit differing tree heights. This type of guard will last a couple of seasons until the young tree develops its own protection.

Figure 22. Foil laminate tree guards provide protection from sun and herbicide damage.

Other advantages of tree guards include:

- protecting young trees from herbicides
- protecting trees from physical damage caused by vertebrate pests
- safer sucker control; young suckers outside the guard can be controlled with a contact herbicide without the risk of affecting the young trunk.

If rabbits, hares or kangaroos are a problem in the proposed orchard area, some form of tree protection is necessary. A netting fence enclosing the orchard area is the best option, but some individual tree guards can provide protection. Guards can be removed once the trees are established.

Mulching

The most common faults observed in establishing the newly planted tree are improper irrigation and lack of weed control. These factors alone cause more stunting and tree loss than any others during the first 2 years. Mulching (Figure 23) helps:

- reduce evaporation and conserve soil moisture
- modify soil temperature to reduce extremes of both hot and cold
- reduce weed growth
- add organic matter and protect and improve soil structure.

Organic mulches such as wheaten straw or other commercial mulches are suitable. To avoid collar rot, keep the mulch from contacting the trunk. Mulch can be applied thickly at tree planting and reapplied until the trees are 3 years old. After this, mulch can interfere with ground harvesting operations, and experience has shown that mulches that break down slowly (such as wood chips) can be a problem when vacuum harvesting machines are used.

Figure 23. Mulch in young hazelnuts.

To be effective, mulch needs to block all light to the germinating weeds. Different mulch materials vary in the depth necessary to accomplish this. Organic mulches should be maintained in a layer at least 100 mm thick.

Irrigating young trees

In areas with inadequate or unreliable rainfall, irrigation will be necessary, especially with young trees, as their roots are small. The following points should be considered when watering young trees:

- in the first year, irrigate often but for only a short time
- short irrigations will replenish dry areas around the roots without waterlogging the soil
- be careful not to apply too:
  - much water, creating an oxygen deficiency and drowning the roots
  - little water, letting the roots become too dry.

For further information on irrigating hazelnut trees, see Irrigation on page 52.

Shelter from wind

Young hazelnut plants are very susceptible to the drying effects of hot winds. Sites exposed to these winds should be avoided as the battering effects from persistent winds in summer can damage large leaves. A well-designed windbreak proves its worth when low humidity, high temperatures and strong winds combine to cause unfavourable conditions for newly planted trees. Good soil moisture is also required, not only for the hazelnut planting but also for the windbreak.

Height is generally the main factor determining the effectiveness of the windbreak. The taller the windbreak, the greater the area protected. On level ground, a windbreak will reduce the wind speed on the downwind side for a distance equal to about 25 times the tree height. Maximum reduction of wind speed is obtained at a distance of 5–15 times the tree height downwind of the windbreak.

The windbreak should be sufficiently permeable to allow air through, rather than acting as a solid barrier. An ideal windbreak will be 50% porous, so the canopy consists of roughly half airspace and half branches, twigs, needles and/or leaves. It should be planted at right angles to the winds from which protection is needed in eastern Australia. Hazelnut orchards are generally most affected by hot drying winds from the west and north–west. Persistent easterly winds cause physical leaf damage or cause young trees to grow away from the vertical plane (Figure 24). Windbreaks planted north–south are a good compromise, as they provide protection from winds from the western quarter.

Figure 24. Frequent winds have caused these hazelnut trees to lean as they grow.

At a sheltered location, windbreaks could be planted at about the same time as the hazelnut trees, whereas in an exposed site, they should be planted so that they are established (e.g. 2–3 years) before the hazelnuts are planted. To protect the trees from wind and still allow adequate air drainage, orchard producers will often thin, but not entirely remove, lower branches from conifer windbreak trees up to 1.2–1.8 m above the soil. Thinning lower branches allows the air to move through the windbreak canopy more effectively, dispersing frost pockets that might otherwise be a problem with dense windbreaks.

A single or double row of trees will provide adequate wind protection. The main disadvantage of single rows is that if a tree is lost, a gap is created, reducing the efficiency of the windbreak. Breaks of up to 3 rows, consisting of one row each of low, medium and tall trees, are most effective (Figure 25).

Incorporating 3–5 species in the windbreak will ensure diversity, provide a healthier windbreak and potential harbour sites for beneficial insects. Most windbreaks comprise fast-growing species that will grow to between 15 m and 30 m (Figure 26). Many fast-growing species also have shorter life cycles and replacement planning should be considered when the windbreak is first designed. Be aware that some shelter species (such as poplars) have vigorous root systems and will compete with the orchard for water. The river oak, *Casuarina cunninghamiana,* has proven to be a worthy windbreak on the NSW Tablelands and in other parts of Australia.

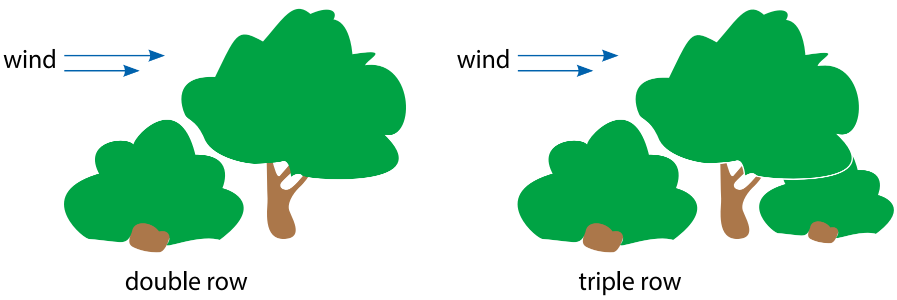

Figure 25. Double or triple row options for windbreak design.

Different varieties of each species have different growing habits and requirements, and some varieties might be susceptible to diseases in certain conditions. Talk to a local tree nursery that has experience in shelter design as they should be able to recommend appropriate shelter species for specific conditions and help determine the appropriate orchard size. Locally native species generally have higher survival and establishment rates and also provide valuable habitat for local wildlife species (Turner 2018).

Figure 26. An effective windbreak in a citrus orchard at Dareton NSW.

Practical implications

- Windbreaks should not shade or compete with the hazelnut orchard.
- Choose appropriate species: some, such as acacia, might harbour pests e.g. borers or provide perches for birds that can compete for the crop.
- Plan windbreaks so they provide a refuge for beneficial predators.
- Include windbreaks in the irrigation design.
- Leave enough turning space at the head of the rows for tractor/harvesting operations.
- Generally, windbreak trees are planted in late autumn (April–May) or winter, but delay planting if the ground is very wet. In extremely cold areas, a spring planting in September can give better results.
- Root pruning might be required if windbreaks compete with the orchard.
- The choice of species is dictated by local experience, conditions and the grower's preference. Key considerations are drought, frost tolerance, growth rates and longevity.
- Planning for windbreak generation or renewal should be considered when planting.

For further information, consult a local nursery that specialises in farm trees.

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Hazelnut phenology

Hazel phenology can be divided into:

1. reproductive (R) phenology, which includes flowering and fruit development
2. vegetative (V) phenology, which focuses on the leafing cycle of the plant.

There are 18 phenological phases that are typically recorded. However, abridged versions of this assessment can be used for specific purposes. For example, recording male flowers (catkins) from R03–R06 and female flowers (pistillates) from R07–R09 would be sufficient to assess floral overlap for pollinising requirements.

Reproductive/flowering phases

Phenological phase	Description
R01	Catkin emergence
R02	Catkins fully developed
R03	Start of catkin maturation (Figure 27)
R04	Catkins in full bloom (Figure 28)
R05	Start of catkin withering
R06	Catkins withered (Figure 29)
R07	Female flower red dot stage (Figure 30)
R08	Female flower full bloom (Figure 31)
R09	End of female flower bloom
R10–12	Flower enlargement
R13	Fruit maturity
R14	Fruit drop

Vegetative phases

Phenological phase	Description
V01	Dormant buds
V02–03	Swollen/opening buds (Figure 32)
V04	First leaves (Figure 33)
V05–07	Juvenile and adult leaves/full vegetation (Figure 34)
V08–12	Leaf discolouration/start of leaf drop (Figure 35)
V13–14	Leaf drop mostly complete/bare trees (Figure 36)

Figure 27. R03, start of catkin maturation.

Figure 28. R04, catkins in full bloom.

Figure 29. R06, catkins withered.

Figure 30. R07, female flower red dot stage.

Figure 31. R08, female flower full bloom.

Figure 32. V02–03, swollen/opening buds.

Figure 33. V04, first leaves.

Figure 34. V05–07, juvenile and adult leaves/full vegetation.

Figure 35. V08–12, leaf discolouration/start of leaf drop.

Figure 36. V13–14, leaf drop mostly complete/bare trees.

Flowering and pollination

The life of a hazelnut begins with the formation of flower clusters more than a year before harvest. During fruit bud differentiation, a cell forms either a reproductive part, such as a flower, or a vegetative part, such as a shoot.

Catkins (Figure 37) begin to form in mid-November and begin to appear in December, but they do not reach maturity until June or July (Figure 38). Pistillates (Figure 39) begin to form at the end of December and beginning of January and are first seen in late May or early June. Most flowers form on the current season's growth in the axils (where leaves join the stems). On some varieties, flowers also form on the peduncles (stems) of the catkins.

Peak pollination is from July to August, but this can vary depending on weather conditions. During pollination, the female cluster is a bright red tuft of feathery stigmatic styles projecting from the bud scales. Within the bud scales are the lower portions of 4–16 individual flowers.

Female hazelnut flowers are very unusual. At pollination, most plants' flowers have an ovary containing ovules with egg cells ready for fertilisation. Hazelnut flowers, however, have several pairs of long styles with surfaces that are stigmatic and receptive to pollen, and a small amount of tissue (0.25 mm or less) at the base called the ovarian meristem.

Within 4–7 days after pollen transfer (pollinising), the pollen tube grows to the base of the style, where the tip of the tube becomes walled off and enters a long resting period. Pollinising stimulates the ovary to develop from the tiny meristematic tissue at the base of the flower. The ovary grows very slowly during the first 4 months (until about mid-November) and then begins to grow rapidly, attaining 90% of its growth in the next 5–6 weeks. During the middle of this rapid growth period (mid-December), when the ovaries are 8–10 mm in diameter, the ovary becomes a mature organ containing egg cells.

Figure 37. Catkins begin to develop. Photo: Filotas (2021).

Figure 38. Expanding catkins.

Figure 39. Female flowers.

The resting sperm become activated, secondary pollen tubes begin to grow, and fertilisation takes place. This 4- to 5-month lapse between pollination and fertilisation is one of the unusual features of hazelnut floral biology. In most other plants, fertilisation follows pollination by a few days.

After fertilisation, the kernel develops rapidly. By mid-January, the ovary's shell is full size, and shell hardening is well underway. Kernels reach full size about 6 weeks after fertilisation (early February). From this time until harvest, there are maturation changes such as increasing oil content. Around mid-March to April, depending on the variety, the husk surrounding the nut dries and spreads open, and the nut falls to the ground.

Hazelnuts are pollinised by wind and self-incompatible. This means a tree cannot pollinise itself or any other tree of the same variety. The pollen from the catkins drifts through the orchard on the wind in winter and is transferred to the open stigmas of the female flower.

Successful pollinising determines the productivity level and viability of the orchard. It is therefore essential to plan correctly at the establishment phase.

Successful pollinising requires:

- suitable amounts of pollen
- pollen of a compatible type that is available at the same time as the female flowers are in bloom
- favourable weather conditions
- maintaining soil moisture during autumn so the catkins do not fall due to the trees becoming water-stressed.

Typically, the start of bloom is correlated with temperature. In regions with milder winters (e.g. the South Coast of NSW), a given set of varieties will flower first, whereas in colder areas (e.g. Orange in NSW), the same set will flower later. Australian research indicates that the length of pollen shed is less in later-flowering varieties. The blooming season can take up to 3 months from the initial pollen shedding of early varieties to the later full bloom of female flowers.

A range of varieties should be planted to ensure cross-compatible pollen is disseminated. Table 5 shows the pollen compatibility of some hazelnut varieties. One polliniser tree to 8 of the main variety should ensure wind cross-pollinising, and in unfavourable areas, a 1:5 ratio might be beneficial. Pollinisers should make up 8–10% of an orchard. Older orchards might require a smaller number of pollinisers. Most overseas orchards use at least 2 pollinisers to compensate for seasonal variation and to ensure full coverage of female bloom. When planning orchards for mechanised harvesting, consider where the pollinisers will be placed.

Hazelnut trees rarely set no nuts, and during flowering they are generally only affected by severe frosts. Female flowers are extremely frost tolerant and will withstand temperatures down to −15 °C. Persistent rain during pollen shed can reduce the amount of pollen available to female flowers, and there might be some yield reduction.

Some defective nuts, known as blanks, can occur when pollination stimulates the shell to develop but the kernel fails to develop. This is a common defect when fertilisation fails or when embryos abort in the early stages. This might be due to several factors, including nutrient deficiency (e.g. boron or calcium). Environmental reasons and moisture stress are also possible. These blank nuts tend to fall earlier, making them easier to separate from the main harvest.

The approximate start and length of pollen shed and female bloom in temperate regions of NSW are shown in Figure 40; the information is adapted from Australian research.

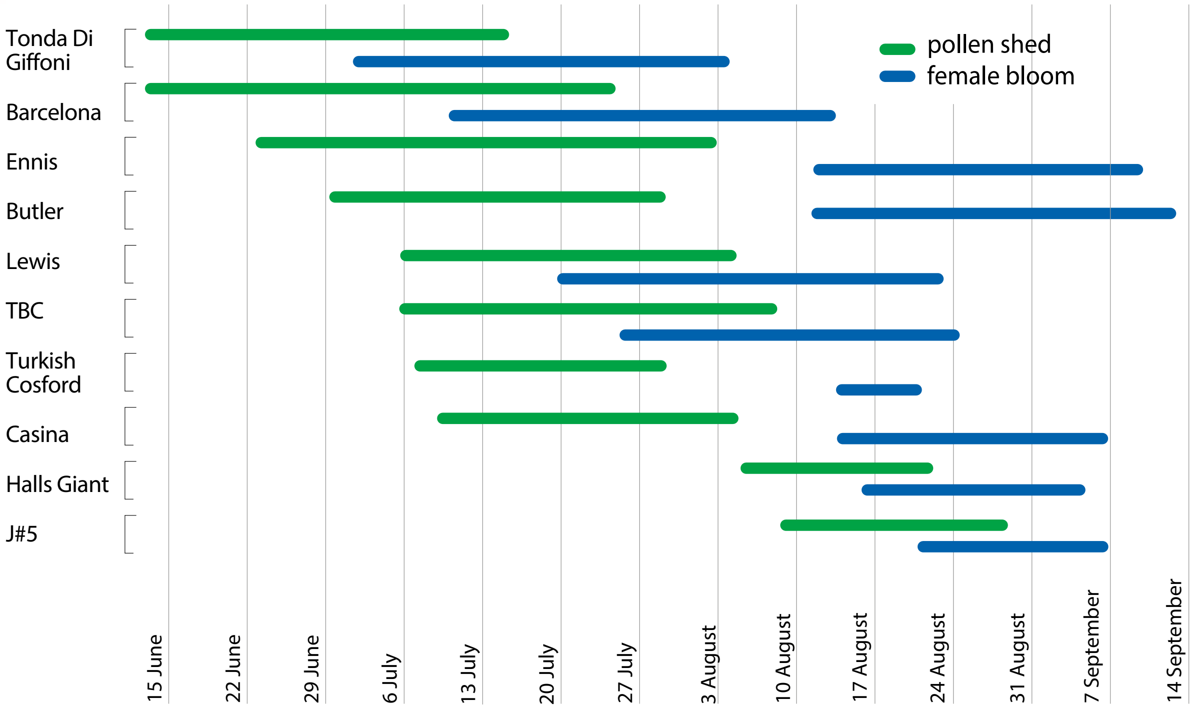

Figure 40. Pollen shed timing and female bloom in different varieties. Source: Baldwin et al. (2007).

Pollinising

As already mentioned, hazelnuts are not self-pollinising and should be considered self-sterile because peak periods of male and female flowering might not coincide for any one variety. It is important to have genetically compatible pollinisers that shed pollen when the female flowers are receptive.

Three different varieties with compatible pollen should be planted with the main crop so there is pollen available when the female flowers are receptive. Pollinisers are usually classified as early, medium or late.

In locations where there are many orchards, there can be large quantities of pollen in the area; however, this is not currently the situation in Australia, where the orchard density is low and existing orchards are small. The proportion of pollinisers and how they are planted among the main crop is important because the nuts from the polliniser trees will need to be separated from those of the main crop when they are sold.

One way of separating polliniser nuts from the main crop during harvest is to choose pollinisers with different sized or shaped nuts or cropping times. If the polliniser nuts are smaller or larger than those of the main crop, they can be graded out. If they fall earlier or later, they can be harvested at a different time, although this will add to costs.

If the polliniser nuts are a similar size and shape and their fall overlaps that of the main crop, the problem can be reduced by having rows of pollinators that can be harvested at the same time but in a separate run. As the trees mature, mixing of the polliniser and main crop nuts will tend to increase.

Planting schemes

Planting schemes will vary for polliniser distribution in the main crop. Some favour a row or rows of pollinisers interspersed between every 3–6 rows of the main crop (Figure 41). In Oregon, pollinisers are planted every sixth tree in every third row in a staggered design (Figure 42). The layouts in both figures can be used by Australian growers.

P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Figure 41. One polliniser to every 5 main variety trees in each row; P = polliniser, M = main variety.

M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	P	M	M	M	M	M	P	M	M	M	M	M	P	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	M	M	M	P	M	M	M	M	M	P	M	M	M	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M	P	M	M	M	M	M	P	M	M	M	M	M	P	M
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Figure 42. A planting scheme used in Oregon. Pollinisers are placed every sixth tree in every third row in a staggered design; P = polliniser, M = main variety.

Compatibility

The genetics of hazelnut fertilisation are complex, but in summary, the allele of the pollen should be different from the allele of the flower it is pollinising.

Table 8 has been adapted for Australian varieties and provides a guide to compatibility for commercial varieties grown in Australia. Australian specialist nurseries can also offer advice on compatibility and selection of pollinators. The example hazelnut cross-pollination guide indicates the pollen compatibility of hazelnut varieties.

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Table 8. Hazelnut compatibility chart.

Female	Alleles	Barcelona	Butler	Casina	Campanica	Clark	Daviana	Dorris	Ennis	Epsilon	Eta	Felix	Gamma	Gem	Hall's Giant	Jefferson	Jemtegaard#5	Keen's Late
		1	3	10, 21	1	3, 8	3	1, 12	1	1	11, 26	15, 21	10	?	5, 15	3	3	?
Barcelona	1, 2	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Butler	2, 3	Y	X	Y	Y	X	X	Y	Y	Y	Y	Y	Y	?	Y	X	X	?
Casina	10, 21	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	X	X	?	Y	Y	Y	?
Campanica	1, 2	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Clark	3, 8	Y	X	Y	Y	X	X	Y	Y	Y	Y	Y	Y	?	Y	X	X	?
Daviana	3, 11	Y	X	Y	Y	X	X	Y	Y	Y	X	Y	Y	?	Y	X	X	?
Dorris	1, 12	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Ennis	1, 11	X	Y	Y	X	Y	Y	X	X	X	X	Y	Y	?	Y	Y	Y	?
Epsilon	1, 4	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Eta	11, 26	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	Y	?	Y	Y	Y	?
Felix	15, 21	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	X	Y	?	X	Y	Y	?
Gamma	2, 10	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	Y	X	?	Y	Y	Y	?
Gem	2, 14	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	Y	Y	?
Hall's Giant	5, 15	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	?	X	Y	Y	?
Jefferson	1, 3	X	X	Y	X	X	X	X	X	X	Y	Y	Y	?	Y	X	X	?
Jemtegaard#5	2, 3	Y	X	Y	Y	X	X	Y	Y	Y	Y	Y	Y	?	Y	X	X	?
Keen's Late	?, ?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	X
Kentish Cob	8, 14	Y	Y	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	?	Y	Y	Y	?
Lansing	1, 3	X	X	Y	X	X	X	X	X	X	Y	Y	Y	?	Y	X	X	?
Lewis	3, 8	Y	X	Y	Y	X	X	Y	Y	Y	Y	Y	Y	?	Y	X	X	?
McDonald	2, 15	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	?	X	Y	Y	?
TBC/Halls Giant	5, 15	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	?	X	Y	Y	?
Montebello	1, 2	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Negret	10, 22	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	Y	X	?	Y	Y	Y	?
Nocchione	1, 2	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
PollyO	2, 10	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	Y	X	?	Y	Y	Y	?
Royal	1, 3	X	X	Y	X	X	X	X	X	X	Y	Y	Y	?	Y	X	X	?
Sacajawea	1, 22	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Santiam	3, 15	Y	X	Y	Y	X	X	X	X	X	Y	X	Y	?	X	X	X	?
TBC	5, 23	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	X	Y	Y	?
TGDL	2, 7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	Y	Y	Y	?
Theta	5, 15	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	?	X	Y	Y	?
Tonda di Giffoni	2, 23	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	Y	Y	Y	?
Tonda Romana	10, 20	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	Y	X	?	Y	Y	Y	?
Tonolo	1, 2	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Wepster	1, 2	X	Y	Y	X	Y	Y	X	X	X	Y	Y	Y	?	Y	Y	Y	?
Whiteheart	2, 10	Y	Y	X	Y	Y	Y	Y	Y	Y	Y	Y	X	?	Y	Y	Y	?

Y = compatible, X = incompatible, ? = unknown. TBC = Tokolyi Brownfield Cosford.

* Both alleles are always expressed in the female flowers but not necessarily in the pollen.

Note: when an allele expressed by the pollen is met by the same allele in the female flower, the cross is incompatible.

Source: Adapted from Mehlenbacher SA and Miller AN (1998).

Kentish Cob	Lansing	Lewis	McDonald	TBC/Halls Giant	Montebello	Negret	Nocchione	PollyO	Royal	Sacajawea	Santiam	TBC	TGDL	Theta	Tonda di Giffoni	Tonda Romana	Tonollo	Wepster	Willamette	Yamhill	York
8, 14	3	3, 8	15	5, 15	1	10	1	10	3	1	3	5	7	5, 15	2	10, 20	1	1	3	8	21
Y	Y	Y	Y	Y	X	Y	X	Y	Y	X	Y	Y	Y	Y	X	Y	X	X	Y	Y	Y
Y	X	X	Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	X	Y	Y	Y	X	Y	Y
Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X
Y	Y	Y	Y	Y	X	Y	X	Y	Y	X	Y	Y	Y	Y	X	Y	X	X	Y	Y	Y
X	X	X	Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	Y	X	X	Y
Y	X	X	Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	Y	X	Y	Y
Y	Y	Y	Y	Y	X	Y	X	Y	Y	X	Y	Y	Y	Y	Y	Y	X	X	Y	Y	Y
Y	Y	Y	Y	Y	X	Y	X	Y	Y	X	Y	Y	Y	Y	Y	Y	X	X	Y	Y	Y
Y	Y	Y	Y	Y	X	Y	X	Y	Y	X	Y	Y	Y	Y	Y	Y	X	X	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y	Y	Y	X	X	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	Y	Y	X
Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	X	X	Y	Y	Y	Y	Y
Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	Y	Y
Y	Y	Y	X	X	Y	Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	Y
Y	X	X	Y	Y	X	Y	X	Y	X	X	X	Y	Y	Y	Y	Y	X	X	X	Y	Y
Y	X	X	Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	X	Y	Y	Y	X	Y	Y
?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
X	Y	X	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	Y
Y	X	X	Y	Y	X	Y	X	Y	X	X	X	Y	Y	Y	Y	Y	X	X	X	Y	Y
X	X	X	Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	Y	X	X	Y
Y	Y	Y	X	X	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	X	Y	Y	Y	Y	Y	Y
Y	Y	Y	X	X	Y	Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	Y
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Y	Y	Y	Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y	X	X	Y	Y	Y	Y	Y

Managing the orchard

Nutrition and fertilisers

An orchard system is defined as the trees and the part of the soil profile exploited by roots (the root zone). Nutrients are removed from orchard systems by movement below the root zone and when nuts are harvested. The availability of mineral nutrients to tree roots is influenced by soil characteristics, soil moisture, the form of that particular mineral nutrient, the orchard cropping history and how much, when and how fertilisers and soil amendments are applied. Different fertilisers and soil amendments have different characteristics that influence why, when and how they are used in orchards. Qualitative and quantitative assessments of tree nutrient status should be used to help decide the appropriateness of orchard fertiliser/soil amendment programs.

Mineral nutrition of the tree is a major part of nut production, affecting all aspects of tree and nut growth, development and maturation. Mineral nutrients are divided into macronutrients (expressed as %) and micronutrients (expressed as parts per million (ppm) or mg/kg). Macronutrients include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). Micronutrients include iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B) and molybdenum (Mo). Sodium (Na) and chlorine (Cl), which are often present at macronutrient levels in plant tissue, are generally considered to be micronutrients. Selenium (Se), nickel (Ni) and cobalt (Co) are considered to be essential micronutrients, but are not usually problematic. Likewise, silicon (Si), which is considered beneficial in helping disease defence mechanisms, is not essential and does not need to be considered further.

Orchard nutrient balance

The mineral nutrient requirements of trees will vary according to many factors such as the variety, rootstock, tree age, production levels, individual site conditions and history. There is no single 'recipe' to suit all situations. Warm regions tend to have problems with Zn deficiencies, and Fe to a lesser extent, while B deficiencies are more likely in cool regions with higher rainfall.

All mineral nutrients are removed by the harvest, but the removal of some, e.g. N and K, is on a much larger scale than others, e.g. Fe and Mn. Some nutrients (e.g. N in the nitrate (NO_3^-) form) can be lost below the root zone by leaching or lost to the atmosphere by denitrification or volatilisation. Towards the end of the growing season several macro-nutrients, particularly N, get mobilised from the leaves and are translocated to the perennial structure.

Most of the biomass (shoots and leaves) produced annually by trees remains in the orchard and releases mineral nutrients back to the soil as it breaks down. The rate of release depends on the materials' carbon:nitrogen (C:N) ratios; wood has a high C:N ratio and breaks down slowly (months to years), and leaves have a low C:N ratio and breakdown quickly (weeks to months). The breakdown of organic matter will also be influenced by temperature, moisture, and the degree of contact between the organic matter and the soil.

Immobilisation and mineralisation within the root zone are two processes working in opposite directions: immobilisation removes nutrients from the available pool, while mineralisation increases the available pool; this is particularly important for P.

Soil fertility

Soil fertility simply means the capacity of the soil to keep plant roots well supplied with mineral nutrients in the inorganic form. Mineral nutrients exist in soil in organic and inorganic forms and are bound in organic matter.

Plant roots cannot absorb mineral nutrients bound in organic material and in organic forms. Inorganic forms are the major source of mineral nutrients for plants. Tree production in highly fertile (i.e. high levels of mineral nutrients in inorganic form) soil requires little if any supplementary mineral nutrient supply. Tree production in infertile soil generally requires considerable supplementary mineral nutrient supply.

Soil tests use various chemical extraction methods to estimate the amount of available nutrients; in other words, soil tests measure soil fertility. The results correlate reasonably well with the amounts of nutrients taken up by most annual crops, and hence have some application in estimating the fertiliser needs of those crops. The correlation is not as strong for perennial crops because of the longer period of nutrient uptake, the greater volume of soil explored, and the amount of mobile mineral nutrients stored in the plant or tree from one growing season to be used in the next growing season. Nonetheless, soil tests can be useful in diagnosing poor tree growth and performance and are useful in the pre-planting phase of orchard development.

Root zone characteristics such as depth, texture, pH, moisture, aeration and amount of organic matter all have considerable influence on the processes governing the availability of mineral nutrients to tree roots.

Soil depth and texture help determine the soil's ability to hold water and supply water to tree roots. Depth and texture are also important because water brings some mineral nutrients to tree roots and soil micro-organisms need water to grow and break down soil organic matter.

The mineral nutrients in organic matter and organic forms must be released and/or mineralised into soluble inorganic forms before they can be absorbed by plant roots. This process is facilitated by micro-organisms as they break down organic matter for energy, and as they die and decompose. Adequate organic matter is critical, as is soil temperature, aeration and moisture. Mineralisation rates are greater in warm, moist, free-draining soil types compared with dry, cold soil types with poor drainage.

Mineral nutrient availability is strongly dependent on the soil pH. The optimum soil pH range for trees is thought to be between 5.5 and 7.0 (Figure 2 on page 10). Outside this range, excesses of certain elements and deficiencies of others become important. For example, soil with a pH <5.5 is likely to contain an excess of available aluminium (Al) ions. In contrast, deficiencies of Fe, Mn and Cu are induced under alkaline soil conditions (pH >7.0).

Nutrient function

Nitrogen and Mg form part of chlorophyll, which uses sunlight to convert carbon dioxide (CO_2) and water to produce sugars. Calcium and B perform roles in plant cell walls. Phosphorus is involved in storing and releasing energy and is a vital structural ingredient of the membrane around each cell. Potassium is involved in carbohydrate metabolism and transport, as well as regulating water movement (stomata regulation).

Root growth and the uptake of nutrients from the soil require energy from stored or recently assimilated carbohydrates. Macro and micronutrients are essential for plant growth because of their roles in metabolic functions and structural components. Nitrogen is one of the most important macronutrients and seasonal N accumulation varies between the different vegetative and reproductive parts of the tree.

Iron, Mn, Zn and Cu are involved in the CO_2 assimilation process and in plant defence mechanisms against stress such as heat. Iron and Mo play significant roles in the conversion of NO_3^- into a useable form where it finally ends up in proteins.

Assessing nutrient status

Assessing tree nutrient status helps to determine fertiliser requirements and effectiveness. Qualitative information (i.e. the appearance of the trees and any leaf symptoms, Figure 43) and quantitative information (i.e. nutrient concentrations in tissue samples) are needed. Visual deficiency or toxicity symptoms generally only become apparent after productivity declines.

Shoot vigour and deficiency or toxicity symptoms on leaves are indicators of tree nutrient status. Table 9 lists visual symptoms of nutrient deficiencies in perennial crops used to make qualitative assessments of tree nutrient status.

Table 9. Visual symptoms used to make qualitative assessments of perennial crop nutrient status.

	Deficiency symptoms (leaf, growth)	Location
Macronutrient		
Nitrogen (N)	Overall leaf yellowing, reduced growth	All leaves but youngest leaves first
Phosphorus (P)	Interveinal areas yellow/pale, reduced growth	Older leaves
Potassium (K)	Leaf curling, interveinal areas/margin yellow	Older leaves
Calcium (Ca)	New leaves will be misshapen or stunted	New leaves
Magnesium (Mg)	Yellow or red leaf interveinal areas/margin	Older leaves
Sulfur (S)	Overall leaf yellowing	Most leaves but youngest leaves first
Micronutrient		
Boron (B)	Interveinal areas pale green, stunted shoots, shoot tips die	Young parts
Copper (Cu)	Small young leaves, interveinal areas yellow, stunted growth	Young leaves
Iron (Fe)	Interveinal areas yellow, stunted growth	Young leaves
Manganese (Mn)	Interveinal areas pale green	Older/mid-shoot leaves
Molybdenum (Mo)	Leaves light green–orange, spots on areas away from veins, sticky secretions under the leaf	All leaves
Zinc (Zn)	Interveinal areas go pale green, stunted growth	Young leaves

Source: Adapted from Holzapfel et al. (2014).

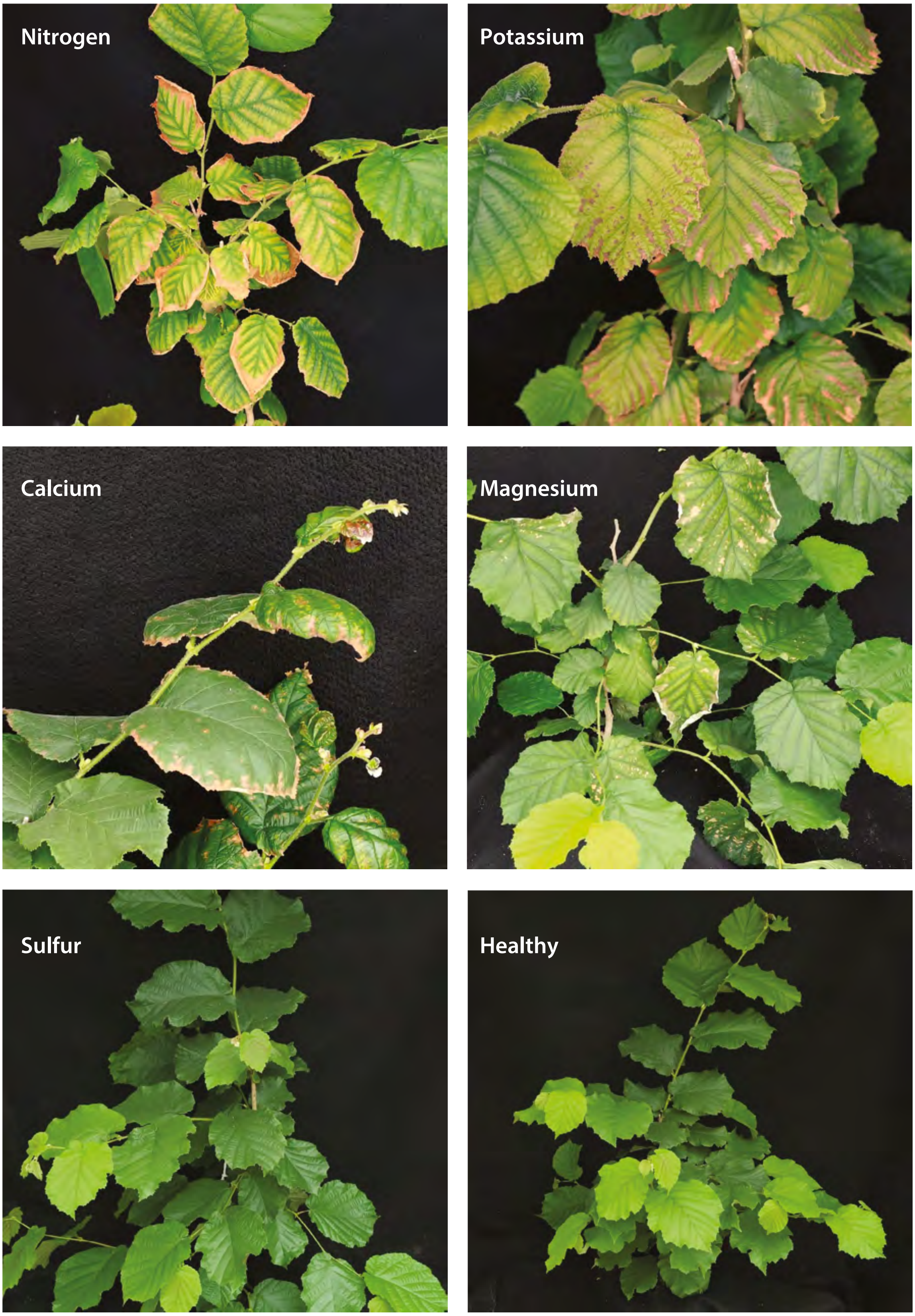

Figure 43. Nutrient deficiencies in young hazelnut trees. Source: Voogt et al. (2023).

Leaf analysis

Established hazelnut orchards should be fertilised according to the results of leaf tissue analyses and limed to manage soil pH according to the results of soil testing. Soil and leaf analyses provide information about the availability of nutrients in the soil and uptake by the tree. Levels provided by these tests can be compared with the optimum levels set for healthy trees (Table 10). Using standard sampling procedures and quality-assured laboratories will allow growers to better understand tree nutritional trends in the orchard. Interpreting the analysis and subsequent fertiliser recommendations need to be linked to an understanding of the soil type, the soil test and the seasonal cycle of the tree.

Leaf analysis can also:

- help with developing and adjusting fertiliser programs
- measure the amount of nutrients removed from the orchard in nuts with a view to replacement
- suggest additional tests to identify a problem
- confirm a diagnosis based on the symptoms.

Regular testing over several seasons will reveal any developing trends and enable this information to be incorporated with other observations such as the effects of crop load, irregular bearing patterns and weather. These effects can cause changes in element levels between growing seasons and need to be considered when interpreting results. A commercial soil test should be used to identify potential deficiencies. For established orchards, leaf tissue analysis standards are available (see Table 10).

Leaves can be sampled during early January and should be collected from the mid-shoot of the current season's growth. Samples can be collected by walking a 'W' across the orchard and collecting leaves randomly. About 100 leaves are required for laboratory processing, which can be completed by private laboratories or NSW DPIRD Plant nutrition services (https://www.dpi.nsw.gov.au/about-us/services/laboratory-services/plant-nutrition).

Table 10. Plant leaf analysis standards for hazelnuts.

Nutrient	Deficient	Below normal	Normal	Above normal	Excessive
Nitrogen (%)	<1.80	1.81–2.20	2.21–2.50	2.51–3.00	>3.00
Phosphorus (%)	<0.10	0.11–0.13	0.14–0.45	0.46–0.55	>0.55
Potassium (%)	<0.50	0.51–0.80	0.81–2.00	2.01–3.00	>3.00
Sulfur (%)	<0.08	0.09–0.12	0.13–0.20	0.21–0.50	>0.50
Calcium (%)	<0.60	0.61–1.00	1.01–2.50	2.51–3.00	>3.00
Magnesium (%)	<0.18	0.19–0.24	0.25–0.50	0.51–1.00	>1.00
Boron (ppm)	<25	26–30	31–75	76–100	>100
Copper (ppm)	<2	3–4	5–15	16–100	>100
Iron (ppm)	<40	41–50	51–400	401–500	>500
Manganese (ppm)	<20	21–25	26–650	651–1,000	>1,000
Zinc (ppm)	<10	11–15	16–60	61–100	>100

Fertilisers and their application

The seasonal pattern of nutrient demand and uptake by trees influences when most fertilisers should be applied. This is usually during the main periods of root growth in late spring to early summer. This is particularly relevant to the supply of nitrogenous fertilisers, which should not be applied until late spring, and autumn application should be modest to avoid re-stimulating shoot growth and having leaves remain on the tree beyond autumn, but sufficient to allow adequate N uptake and storage to support spring growth the following season.

An exception to this generalisation is phosphorus. Phosphate (PO_4^{-3}), which is the form of P absorbed by plants, is so sparingly soluble and moves so slowly through the soil profile that application any time of the year will have the same effect.

The N, P and K fertilisers available vary in concentration and solubility (and hence the speed of nutrient availability) and often contain more than one macronutrient. Selection depends upon many factors such as the effect on soil pH, suitability for delivery by fertigation, cost per unit nutrient, and the need for rapid results where a deficiency is obvious. Ease of spreading is also a consideration, and inorganic fertilisers have an advantage over organic fertilisers, which tend to be more voluminous and have variable and lower macronutrient content.

Applying fertiliser through a drip irrigation system (fertigation) is significantly easier than broadcasting fertiliser, but the higher solubility and purity needed for fertigation come at a cost. Several alternative fertilisers (e.g. organic and bio-dynamic products) claim a range of nutritional benefits associated with their use, but Australian experience with these materials is limited. Consequently, there is little information available to assist with using organic fertilisers in Australian orchards.

A consideration for those using organic fertilisers is that mineral nutrients in those materials need to be released and/or transformed into available forms by decomposing in the soil. This is not a rapid process for materials with a high C:N ratio, and if conditions are not conducive to microbial activity in the soil, then that breakdown process can be prolonged. A material that was being used to correct a chronic N deficiency, for example, would need to have a low C:N ratio to ensure the N in the material was mineralised reasonably quickly and not used to contribute to the decomposing process.

As indicated earlier, there is no recipe to suit all orchards; it can be difficult to estimate how much fertiliser needs to be applied. As a general rule, provided that irrigation is managed to avoid excessive mineral nutrient loss through run-off or leaching, the main loss of nutrients from an orchard will be in the nuts harvested and moved off-site. A reasonable approach and starting point to simply replacing what has been removed, therefore, is to estimate the amount of mineral leaving the orchard in the nuts. For example, if a tonne of nuts removes 10–15 kg N, then a yield of 3 t/ha would require approximately 30–45 kg N/ha to be replaced. This amount of N fertiliser can be the basis of the annual application needed, mindful of the other considerations around timing and not leaching NO_3^- down the profile. It can then be adjusted upwards or downwards by analysing plant tissues at flowering. Assessing nutrient (especially N) concentrations in winter growth is a useful indication of the amount of nutrients that the tree has available to support spring growth.

Fertilising

Hazelnuts benefit from a balanced nutritional program such as annual applications of a complete NPK fertiliser. Nitrogen, K and B are the main elements that have proven to provide increased yields and are the elements most commonly deficient in hazelnuts. Fertiliser can be applied using different techniques, such as broadcasting or banding down tree rows, applying foliar sprays or fertigation.

Nitrogen

The main nutrient to be supplied as fertiliser, or as organic matter and legumes, is N. Plants take N from the soil during the growing season, and this is harvested mainly as protein in the kernels. Therefore, N needs to be replaced after a crop has been grown.

The likely N requirements can potentially be judged by observing the length of new branch growth at the end of the growing season. In established trees this should be about 300 – 500 mm. A more accurate method is to have a leaf analysis completed on a sample of leaves taken in January. Much research on fertilisers has been completed in the USA, so the following is provided as a guide only. Younger trees require less than mature trees: at year 2, about 50 g/tree can be applied, with the rate increasing to maturity. Nitrogen can be applied (3 applications per year) from September through to early December.

The normal requirement for a mature tree is 450–680 g N/tree (broadcast), depending upon tree densities. If N is banded under the trees, then about 20% less can be used. Even distribution around young trees is critical, as improper application can kill them. Do not apply fertiliser of any kind to the planting hole, as it can burn the developing roots.

If N is applied frequently in small amounts, the plants will be able to use most of it, as frequent applications reduce leaching.

Practical implications

- Do not apply more than 20% of the total annual N application during summer; heavy applications increase vegetative growth, which competes with kernel development.
- Avoid using uncomposted animal manures as they can cause problems at harvest, especially with sweepers and vacuum machines; *Salmonella* spp. can also persist in manures that have not been properly composted.
- Consider fertigation to fertilise trees in the absence of good rain; calcium nitrate and liquid NPK fertilisers might be suitable.
- Be sure to calculate the N content of each fertiliser. For example, if the N content of a fertiliser is 27%, then to apply 50 g of N, 185 g of product should be spread ($50 \times 100 \div 27 = 185$).
- Use non-acidifying N fertilisers where possible. These include:
  - potassium nitrate (13% N)
  - calcium nitrate (15.5% N)
  - composted poultry manure (3% N)
- Maintain optimum soil organic matter levels to buffer the effect of the fertiliser on soil pH levels.

An N deficiency is indicated by short shoot growth and pale green to yellow leaves. Calcium nitrate applied via fertigation provides N in an immediately available water-soluble form when broadcast. Calcium nitrate is a granular fertiliser and is the N not lost to the atmosphere like that contained in ammonium-based fertilisers.

Potassium

Potassium is important for growth but is normally applied only in autumn in accordance with the results of leaf and soil analyses. Potassium can be low or deficient in some sandy soil and is slower-acting and less mobile than N. The most common K fertilisers are muriate of potash (potassium chloride, KCl) and potassium sulfate (K_2SO_4). Potassium deficiency is indicated by the presence of small leaves with some burning on the margins and short nut husks. Care needs to be taken with KCl to avoid its build-up and subsequent salinity problems.

Boron

Annual B sprays in late spring can increase nutset in trees over 6 years old, although a response is not always obtained. Boron deficiency shows up as shoot tips die back and the lowest leaves drop from new shoots. Research has shown that foliar B applications can increase nutset by as much as 33% in some situations. Foliar B can be toxic when used to excess, and applications should not exceed more than 1.1 kg B/ha.

Boron availability is reduced in dry conditions, and trees can produce deficiency symptoms in one season, despite the problem not having been seen for several years.

Conclusions and recommendations

Many growers use a variety of inorganic and organic fertilisers. Although some have found that trees yield good crops without annual applications of fertiliser, annual nutrient removal makes it unlikely they would continue to maintain these good yields. Response to fertilisers depends on the amounts of available nutrients and other factors such as soil pH. To maximise the production potential of trees, growers should ensure that factors under their control, such as fertiliser programs, provide nutrients at optimum levels.

It is a good idea to determine the soil nutrient status before establishing an orchard and to supply the necessary nutrients to avoid early poor tree growth. Subsequently, it is recommended to determine tree nutrient levels and modify fertiliser programs accordingly. In addition, soil samples should be taken every 2–3 years to assess soil nutrient levels. Maintaining accurate records of yields and sample results is important. This information, together with visual observations of tree growth, can greatly assist orchard nutrient management. Selection of mineral nutrient source (i.e. inorganic vs organic, readily soluble vs sparingly soluble, high analysis vs low analysis, multi-nutrient vs single nutrient) needs to be based on the compatibility with the orchard's fertiliser delivery system and the response needed. The timing and amount of fertiliser applied should be matched with tree demand, yield and nut quality targets, while being mindful of the need to avoid losses through leaching and waterlogging.

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Irrigation

Irrigation is an important component of achieving optimum yields and nut quality throughout hazelnut growing regions in Australia. Irrigation is critical for semi-arid regions and for temperate regions that have irregular rainfall. Often these temperate regions require more intensive management because rainfall can give a false sense of available soil moisture, resulting in water stress and yield decline. Hazelnuts grown in semi-arid regions are intensively irrigated using scheduling devices.

While literature often states that hazelnuts are shallow-rooted, nowhere is this defined, nor is the effect of different soil types and climatic conditions clarified. Hazelnut trees grown at Dareton, NSW, have extensive fibrous root systems 500 mm deep in sandy loam soil (Figure 44). This emphasises the importance of monitoring hazelnut root zones and site conditions.

Figure 44. The root zone of a mature hazelnut tree at the NSW DPIRD Dareton Research Institute. Fibrous roots are present to at least 500 mm soil depth.

Providing hazelnut trees with the optimum irrigation to achieve good yields and sustainably manage the available water supply requires good irrigation management skills that incorporate field soil moisture assessments (e.g. hand auger soil assessments), devices to measure the soil moisture (e.g. capacitance probes, tensiometers) and climate-based monitoring (evapotranspiration).

A prerequisite to good irrigation management is a well-designed irrigation system that provides an acceptable level of distribution efficiency, which is the evenness of irrigation application over the entire orchard. Distribution efficiency can be affected by sprinkler or dripper spacing and blockages, inadequately sized pipes causing pressure decline and poor maintenance.

Correctly managing irrigation helps to:

- achieve targeted yields
- produce quality kernels

- maintain tree health by reducing moisture stress
- deliver nutrients to the plant through fertigation for sustained growth.

In the same way that water stress can lead to catkin drop, early leaf fall and reduced yields, excessive water can lead to plant health problems, increased pumping costs, nutrient leaching and wasted water. Good irrigation practice comes from understanding the soil's characteristics and the tree's growth and development cycle. It is desirable to have good water availability from October (early leaf) and optimum levels from December onwards as the kernel fills. Stress during this period can reduce the final nut size.

Water quality

Water should be assessed when considering the suitability of water for the orchard. Marginal or poor water quality can reduce yields and damage plants and the soil. The main water quality characteristics include:

- Electrical conductivity (EC), a measure of salinity: if this is <0.8 dS/m, then the water is generally suitable for irrigation on well-drained soil.
- pH: water with a pH between 6 and 8.5 is generally suitable for irrigation. Highly alkaline water can affect Ca and Mg uptake; levels up to 150 mg/L are acceptable.
- Calcium carbonate saturation index: this is determined from pH, salinity, alkalinity and hardness; figures between -0.5 and +0.5 are usually acceptable.
- Chloride: levels <140 mg/L (140 ppm) are generally acceptable.
- Impurities: algae can cause blockages in filters and drippers.

More information on water quality testing is available from the NSW DPIRD website (https://www.dpi.nsw.gov.au/agriculture/water/quality).

Delivering irrigation

The irrigation system chosen will depend on many factors and every grower's situation will vary. The amount and source of water available, evaporation rates, soil composition/profile, available funding, and harvest techniques are some considerations.

In Australia, most hazelnut orchards are generally irrigated with drip, mini-sprinkler or sub-surface delivery systems. These are well suited to fertigation. Some of the advantages and disadvantages of these systems are highlighted in Table 11.

Table 11. Advantages and disadvantages of irrigation systems for hazelnuts.

Low level sprinklers		Drip irrigation	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Wets a large volume of soil that provides a good bank of soil moisture. • When used to supplement rainfall in temperate climates, it helps to irrigate a soil volume similar to rainfall. • Irrigates the inter-row that can grow a sod. The sod keeps the inter-row cooler than bare soil during hot conditions and feeds beneficial insects.	• Uses more water than drip irrigation. • Checking sprinkler operation is expensive. • Good weed control is necessary for distribution. • Greater susceptibility to physical damage from animals and harvesting equipment. • Requires a higher operating pressure than drip irrigation. • The sod can sometimes harbour pests.	• No wearing parts. • Large water savings in young plantings due to accurate and even water placement. • Potentially the most water efficient system.	• High frequency of irrigation means a flexible and frequent water supply system is required. • The smaller wet soil volume than with a sprinkler means there is less soil water storage to buffer against pump failures and repair times. • High degree of filtration is necessary. • Susceptible to damage from orchard operations.

In young orchards, a single lateral with appropriately spaced emitters might suffice for drip irrigation (Figure 45). As trees mature, 2 drip laterals can be used per row to provide a larger wetted area for the root system. Alternatively, if the laterals permit, micro-sprinklers can be added as the trees mature. Some growers prefer to run laterals below the surface with emitters above ground as this accommodates cross-mowing. Further water saving can be made for drip irrigation when the plants are young by using clips to block drippers that are beyond the young root zones.

Sub-surface drip irrigation (SSDI), where drip tape or tube is buried below the soil surface (Figure 46), is highly efficient as evaporation is reduced. Depth of tube placement, emitter spacing, flow and soil properties should be considered carefully. The wetting pattern in the soil from the emitters must reach the tree roots in both young and mature plantings; water must be available to at least 30% of the root surface (orchard floor) area.

Regardless of the system used, water quality is still important. Using poor quality water can create limitations, and filters need to be able to handle worst-case scenarios. Generally, filters should be able to remove particles one-quarter the size of the emitter opening, as particles can clump together and clog emitters.

Flow meters form part of any system (Figure 47). They record the amount of water delivered to the tree, which can be compared with the estimated water usage to aid efficient management.

Maintenance is required on all systems, and regularly flushing lines and adding chlorine will minimise clogging. Expert advice is readily available from many equipment suppliers, who will also provide designs for the total system.

Figure 45. 90° spray jets watering a row of young hazelnut trees. Photo: Vanessa Cox, Hazelnut Growers of Australia.

Figure 46. Sub-surface irrigation along a row of young fruit trees. Photo: Vanessa Cox, Hazelnut Growers of Australia.

Figure 47. Flow meters provide an accurate record of water delivery to the orchard.

Irrigation scheduling basics

There are many methods for measuring tree water use. These methods can be grouped into 3 categories:

1. **Field**: this is information from the plant itself, including leaf observations.
2. **Soil**: taking soil cores from around the orchard (Figure 48 to Figure 50) is an excellent way to check for extremes (very dry or wet soil) but it can be difficult to estimate soil water content near the refill point. Measuring soil moisture content with capacitance probes and tensiometers (Figure 51 and Table 12) can provide accurate readings. However, only a very small volume of soil is measured and sometimes probes can be installed in slightly drier or wetter parts of the orchard, giving a misleading result. Once calibrated and checked for positioning in a representative site, they can provide very good information.
3. **Weather**: using evapotranspiration to estimate tree water use. When using spreadsheets and automatic updating, this provides a very good guide on predictive water use to estimate irrigation requirements 2 to 5 days in advance. This is useful for ordering water. It has a good level of accuracy over a 7-day period but requires soil-based monitoring to calibrate to actual field conditions.

Figure 48. Sampling for soil moisture can be quick and easy using a cordless drill and an extended drill bit.

Figure 49. Soil moisture can be determined by observing and feeling the soil removed from the auger bit.

Figure 50. A soil auger can be built by welding a 200–300 mm wood auger drill bit onto a 12 mm rod.

Figure 51. Tensiometers with ceramic tips and vacuum gauges.

Each method has advantages and limitations. Soil-based monitoring is the most accurate but can be misleading due to variability within the orchard. When used in combination with field and weather-based monitoring, realistic estimates of soil moisture and irrigation requirements are achievable.

Field and soil-based monitoring and irrigation scheduling are universal methods used in all crops. This includes digging soil pits around trees, estimating the size of the root zone and establishing the soil type, then using this information to calculate the amount of water available to the trees. The orchard is then monitored to determine when the soil has reached the refill point. The detailed explanation of how to conduct these steps is extensive. Numerous detailed resources are available on the NSW DPIRD Soil water monitoring and irrigation scheduling webpage (https://www.dpi.nsw.gov.au/agriculture/water/irrigation/scheduling).

Table 12. Interpreting common tensiometer readings.

Reading (centibars or kPa)	Interpretation
0–8	Soil is saturated (0) to near field capacity (8). Continued low readings indicate waterlogging.
8	Field capacity.
8–25	The best conditions for soil moisture and aeration.
25–35	Consider irrigation at critical stages of the crop cycle, i.e. ovary growth and kernel expansion.
35–50	Mild stress on well-drained soil.
50+	Soil is very dry: this will affect yield and kernel quality.

Devices to measure trunk girth and other plant attributes are becoming more affordable and are offered for use in conjunction with soil moisture monitoring systems. These devices should be considered as providing supplementary information rather than being used as scheduling tools. Measuring soil moisture is the foundation of any scheduling program and this needs to be successfully implemented and confidently understood before plant-based sensor information can be incorporated into the system. Plant-based sensors are very good at identifying when the trees are working hard to draw water from the soil into the canopy. While this might indicate that irrigation frequency needs to increase, other factors such as soil moisture content, need to be considered. Applying extra water can sometimes harm the crop by depleting the soil of air and oxygen that is required for root function.

In some very hot and dry situations, the limitation might not be the amount of soil moisture, but the rate at which water can flow up the trunk; the rate of evaporation from the leaves is greater than the rate of trunk flow.

The key issues remain how much to irrigate and when to irrigate. Knowing how much to irrigate requires firstly establishing how much water is held in the root zone. Not all water applied or already in the soil is available to the tree. Some water is held tightly in the soil; this is measured by soil moisture tension (in kPa), i.e. how hard the plant has to work to extract moisture from the soil.

Understanding the following terms (used in Figure 52) helps to understand how water behaves in soil:

- **Field capacity**: this is when the soil profile has been filled (been irrigated or had good rain) and has naturally drained for about 24 hours; the soil moisture tension is approximately 8 kPa at field capacity.
- **Readily available water** (RAW): this is the volume of water that is easily available to the tree, between field capacity and refill point.
- **Refill point**: this is the driest soil from which the plant can extract water without stress occurring, between 40 kPa and 60 kPa.
- **Permanent wilting point**: this is when the tree cannot take up any more water, despite there being some water left in the soil; soil moisture tension is approximately 1,500 kPa.

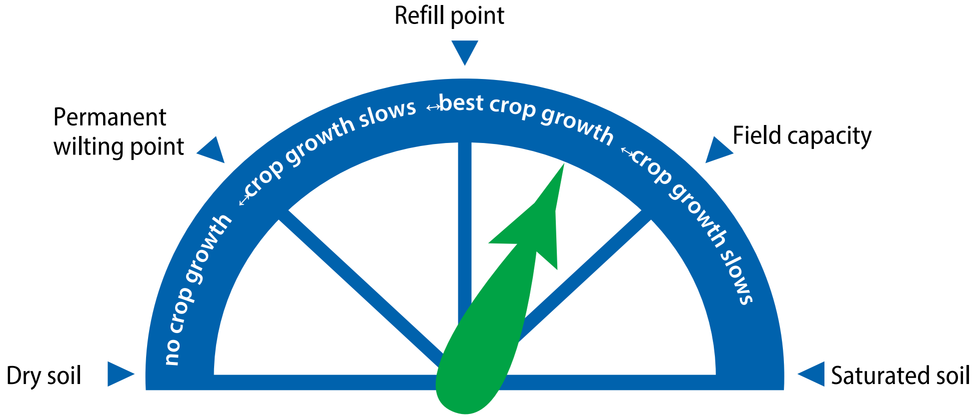

Figure 52. Water availability indicator.

Crop coefficients

Crop coefficients (Kc) are used in evapotranspiration climate-based irrigation scheduling and are specific to each crop and orchard. Crop coefficients can vary with:

- tree characteristics such as variety and size
- soil characteristics
- changes in canopy density due to the deciduous nature of the tree
- differences in wind between the orchard and the evapotranspiration reference point as affected by topography and windbreaks
- other sources such as slight variations in formulae used to calculate reference evapotranspiration.

Customising predetermined crop coefficients to suit the site conditions involves comparing calibrated and reliable soil moisture information with predicted crop evapotranspiration. If the crop evapotranspiration over or underestimates irrigation requirements, then the crop factor will be incorrect. A customised crop coefficient will help schedule and predict irrigation requirements.

The crop coefficients in Table 13 are for the beginning (initial) growth stage (Budburst to leaf expansion), fully expanded leaves and shoots (mid) and leaf senescence during autumn (end). The crop coefficients will change rapidly from Budburst to fully expanded leaves and similarly during leaf senescence. During tree dormancy in winter, when no leaves are present, the crop coefficient will be similar to the bare soil crop coefficient of 0.1. When Budburst occurs, resuming good irrigation monitoring and scheduling practices is important because as leaves begin to expand, they transpire, and along with increasing temperatures, soil moisture levels can rapidly decrease.

Practical considerations

Having sensors located in positions representative of soil type, tree health and tree size is important. When installing sensors, dig under the emitters to establish the wetting pattern. Sensors need to be located at the following depths:

- in the middle of the root zone, about 300 mm
- near the bottom of the main fibrous root zone, about 600 mm
- below the root zone, about 1,200 mm.

Table 13. Crop coefficients published by the Food and Agriculture Organisation (FAO) for stone fruit.

	Crop coefficients* (Kc) and growth stage		
Apricots, peaches, stone fruit	Budburst to leaf expansion	Fully expanded leaves and shoots	Leaf senescence during autumn
No ground cover, killing frost	0.45	0.90	0.65
No ground cover, no frosts	0.55	0.90	0.65
Active ground cover, killing frost	0.50	1.15	0.91
Active ground cover, no frosts	0.80	1.15	0.85

Source: Allen et al. (1998).

*These, and many other crop coefficients, can be found in Chapter 6 of the *Crop evapotranspiration – Guidelines for computing crop water requirements* (https://www.fao.org/3/x0490e/x0490e0b.htm).

Crop coefficients used for hazelnuts grown at the Dareton Research Institute, NSW, are shown in Figure 53.

Figure 53. Crop coefficients used to irrigate hazelnuts grown at Dareton, NSW.

References and further reading

Allen G, Pereira L, Raes D and Smith M (1998) *Crop evapotranspiration guidelines for computing crop water requirements*, Food and Agriculture Organisation Irrigation and Drainage paper 56 (www.fao.org/docrep/X0490E/X0490E00.htm).

Boland A, Ziehrl A and Beaumont J (2002) *Guide to best practice in water management: orchard crops*, Department of Natural Resources and Environment, Highway Press, Victoria (https://apal.org.au/wp-content/uploads/2019/09/fo-ow-handout-09-sept-best-practice-water-mgmt-boland.pdf).

Charlesworth P (2005) *Soil water monitoring: an information package*, Land and Water Australia, Canberra.

Gispert J, Tous J, Romero A, Plana J, Gil J and Company J (2005) The influence of different irrigation strategies and the percentage of wet soil volume on the productive and vegetative behaviour of the hazelnut, Proceedings of the Sixth International Congress on Hazelnut, *Acta Horticulturae,* 686: 333–341.

NSW DPIRD website (https://www.dpi.nsw.gov.au/agriculture/water/irrigation).

The orchard floor

Permanent sods can be incorporated by using a regular herbicide program to reduce competition and encourage tree growth. This is particularly important in the early years as well-managed inter-rows provide improved soil structure, increased water penetration and maintain organic matter levels. Growth can be mown for use as mulch under trees and flail-mowed before nut fall. Flail-mowing after nut harvest is also useful for mulching leaves.

A typical sward (Figure 54) for cooler tableland areas might consist of a grass/clover mixture. Commercial mixtures generally consist of fescue, ryegrass and clover. Clovers have a good capacity to fix nitrogen and support the general fertiliser program. Optimum sowing time is typically early to mid-autumn, with sowing rates up to 50 kg/ha to ensure rapid establishment and to provide effective competition for weeds.

If a pre-planting cover crop is sown before establishing the orchard, it should be mown before incorporation. A typical cover crop might consist of oats (30 kg/ha) and vetch (20 kg/ha), or oats (35 kg/ha) and field peas (30 kg/ha).

When preparing the area for planting, some growers might wish to rip the soil, depending on soil type and previous ground usage. Ripping can help to remove tree roots from a previous orchard. To prepare the area for planting, trees and vegetation can be cleared and the land deep-ripped in both directions to a 0.5 m depth. The land should then be levelled and fertilisers and lime added, as determined by soil testing.

Figure 54. A mown, grassed inter-row and a weed-free strip along the tree row.

Weed control

Rapid canopy establishment and early cropping are vital to profitability in any orchard, particularly in modern, capital-intensive systems. Weeds compete with trees for moisture and nutrients. They can also create a favourable microclimate for pests and diseases. Competition from weeds in young, developing orchards (Figure 55) can result in slower canopy establishment and delayed productivity. A poor weed management strategy will also have a negative effect on yields in established orchards.

Figure 55. Weed infestations in the planting year can compete with young trees for moisture and nutrients. Photo: Filotas (2021).

The most appropriate weed management strategy will vary from site to site and will depend on factors such as orchard size, tree age, weed spectrum and density, soil type, available moisture and choice of under-tree management (i.e. bare earth, mulched or sod culture). For most growers, the key objective is to reduce weed competition and reproduction to acceptable levels.

Weed populations react to the environmental conditions and to the control measures being applied. Failure to adjust management appropriately could alter the weed population to harder-to-control weeds, such as persistent perennial weeds with long-lived tubers and rhizomes, or the development of herbicide resistance in the weed population. Weed management methods can be grouped as either physical or chemical, or can incorporate elements of both.

How the orchard floor is managed will be influenced by location, climatic conditions, soil, irrigation practices, topography, grower preferences and the types of weeds that might be dominating. A weed management program should start before the trees are planted because the more difficult-to-control weeds are easier to manage before planting. If time permits, pre-planting cultivation for 2 years can reduce infestations of undesirable weeds. Cultivation should be kept to a minimum: to control weeds, a depth of 100 mm should be sufficient.

Hygiene comes first

Good orchard hygiene is the first step in any weed management strategy. Moving weeds on and throughout a property and the appearance of new weed species are largely determined by the degree of weed hygiene employed. Be aware of new weeds appearing on the property, have them identified if necessary, and work towards eradicating them or reducing their spread. Moving machinery from non-orchard areas to the orchard and between blocks is the most likely method for spreading new weeds. Reduce the spread of new weeds by regularly cleaning orchard equipment.

Physical weed control

Cultivation

Cultivation was once a common practice in orchards and does reduce competition from weeds, but at some cost. Disturbing the topsoil is now known to negatively affect soil structure, levels of organic matter and can result in some root damage to trees, especially in orchards on dwarf rootstocks. Cultivation also increases erosion risk and evaporation. Spot cultivation (e.g. using a hoe) is labour-intensive but might be an option for smaller orchards as an alternative to broad-scale cultivation or spot spraying.

Thermal weeding

Research shows that flame or thermal weeding using propane burners, hot air or hot water can be effective on small seedlings but is less effective on larger annuals or perennial weeds. There are also occupational health and safety issues and fire hazards associated with these methods. Do not use thermal weeding near trees less than 3 years old, as this can severely damage trees.

Grazing animals

Grazing with animals such as sheep, geese and fowl can be used to suppress weed growth and reduce seed load in the orchard. Geese are heavy feeders of weeds and grasses. Sheep can cause damage to trees if other feed is scarce. Animal excrement could cause contamination of nuts at harvest. If orchard-grazing animals are intended for sale, be aware of chemical residue issues. Consult chemical labels for information on stock withholding periods.

Mulching

If done correctly, mulching represents the most effective alternative to chemical weed control (Figure 56). Mulching the under-tree row with large quantities of organic materials such as straw, clean hay or bark chips has multiple added benefits including moisture retention, soil temperature regulation, organic matter and soil microbe accumulation. To provide effective weed control, mulch must be applied at sufficient thickness to act as a physical barrier to sunlight and weed growth. This thickness will depend on the type of mulch being applied. However, excessive thickness will reduce the amount of rainfall reaching the soil as moisture can be trapped in the mulch.

Side-cast mowers that deposit slashings along the tree row can help build up organic matter. This is not effective as a stand-alone mulch treatment but can supplement an existing mulch treatment.

Growers should also be aware of the nitrogen drawdown effect that is possible when using some raw, non-composted mulches with high C:N ratios.

Figure 56. Mulch is used in young orchards to help suppress weeds.

Slashing

Slashing the inter-row is a good way to manage grasses and prevent upright-growing weeds from setting seed. Grasses help to reduce the temperatures in the orchard and provide a food source for some beneficial insects. Slashers that reach under trees in sprinkler-irrigated orchards are available (Figure 57). These have a retractable slashing head that can move out of the way of tree trunks and sprinkler heads. A sturdy stake needs to be placed beside the sprinkler for the slasher head to detect an obstruction.

Figure 57. An under-tree slasher. Photo: Fischer Australis.

Chemical weed control

Chemical herbicides have been the mainstay of weed management in orchards since the mid 1940s. Using herbicides remains the most cost-effective and reliable approach to managing weeds in commercial orchards.

Types of herbicides and when to spray

Generally the best time to spray for weeds is either just before (pre-emergent) or just after weed seed germination (post-emergent). Most weeds germinate in either spring or autumn. Small weeds are easier to control than older, more mature weeds.

Orchard herbicides can be grouped into 3 broad categories:

1. pre-emergent residual herbicides
2. post-emergent selective grass herbicides
3. post-emergent non-selective knockdown herbicides.

Pre-emergent residual herbicides perform best when applied to bare soil that is free from weeds and other debris. Any material that prevents the pre-emergent herbicide from contacting and penetrating the soil surface will reduce the level of control. Most pre-emergent herbicides will provide effective control for a wide range of annual broadleaf weeds and grasses if applied correctly. Most require rain or irrigation within a set time for the herbicide to be effective.

Post-emergent selective herbicides are useful where grass is the predominant weed species. The active ingredients with registrations for use in NSW as selective grass herbicides are all members of the herbicide mode of action Group 1 (previously A). This means they are highly prone to developing resistance and should be used in accordance with resistance-management principles.

Post-emergent non-selective knockdown herbicides perform best when applied to young, actively growing broadleaf weeds and some grasses. Due to their non-selective nature, many herbicides in this group can be harmful to fruit and nut trees. Young trees are particularly prone to injury if not protected from knockdown herbicides. Using tree guards on young trees will protect them from herbicides and other sources of damage. Consult herbicide product labels for specific recommendations.

Please read the product labels thoroughly before applying any herbicide in an orchard. Failure to do so could result in poor product performance and/or damage to trees.

Avoiding herbicide resistance

Herbicides work by interfering with specific processes in plants. This is known as the mode of action (MoA). Herbicide MoA classifications have been updated internationally to capture new active constituents and ensure the MoA classification system is globally relevant.

The global MoA classification system is based on numerical codes that provide infinite capacity to accommodate new herbicide MoA becoming available, unlike the alphabetical codes previously used.

To minimise the risk of herbicide resistance developing in an orchard:

- know the herbicide groups
- do not rely on chemicals from the same group for every spray
- use a lower-risk herbicide in preference to a high-risk one; herbicides are ranked for their risk of developing resistance, with groups 1 and 2 considered the highest risk
- look for surviving weeds after spraying and prevent these from setting seed
- use as many weed control techniques as practical and do not rely solely on herbicides.
- only spray during the appropriate weather conditions such as low wind and suitable Delta T conditions (for more information on weather conditions and spraying, refer to *Reducing herbicide spray drift*, https://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift)
- using a recommended adjuvant can improve effectiveness by:
  - increasing herbicide penetration into the leaf
  - increasing the spread and subsequent leaf coverage
  - reducing incompatibility issues with other herbicides
  - modifying the droplet size for good coverage and reduced spray drift.

Herbicide resistance testing

Any weedy outbreak that is suspected of having herbicide resistance should be tested. This will provide valuable information about the herbicides that do not work, but more importantly, those that are effective.

There are 2 types of tests available: a quick test and a seed test. The quick test involves live seedlings being sent for re-potting and spraying. Once the plants have fully recovered, they are sprayed with the selected herbicide. Results are usually reported between 4 and 8 weeks after arriving at the testing facility. This is usually too late to enable re-treatment of the 'suspect' patches in the orchard, but does provide early knowledge about the nature of the problem. One disadvantage of the quick test is it cannot test for pre-emergent herbicides, as the plants have already emerged.

A seed test requires seed to be sent and often involves breaking seed dormancy upon arrival. It is useful to test for resistance to pre-emergent herbicides. The turnaround time is approximately 4 months.

A standard weed control program

Weed control in the orchard is normally associated with a flailing/mowing program and banded herbicide strips. A typical weed control program begins with a non-selective herbicide in late winter or early spring to kill any weeds present. A residual herbicide can then be applied to give control through spring and early summer. Weeds that escape the residual herbicide treatment can be controlled with a non-selective knockdown herbicide through summer if necessary.

Paraquat and diquat herbicides (Group 22, previously L) act on contact by destroying the chlorophyll-forming tissue in the plant (usually the leaves); in conditions of rapid growth, the effect might be visible after only a few hours. Effectiveness is increased when these are applied in overcast weather or late in the afternoon. Although only tissue that is contacted is affected, caution must be exercised when spraying close to young hazelnut plants, as the spray might destroy enough green or tender bark to seriously affect plant health.

Systemic herbicides such as glyphosate (Group 9, previously M) are absorbed by the plant, disrupting the function of the root system and ultimately destroying the plant (Figure 58). Care should be taken around young trees, as over-spray might be taken up by the green bark and kill the tree. Take care not to spray suckers, as any chemical absorbed in this way will be transferred to the main root system, affecting the health of the whole plant.

Some key points to take note of when using herbicides include:

- Do not always use the same chemical groups to prevent resistance from developing. Monitor for resistance, especially if using glyphosate. Resistance status can be confirmed by a recognised herbicide resistance-testing service.
- Use only pesticides registered or permitted and observe any withholding periods. The presence of unacceptable chemical residues can lead to the loss of potential markets.
- Minimise the risks of off-target spray drift.
- Maintain records and a spray diary so that the effectiveness of the program can be monitored. Good records can also help processors with any food safety issues.

Figure 58. Glyphosate damage to a hazelnut tree. Photo: Filotas (2021).

Chemical registrations often change, so growers should confirm whether any chemical they intend to use is approved for that use. Check the Australian Pesticides and Veterinary Medicines Authority (APVMA) PubCRIS database for registered controls (https://portal.apvma.gov.au/pubcris).

Your responsibilities when applying pesticides

The APVMA, NSW Environment Protection Authority (EPA), SafeWork Australia and SafeWork NSW are the government agencies that regulate pesticides in NSW.

Agricultural and Veterinary Chemicals Code Act 1994 (Commonwealth)

The APVMA administers the *Agricultural and Veterinary Chemicals Code Act 1994*. Under the Act, the APVMA is responsible for the import, registration and labelling of pesticides. States and territories regulate the use of pesticides.

Permits for off-label use

Where there is a need to use pesticides outside the registered use pattern, the APVMA can approve off-label use by issuing a minor use, emergency or research permit. The *NSW Pesticides Act 1999* does not allow off-label use unless a permit is approved by the APVMA. Lists of current permits and registered products are available from the APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris).

Any individual or organisation can apply for a permit. The APVMA can be contacted on 02 6770 2300 or by email (enquiries@apvma.gov.au).

The label

Chemical labels are legal documents. Legislation in each state and territory requires all chemical users to read and comply with label instructions.

Signal heading

Pesticides fall into 3 of the 10 schedules in the Poisons Standard. All pesticides carry a signal heading; for pesticides these include:

- Caution (Schedule 5)
- Poison (Schedule 6)
- Dangerous Poison (Schedule 7).

Re-entry intervals

The re-entry interval is the time that must elapse between applying a pesticide and entering the sprayed orchard unless the person is wearing full personal protective equipment (PPE).

Pesticides and the environment

Many pesticides are toxic to aquatic organisms, bees and birds. Following label instructions will minimise the risk to off-target organisms.

Many labels carry the warning: 'Dangerous to bees. Do not spray any plants in flower while bees are foraging'. It is often safe to spray early in the morning or late in the afternoon but only when bees are not foraging.

Organophosphate and carbamate insecticides are toxic to some birds, especially in granular formulations. See the label for details on how to minimise the danger to birds.

Withholding period

The withholding period (WHP) is the minimum time that must elapse between the last application of a pesticide and harvest. The purpose of the WHP is to minimise the risk of residues in agricultural commodities and in foods for human and animal consumption.

Some export markets have a lower residue tolerance than Australian maximum residue limits (MRLs). Contact your processor or packing shed to determine their market requirements.

Managing spray drift

Spray drift is the physical movement of chemical droplets or vapour onto a non-target area, causing a risk of injury or damage to humans, plants, animals, the environment or property. Buffer zones reduce the risk of chemical drift reaching sensitive and non-target areas. Applicators must adhere to drift reduction instructions on labels.

Safety instructions

Safety instructions on labels provide information about PPE and other safety precautions that are essential when using the product.

Note: before opening and using any farm chemical, consult the label and the Safety Data Sheet (SDS) for safety directions.

Applying pesticides by aircraft

Product labels indicate which products are suitable for application by aircraft (e.g. aeroplane, drone or helicopter). They also provide a recommendation for the minimum water volume for aerial application. More information on the legal requirements for aerial application is available on the environmental protection or equivalent agency in your state or territory.

Pesticide legislation

Each state and territory has established legislation and regulations relating to the use of pesticides. These aim to minimise the risks to human health, the environment, property, industry and trade. Pesticide legislation and regulations can be found on the website of the respective environmental protection agency or equivalent in your state or territory.

Legislation and regulations in each state and territory require growers to:

- only use pesticides registered or permitted by the APVMA
- obtain an APVMA permit if they wish to use a pesticide contrary to label instructions
- read the approved label and/or APVMA permit for the pesticide product (or have the label/permit read to them) and strictly follow the directions on the label
- keep all registered pesticides in containers bearing an approved label and in an approved location
- prevent damage to people, property, non-target plants and animals, the environment and trade when applying pesticides.

Training

The minimum prescribed training qualification is the AQF2 competency unit, 'Apply chemicals under supervision'. However, chemical users are encouraged to complete the AQF3 competency units: 'Prepare and apply chemicals' and 'Transport, handle and store chemicals'. Contact your local TAFE or vocational education training provider for more information.

Record keeping

All people who use pesticides for commercial or occupational purposes must make a record of their pesticide use. Records must be made within 24 hours of applying a pesticide and include:

- date, start and finish time
- operator details e.g. name, address and contact information
- crop treated e.g. hazelnuts
- property address and a clear delineation of the area where the pesticide was applied
- type of equipment used to apply the pesticide e.g. knapsack, air-blast sprayer or boom spray
- full name of the product or products (e.g. Grochem Tribasic Liquid Flowable Copper Fungicide, not just Copper)
- total amount of concentrate product used
- total amount of water, oil or other products mixed in the tank with the concentrate
- size of the block sprayed and the order of blocks treated
- an estimate of the wind speed and direction at the start of spraying
- weather conditions at the time of spraying and weather conditions specified on the label
- changes to wind and weather conditions during the application
- records must be made in English and kept for 3 years in NSW and Victoria and 2 years in all other states and territories.

Globally Harmonised System of classifying and labelling chemicals

The Globally Harmonised System (GHS) is an international system for classifying hazards and communication about dangerous goods and hazardous substances. The GHS replaces the old hazardous substances and dangerous goods classification.

To obtain further information on your responsibilities in relation to handling, labelling and storing workplace chemicals, check the website of the safe work agency in your state or territory.

Commonwealth *Work Health and Safety Act* 2011

SafeWork Australia administers the *Commonwealth Work Health and Safety Act* 2011 and the Work Health and Safety Regulation 2011.

The Act defines the responsibilities of employers or the person conducting a business or undertaking (PCBU) and the responsibilities of workers.

The Regulation covers hazardous substances and dangerous goods, including applying the GHS in Australia.

SafeWork Australia has published several Codes of Practice (https://www.safeworkaustralia.gov.au/law-and-regulation/codes-practice) for different industries and situations to provide guidance for industries.

Work Health and Safety

Each state and territory has passed legislation and regulations to deal with work health and safety (occupational health and safety in Victoria). This legislation requires employers to consult with workers, maintain safe workplaces, undertake risk assessments and emphasise worker training and supervision.

WHS legislation also includes managing hazardous substances (i.e. most pesticides). It covers identifying hazardous substances in the workplace, assessing and managing risks associated with chemical use and responsibilities for managing risks to health and safety at a workplace. These responsibilities include:

- correctly labelling containers
- maintaining a register of hazardous chemicals
- identifying risk and ensuring the stability of hazardous chemicals
- ensuring that exposure standards are not exceeded
- information, training and supervision for workers
- spill containment kits kept on-site
- SDS for chemicals kept on-site
- controlling ignition sources and accumulation of flammable and combustible materials
- provision of fire protection, firefighting equipment, emergency and safety equipment
- developing and displaying an emergency plan for the workplace
- stability, support and appropriate plumbing for bulk containers.

Transporting dangerous goods

The Australian Code for the Transport of Dangerous Goods by Road and Rail (ADG Code) sets out the requirements for transporting dangerous goods by road or rail.

Growers involved in transporting dangerous goods must understand their responsibilities to help prevent and reduce damage to people, property and the environment.

Operational advice on transporting dangerous goods is provided by the competent authority in each state or territory. As regulators, they can advise on issues such as labelling, packaging, quantities or using placards.

References and further reading

Agricultural and Veterinary Chemicals Code Act 1994, https://www.legislation.gov.au/C2004A04723/latest/text

APVMA website (https://apvma.gov.au/node/1060)

Australian Code for the Transport of Dangerous Goods by Road and Rail (www.ntc.gov.au/heavy-vehicles/safety/australian-dangerous-goods-code/)

Bureau of Meteorology (www.bom.gov.au)

Environment Protection Authority (www.epa.nsw.gov.au/)

Hazardous Substances Information System (http://hcis.safeworkaustralia.gov.au/)

Managing risks of hazardous chemicals in the workplace https://www.safeworkaustralia.gov.au/doc/model-code-practice-managing-risks-hazardous-chemicals-workplace)

National Association of Testing Authorities (www.nata.com.au/)

NSW DPIRD resources on QFF (www.dpi.nsw.gov.au/biosecurity/insect-pests/qff)

Safe use and storage of chemicals in agriculture (https://www.safework.nsw.gov.au/advice-and-resources)

Work Health and Safety Act 2011 (www.legislation.gov.au/Details/C2017C00305)

Work Health and Safety Regulation 2011 (www.legislation.gov.au/Details/F2011L02664)

Pruning and shaping

Pruning

At planting, nursery trees should be root-pruned to reduce suckering and have any basal buds removed. Trees should then be headed to approximately 0.8 m. Pruning in the next 2–5 years is used to produce a modified leader tree with 3–5 main branches. Pruning in the following years is not required until vigour declines.

Hazelnuts generally crop on 1-year-old shoots (the previous year's growth). In established orchards in the USA, 15–20% of the orchard might be pruned on a 5–6-year rotation plan. Since the crop is borne on moderately vigorous 1-year annual twig growth of about 100 mm, care must be taken during the pruning program.

Pruning should be done carefully as it is one of the factors contributing to an alternate bearing pattern. With mature trees, insufficient pruning can encourage excessive shading that will reduce flower bud formation, fruit set, yield and nut size and can also reduce shoot vigour and diminish cropping potential.

Unlike other deciduous trees, hazelnuts require minimal pruning. Pruning is carried out in late winter and normally after the catkins have shed pollen. In temperate areas of Australia, this is usually in August. Warmer, sunny winter days are best; pruning in wet weather can spread bacterial blight on open cuts. Large pruning cuts should be avoided to prevent infections from wood rots.

There are 2 main objectives of pruning:

1. to establish the required tree shape so that the long-term management of the orchard can be achieved efficiently
2. maintenance: regular pruning maximises fruit production.

Tree shaping

The hazelnut is naturally a suckering plant (Figure 59), with most varieties tending to develop into multi-stemmed bushes (Figure 60). The desired tree shape depends on the grower's preference and orchard management system. Typically, that shape can be a single trunk tree (Figure 61), multiple 2- to 4-trunk trees, or a multi-stemmed bush.

Figure 59. Single stem hazelnut tree with multiple suckers. Photo: Ranford (2016).

Figure 60. Multi-stem hazelnut tree.

Figure 61. Single stem hazelnut tree.

For commercial orchards, a single trunk tree with an open V-shape is more desirable for several reasons, including:

- The shape facilitates mechanical harvesting by allowing easier equipment access under the tree canopy, and fewer nuts are lost by being trapped in the network of trunks or stems.
- The single trunk permits better sunlight penetration.
- General orchard operations such as sucker removal, irrigation, mulching and spraying are easier.
- Field evidence suggests that there is no significant difference in yield between a single trunk open vase form and a multi-stemmed tree.

The disadvantage of the single trunk hazelnut plant is that, being relatively shallow-rooted, it is more vulnerable to storm damage.

Assuming that a single trunk tree with an open V-shape is required and a strong, healthy whip is supplied, the young plant can be headed to about 0.8 m high. Leave at least 4–6 buds at the top of the whip, and gently rub off the remaining buds below. As well as establishing the shape of the tree, this process will help to redress the balance between the top of the plant and the root system, which might have been damaged during planting. For the first 2–3 years, the main objective of pruning is to establish an open vase shape with 4–6 permanent scaffold limbs well-spaced down and around the trunk.

Controlling suckers

Whichever system is chosen, suckers (Figure 62) are undesirable for several reasons:

- They divert growth from the main tree structure; energy is wasted on a shoot that will need to be removed.
- An abundance of suckers at the base of the plant traps fallen nuts, which can contaminate harvest the following year.
- Excessive sucker growth interferes with tree shaping.
- Young fleshy suckers can be attractive to insect attack.
- Suckers act as a site for undesired herbicide uptake, which can affect tree health, especially with fully systemic herbicides combined with side-boom application.

Suckers can be controlled chemically (Figure 63) and mechanically. Chemical control involves spraying the suckers with a knockdown registered herbicide such as paraquat. This is normally applied when suckers are 50–100 mm tall and best results are achieved in overcast weather.

Figure 62. Suckers that have not been pruned. Photo: Ranford (2016).

Figure 63. Chemically treated suckers. Photo: Ranford (2016).

Occasionally the suckering habit of the hazelnut, apart from the role played in nursery production, is used to advantage in the orchard. If the main nursery whip has failed or succumbed to disease or dieback, the original whip can be cut back and a healthy sucker selected to become the new tree. This applies only to those plants originally planted on their own roots and not grafted.

Correct timing of chemical sucker control is important: applying when the sucker is fleshy gives optimum control. Care is necessary not to over-spray onto the trunks of young plants. Larger suckers that have become woody need to be cut out. As the orchard matures and trees settle into cropping, de-suckering becomes less of a task.

Mature trees

Once a vase shape is established, the inward and crowded growing shoots can be removed (Figure 64). Strong upright water shoots are usually removed annually, as this type of growth can attract aphids, unless the shoots are to become additional main branches for replacements. Tree management now consists of:

- Maintaining the basic vase shape that was established during the initial training.
- Encouraging light into the canopy to maintain fruitfulness and good rates of photosynthesis.
- Removing diseased shoots.
- Removing large side shoots or branches to allow for tractor access (Figure 65); this will still be required even with a low-profile tractor configuration.

Figure 64. Trees are lightly pruned to encourage a vase shape and to allow machinery under the trees.

Figure 65. Hedged hazelnut trees at Dareton, NSW.

In older plantings where tree vigour has declined, rejuvenation pruning can stimulate new growth. Where large cuts are to be made, an angled bench cut can provide direction to form new main limbs. Treat big cuts with a product such as Greenseal®. The drawings in Figure 66 show the development of the tree framework.

References

Kentish Cobnut Association (2001) *Pruning Kentish Cobnuts*. Kentish Cobnut Association, Norwich, UK.

Ranford T (2016) *Communications support for the hazelnut industry*, Final report to Horticulture Innovation Australia, Project HZ13001, (https://www.horticulture.com.au/globalassets/hort-innovation/historic-reports/communications-support-for-the-hazelnut-industry-hz13001.pdf).

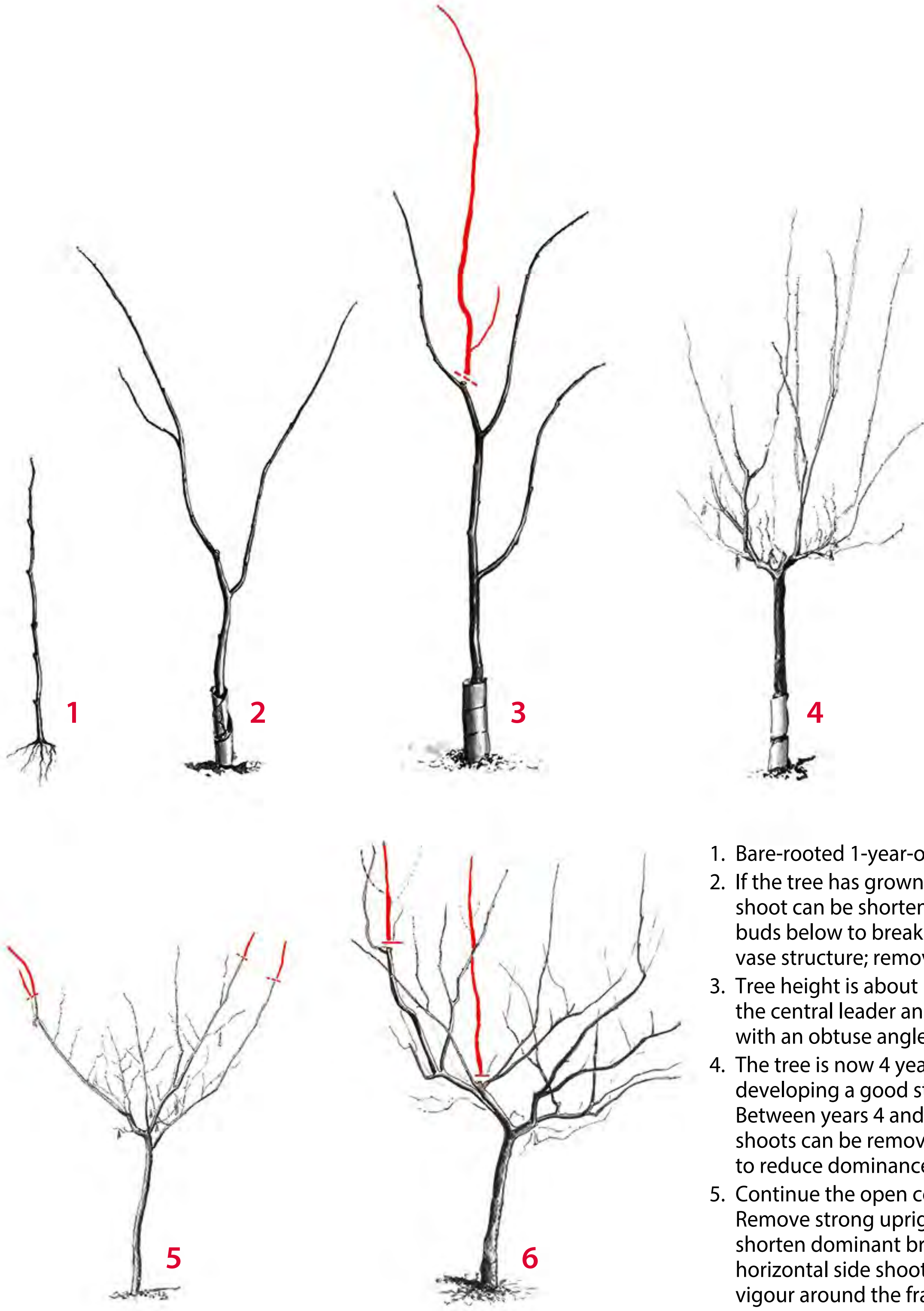

Figure 66. Development of the tree framework. Red branches indicate those to be removed. Source: Kentish Cobnut Association.

1. Bare-rooted 1-year-old nursery plant.
2. If the tree has grown well, the leading shoot can be shortened to encourage buds below to break and develop a vase structure; remove all suckers.
3. Tree height is about 1.1 m. Remove the central leader and cut to a shoot with an obtuse angle.
4. The tree is now 4 years old and developing a good structure. Between years 4 and 5, centre upright shoots can be removed or shortened to reduce dominance.
5. Continue the open centre shape. Remove strong upright shoots and shorten dominant branches to horizontal side shoots. Attain even vigour around the framework.
6. Maintain framework branches. Remove crowded upright growth and ensure new cropping wood. Shorter, weaker branch tips can be removed and renewed over the years.

Pests and diseases

Hazelnuts are affected by fewer pests and diseases than most other temperate fruits. Vertebrate pests, insect pests and diseases can constrain production and need to be monitored.

Depending upon the region, management strategies and environmental conditions, hazelnuts might not be affected by many pests. Most Australian orchards are unsprayed, possibly because of their isolation, previous lack of insecticide use and a natural ecological balance. This status of balance is desirable, and the Australian industry is well-situated to maintain this position.

Pest monitoring and management systems are complex and require an understanding of the pest and available control measures. Integrated pest management (IPM) systems, in which all available forms of control (biological, physical and chemical) are used to lower pest populations safely and economically, are preferred.

Vertebrate pests

Birds, rabbits, hares, kangaroos, wallabies, mice, rats, foxes, deer and wombats have been identified as affecting hazelnut production. To control these, it is important to gain a basic understanding of their biology and population dynamics. This allows producers to develop effective control programs that target different species at critical times. To achieve the best results, individual control programs should be linked to a combined neighbourhood or area-wide program.

Birds

Bird damage to hazelnut orchards can be significant (up to 70%) and includes pruning foliage and buds, ringbarking trees, and cracking and eating hazelnuts (Figure 67 and Figure 68). Hazelnuts can be removed from the trees before the kernels are mature and also as they are awaiting harvest. Sulfur-crested cockatoos, galahs, little corellas and long-billed corellas are the main bird pests of the hazelnut industry. Other species such as crows, ravens and a variety of rosellas and parrots cause damage to growing tips, buds and mature fruit. Surveys in Australia have indicated the damage caused by birds is higher in nut crops than any other horticultural crops.

Figure 67. Examples of bird-damaged leaves and nut clusters from hazelnut trees.

Figure 68. Bird-damaged nuts on the orchard floor.

Management options

Multiple management options exist for pest birds with variable effectiveness, unfortunately no single solution is applicable to all situations. The most crop damage usually occurs in late harvest, although hazelnuts can be attacked as they mature. Bird management is often not initiated until considerable damage has already occurred. Integrated pest management is a concept well understood for insect and disease problems; however, birds have not often been managed in the same strategic way.

Rather than focusing on killing as many pests as possible, it is now realised that, similar to most other aspects of agriculture, bird management needs to be carefully planned and coordinated. Bird control is just one aspect of an integrated approach to managing production. Many birds are highly mobile and those that are killed in control programs are readily replaced. Unless actions are well planned and coordinated, they are unlikely to have a lasting effect.

Management options include scaring, netting, lethal control and birds of prey. Scaring is most commonly practised, and netting might be an option for some growers. As some bird pests in orchards are native to Australia, a control licence may be required. See the NSW DPIRD website (https://www.dpi.nsw.gov.au/hunting/game-and-pests/native-game-birds) for more information.

Scaring

Scaring uses visual and audio devices (Figure 69) and can include LPG gas guns, reflective mirrors or tape and flashing or rotating lights. Habituation is the main drawback of all types of scaring; birds quickly become accustomed to audio or visual cues.

Best results for scaring are achieved when:

- combinations of techniques are used
- scaring starts before the birds establish a feeding pattern
- the sound produced by the audio devices is supplemented by shooting or a threat
- the timing and placement of devices are changed frequently, but not at regular intervals.

Netting

Exclusion netting using drape-over or permanent nets has high up-front costs but might be appropriate where levels of damage are high. Several netting options are available (Figure 70 to Figure 72).

Figure 69. An automatic laser bird repeller. Photo: Guy Rischmueller, Hazelnut Growers of Australia.

Managing the orchard: pests and diseases

Figure 70. Hazelnuts under nets at Orange, NSW.

Figure 71. Drape-over netting on hazelnuts in Orange, NSW.

Figure 72. Throw-over netting on walnuts in Gippsland. Photo: Guy Rischmueller, Hazelnut Growers of Australia.

Machines (Figure 73) can be used to install and remove drape-over nets of varying width (for example, one, 2 or 4 rows). 'Lock-out' netting provides a continuous cover of netting by joining draped nets without the need for poles and cables. Nets can also be used on infrastructure to prevent birds from roosting or nesting. If maintained, netting with ultra-violet stabilisers can provide between 5 and 10 years of protection. Permanent netting is easier to maintain, allows easier spraying of trees, and does not need to be removed before harvest.

Figure 73. A bird netting tractor in Gippsland. Photo: Guy Rischmueller, Hazelnut Growers of Australia.

Netting overcomes many of the legal, environmental, social and animal welfare concerns of other techniques. The decision to net is mainly an economic one. Will the increase in returns from excluding birds be beneficial over the life of the netting? As an example, a cost-benefit analysis on netting in Orange, NSW, suggests drape-over nets are cost-effective when damage is consistently greater than 10% and permanent nets are cost-effective where damage is over 25%.

Hares and rabbits

Hares (Figure 74) prefer tender, long grass shoots and more woody plants. They can be seen individually or in small loose groups when feeding. Hares will gnaw as well as chew; the gnawing action is designed to keep their growing teeth at a functional level and will cause economic and aesthetic damage to crops, orchards, gardens, nurseries and shelter belts. They are well known for pruning plants, nipping new buds and bark off small trees and bushes, which in severe cases, cause ringbarking and possible death of the plant. Damage is greatest in late winter until spring when weather conditions limit food supply and where overgrazing or drought conditions force hares to attack trees as an alternative food source.

Rabbits (Figure 75) eat a wide variety of plants including crops, roots, pastures, young trees and vines. Their preference is for short, succulent, high-protein green grasses. Damage to newly planted hazelnut groves consists of stem damage to young trees and exposure of roots to sunlight and air. In nursery stool beds, rabbits can disturb the root development of hazelnut suckers. Rabbits usually do not travel very far.

Figure 74. European hare. Photo: Mark Norman, Museums Victoria.

Figure 75. European rabbit. Photo: Department of Primary Industries and Regional Development.

Control

Tree guards (Figure 76 and Figure 77) made of aluminium foil or thick plastic placed around the trunks of young hazelnuts have been successful in preventing damage. This also assists with sunburn protection to the stem.

Figure 76. An aluminium tree guard to protect young trees from hares and rabbits.

Figure 77. A rabbit-proof tree guard. Photo: Agriculture Victoria.

Ground cover in the inter-row and around fence lines should be kept mown. The more a hare feels exposed, the less likely it will remain for long periods. If possible, try and include perches that will allow large raptors to roost at the site (Figure 78) as this will increase the chances of naturally discouraging hares. This can also assist with bird control.

Monitoring the numbers is critically linked to rabbit control options, which will depend on the level of infestation. Exclusion fencing can be used as a means of control, but might be cost-restrictive. Trapping, poisoning and shooting are generally ineffective and/or time-consuming. Rabbit control programs have to be regular and systematic to remain economical and avoid re-infestation. It is strongly advised to link your control program with adjoining land managers to minimise economic and environmental damage.

Figure 78. A nankeen kestrel landing at a bird perch in Griffith, NSW.

Poison: sodium fluoroacetate, more commonly known as 1080, is an effective poison. This substance must be used in accordance with specific conditions stated in the Pesticide Control Order (https://www.epa.nsw.gov.au/your-environment/pesticides/pesticides-nsw-overview/pesticide-control-orders) for its use. The conditions will be explained with the purchase of the substance from an authorised control officer. In NSW, this is usually your Local Land Services office (https://www.lls.nsw.gov.au/).

Warren destruction by ripping is the main type of harbour destruction that can be very useful as a control method. Ripping techniques depend heavily on local conditions such as soil type and position of the warren as well as the equipment available. Blasting is a follow-up technique sometimes used to destroy warrens that cannot be ripped. Explosives can only be used by authorised persons.

Fumigation can be very effective for controlling rabbits as a follow-up technique to ripping. It can also be used for treating small, isolated infestations where ripping is undesirable because of the risk of erosion.

Trapping and shooting are other options but are time and labour-intensive. Support and assistance in coordinating these tasks can be obtained from your Local Land Services office (https://www.lls.nsw.gov.au/) in the first instance.

Kangaroos and wallabies

Kangaroos and wallabies belong to the family Macropodidae and can damage young plants.

Control

Kangaroos and wallabies are protected under all state and territory laws. To kill, buy, sell or possess kangaroos is an offence. Landholders need a licence from their state authority to shoot kangaroos and wallabies on their property.

Shooting: participating shooters must read the *Volunteer non-commercial kangaroo shooters best practice guide* (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/826988/Volunteer-Non-Commercial-Kangaroo-Shooters-Best-Practice-Guide.pdf) and comply with the principles for the humane and ethical shooting of kangaroo species.

Fencing: several fence designs have been developed to control or exclude kangaroos and wallabies. The configuration of the fence will depend on the species to be excluded. Suggested fencing or larger species includes an electrified 7-line plain wire fence.

Research in Tasmania has shown that wallabies will test out electrified fences and if the fence is switched off for 4–5 days, they will re-establish a route through the fence. Electric fencing should be checked regularly for faults, or have a device attached to the fence that signals any faults. In some orchards, ring lock or hinge joint fencing has been used with and without electrified offsets and with varying results.

Total wildlife exclusion fencing designs that use a combination of offset wires, galvanised standard rabbit netting, and hotwires are available, but can be 10 times the cost of normal rural fencing to install. As with rabbits and hares, fencing might be cost-prohibitive compared with the amount of damage they cause.

Mice and rats

The house mouse (*Mus musculus domesticus*), the black rat (*Rattus rattus*) and the brown rat (*Rattus norvegicus*) are largely a problem in processing and storage sheds where in-shell and processed kernel is stored. Processing equipment and conveyors can be contaminated, causing product loss and food safety concerns.

Control

Control options can be physical, ultrasonic or chemical. Physical rodent control includes using mesh guards on trees, keeping trees well-managed, vermin-proofing facilities, grazing or mowing between rows and surrounds, keeping rubbish around farm buildings to a minimum, trapping and using deterrents.

Trapping will have little effect on large plagues and is labour-intensive. While there have been many ultrasonic devices promoted to either repel or reduce the number of mice in buildings, these devices have no scientific validity and are not recommended.

Most chemical control uses 2 anticoagulants: indandiones and hydroxycoumarins. If baiting is used, caution should be taken if vacuum harvest equipment is used to collect nuts from the orchard floor. Strict safety procedures have been developed to avoid any hazards while handling bait. Do not use poisons that are not registered for rodent control as they are ineffective and have the potential to cause major ecological disasters. For details on registered products available for controlling rodents, check the APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris).

Further information on controlling rodents is available on the NSW DPIRD website (https://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/mice/mouse-management).

Deer

Six deer species have established wild populations in NSW. Five of these species are widespread: fallow (*Dama dama*), red (*Cervus elaphus*), sambar (*Cervus unicolor*), chital (*Axis axis*) and rusa (*Cervus timorensis*) deer. In 2020, feral deer species were recorded across 180,443 square kilometres, or 22 per cent, of NSW. This was a significant increase in the feral deer distribution of 138,000 square kilometres recorded in 2016.

Feral deer can damage plant seedlings by browsing and grazing, vegetation by trampling and antler rubbing, water quality by wallowing and faecal contamination and transporting weed seeds.

Control

Feral deer are difficult to exclude from agricultural areas and sensitive environmental areas as the cost of deer-proof fencing is very expensive.

The new Game and Feral Animal Control Regulation, effective 1 September 2022, is the main legislation supporting the implementation of the *Game and Feral Animal Control Act* 2002 (the Act). The Act provides for the effective management of introduced species of game animals and promotes responsible and orderly hunting of those game animals on public and private land and certain pest animals on public land.

Copies of the Act and the Regulation are available through the NSW Legislation website (https://www.legislation.nsw.gov.au/). Read the updated Rules and regulations page (https://www.dpi.nsw.gov.au/hunting/rules-and-regulations) for details.

Individuals seeking to target deer on private land must have:

- permission to hunt from the landholder or manager
- a current firearms licence (where firearms are used)
- comply with regulations around how deer are hunted.

Deer on private land are managed in the same way that rabbits, foxes, pigs and goats are controlled. Landholders may give permission to individuals holding a firearms licence and an appropriate combination of firearm and ammunition, or skilled bow hunters using an appropriate bow and arrow, to target deer on their private property.

For more information on controlling deer, see the Managing feral deer in NSW webpage (https://www.dpi.nsw.gov.au/hunting/game-and-pests/managing-feral-deer-in-nsw).

Summary

The size of all control programs should be directly linked to the damage caused and not the number of species sighted. Understanding the breeding cycle, behavioural and dispersal activities of the species are important for efficacy and timing of control options. The most effective control programs usually involve a combined approach by all land managers. Co-ordinated groups of land managers have a greater degree of success when they combine their individual efforts. Native species including kangaroos, wallabies, wombats, possums, goannas and native birds like brush turkeys, ducks and emus, are all protected and must not be hunted with bows.

Insect pests

Hazelnuts can be prone to insect attack, and growers should regularly check their plantings for the most commonly occurring insects. Sucking and chewing pests all require monitoring.

Sucking pests

- Big bud mite (*Phytoptus avellanae*)
- Hazelnut mite (*Tetranycopsis horridus*)
- Aphids
  - Hazel aphid or black aphid (*Myzocallis coryli*)
  - Green peach aphid (*Myzus persicae*)
- Scales
  - Plum scale (*Parthenolecanium corni*)
- Mealybugs (Family: Pseudococcidae)

Chewing pests

- Brown or black weevils (*Aades cultratus*)
- White fringed weevil (*Naupactus xanthographus*)
- Loopers (*Ectropis* spp.)
- Noctuid moths
  - *Colocasia coryli*
  - *Helicoverpa* spp.
- Faggot case moth (*Clania ignobilis*)
- Painted apple moth (*Teia anartoides*)
- Fruit tree borer (*Maroga melanostigma*)
- European earwig (*Forficula auricularia*)
- Wingless grasshopper (*Phaulacridium vittatum*)

Big bud mite (*Phytoptus avellanae*)

Big bud mite, also known as filbert bud mite or hazelnut gall mite, is a significant pest in most major hazelnut-producing regions worldwide, including Australia. These mites live inside buds, where they are protected from harsh winter conditions. However, they become vulnerable to desiccation in warm, dry air when they begin migrating to new leaf buds in spring.

Figure 79. Hazelnut buds infested with bud mites are usually enlarged. Photo: Filotas (2021).

Infestations typically become noticeable in late summer to early autumn, with damage characterised by enlarged terminal buds (Figure 79) that swell up to 10 mm in diameter and become deformed. These buds are prone to desiccation and might fall prematurely, potentially reducing yield if the affected buds are female.

Some hazelnut cultivars are more susceptible to big bud mite infestation:

- **Loose-bud cultivars**, such as Royal and Daviana, are particularly sensitive.
- **Highly susceptible cultivars** include Butler, Ennis, Negret, and Tonda Gentile delle Langhe.
- **Resistant cultivars** include Barcelona, Tonda Romana, Riccia di Talanico, and Halls Giant.
- **Moderate resistance** is found in Lewis, while Casina shows an intermediate level of tolerance.

In Australia, no chemicals are currently registered for controlling big bud mites. However, studies from Europe have shown that a single application of sulfur 80% wettable powder (400 g/100 L) applied just before the peak mite migration from old buds to new buds in late winter to early spring can effectively reduce mite populations. Monitoring leaf-out dates, which typically occur in late winter to early spring, is crucial for timing the application. For instance, early varieties such as Tonda di Giffoni might leaf out as early as late August, while Halls Giant might leaf out in late September.

As a non-chemical alternative, growers can manually remove and burn swollen buds during autumn and winter before mites emerge in spring. Additionally, naturally occurring predators, such as phytoseiid mites, might also aid in controlling big bud mite populations.

Hazelnut mite (*Tetranycopsis horridus*)

Hazelnut mite was identified for the first time in Australia in January 2016. The mites were discovered on established hazelnut trees in Victoria's north-east and have since been identified on several commercial and non-commercial properties extending to the Dandenong Ranges. Surveillance carried out in NSW in February 2016 confirmed the presence of hazelnut mite in NSW.

Although these are the first detections of hazelnut mite in Australia, their widespread distribution and the lack of visual symptoms in some infestations suggest that they might have been in Australia for some time.

To the naked eye, adult hazelnut mites appear as tiny moving dots. They are less than 0.5 mm long. Adults have 8 legs, an oval body and are brownish–black. The body is covered in fine spines or hairs, giving the mite a 'spiky' appearance (Figure 80). Hazelnut mites are found mostly on the underside of host leaves but will move to the upper surface when population densities increase in summer. As mite numbers increase, detection becomes easier.

Light infestations of hazelnut mite do not show obvious symptoms in host plants. An uncontrolled infestation can cause whole leaves to appear burnt and eventually die (Figure 81). Hazelnut mites attack host leaves, both young and mature, by puncturing plant cells and feeding on the contents. The feeding causes white or yellowish spots on the upper leaf surface, reducing the plant's ability to provide energy for developing nuts.

Mites can spread over long distances via clothing and infested plant material or equipment. Mites tend to be associated with plant leaves but can spread to nuts when leaves become overcrowded.

Chemical control is one of the methods available for plant pests as part of an IPM program. For information on currently registered and or permitted chemicals, check the APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris).

Figure 80. Hazelnut mite.

Figure 81. Hazelnut mite damage on hazelnut leaves. Photo: Department of Economic Development, Jobs, Transport and Resources (DEDJTR), Victoria.

Aphids

Aphids can be significant pests in hazelnuts, attacking leaves and shoots, reducing crop potential and causing fruit quality issues. Aphid infestation can cause leaf and shoot tip distortion. Aphids feed on sap from the leaves, causing them to turn yellow and drop prematurely. Additionally, heavy infestations produce honeydew, which can lead to the development of sooty mould.

Hazel aphid or black aphid (*Myzocallis coryli*)

Hazel aphid is a common pest in Australian hazelnut plantings and should be controlled when populations are high. In spring and early summer, aphids feed on the leaves (Figure 82), causing them to become yellow and drop. In heavy infestations, honeydew is produced, aiding sooty mould development. Nuts can be stained and nut size and fill ratios can be affected. In mid-summer, aphid numbers decline due to high temperatures. In autumn, aphids produce eggs, which are deposited in cracks and around bud scales.

Green peach aphid (*Myzus persicae*)

The green peach aphid (GPA) is not typically a major pest of hazelnuts, but it can occasionally cause problems. Green peach aphid nymphs are pale yellowish-green and have 3 dark lines on the back of the abdomen. Mature aphids are pale green or pinkish and about 2 mm long (Figure 83). GPA is a particular concern because of its role in transmitting plant viruses.

To manage aphids, avoid excessive amounts of nitrogen fertilisers as these promote soft plant tissue growth that is favoured by aphids. Prune out water shoots and control weeds around the orchard as these can act as a reservoir for migrating aphids. In cooler regions, GPA can overwinter as eggs around the buds.

There are several natural biological predators of the aphids including lacewings and lady beetles. The activity and efficiency of biological control agents are affected by the use of insecticides toxic to aphids. To maximise the effect of beneficial insects, avoid using broad-spectrum insecticides, particularly in spring and summer. Oil sprays at bud swell are effective at smothering eggs. A registered aphicide can also be used to control aphids.

Figure 82. Aphids on the underside of a leaf.

Figure 83. Wingless adult female and nymph green peach aphids.

Scales

Scales are closely related to aphids, mealybugs and whiteflies, which all have piercing-sucking mouthparts. Large infestations can kill twigs, retard growth and produce honeydew. Overwintering occurs as immature scales or as fertilised females on twigs and branches. The immature scales resume feeding in spring and newly mature female scales lay their eggs underneath the scale cover. These eggs hatch in early summer and crawlers migrate to the undersides of leaves to feed.

Figure 84. Overwintering plum scales.

Sooty mould development on the honeydew can give the tree a blackened, sticky appearance. Nuts and husks can be occasionally stained. Although the mould is not feeding on the plant, it can restrict light from reaching the leaves.

Lacewings are aggressive predators of scales and can help with biological control.

Chemical control should be timed to target the overwintering scales using oil sprays while the trees are dormant in late August. Ornamental trees and neglected fruit trees can be alternative hosts, and infested trees should be treated. Infested branches should be removed and burned before crawlers emerge.

Plum scale (*Parthenolecanium corni*), also known as lecanium scale

Plum scale (Figure 84 to Figure 86) has been found in hazelnut orchards in Victoria, Tasmania and the Central West of NSW.

Figure 85. Plum scales on a hazelnut twig. Photo: DKB Cheung, DKB Digital Designs.

Figure 86. Lecanium scale immature crawlers. Photo: Filotas (2021).

Mealybugs

Corylus species are susceptible to mealybugs, which belong to Coccoidea, the same family as scales (Family: Pseudococcidae). Mealybugs can be an occasional problem, with damage most likely to be significant in the nursery stool bed environment and where apple orchards are planted close by.

Mealybugs are small (<6 mm long) and covered in a woolly substance. The bodies are oval and can be white to off-pink, with waxy filaments around the body (Figure 87). When the long-tailed mealybugs are squashed, their body fluid is usually pinkish.

Mealybugs excrete honeydew, which is a medium for sooty mould growth. Trees infected with mealybug tend to develop a coating of black, soot-like fungus on the surfaces of branches and leaves, which inhibits photosynthesis. Ants are also commonly associated with mealybugs.

Figure 87. Long-tailed mealybug (*Pseudococcus longispinus*) adult. Photo: David Cappaert, Bugwood.org.

Mealybugs have been known to attack the roots just below the level of the soil, especially where the root meets the stem.

Mealybugs are preyed upon by many natural predators including lady beetles and lacewings.

Weevils

Brown or black weevils (*Aades cultratus*)

Weevils, particularly those associated with woody plants, often feed on various parts, including wood, cambium, roots, leaves, seeds, fruits, flowers, and terminal shoots. They can cause significant damage, and usually take advantage of decreased plant resistance.

This weevil is a member of the Curculionidae family and was recorded in hazelnuts in Victoria in 2005. Damage resulted in the death of hazelnut trees older than 2 years. The larvae are about 6 mm long, plump and have a brown head (Figure 88). Damage is caused by a boring action into the cambium and then ringbarking the tree. Adults are characterised by an elongated head and mouth, which they use to chew holes in plants for food and to make egg chambers.

Figure 88. *Aades cultratus* larvae.

White-fringed weevil (*Naupactus leucoloma*)

The white-fringed weevil feeds on a wide range of plant species, including grape, peach and willow. Significant damage to hazelnuts in Australia has occurred in the Braidwood region of NSW, and the pest is widespread in Victoria and Western Australia.

Adults (Figure 89) feed on the leaves but it is the damage caused by larva feeding that causes most concern. Larva pupates in the soil (Figure 90) in early summer and adults emerge later in summer. Larvae feed on roots, causing plants to show signs of stress, become yellow and stunted. With newly planted nursery whips, fibrous roots are attacked and the main root can be severed.

Ants and wireworms feed on this pest, while birds feed on adult beetles. Poultry (around 50 birds per hectare) can be used to reduce weevil numbers.

Chemicals, if necessary, should be confined to trunk sprays and to the soil immediately around the trunk. Pesticide registration for use on hazelnut plantings is limited and chemicals should be used as a last option.

Figure 89. White-fringed weevil adult. Photo: Natasha Wright, Braman Termite and Pest Elimination, Bugwood.org.

Figure 90. White-fringed weevil larva. Photo: JC French Sr, Auburn GA, Bugwood.org.

Loopers (*Ectropis* spp.)

Loopers belong to the Geometridae family, which is characterised by their looping caterpillar movement, hence the name 'looper'. These moths are covered in scales, which is a characteristic of moths in general.

Ectropis spp. have been reported in Australia, with notable cases such as those in the Mudgee district (NSW), where the caterpillars have been observed feeding on developing catkins (Figure 91). The caterpillars are typically green or brown, slender, and hairless, providing effective camouflage. Adult moths also blend in by pressing against the plant surface with outspread wings. Eggs are usually laid on or near the caterpillar's food plant, either singly or in clusters (Figure 92).

Caterpillars feed on a wide host range that includes walnuts, eucalypts and acacias. Despite their wide host range, damage from loopers in Australia has so far been of limited economic significance.

Figure 91. Looper adult moth.

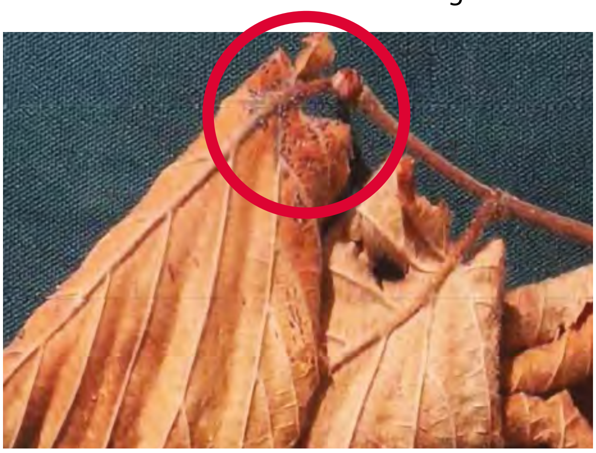

Figure 92. Lepidopteran eggs on hazelnut leaves.

Noctuid moths

Noctuid moths, also known as owlet moths, belong to the Noctuidae family, which is one of the largest families of moths in the world, with around 25,000 species. This family includes economically important pests like cutworms and armyworms. Some caterpillars within this family are called semi-loopers due to their distinctive movement. The moths have scales covering their wings and can usually be distinguished from butterflies by their antennae, which are typically threadlike or feathery (Figure 93). Their caterpillars are distinctive, smooth, have very few hairs and are voracious feeders (Figure 94). They are often found near the soil surface but can climb trees and feed on leaves (Figure 95).

Figure 93. Noctuid moth adult. Photo: Gyorgy Csoka, Hungary Forest Research Institute, Bugwood.org.

Noctuid moths in hazelnuts in Australia include:

Colocasia coryli is commonly known as hazel looper. The caterpillars feed on hazelnut leaves and can cause notable damage. The caterpillars are smooth and have few hairs and are found near the soil surface but can climb trees to feed on foliage.

Helicoverpa spp. (formerly known as *Heliothis*) are also part of this family and are known to feed on hazelnuts and other deciduous fruit trees. The larvae also infest a range of plants, including clovers, medics, and various weeds.

Figure 94. Noctuid moth larva that has emerged from the nut.

Figure 95. *Helicoverpa* spp. larva. Photo: David Williams, Agriculture Victoria.

Faggot case moth (*Clania ignobilis*)

Case moth is a common name given to caterpillars that make coverings of silk and woody debris (sticks) for protection (Figure 96). Different case moths attack different plants, feeding on and usually damaging leaves. The faggot case moth makes cases approximately 40 mm long, with some sticks extending significantly longer than others.

The caterpillars are highly mobile and can move readily between trees. Each species makes cases in different shapes. The case has 2 openings, one at the top and the other at the bottom. The caterpillar comes out from the top to feed and ejects waste from the other end.

Control is generally not required, however, hazelnuts in the Canberra region have suffered from heavy infestations in the past.

Figure 96. Faggot case moth stick-like cases conceal the caterpillar.

Painted apple moth (*Teia anartoides*)

The painted apple moth (Figure 97) is an Australian native insect (family: Erebidae) that has been recorded on hazelnuts in NSW in low populations. Its host range includes apple, stone fruit, pine, acacia and various ornamentals. Caterpillars (Figure 98 and Figure 99) make small, window-pane like injuries on the leaf surface and later skeletonise the leaf. There are normally several generations each year, and in most orchards, it is usual for only a few trees to be infested. Damage has not been observed on developing nuts or husks.

Painted apple moth is not established in Western Australia, where a surveillance program is maintained for this species.

Figure 97. Painted apple moth adult male. Photo: Pest and Diseases Image Library, Bugwood.org.

Figure 98. Painted apple moth damage. Photo: Lesley Ingram, Bugwood.org.

Figure 99. Painted apple moth larva. Photo: Pest and Diseases Image Library, Bugwood.org.

Fruit tree borer (*Maroga melanostigma* syn *Cryptophasa melanostigma*)

The fruit tree borer (*Maroga melanostigma*, Figure 100) can cause severe damage to hazelnuts by ringbarking the tree, weakening laterals and boring tunnels into the wood (Figure 101 and Figure 102). Infestation is usually in the fork of the tree and is evidenced by a fine, sawdust-like frass (the debris or excrement of insects or insect larvae) on the surface (Figure 103).

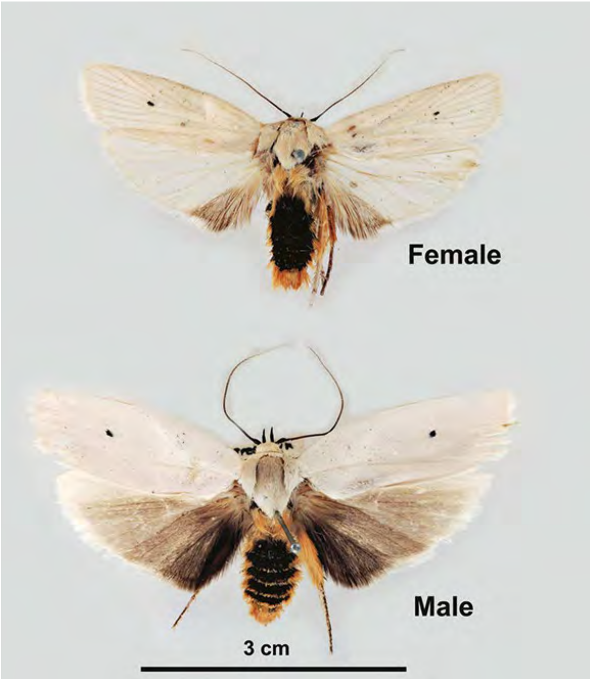

Figure 100. Fruit-tree borer. Photo: Pest and Diseases Image Library, Bugwood.org.


Figure 101. Fruit tree borer. Photo: Ranford (2016).


Figure 102. Evidence of borer in a tree trunk.


Figure 103. Fruit tree borer damage to hazelnut stems.

Control measures are limited to scraping away the frass and flooding the entrance holes with a registered insecticide or infiltrating the borer hole with a thin piece of wire and piercing the larva. Any black wattle thickets in the immediate vicinity should be removed as they can harbour borers.

Chemical control to prevent egg-laying and damage from the new generation of insects might be an option. However, it can be difficult because the borer is only exposed to the insecticide when it hatches from the egg and before it bores into the tree. External trees in an orchard tend to be affected first. Where infestation is high, entry points have been observed where larger pruning cuts have been made.

European earwig (*Forficula auricularia*)

The European earwig is an occasional inhabitant of hazelnut orchards (Figure 104). Earwigs are brown elongated insects with distinctive pincers at the end of their abdomen (Figure 105). They are nocturnal and nest during the day in cool, shady places. Overwintering occurs in underground nesting chambers. Adults can migrate onto young suckers in spring and feed on foliage. The chewing mouth parts can be a problem in nursery stool beds where growth is young and succulent. Earwigs can be associated with nuts that are discoloured and damp around the basal scar. Generally they are considered a nuisance value only rather than a serious threat. Tree guards can also become a nesting site for earwigs, and if they are not needed, it's advisable to remove them. Aside from being nuisance pests, they primarily prefer live prey such as aphids and are also known to feed on European red mites and certain scale insects.

Figure 104. European earwig in a hazelnut in Orange, NSW.

Figure 105. Adult European earwigs, male on the left and female on the right.

Wingless grasshopper (*Phaulacridium vittatum*)

The wingless grasshopper is a native insect that feeds on a great variety of plant material. They are widely distributed in pastures in eastern and southern Australia and appear in orchards from December to February. Their distribution is related to rainfall. In dry summers, these pests move into orchards only when other sources of herbage and broad-leafed plants become limited. In hazelnut orchards, damage usually occurs to the leaves (Figure 106) on the lower branches. In severe infestations, trees can be defoliated, with young trees the most likely to be affected. No damage has been noted to nut husks or developing nuts.

Wingless grasshoppers lay eggs in open, dry, bare patches of soil. Egg beds can be destroyed if located early in the season, which will assist in controlling emerging grasshoppers in September and November.

Baiting, spot spraying and strip spraying orchard perimeters can help control pest numbers. Effectiveness is increased if the grasshoppers have not yet entered the orchard. Where pesticides are not used, poultry in the orchard might be a control option.

Figure 106. Wingless grasshoppers feeding on hazelnut leaves. Photo: D Campbell.

Exotic pests

Any unusual plant pest or disease should be reported immediately to the relevant state or territory agriculture agency through the **Exotic Plant Pest Hotline on 1800 084 881**. Early reporting increases the chance of effective control and eradication.

More information on reporting unusual plant pests or diseases is on the Plant Health Australia website (https://www.planthealthaustralia.com.au/biosecurity/emergency-plant-pests/reporting-suspect-pests/).

If you do find an unusual plant pest or disease, put samples into a labelled small container in the freezer in case they are needed for identification.

To minimise risks, put in place biosecurity best practice actions to prevent the entry, establishment and spread of pests and diseases into the orchard by:

- Inspecting all newly purchased items including the item itself and all packaging, particularly any items purchased from overseas.
- Opening packages inside a semi-confined space (where appropriate) so if anything unusual is spotted, it can be caught and isolated and sent for identification if required.
- Practising 'Come clean, go clean' (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/724978/factsheet-your-requirements-when-visiting-a-farm.pdf).
- Treating all stored nuts for pests and regularly monitoring storage facilities.
- Reporting anything unusual to 1800 084 881.
- Keeping records and taking photos.

If you see a pest that you have not seen before, get it identified immediately.

High priority exotic pests for hazelnuts in Australia include:

Brown marmorated stink bug

The brown marmorated stink bug (*Halyomorpha halys*) is an exotic plant pest that is a serious threat to Australia's horticultural industries. It is a typical stink bug with a shield-shaped body and it emits a pungent odour when disturbed. There are several Australian native stink bugs that are similar to the brown marmorated stink bug (BMSB). However, the distinct features of adult BMSB are the white bands on the antennae, sides of the abdomen and the legs (Figure 107).

Adult BMSBs are approximately 12–17 mm long and 7–10 mm wide. They generally have a mottled brown body with alternating light and dark bands on the antennae, legs and the side margins of the abdomen.

Young nymph stages are yellowish brown and mottled with black and red. Older nymph stages are darker with the banding pattern on the legs and antennae beginning to appear. Eggs are light green, barrel shaped and found in groups of 20 to 30 (Figure 108).

Figure 107. Adult brown marmorated stink bug.

Figure 108. Brown marmorated stink bug eggs and newly hatched nymphs. Photo: Gary Bernon, USDA APHIS, Bugwood.org.

In the USA, BMSB has caused blank nuts, shrivelled kernels or 'corking' damage (Figure 109). Damage depends on the timing of feeding, with experiments showing up to 30% of nuts can be affected due to BMSB feeding (Hedstrom 2014).

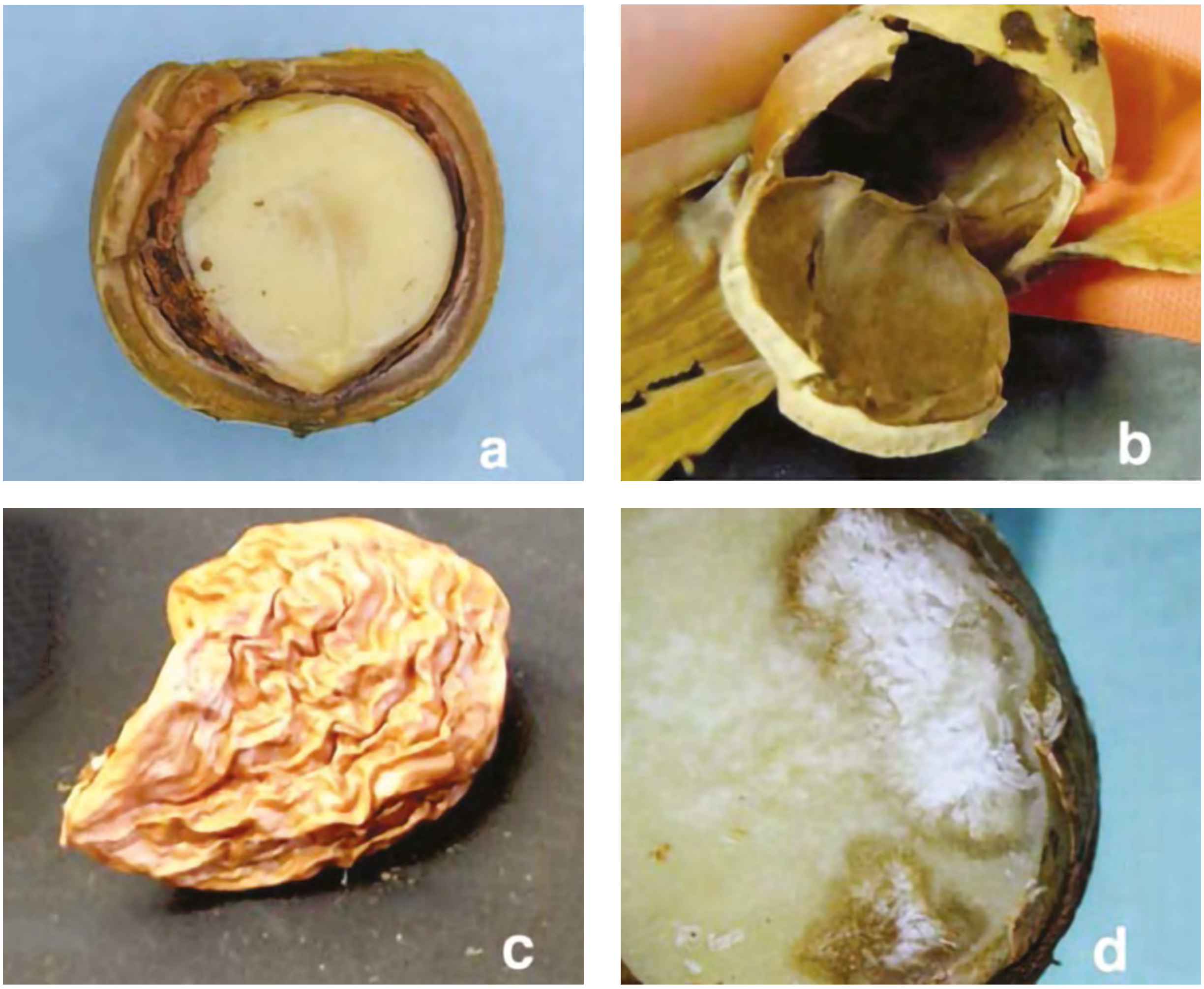

Figure 109. Brown marmorated stink bug damage; **a** healthy, **b** blank nut, **c** shrivelled kernel, **d** corking damage. Photos: Chris Hedstrom, Oregon State University.

European leaf roller, filbert leaf roller, rose leaf roller (*Archips rosana*)

The European leaf roller (Figure 110) is found in Europe and North America. Larvae are polyphagous, feeding on more than 15 plant families, including Betulaceae (hazelnut).

Adult moths are 13–20 mm long, dark brown, with darker transverse lines on the forewings. The larvae are green with a light to dark brown head. They overwinter as eggs on the bark or limbs in irregular flat masses that appear greyish by spring. Eggs hatch in spring as buds are opening until petal fall. The larvae feed for 4–6 weeks, then pupate in the rolled leaves and emerge as moths in early summer.

Damage begins early in spring and includes leaf rolling and feeding on foliage and buds. There is one generation each season.

Figure 110. Several leaf roller species feeding on the leaves. Photo: Filotas (2021).

Filbert worm (*Cydia latiferreana*)

The Filbert worm is widespread in the USA. Fruit, nuts and plant material can carry the pest. Moths (Figure 111) are weak fliers and will be limited in Australia by available hosts (no endemic *Corylus* spp. as in North America). Eggs are laid very close to nut clusters and the larvae feed inside the nuts (Figure 112). At maturity, they chew out of the nut and pupate in the soil.

Figure 111. Filbert worm adult. Photo: Larry R Barber, USDA Forest Service, Bugwood.org.

Figure 112. Filbert worm larva in a hazelnut. Photo: Todd M Gilligan and Marc E Epstein, TortAI Tortricids of Agricultural Importance, APHIS PPQ, Bugwood.org.

Green stink bug (*Chinavia hilaris* syn *C. hilare*, *Acrosternum hilare*, *Pentatoma hilaris*, *Nezara hilaris*)

The green stink bug (*Chinavia hilaris*) is from North America and feeds on a wide range of crops including grains, fruit and nuts (including hazelnut, pistachio and almonds). Feeding on hazelnuts causes kernel damage.

The adult green stink bug is 14–19 mm long, green and shield-shaped (Figure 113). The nymph's head and thorax are black and orange (Figure 114) when they first hatch, becoming green as they mature (Figure 115). Nymphs have 2 black patches in the middle of their abdomen that become more obvious as they mature. Eggs are yellow and laid in masses (Figure 116).

The green stink bug could be confused with the other green stink bugs that occur in Australia, such as the green vegetable bug (*Nezara viridula*; Figure 117), which is slightly smaller than the exotic green stink bug, the red-banded shield bug (*Piezodorus hybneri*) and the Australian green stink bug (*Plautia affinis*; Figure 118), which have different colourations to the exotic green stink bug.

Figure 113. Green stink bug (*Chinavia hilaris*) adult. Photo: Susan Ellis, Bugwood.org.

Figure 114. Green stink bug (*Chinavia hilaris*) nymph. Photo: Russ Ottens, University of Georgia, Bugwood.org.

Figure 115. Green stink bug (*Chinavia hilaris*) nymphs. Photo: Brian Little, University of Georgia, Bugwood.org.

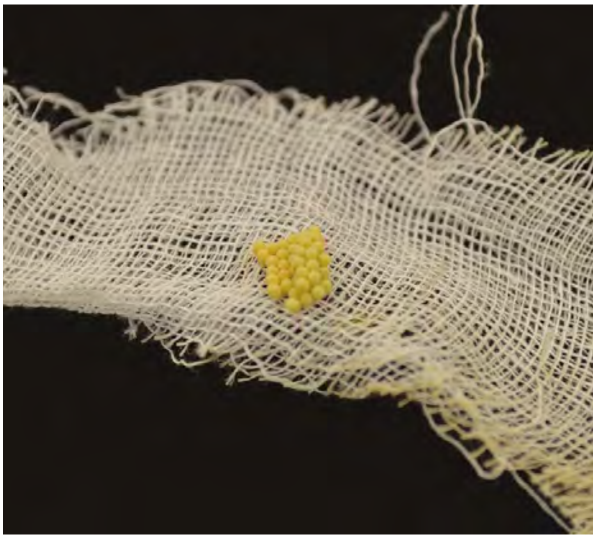

Figure 116. Green stink bug (*Chinavia hilaris*) eggs. Photo: Brian Little, University of Georgia, Bugwood.org.

Figure 117. Green vegetable bug (*Nezara viridula*) adult. Photo: Johnny N Dell, Bugwood.org.

Figure 118. Australian green stink bug (*Plautia affinis*) adult. Photo: John Eichler, iNaturalist.

Large hazelnut aphid (*Corylobium avellanae*)

The large hazelnut aphid (Figure 119) is reported in the United States and Europe. It affects shoots and twigs. They vary in colour and are only 1.7 to 2.9 mm long.

Figure 119. Large hazelnut aphid. Photo: Mihajlo Tomić, iNaturalist.

Oblique-banded leaf roller (*Choristoneura rosaceana*)

The oblique-banded leafroller (OBLR; Figure 120) is native to North America. It is part of the spring-feeding caterpillar complex (Figure 121) but has a second generation that feeds on leaves and fruit later in the summer. The OBLR can be a significant hazelnut pest.

Figure 120. Oblique-banded leaf roller adult and pupa. Photo: Ansel Oommen, Bugwood.org.

Figure 121. Oblique-banded leaf roller larva. Photo: Neil Thompson, University of Maine at Fort Kent, Bugwood.org.

Diseases

Armillaria root disease/root rot

Armillaria is a soil-inhabiting fungus that causes root rot (Figure 122). *Armillaria* species are native to forests worldwide, and most infections arise because orchards are planted on recently cleared land that contains infected native trees (especially acacia). The main species affecting hazelnuts is *Armillaria mellea*.

Figure 122. Armillaria root rot. Photo: Steve Renquest, Oregon State University.

Foliar symptoms include poor shoot growth, defoliation, branch dieback, premature yellowing and stunted leaves. The presence of white, fan-shaped mycelia (fungal strands) between the bark and the wood indicates infection. In severe cases, the wood on the tree can be stringy, and light-golden mushrooms can grow around infected trees in autumn.

Spread is via roots. Where possible, previously infected root material should be removed from the orchard and burnt. Infection is common in light sandy soil and the history of new orchards should be considered before they are planted.

Aspergillus spp.

Aspergillus is a genus of around 200 fungi found worldwide. The aflatoxin-producing species are saprophytic fungi (they use the nutrition from plant or animal debris), commonly found in areas with hot, humid climates. *Aspergillus flavus* and *Aspergillus parasiticus* can produce aflatoxins. Hazelnuts affected by these cannot be used for human consumption. Hazelnut samples from the Central Tablelands of NSW have been identified with *Aspergillus* fungi.

Postharvest handling has a major influence on hazelnut mycoflora and nuts are usually colonised by several fungi rather than by a single species. Usually, hot, humid conditions lead to mould growth on the nuts (Figure 123) and to high aflatoxin levels. Improper storage conditions can lead to aflatoxin contamination after nuts have been harvested. If a long delay is anticipated, nuts should be stored in controlled conditions to prevent aflatoxin production.

Figure 123. *Aspergillus* spp. on the surface of stored hazelnuts.

Harvesting of nuts should begin as soon as practical after maturation to minimise diseases caused by fungal attacks and insect infestation. Containers, equipment and machinery that have been used for harvesting operations should be cleaned and stored to reduce contamination with fungi, chemicals, fertilisers or toxic substances.

Processors need to establish good quality control, product traceability and safety procedures at every step in the processing sequence to avoid cross-contamination of aflatoxins between batches of nuts during processing. If contamination is suspected, the orchard floor should be cleared of litter and debris to reduce the colonisation of *Aspergillus* spp. fungi in the orchard.

Nuts should be dried as soon as possible. The drying rate and heat intensity should be determined by the intended end use of the final nut product. Decay problems are most commonly related to insufficient drying, or not collecting nuts from the ground quickly enough in damp harvest conditions.

Precautions need to be taken to reject insect-damaged or split nuts because they can be associated with a risk of aflatoxin contamination. Finished processed products, raw kernels or in-shell nuts should have the appropriate moisture content and be packaged so their quality is maintained in normal transportation and storage conditions.

Bacterial blight (syn hazelnut blight)

Hazelnut blight is one of the most debilitating diseases affecting hazelnut production in Australia. It was first recorded on hazelnuts in Australia (Victoria) in 1980. The disease is caused by *Xanthomonas arboricola* pv. *corylina*, a bacterium that affects the buds, leaves (Figure 124 and Figure 125), branches and trunk.

Figure 124. Early stage bacterial blight. Photo: BC Ministry of Agriculture, Food and Fisheries.

Figure 125. Hazelnut blight.

Hazelnut blight is most injurious to trees up to 4 years old as succulent tissue can be badly affected by lesions that girdle the shoot. Trees more than 4 years old rarely die following infection, but nut yields can be reduced through the loss of nut-bearing branches.

The first infection on current season stems appears as dark green water-soaked areas on the bark, turning to reddish brown (Figure 126). Infection occurs through wounds, blighted buds and shoots of the current season's growth. Dead leaves often cling to diseased stems for longer periods than in a normal leaf fall (Figure 127). Occasionally spotting is observed on the husks, although this is normally superficial (Figure 128).

Trees are generally more susceptible in wet seasons as the disease requires moisture to develop. Heavy dew, hail and exposure to high winds causing mechanical rubbing of leaves also favour hazelnut blight development. Sites protected from wind generally have fewer incidences of blight symptoms.

Varieties that leaf out early, which can be associated with early spring rains, are often affected by early blight strikes.

Poor environmental conditions, such as sun scald, poor soil drainage, moisture stress, cold injury, mechanical equipment damage, pruning cuts and general cultural neglect, can contribute to making trees susceptible to blight.

Control should be based on using clean planting material, reducing the risk of transmission when pruning, and using registered copper-based sprays from late summer to autumn and in early spring. Copper applications create a protective coating where spores are destroyed as they contact the treated surface. Several copper products are registered for hazelnuts. Check the APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris) for registered controls.

In seasons with heavy winter rainfall, 2 or 3 applications might be required. Using a suitable spreader/wetting agent will make these treatments last longer. Effectively containing this disease involves securing disease-free planting material, using appropriate copper-based sprays, and maintaining good sanitation in the orchard. Removing and destroying infected plant material, including dead trees, will decrease the chances of inoculum spreading.

Figure 126. Bacterial blight lesion on a stem. Photo: Ranford (2016).

Figure 127. Bacterial blight causes dieback of hazelnut leaves. Photo: L Gardan, INRA, Angers, Bugwood.org.

Figure 128. Bacterial blight on hazelnut husk. Photo: Filotas (2021).

Mosaic viruses

Hazelnut mosaic virus was first recorded in 1957 and is now widespread in Europe. In Australia, symptoms indicative of virus patterns have been observed in hazelnut variety trials. Leaf symptoms include general yellowing, yellow rings and lines (Figure 129). However, infected trees might also be symptomless.

Figure 129. Hazelnut mosaic virus symptoms. Photo: L Bosco, DISAFA, University of Torino.

Apple mosaic virus (ApMV) is commonly associated with mosaic symptoms and can cause reduced yield. In young trees, vegetative growth can be reduced. Trials in Spain indicate no reduction in nut size or quality. ApMV is worldwide in apple and birch trees and is spread largely by vegetative propagation.

Chemical control is ineffective against viruses. Avoid planting and propagating with virus-infected material, or if possible, avoid any material that has not been virus-tested. ApMV is best detected by enzyme-linked immunosorbent assay (ELISA) testing.

Powdery mildew

Powdery mildew is a minor disease in Australian hazelnut plantings. In most cases, the disease is not severe enough to warrant control. Colonies appear mid- to late-season when the weather is hot and humid. They appear as a dusty white covering (Figure 130) and eventually cover the surface of infected leaves (Figure 131) and sometimes nuts (Figure 132). The fungi are readily disseminated by wind. Some growers have observed infected hazelnut leaves when near pome and vineyard plantings. Identifying the fungus causing powdery mildew in Australia has been difficult due to the small number of samples submitted for analysis.

Preventative control includes pruning to open the canopy for maximum air movement and reduced humidity. No chemicals are specifically registered for powder mildew in hazelnuts in Australia.

Figure 130. Powdery mildew presents initially as white fuzzy patches on the leaf underside. Photo: Filotas (2021).

Microsphaera coryli syn. *Erysiphe corylicola* affects leaves. It is spread quickly within orchards but spread slowly between regions due to the distribution of host plants in the environment.

Figure 131. Powdery mildew. Photo: R Botta, DISAFA, University of Torino.

Figure 132. Powdery mildew on nuts. Photo: United States Agency for International Development (USAID).

Phytophthora root rot

Phytophthora root rot is caused by *Phytophthora cinnamomi*, a water-borne soil mould. *Phytophthora* spp. can reduce tree vigour and productivity and ultimately kill the tree. It will often appear at the bottom of slopes where water can pond, as well as on drainage lines and at the tops of slopes where soil has been eroded. Phytophthora root rot becomes more apparent when trees are suffering, such as from nutritional or moisture stress.

Affected trees will look pale green and sickly. They will lack vegetative vigour, and leaves will turn yellow and drop off. Trees can also be stunted. Trunk canker mostly occurs on the main trunk but can also spread to the limbs. It appears as cracking up the length of the trunk from the ground (Figure 133). Red resin will often ooze from these vertical cracks. Over time, the bark will become corky and deeply furrowed, when it can be easily peeled away, revealing reddish wood (Figure 134). The affected trees often have healthy suckers sprouting from the rootstock at ground level. The death from trunk canker results from the cankers girdling the trunk.

Figure 133. Phytophthora root rot. Photo: Dr Jay Pscheidt, Oregon State University.

Figure 134. Phytophthora root rot. Photo: Oregon State University Plant Clinic.

Stem canker (*Phomopsis* spp. and *Botryosphaeria* spp.)

Symptoms of *Phomopsis* include brown to dark brown cankers or lesions, sometimes with light brown margins on stems (Figure 135). *Phomopsis* reproductive structures called pycnidia that look like dark spots on trunks have also been reported. Occasionally, the tree tissue decays under cankers, resulting in sunken lesions with cracked margins. Enlarged cankers cause dieback, defoliation of infected branches and reduced tree vigour.

Figure 135. Phomopsis stem canker on Jefferson hazelnut. Photo: Oregon State University Plant Clinic.

Exotic diseases

High priority exotic diseases for hazelnuts in Australia include:

Eastern filbert blight (*Anisogramma anomala*)

Eastern filbert blight is a destructive fungal disease of European hazelnut and is known to occur in North America. The disease was initially noted in Washington State and then spread to the Willamette Valley in Oregon. The fungus has a life cycle of 2 years and a 15-month latent period when no symptoms are visible. It is spread by wind-driven rain and splashing droplets onto shoots, usually in cooler weather. Trees become susceptible during leaf out and initial shoot elongation. The disease is often not identified for some years following initial infection.

Although not present in Australia, growers should be aware of symptoms and observe their orchards in spring. The pathogen typically develops under the bark of diseased branches (Figure 136), causing potentially fatal cankers (Figure 137) on the trunk and branches. Wilting and dead leaves attached to a branch in summer can also be symptomatic (Figure 138).

Figure 136. A twig infected with Eastern filbert blight showing white fungal spores. Photo: Plant Health Australia.

Cultivars differ in their susceptibility and growers might wish to consider this when establishing new plantings. Daviana and Ennis are highly susceptible, whereas Barcelona, Butler and Halls Giant have intermediate susceptibility.

Control strategies include using resistant varieties, applying fungicides in spring and pruning infected branches.

Figure 137. Eastern filbert blight cankers. Photo: C Bakker, University of Guelph.

Figure 138. Leaves infected with Eastern filbert blight. Photo: Filotas (2021).

Sudden oak death (*Phytophthora ramorum*)

Sudden oak death is an exotic plant disease that is a serious threat to Australia's forestry, nut and nursery industries.

The sudden oak death pathogen is known to infect over 130 plant species and hazelnut is reported to be susceptible (Moralejo et al. 2009). Symptoms vary depending on the plant species affected, but *Phytophthora ramorum* differs from most other *Phytophthora* species by affecting aerial parts of the plants e.g. stems, branches, shoots and leaves, rather than the roots.

There are 3 common disease symptoms caused by *P. ramorum*. Infected plants can display one or more of these:

- stem or trunk canker
- leaf blight
- twig dieback

Shrubs typically show symptoms of blackened shoots and dark brown blotching of leaves (Figure 139). Starting at the leaf tip, the brown lesions spread to cover the entire leaf.

Trees often develop stem cankers in branches and on the lower portion of the trunk. Red to black thick sap oozes from the bark surface with the sunken, discoloured cankers observed beneath (Figure 140).

Branches can die rapidly when expanding cankers restrict the movement of water and nutrients.

Figure 139. Sudden oak death symptoms on rhododendron leaves. Photo: Joseph O' Brien, USDA Forest Service, Bugwood.org.

Figure 140. Sudden oak death symptoms showing bark discolouration and bleeding canker on an oak trunk. Photo: Bruce Moltzan, USDA Forest Service, Bugwood.org.

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Harvesting and postharvest

Harvesting

Hazelnuts mature and drop to the ground in late February to early March, with most usually falling by the end of March. Mature nuts should be brown and ideally free from the husk. Production costs are greatly affected by the harvesting technique. Mechanised harvesting relies on the area under the trees being free from weeds, reasonably level and firm. Many harvesting machines include husk removal as part of the cleaning process. Some varieties fall with the husk intact (e.g. TBC) and require some form of mechanical action to remove the husk.

In dry conditions, the nuts can remain on the ground without much deterioration, but moist conditions and rainfall mean the nuts need to be collected as soon as possible. Rain can cause the nuts to discolour and darken, becoming less attractive and prone to fungal attack (Figure 141 and Figure 142). This is undesirable, especially if the nuts are to be sold in-shell.

Figure 141. Mould on shells of nuts that were wet at harvest. Photo: Dr Jay Pscheidt, Oregon State University.

Figure 142. Mould on kernels can persist even after blanching. Photo: Dr Jay Pscheidt, Oregon State University.

Removing blank nuts or nuts with shrivelled kernels is essential to maintain quality but identifying blank nuts can be difficult. With small quantities, nuts can be placed in water and the blanks floated off. With some varieties, blanks will fall a week ahead of the remaining crop and can, therefore, be harvested separately (Figure 143).

Figure 143. A small-scale net harvest test. Photo: Filotas (2021).

Orchard floor preparation

Mature orchards require suitable preparation for a trouble-free mechanised harvest and this preparation starts through summer. Any debris, including pruned suckers and nuts from last season, needs to be flail-mowed or removed. This pre-harvest preparation reduces the chances of any of the previous year's nuts being harvested and should prevent blockages in machines.

After the ground is prepared, the hazelnuts are either raked manually or mechanically into windrows. Portable blowing machines or shoulder fans can be used to blow nuts out from under the trees. In this case, some slight soil moisture can help reduce the amount of dust.

Harvesters

Innovation in machinery has led to increased efficiencies in harvesting units. When orchards are young or small, it might not be economical to commit the capital required for mechanical harvesters. For medium to large-scale commercial operations, mechanical harvesting is essential.

Harvesting machine design has not only improved operating times and costs, but also the operator's health and safety by reducing dust and noise.

Harvesters can be classified into 3 types:

- towed vacuum harvesters with aspirating tubes (Figure 144)
- towed or tractor-mounted harvesters with automatic pick-up systems
- self-propelled harvesters (aspirating or pickup) (Figure 145).

Vacuum harvesters are usually equipped with one or 2 aspirating hoses (Figure 146); the operators walk along and pass the tubes over the windrowed nuts. Recent developments have the tubes fitted to a side-mounted head (Figure 147); this reduces the number of operators required. Towed vacuum harvester rates with or without side pickers can harvest an area between 0.2 to 0.4 ha/h. After harvest, nuts can be deposited from the harvester into a trailer or towed bin.

Figure 144. A smaller vacuum unit can be towed with a quad bike.

Figure 145. A compact harvester picking up ripe hazelnuts from under trees. Photo: Filotas (2021).

Figure 146. Vacuuming a crop in the early years.

Figure 147. A vacuum harvester fitted with a side-mounted head.

The following points should be considered to ensure optimum quality:

- Picking up nuts as often as possible will maximise quality. Up to 3 passes might be necessary. Kernel quality and shelf life will deteriorate the longer the nuts are left on the ground.
- Maintain and adjust harvest equipment to avoid cracking the shells during harvest.
- If practical, keep nuts from each harvest round separate. This will be helpful if later harvests have quality problems such as wet weather or machinery breakdown.
- Keep harvest boxes clean to avoid contamination.

Postharvest

Following collection, the nuts should be cleaned and dried to approximately 8–10% moisture (see Appendix B on page 125). Depending on how the nuts have been collected (by hand, mechanical sweeper or vacuum sucker), loose grass, dirt and dust need to be removed. To help with this, storage bins with grated bottoms can be used. These types of bins also have the advantage of allowing air to circulate between the nuts, allowing some initial drying to occur, especially if the nuts have been collected wet or damp after rain. Any husks not already removed from the nut by the harvester will need to be removed at this stage. Some varieties (e.g. TBC) maintain their husks to a greater degree. Ideally, husks should be promptly removed as nuts left in the husk can generate respiratory heat, which can cause an increase in mould and rancidity.

Drying

The degree of drying required depends on the end-use of the nut and the anticipated length of storage. For example, some on-sellers in the shell trade sell very quickly and prefer nuts that are not dried or are only partly dried. However, this is more the exception than the rule.

For many confectionery companies, 6% moisture is the maximum required. If drying is not completed correctly, the kernel will go rancid and/or mouldy very quickly and will not be suitable for longer storage. Drying can be done either on open racks or by heat fan-forced into a large silo. Appendix A on page 123 provides information on drying.

Small enterprises will often air-dry their nuts in drying racks and, given the general climatic conditions prevailing during the Australian harvest, this might take up to 3 months. The racks should ensure airflow around the nuts and should be in a well-ventilated, warm (Figure 148), vermin-proof shed.

Figure 148. Purpose-built racks for drying hazelnuts.

Larger enterprises use fan-forced drying silos, which have the advantage of allowing the crop to be processed more quickly. A benefit of this is that producers can sell the crop into markets directly after harvest in March and April. Most driers operate with fans blowing air up through the nuts in a silo. Temperatures between 32 °C and 38 °C are commonly used for drying. Equipment for other purposes, such as prune driers or small dehydrators, can also be adapted to dry the nuts. A 2 m diameter silo with a 7.8 cubic metre capacity will hold about 4.7 t of nuts.

After drying, the nuts are graded for size, bagged and sold. Conveyors between the drying operation and nut grader can be used as an inspection table to remove blanks, marked and disfigured nuts and any rubbish not previously removed.

Figure 149. Nuts can be packaged into woven poly mesh bags for ease of handling.

Once dried, the nuts can be stored in onion bags (Figure 149) or other types of bags (excluding plastic bags). The nuts can be stored for extended periods, provided that temperature extremes are avoided.

Careful marking is required to ensure a record of nut type and size on each bag. Larger enterprises will use silos to store nuts.

Postharvest handling

The following points should be noted with postharvest handling:

Shed and equipment

- Maintain the processing shed in an orderly, sanitary condition. Frequently remove and dispose of any waste, including rejected nuts. Monitor and control insects, birds, rodents and other animals entering the shed. Covered bait stations should be used and located so there is no chance of nuts becoming contaminated. If moth larvae are a problem in storage areas, pheromone traps can be used to reduce populations.
- Ensure no contamination by broken glass and use covered light fittings.
- Keep daily records of nuts processed and their source. These records should provide the ability to track the product from the consumer back to the farm.
- Maintain sorting equipment in a sound, clean condition. Sufficient guarding and lighting are required for efficiency and safety.
- Avoid high humidity through the processing chain; humidity is conducive to mould and aflatoxin development. The optimum temperature for mould development ranges from about 37 °C to 42 °C.
- Monitor rejected nuts during sorting by cracking a sample and recording the reasons for rejection. Nuts are best sorted when dry, at which time defective nuts are easily identified.

Drying, storing and sizing

- Monitor moisture content at harvest and then at least weekly during drying, or daily if using heated air.
- Try to avoid using temperatures >5 °C above ambient air temperature as this can cause internal browning and discolouration of the kernel during drying.
- Maintain good air circulation during storage once the desired level of moisture is achieved.

If growers intend to store nuts, they need to ensure that there is enough storage to hold at least 50% of the crop. This will become an issue as more mature plantings start to bear. Be aware that some processors crack to order and might not have large storage capacities. Following appropriate drying, hazelnuts can be stored for up to 2 years, but growers must be aware that the shelf life of the processed product will be affected by the kernel's storage length.

Nuts are normally graded in a rotating cylindrical size grader (Figure 150) with various sized holes (Table 14) for the nuts to fall through.

Kernels should also be:

- well dried and clean
- free from foreign material, mould, rancidity, decay and insect damage
- free from damage caused by chafing or scraping, deformity and internal flesh discolouration
- free from serious damage caused by shrivelling and broken kernels.

A full description of standards for Australian hazelnuts in-shell is included in Appendix B on page 125.

Figure 150. Grading hazelnuts for size. Photo: Vanessa Cox, Hazelnut Growers of Australia.

Table 14. Nut size standards for Australian hazelnuts in-shell.

Class	Size (mm)
Small	≤13.0
Medium	>13.0 to ≤18.0
Large	>18.0 to ≤19.5
Very large	>19.5 to ≤22.0
Giant	>22.0

Source: Hazelnut Growers of Australia Inc (https://www.hazelnutgrowersaustralia.org.au/).

Cracking

Many growers wish to value-add and many crack their own nuts (Figure 151). There is a range of cracking machines: they use either drum/roller or disc crackers. These are normally combined with air to separate the shell from the kernel.

Growers should be aware of their potential liability to the consuming public if nuts of an unacceptable standard are supplied. Processing facilities should comply with relevant health regulations, which might vary from state to state.

Figure 151. An on-farm nut cracking and processing facility. Photo: Filotas (2021).

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Marketing hazelnuts

Hazelnuts are purchased worldwide both in-shell, as kernels, as a major ingredient in baking and cooking and in processed foods such as confectionery, desserts, cakes and snack foods. Hazelnuts can also be used in oil production (research continues to show that nut oils are heart-friendly and help lower levels of 'bad' cholesterol) and can be included as a component in cosmetics. Shells are used in landscaping as pathway surfaces; they are slow to decompose and burn slowly.

Australian production is largely from individual growers with orchards smaller than 5 ha. These growers sell small quantities locally and are able to gain premium prices in niche markets or by direct selling. Larger processors are interested in dealing in large quantities only, such as the standard 20 t container load, although there is some 'spot' buying by wholesalers.

Producers have to meet international quality standards and be competitive with price. They must identify their markets and discuss the specific requirements with buyers or processors.

To enter the processing market and to supply larger processors, producers first have to be able to produce nuts in the volume and varieties that processors want. Most users of kernels have their own product specifications, which commonly include size, shape, appearance, and quality standards, and importantly, blanching characteristics.

Australia is a net importer of hazelnuts, with most imports being in kernel form (Hort Innovation 2021). Turkey is the dominant world trader in hazelnuts, but a long-term opportunity exists to expand Australian hazelnut plantings to take advantage of profitable markets for healthy food and growth in Asian economies. This is evidenced by a substantial proportion of the USA in-shell production now being exported to China and Vietnam. Often prices are negotiated and contracted before harvest.

With the majority of the world's hazelnuts supplied by one area, there is a significant risk that storms, climate, pests and/or diseases could affect supply. Increasing Australia's production could alleviate some of this risk and secure the global hazelnut supply. There is great potential for production expansion in the cooler parts of Australia, such as north-eastern Victoria, parts of Tasmania and the Central Tablelands of NSW. Plantings in these areas could lead to a substantial industry and secure a place on the global market.

Increasing hazelnut production in Australia will provide opportunities to help relieve the need for importing, expand local consumption and look at developing export markets.

Current hazelnut exports from Australia are limited, with small consignments destined for New Zealand, Vietnam and South Africa (Hort Innovation 2021). There are some opportunities for both in-shell and kernel hazelnuts in markets around the Asia–Pacific region due to the counter-seasonal advantage of Australian hazelnuts. For Australia, China is the most significant potential market, but competing with countries such as Chile with low-cost inputs might be difficult.

Markets

With the increase in knowledge of the health benefits of nuts (Appendix C on page 126 provides basic nutritional information for 100 g of raw hazelnut), there is a global increase in demand for these products (Snare and Gottschall 2017). With the increasing demand, there are several marketing alternatives available for growers, including options for smaller orchards looking at farm gate sales. Market potential and expansion are being led by research that is showing the health benefits of including nuts daily in our diet.

The major markets for hazelnuts are for round kernels of 11–13 mm and confectionery kernels of 9–15 mm. Kernels for confectionery should be plump, not shrivelled, and free of mould and extraneous matter. They should have a non-rancid flavour and uniform-coloured flesh. The in-shell trade is developing as newer plantings of varieties such as Ennis start bearing.

The 2 main markets for kernels are:

1. processed foods: confectionery, desserts, cakes and snack foods
2. nuts to be eaten raw.

Some uses for hazelnut kernels are outlined in Table 15.

Table 15. Some uses for hazelnut kernels.

Appearance	Comments	Use
Whole roasted or whole natural kernels	Flavour intensifies when roasted	Snacks, confectionery, cereal and bakery
Diced/chopped, natural or roasted	Uniform distribution and intensified flavour if roasted	Bakery, confectionery, salads, soups, health bars, encrusting material, toppings, dairy products and muesli
Sliced kernels	Adds crunchy texture and appearance	Decorating cakes, biscuits and as a garnish
Meal	Can be used as a gluten-free flour substitute	Bakery, health foods, confectionery, stuffings, ice cream and sauces

Marketing alternatives

Several potential marketing alternatives are available for hazelnuts from new plantings, particularly from those with smaller-scale production. These include sales through:

- grower cooperatives
- supermarket chains
- specialised nut retailers
- manufacturers for confectionery, baking, health foods
- commission agents in the wholesale produce markets
- health food outlets
- wineries as an adjunct to cellar door sales
- local fruit and vegetable outlets
- direct sales from the farm gate.

A potential competitive advantage for Australian-grown products is freshness, availability throughout the year and freedom from pesticides. To capitalise on these opportunities, the current Australian production sector of the industry needs to expand considerably, to work in a collaborative manner, and to market hazelnuts in a way that meets the needs of buyers and consumers.

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Orchard economics

This chapter presents an economic analysis for the hazelnut industry and includes gross margins for the industry in NSW.

The economic potential can be estimated from the cash flow investment budgets created (Table 16 to Table 20) from current market trends. Growers in NSW and Victoria were contacted to understand the inputs used. Growers also shared their budgets to incorporate and inform the larger cash flow investment budgets. Inputs such as chemicals, irrigation and composts were researched and costed. A cash flow investment template generated by NSW DPIRD development officers was then adapted to suit the hazelnut industry.

The budgets published in this section are only a guide to the relative profitability of the different enterprises based on a specific set of assumptions. Budgets will be influenced not only by general factors such as prices, yields and costs, but also by each farm's characteristics. Be aware that the budgets do not incorporate taxation (either GST or income tax) into the cash flows. Before using any information from this section, the user should read and understand all the assumptions used to develop the budgets. If assumptions vary between the published budgets and the user's circumstances, these must be taken into consideration.

Minor changes to some variables can dramatically change an enterprise's profitability. Yield and prices are 2 of the main variables that can significantly affect returns. A sensitivity analysis is provided to help obtain an estimate of gross margin returns and long-term cash flows with different yields, prices and finance. Expensive inputs, such as pruning, can also significantly affect budgets.

Assumptions

Labour provided by the grower is not budgeted in the analysis. Examples of labour provided by the grower can include conducting irrigations, spraying, cultivating, miscellaneous repairs (i.e. machinery, fences, irrigation lines and heads) and bookkeeping. However, where an operation would warrant contract labour, this has been included in the budgets.

Table 16 is a 20-year financial summary for each enterprise. Table 17 to Table 20 show the individual year variable cost budgets that formulate the 20-year summary tables. Variable cost budgets have not been developed for every year, instead they have been grouped into relevant major stages. This is because the variable costs within these years do not change dramatically and it makes the budgets easier to use. The budgets presented are for:

- year 1 (land preparation and planting)
- years 2–4 (early growth)
- years 5–7 (early bearing)
- years 8–10 (pre-maturity)
- years 11–20 (maturity).

Note that yield and water use are not included in the individual year variable cost budgets, but are included in the 20-year summary budgets. Yield and water use can change quickly in the early years and therefore must be budgeted for each year.

The yield, prices and variable inputs used in the budgets are derived from a combination of current and best practices. The prices and yields are considered conservative at the time of publication. Growers should contact agricultural consultants and accountants for specific information on cultural practices, how these investments will affect their individual financial position, and the implications such investments have for taxation purposes.

Number of chemical applications

The number of chemical applications has been averaged based on grower and industry use. It is an estimation and will vary from year to year.

Land preparation and planting

Year 1 is designated as land preparation and planting. It is assumed that the hazelnut orchard will be planted on virgin land. Should this not be the case, the ongoing variable costs and income foregone from removing the enterprise should also be considered as part of economic returns. Many of the activities required at planting will be contracted work and are accounted for in the individual activities.

Fertiliser application

Nitrogen fertiliser is assumed to be applied in split doses throughout the year, matching tree requirements; other fertilisers might be in a single application. Although not usually undertaken currently by the industry, but regarded as best practice, foliar sprays are included to help promote good tree growth.

Spraying pesticides and fungicides

An oscillating boom or air-blast sprayer is used for foliar spraying. The spraying speed is related to the volume of application and affects the time and cost to conduct spraying. The spraying speed is categorised as 2, 4 or 6 km/h. For younger trees, use a lower water volume rate for spraying.

Irrigation

Irrigation prices are based on the Riverina as this is where much of the hazelnut expansion is occurring. It is assumed that growers in the Orange area will not require a water licence. A $19/ML irrigation maintenance and pump maintenance charge are included. It is assumed that all irrigation is drip applied, water is available upon demand and no on-farm storage is required. Checking emitters in the 'tractor implements' section is for the farm operator to check sprinklers or drip irrigation lines for blockages or breakages. The cost of an irrigation pump and pump shed are not included as it assumes that these are already available on the farm.

Water prices

Fixed water costs based on a 30 ha orchard @ 10 ML/ha allocation, 300 (30 × 10) delivery entitlement (DE), one outlet, one account and Riverina high security licence:

Per account fee	$352.00/account
	$11.73/ha
Access charge	$68.07/ha
Delivery entitlement	$95.70/ha
Fixed charge	$175.5/ha

Variable water costs (i.e. related to volume of water used)

Water usage charge:

Normal use (below 100% DE)	$11.30/ML
Government bulk water WaterNSW	$ 6.32/ML
Government bulk water conveyance	$ 1.53/ML
Total variable water distribution charge	$19.15/ML

Tractor implements

The type of implement and associated costs used in the budget for the tractor usage are:

- sod mowing = tractor-mounted slasher
- general maintenance e.g. checking emitters = quad bike
- herbicide rows = herbicide spraying with tractor-mounted tank and boom
- spot spray quad bike = herbicide spot spraying with a quad and mounted tank and gun
- ground fertilise = ground application of fertiliser with a tractor-mounted fertiliser spreader

- oscillating boom = oscillating boom spraying
- air-blast tower sprayer = air-blast tower spraying
- mulching = hammer type mulcher.

Harvesting

There are 3 methods of harvesting hazelnuts. For these budgets, machine harvesting was used as an example, but other options include hand harvest using steel rollers and vacuum harvesting. An estimation of harvest cost assumes 1,000 trees or 3 ha are harvested per day. This is broken down as follows:

$150/hr cost of harvester × 8 hour day = $1,200/day

$1,200/day ÷ 3 ha = $400/ha

Yield

Yield is based on data from various trials at the NSW DPIRD Research Stations at Orange, Yanco and Dareton and industry data. Yields are conservative estimates, and a well-managed orchard could achieve these yields quite easily.

Bird netting

Birds can cause significant nut damage to a small orchard. Large orchards in the Riverina have not suffered extensive bird damage due to the vast area of nuts planted compared with the number of birds. To assess the benefit of using bird netting, a vacuum-harvested orchard with a 30% yield reduction from birds was compared with the same orchard at full yield using single row netting to protect nuts from damage. The change to single row netting is assumed to cost $5/m and one hectare uses 1,800 m.

Nets are placed over the trees before nut maturity and removed after harvest. A specialised tractor-drawn net applicator is used ($14,000). The cost of the implement is shared over 10 ha to provide a cost of $1,400/ha. Net tearing requires extra labour to repair the net each year. The budget assumes that 60 hours/ha annually is used to apply, remove and fix the nets. The net can survive UV degradation for up to 10 years, however, tears during removal reduce the net's life. The nets might only last 5 years due to tears, therefore, a lifespan of 7 years is assumed in the budgets.

Mature trees also need annual topping to keep their height within the net's dimensions.

Overhead and fixed costs

Overhead and fixed costs include shire rates, telephone, insurance, vehicle registration, accountancy and bank charges. For the budgets, these costs are an estimate based on industry consultation at $1,260/ha/year. They do not include capital costs such as purchasing land, farm machinery, sheds or tools.

Finance

The budgets are presented without finance. Financing assumes that all money used in the budget is borrowed and interest charged. All net returns are put back into repaying the loan. The cumulative cash flow (after finance) includes the interest charges on borrowings. The budgets assume a 0% inflation rate for easier interpretation and to standardise net present value calculations.

Net present value

Also important to cash flow analyses are net present values (NPVs). These are displayed in the sensitivity graphs and in the summary table (Table 16). NPVs are the sum of the discounted values of future income and costs associated with a farm project or plan. The NPV is derived from discounting the cash surplus/deficit each future year to today's dollar terms, then adding all the present values (PVs) for each year. Projects with a positive NPV provide positive returns; those with the highest NPV repay the highest return on investment.

NSW Treasury guidelines for economic appraisal recommend a rate of 8% per year in undertaking economic evaluation of proposals. It presumes that all future costs and benefits will be measured in relation to the current purchasing power of money (i.e. that the effect of inflation on future costs and benefits will be ignored).

For the purpose of this section, one hectare of 519 hazelnut trees planted in the Riverina, NSW, was used as an example to show the output of the budgeting tool. Input costs and income expected for an orchard operated in this area are considered for each year. This budget is captured in an Excel™ sheet and can be made available for growers.

The budget summary (Table 16) shows that 1 ha of hazelnuts planted in the Riverina, NSW, will break even in year 9, with an annual cash surplus starting in year 7 when the nut yield increases to 2 t/ha. Growers should understand the implications of this before investing in this industry. The long time to reach break-even exposes the investment to risks such as fluctuations in market prices, disease and pest incursions and extreme weather. Break-even is extended further if finance has been used to invest in the orchard. The establishment costs of this orchard are approximately $18,482, assuming the trees are being planted into land that has not previously been used for horticulture.

There is a detailed analysis of costs such as irrigation, herbicide, fertiliser, fungicide, insecticide, pruning and year specific costs such as netting (Table 17 to Table 20). When the orchard is in full production, input costs per hectare are estimated to range from $5,000 to $6,000 per annum. Hazelnuts should start producing low yields in year 4 (0.5 t/ha) and be in full production, which is around 3 t/ha, by year 8.

When the yield is modelled at 2.25 t/ha (below average), the NPV significantly decreases to $7,892 with no finance and at an 8% interest charge (Figure 153), break-even does not occur during the 21-year span. If yield was increased to 3.75 t/ha and 4.5 t/ha, the NPV nearly doubled with each increment increase in yield. This indicates that a yield of at least 3 t/ha is required for marginal viability and about 4 t/ha is required for reasonable profitability.

The yield assumed in Figure 154 and Figure 155 is 3 t/ha. Machine and vacuum harvesting will see greater returns compared with harvesting by hand rake (Figure 155). Without finance on borrowings, all types of harvesting provide a break-even between 10 and 13 years. However, when 8% interest is applied on borrowings, then hand rake harvesting becomes unviable and vacuum harvesting adds an extra 4 years until break-even compared with machine harvesting. Small orchards often use hand rake harvesting and these enterprises are at risk of being unviable, unless they can obtain a premium on their hazelnuts by value-adding or maximising yields through cultural practices.

Figure 156 and Figure 157 show the benefit of using bird netting in a vacuum-harvested orchard with a potential 30% yield reduction from bird damage. Figure 156 indicates that bird netting costs similar to a 30% yield loss. However, both scenarios provide a negative NPV, indicating that either scenario is profitable. When 8% interest is charged on borrowing, break-even is not reached over the 21-year budget. These results emphasise the marginal nature of a small orchard enterprise that could be susceptible to bird damage. Viability would require an increase in yields or prices.

Hazelnuts will provide a good cash flow and profit, provided the yields and types of harvesting are considered. Hazelnuts require upfront investments and break-even does not occur for a long period.

Sensitivity graphs (Figure 152 to Figure 155) highlight cost sensitivity, income and loan repayment variables on returns. The graphs show that slight changes in price, yield or finance can have a dramatic effect on an enterprise's profitability. From the cash flow budgets, sensitivity analyses with yield variations were calculated with and without estimated finance costs. The yield sensitivity graph (Figure 152) shows a positive NPV of $31,478 and a 21-year cumulative cash flow of $144,291 when the yield is 3 t/ha and a nut price of $5,000/ha, with no finance. Borrowing finance with an interest rate of 8% for purchasing a hazelnut investment in the same scenario, break-even occurs at about year 13 and the cumulative cash flow is $82,942.

Table 16. An overall summary of the cash flow budget for hazelnuts grown in the Riverina using mechanical harvesting.

Enterprise (per ha): hazelnuts in the Riverina
Description: sod culture, drip irrigation — Water price: Riverina
Tree density: 519 trees/ha — Unit size: 1 ha
Harvest: machine — Loan interest rate: 8%
7% NPV (no finance): $21,967 — Inflation: 0%

Year	1	2	3	4	5	6	8	10	11	16	21
Water use											
Water use (ML/ha)	3	3	3	4	5	6	8	8	8	8	8
Income											
Yield (t/ha)	0	0	0	0.5	0.8	1	2.5	3	3	3	3
Nut price ($/t no shell)	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Total enterprise income	$-	$-	$-	$2,500	$4,000	$5,000	$12,500	$15,000	$15,000	$15,000	$15,000
Costs											
Year 1 site preparation	$16,188	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Irrigation	$437	$437	$437	$524	$611	$698	$873	$873	$873	$873	$873
Herbicide	$111	$387	$387	$387	$387	$387	$85	$85	$85	$85	$85
Fertiliser	$-	$74	$74	$74	$1,120	$1,120	$1,249	$1,249	$1,249	$1,249	$1,249
Fungicides	$-	$159	$159	$159	$266	$266	$372	$372	$372	$372	$372
Insecticides	$-	$156	$156	$156	$226	$226	$287	$287	$287	$287	$287
Pruning	$-	$227	$227	$227	$303	$303	$454	$454	$454	$454	$454
Crop management	$150	$129	$129	$129	$69	$69	$69	$69	$69	$69	$69
Tractor	$88	$479	$479	$479	$667	$667	$676	$676	$676	$676	$676
Harvesting	$-	$-	$800	$800	$800	$800	$800	$800	$800	$800	$800
Overhead fixed coasts	$1,350	$1,350	$1,350	$1,350	$1,350	$1,350	$1,350	$1,350	$1,350	$1,350	$1,350
Machinery hours	3	20	20	20	23	23	28	28	28	28	28
Total costs	$18,324	$3,398	$4,198	$4,285	$5,799	$5,886	$6,215	$6,215	$6,215	$6,215	$6,215
Annual cash surplus/deficit	-$18,324	-$3,398	-$4,198	-$1,786	-$2,049	-$886	$6,286	$8,786	$8,786	$8,786	$8,786
Cumulative cash flow (no finance)	-$18,324	-$21,723	-$25,922	-$27,708	-$29,757	-$30,643	-$20,330	-$2,758	$6,028	$49,957	$93,886
Interest charges	-$1,100	-$1,785	-$2,220	-$2,757	-$3,223	-$3,664	-$4,063	-$3,471	-$3,030	-$223	$-
Cumulative cash flow (after finance)	-$19,424	-$24,608	-$31,027	-$35,571	-$40,842	-$45,392	-$43,188	-$32,967	-$27,212	$9,564	$53,493

Note: this spreadsheet has been developed by NSW DPIRD for private use. The user has made their own assumptions in entering inputs into the spreadsheet (e.g. prices, yields and cultural practices) to generate these outcomes. NSW DPIRD does not accept any responsibility for the applicability of the outcomes from the model to the individual orchardist's situation. Orchardists should rely on their own independent advice before taking action based on the outcomes derived from this model.

Table 17. Cash flow budgets for hazelnuts in the Riverina, NSW, for year 0–1.
Enterprise (per ha): hazelnuts in the Riverina
Description: sod culture, drip irrigation
Water price: Riverina
Tree density: 519 trees/ha
Unit size: 1 ha

Costs year 0–1 **Redevelopment**	**Rate per application**	**$**	**$**	
1 × install irrigation lines	16.0 h/ha	25.00/h	400.00	
1 × ripping	2.0 h/ha	255.00/h	510.00	
1 × gypsum		280.00/ha	280.00	
1 × levelling	1.6 h/ha	145.00/h	232.00	
1 × cultivating	3.0 h/ha	26.70/h	80.20	
1 × discing	4.0 h/ha	26.70/h	106.90	
1 × surveying		40.00/ha	40.00	
1 × pegging (labour)		80.00/ha	80.00	
1 × sod culture (seed + contract sowing)		250.00/ha	250.00	
			Total	**$1,979.10**
Irrigation system				
1 × drip irrigation system		6,500.00/ha	6,500.00	
1 × sub mains		2,000.00/ha	2,000.00	
			Total	**$8,500.00**
Planting, added to year 1	Trees	$/tree		
1 × trees	519	10.00	5,190.00	
1 × planting	519	1.00	519.00	
			Total	**$5,709.00**
			Total costs for land preparation and year 1 planting	**$16,188.10**
Herbicide				
2 × glyphosate 450 g/L via boom (50%)	2.4 L/ha	18.20/L	43.70	
2 × glyphosate 450 g/L via spot	0.7 L/ha	18.20/L	51.00	
6 × wetter	0.4 L/ha	7.70/L	16.10	
			Total	**$110.80**
Fertiliser and crop management				
1 × fertiliser (Diamond Blue) via fertigation	0.1 kg/ha	2.00/kg	0.20	
1 × soil test (per sample)	1.0 /ha	150.00	150.00	
			Total	**$150.20**
Tractor and machinery				
2 × herbicide rows via boom	1.2 h/ha	36.60/h	87.70	
1 × fertigation	0.3 h/ha	2.50/h	0.80	
			Total	**$88.50**
			Total partial variable costs year 1	**$16,537.60**

Table 18. Cash flow budgets for hazelnuts in the Riverina, NSW, for years 2–4.
Enterprise (per ha): hazelnuts in the Riverina
Description: sod culture, drip irrigation
Water price: Riverina
Tree density: 519 trees/ha
Unit size: 1 ha

Costs years 2–4 **Herbicide**	**Machinery**	**Rate per application**	**$**	**$**	
1 × glyphosate 450 g/L	spot spray 4WB	0.7 L/ha	18.20/L	12.80	
2 × glyphosate ammonium	boom (30%)	2.5 L/ha	27.00/L	40.40	
2 × carfentrazone	boom	1.2 L/ha	100.00/L	235.20	
8 × wetter		1.5 L/ha	8.30/L	99.00	
				Total	**$387.40**
Fertiliser					
1 × fertiliser (Diamond Blue)	fertigation	0.2 kg/ha	2.00/kg	0.40	
1 × calcium nitrate	fertigation	40 kg/ha	1.80/kg	73.60	
				Total	**$74.00**
Fungicide					
2 × copper hydroxide	spray (6 km/h)	3.0 kg/ha	26.60/kg	159.30	
				Total	**$159.30**
Insecticides					
1 × oil spray (high grade)	spray (4 km/h)	20 L/ha	7.50/L	150.00	
1 × sulfoxaflor	spray (6 km/h)	0.2 L/ha	415.00/L	74.70	
				Total	**$224.70**
Pruning					
1 × hand pruning		0.8 min/tree	35.00/h	227.10	
				Total	**$227.10**
Crop management					
1 × sod seed	sod seeder	25 kg/ha	0.40/h	8.80	
1 × tree replacement		10 tree/ha	12.00/h	120.00	
1 × mulching (fast)	mulcher (PTO)	1.0 h/ha	39.00/h	39.00	
1 × sod sowing	sod seeder	1.0 h/ha	19.10/h	19.10	
1 × spot spray	4 wheel bike + tank sprayer	2.0 h/ha	4.20/h	8.40	
1 × spray (4 km/h)	air-blast tower	1.5 h/ha	41.70/h	62.60	
2 × fertigation		0.3 h/ha	2.50/h	1.50	
2 × sod mowing	slasher	0.5 h/ha	31.70/h	31.70	
3 × spray (6 km/h)	air-blast tower	1.0 h/ha	41.70/h	125.20	
4 × herbicide rows	boom	1.2 h/ha	36.60/h	175.50	
25 × check emitters	4WB	0.2 h/ha	3.30/h	16.50	
				Total	**$608.30**
				Total partial variable costs	**$1,680.80**

Table 19. Cash flow budgets for hazelnuts in the Riverina, NSW, for years 5–7.
Enterprise (per ha): hazelnuts in the Riverina
Description: sod culture, drip irrigation
Water price: Riverina
Tree density: 519 trees/ha
Unit size: 1 ha

Costs years 5–7 **Herbicide**	**Machinery**	**Rate per application**	**$**	**$**	
1 × glyphosate 450 g/L	spot spray 4WB	0.7 L/ha	18.20/L	12.80	
2 × glyphosate ammonium	boom (30%)	2.5 L/ha	27.00/L	40.40	
2 × carfentrazone	boom	1.2 L/ha	100.00/L	235.20	
8 × wetter		1.5 L/ha	8.30/L	99.00	
				Total	**$387.40**
Fertiliser					
1 × calcium nitrate	fertigation	100 kg/ha	1.80	184.00	
1 × mono-ammonium phosphate	fertigation	25 kg/ha	3.40	86.00	
1 × potassium nitrate	fertigation	200 kg/ha	3.40	672.00	
1 × urea ammonium nitrate	fertigation	100 L/ha	1.60	164.00	
Foliar					
3 × boron foliar spray	spray (6 km/h)	0 kg/ha	50.00	0.02	
3 × ZM (foliar 17% Zn + Mn)	spray (6 km/h)	2.0 kg/ha	2.40	14.30	
				Total	**$1,120.32**
Fungicide					
2 × copper hydroxide	spray (6 km/h)	5.0 kg/ha	26.60/kg	265.50	
				Total	**$265.50**
Insecticides					
1 × oil spray (high grade)	spray (4 km/h)	30 L/ha	7.50/L	225.00	
1 × sulfoxaflor	spray (6 km/h)	0.3 L/ha	415.00/L	103.80	
				Total	**$328.80**
Pruning					
1 × hand pruning		1.0 min/tree	35.00/h	302.80	
				Total	**$302.80**
Crop management					
1 × leaf analysis		0.5	120.00	60.00	
1 × mulching (fast)	mulcher PTO	1.0 h/ha	39.00	39.00	
1 × sod seed	sod seeder	25 kg/ha	0.40	8.80	
1 × sod sowing	sod seeder	1.0 h/ha	19.10	19.10	
1 × spray (4 km/h)	air-blast tower	1.5 h/ha	41.70	62.60	
2 × herbicide rows	boom	1.2 h/ha	36.60	87.70	
4 × fertigation		0.3 h/ha	2.50	3.00	
4 × sod mowing	slasher	0.5 h/ha	31.70	63.50	
9 × spray (6 km/h)	air-blast tower	1.0 h/ha	41.70	375.80	
25 × check emitters	4WB	0.2 h/ha	3.30	16.50	
				Total	**$736.00**
				Total partial variable costs	**$3140.82**

Table 20. Cash flow budgets for hazelnuts in the Riverina, NSW, for years 8–21.
Enterprise (per ha): hazelnuts in the Riverina
Description: sod culture, drip irrigation
Water price: Riverina
Tree density: 519 trees/ha
Unit size: 1 ha

Costs years 8– 21 **Herbicide**	**Machinery**	**Rate per application**	**$**	**$**	
1 × glyphosate 450 g/L	boom (30%)	2.4 L/ha	18.20	13.10	
2 × glyphosate 450 g/L	spot spray 4WB	0.7 L/ha	18.20	25.50	
8 × wetter (Agral)		0.4 L/ha	7.70	21.40	
2 × wetter (Hasten)		1.5 L/ha	8.30	24.80	
				Total	**$84.80**
Fertiliser					
1 × calcium nitrate	fertigation	20 kg/ha	1.80	36.80	
1 × mono-ammonium phosphate	fertigation	40 kg/ha	3.40	137.60	
1 × potassium nitrate	fertigation	200 kg/ha	3.40	672.00	
1 × iron EDHHA chelated fertiliser	fertigation	20 kg/ha	20.10	40.20	
5 × urea ammonium nitrate	fertigation	40 L/ha	1.60	328.00	
Foliar					
2 × wetter (Agral)	spray (6 km/h)	0 kg/ha	50.00	0.02	
2 × zinc + manganese	spray (6 km/h)	6 kg/ha	2.40	28.60	
3 × boron foliar spray		0.4 kg/ha	7.70	5.40	
				Total	**$1,148.62**
Fungicide					
2 × copper hydroxide	spray (6 km/h)	7 kg/ha	26.60/kg	371.70	
				Total	**$371.70**
Insecticides					
1 × oil spray (high grade)	spray (4 km/h)	35 L/ha	7.50	262.50	
1 × sulfoxaflor	spray (6 km/h)	0.4 L/ha	415.00	145.30	
				Total	**$407.80**
Pruning					
1 × hand pruning		1.0 min/tree	35.00/h	454.10	
				Total	**$454.10**
Crop management					
1 × bee exclusion netting (install + remove)	Bee net roller	11 h/ha	18.90	208.30	
1 × bird exclusion netting (install + remove)	Bird net roller	60 h/ha	25.00	1,500.00	
1 × herbicide rows	boom	1.2 h/ha	36.60	43.90	
1 × leaf analysis		0.5	120.00	60.00	
1 × mulching (fast)	mulcher PTO	1.5 h/ha	39.00	48.70	
1 × mulching (medium)	mulcher PTO	1.0 h/ha	39.00	58.50	
1 × ripping	ripper tyne	0.2 h/ha	29.20	5.80	
1 × sod seed	sod seeder	25 kg/ha	0.40	8.80	
1 × sod sowing	sod seeder	1.0 h/ha	19.10	19.10	
1 × spot spray	4WB + tank sprayer	0.2 h/ha	4.20	16.80	
1 × spray (4 km/h)	air-blast tower	1.5 h/ha	41.70	62.60	
4 × sod mowing	slasher	0.5 h/ha	31.70	63.50	
8 × spray (6 km/h)	air-blast tower	1.0 h/ha	41.70	333.80	
9 × fertigation		0.3 h/ha	2.50	6.80	
25 × check emitters	4WB	0.2 h/ha	3.30	16.50	
				Total	**$2453.10**
				Total partial variable costs	**$5020.12**

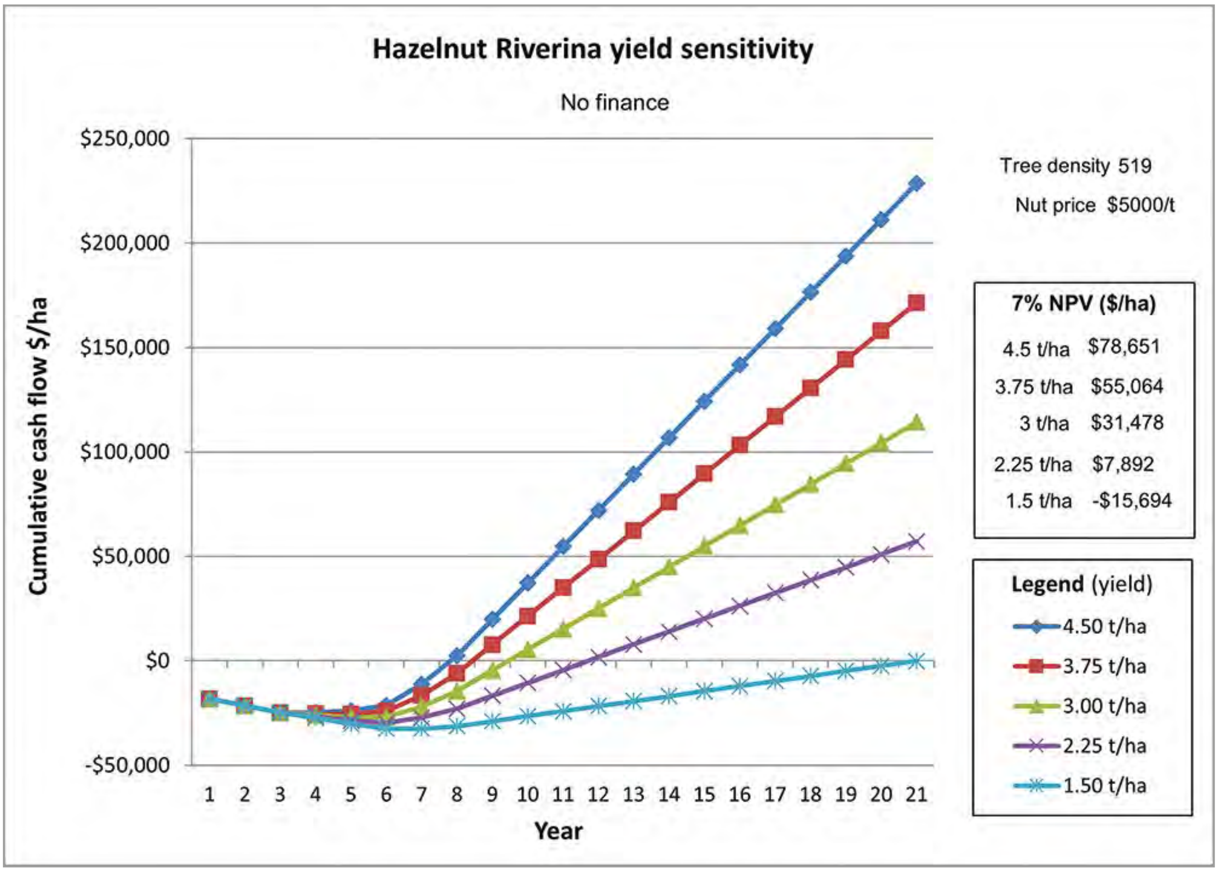

Figure 152. Yield sensitivity for hazelnuts grown in the Riverina NSW with no finance.

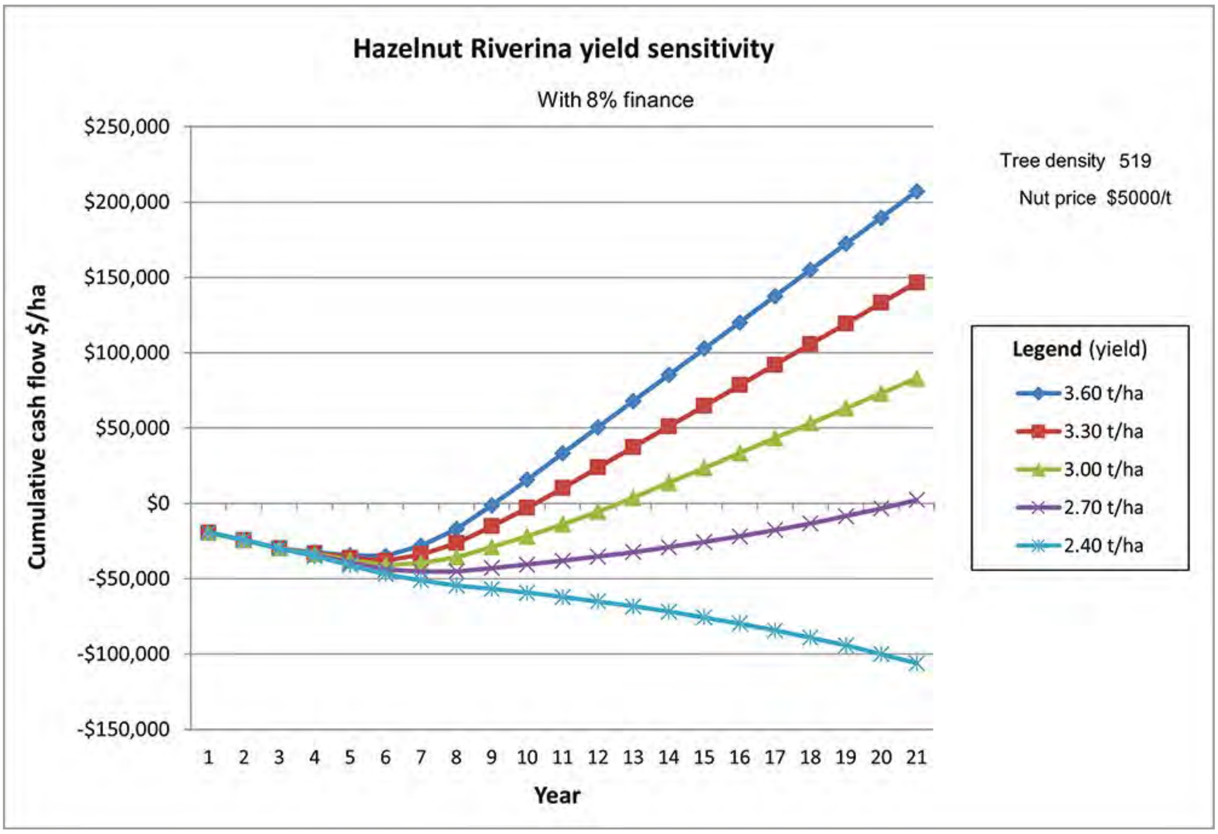

Figure 153. Yield sensitivity for hazelnuts grown in the Riverina NSW with finance.

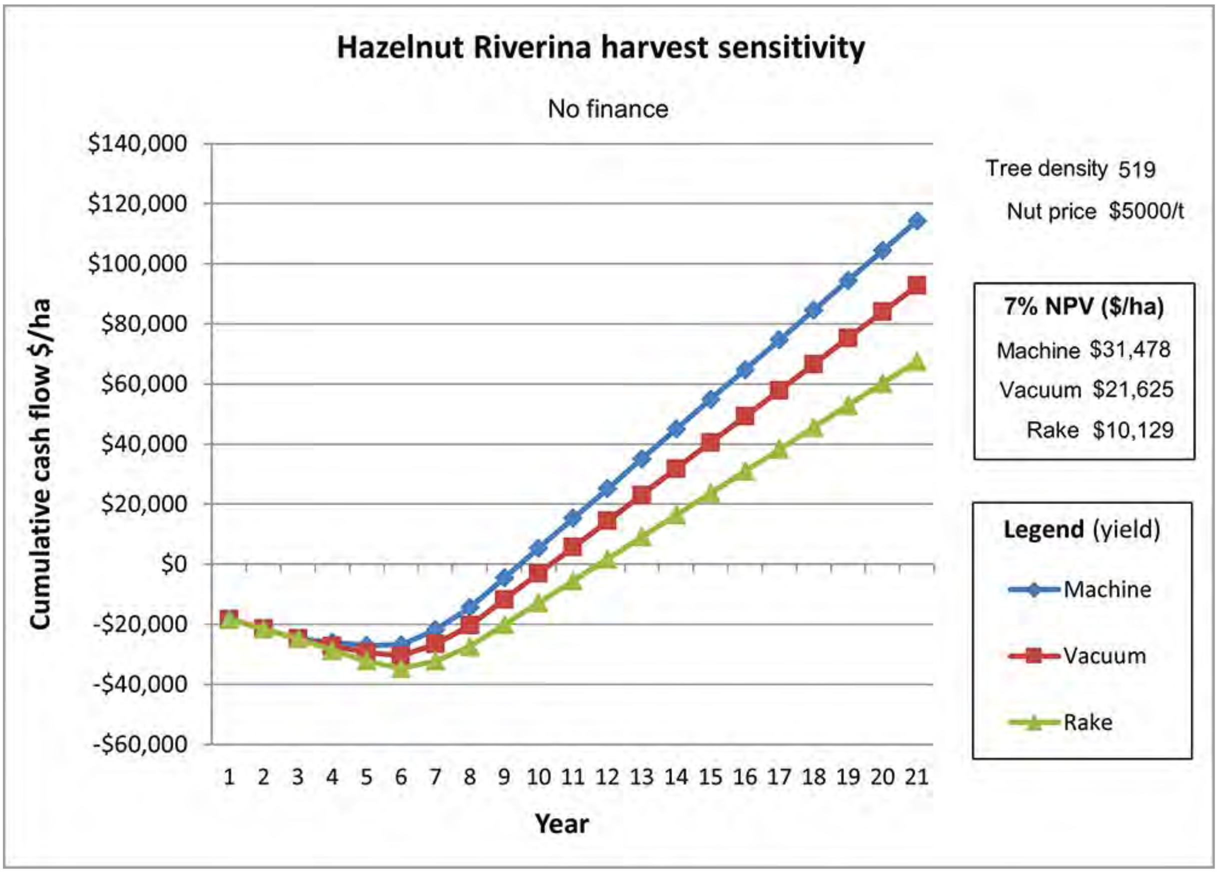

Figure 154. Harvest sensitivity for hazelnuts in the Riverina NSW with no finance.

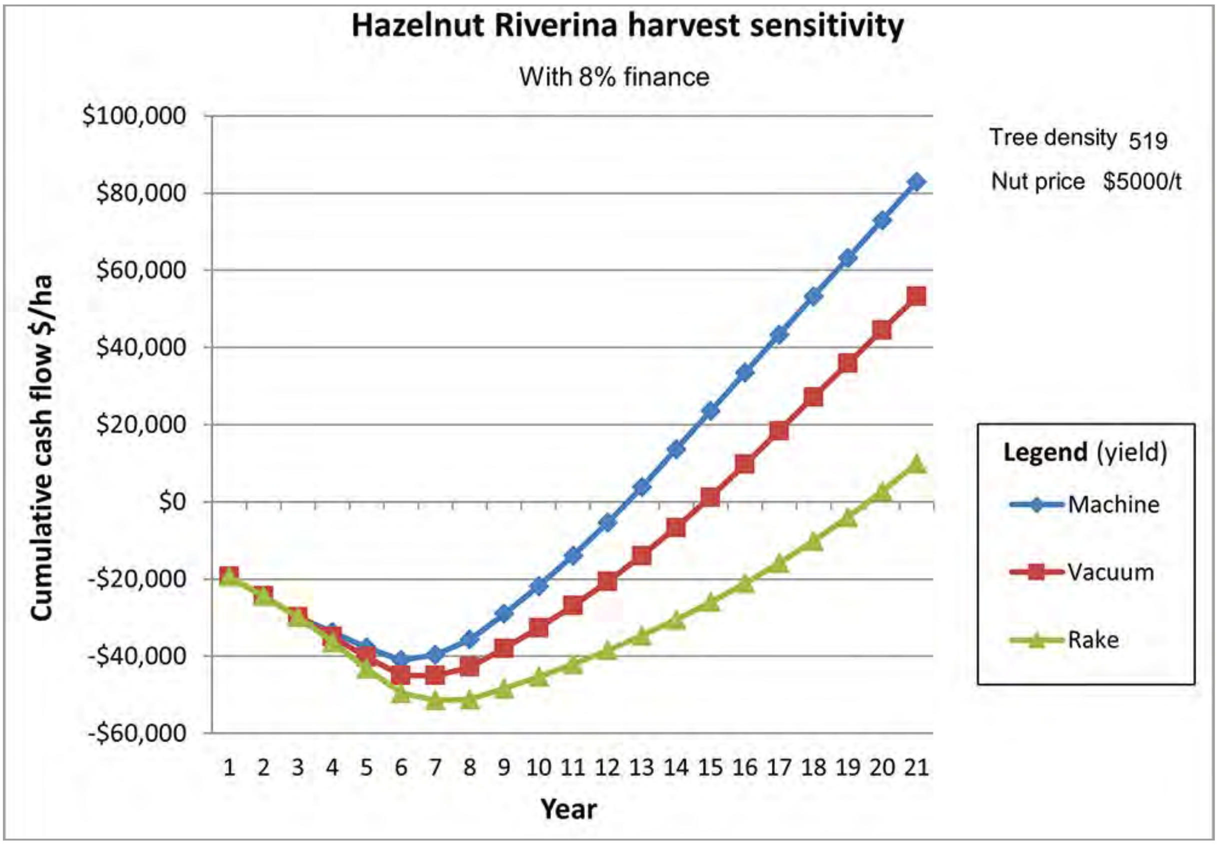

Figure 155. Harvest sensitivity for hazelnuts in the Riverina NSW with finance.

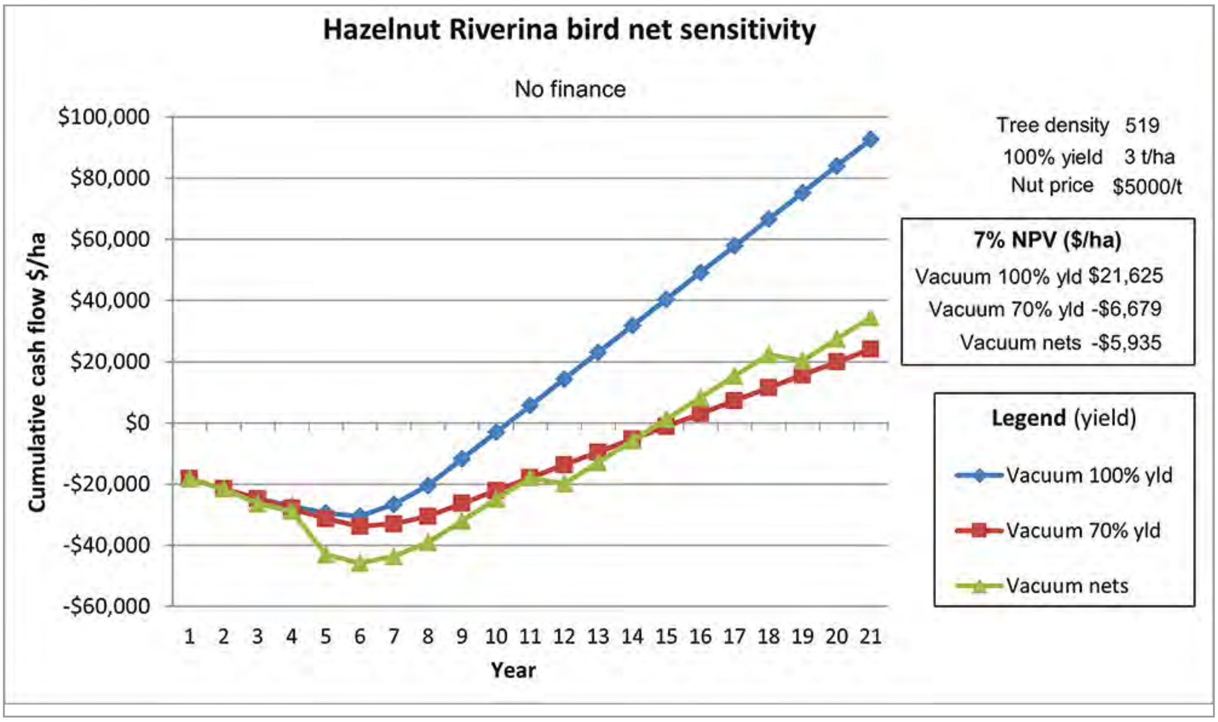

Figure 156. Bird net sensitivity for hazelnuts in the Riverina NSW with no finance.

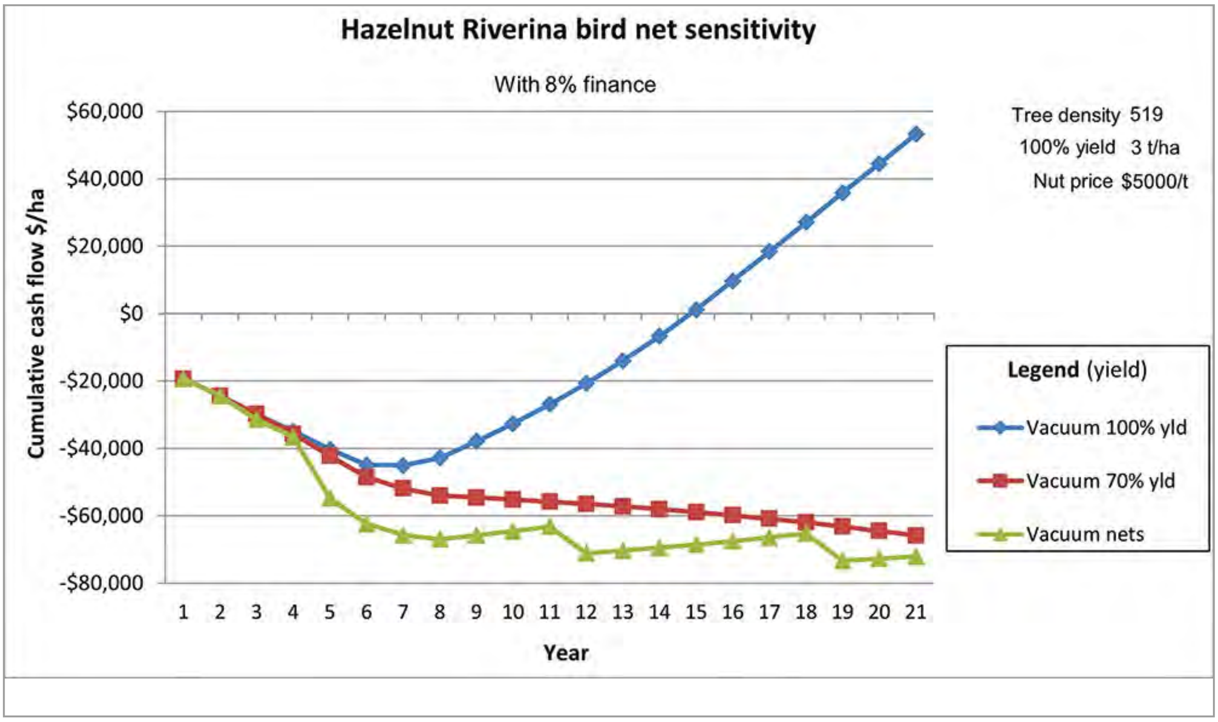

Figure 157. Bird net sensitivity for hazelnuts in the Riverina NSW with finance.

Appendices

Appendix A: Determining nut-in-shell moisture content

Source: *Hazelnut Growers Handbook* 1998, Hazelnut Growers of Australia Ltd, Melbourne.

How to dry nuts

1. Select a sample of 100 nuts from the rack and divide it into 2 lots of 50 nuts. Label them Sample A and Sample B.
2. Weigh both samples and record the weight on a proforma sheet (an example is provided on the next page). Place Sample B in a net bag and place it back in the rack.
3. Take Sample A and crack all the nuts, keeping the shell and kernel together. Note the number of blanks, shrivelled, mouldy or stained kernels. Record the numbers on the proforma.
4. Re-weigh Sample A (nuts and shell combined). This is known as the **wet weight** of the nuts. Place Sample A on a microwave plate and place it in a microwave (it is easier if you weigh the plate separately and then weigh the plate plus Sample A. The final weight of the nuts can then be calculated by subtracting the weight of the plate.) Heat for 1 minute on high power and then re-weigh nuts and record the result. Using times longer than 1 minute usually burns the nuts and will give inconsistent results.
5. Repeat the process, weighing and recording the result, until the weight of the sample does not change. This is known as the **dry weight** of the nuts (i.e. no moisture). Depending on the amount of moisture, this might take up to 14 bursts of heat. Note also that the weight will stabilise, but after 30 seconds on the scales, the nuts will start to take up moisture and the weight will increase.
6. Calculate the **moisture content** (MC):
   a. wet weight – dry weight = total weight of moisture removed

   b. $\text{moisture content (MC)} = \dfrac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$
7. The moisture content calculated represents the moisture content present in the nuts at the time of selecting the samples, i.e. the moisture level in both Sample A and Sample B. To calculate the weight when the nuts will be at a 5% moisture content, use the following formula:

   c. $5\%\ \text{MC} = \text{dry weight} + \dfrac{5 \times \text{dry weight}}{100}$
8. To calculate the weight of **Sample B** when it is at 5% MC, use the formula at 6 b. By transposing the formula, the **dry weight** becomes:

   d. $\text{dry weight} = \dfrac{\text{wet weight} \times 100}{\text{MC} + 100}$

Then use the formula at 7c. to calculate the weight for 5% MC of Sample B. This is the weight Sample B should reach when the nuts have been dried sufficiently. Checking the weight of Sample B every 4 or 5 days and recording the result is the best way to monitor the moisture content. Air drying takes approximately 2 to 3 months to lower the moisture content to the correct level.

The nuts should now be stored in either airtight containers or in a dry, temperature-stable location until they are used.

Recording proforma

Sample A	Measurement	Sample B
Wet weight, date		Wet weight, date
No. of blanks		Wet weight, date
No. of shrivelled kernels		Wet weight, date
No. of mouldy kernels		Wet weight, date
No. of stained kernels		Wet weight, date
		Wet weight, date
Dish weight		Wet weight, date
		Wet weight, date
Weight of dish plus nuts		Wet weight, date
		The final weight should equal 5% MC as calculated below

Microwave heat weight

1st		5th		9th		12th	
2nd		6th		10th		13th	
3rd		7th		11th		14th	
4th		8th					

Remember to subtract the dish weight.

Final weight = dry weight = wet weight – dry weight = moisture weight

$$\text{Moisture content (MC)} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

$$5\%\ \text{(MC)} = \text{dry weight} + \frac{5 \times \text{dry weight}}{100}$$

For Sample B:

$$\text{Dry weight} = \frac{\text{wet weight} \times 100}{\text{MC} + 100}$$

$$5\%\ \text{(MC)} = \text{dry weight} + \frac{5 \times \text{dry weight}}{100}$$

= weight of Sample B when dried to 5% MC

Appendix B: Standards for Australian in-shell hazelnuts

These are adopted by the Hazelnut Growers of Australia Inc (https://www.hazelnutgrowersaustralia.org.au/).

1. **Packages of nuts offered for sale shall be:**
   - free of all foreign material, husks, stalks and mechanical damage
   - free of rancidity, mould and insect injury.
2. **Not more than 5% of the content of any package containing nuts-in-shell of any grade shall be blank (i.e. contain no kernel)**.
3. **The nuts shall be dried so the moisture content of the kernel is not more than 5% of the kernel mass**.
4. **Nuts in-shell are graded in accordance with the following sizes**:

Small	≤13.0
Medium	>13.0 to ≤18.0
Large	>18.0 to ≤19.5
Very large	>19.5 to ≤22.0
Giant	>22.0

5. **The nuts shall be adequately packed to withstand transport and packaging. The packaging shall be clean and of a suitable quality, design and construction to avoid causing damage to the nuts. The materials used inside the package, particularly any paper, shall be new and clean, and of a quality to avoid causing any damage to the nuts**.

   One end of the package, or a card within the bag, containing Australian hazelnuts shall bear the following information in characters that are legible and not handwritten:

   A. Australian hazelnuts

   B. Full name and address of producer (individual, firm or corporation)

   C. Name of variety or nuts

   D. Grade of nuts

   E. Net mass (weight of nuts)

   F. Moisture content of nuts

   G. Year nuts were harvested

Note: A shall be in letters at least 30 mm high; B to G shall be in letters at least 15 mm high.

Appendix C: Nutritional composition of raw hazelnut

Table 21. Nutritional composition of raw hazelnut (per 100 g).

Item	Quantity
Energy (kJ)[A]	2693
Protein (g)	14.8
Total fat (g)	61.4
Saturated fat (g)	2.7
Monounsaturated fat (g)	48.6
Polyunsaturated fat (g)	7.1
Omega 3 fat (mg)[B]	100
Plant sterols (mg)[C]	96
Cholesterol	0
Total carbohydrate (g)	5.1
Carbohydrate sugars (g)	4.4
Dietary fibre (g)	10.4
Calcium (mg)	86.0
Copper (mg)[C]	1.72
Iron (mg)	3.2
Magnesium (mg)	160
Manganese (mg)[C]	6.17
Potassium (mg)	680
Selenium (µg)	2.4
Sodium (mg)	3.0
Zinc (mg)	2.2
Vitamin A (µg RE)	1.0
Vitamin B1 (Thiamin, mg)	0.39
Vitamin B2 (Riboflavin, mg)	0.17
Vitamin B3 (Niacin, mg)	2.20
Vitamin B5 (Pantothenic acid, mg)	0.918
Vitamin B6 (mg)[C]	0.563
Vitamin B9 (Folate, µg)	72
Vitamin E (µg)	15.0

[A] Kilojoule content includes the energy from dietary fibre.

[B] Meyer B, Tsivis E, Howe PRC, Tapsell L and Calvert GD (1999) Polyunsaturated fatty acid content of foods: differentiating between long and short chain Omega-3 fatty acids. *Food Australia,* 51: 81–95.

[C] *US Department of Agriculture National Nutrient Database for Standard Reference*. Release 22. (www.nal.usda.gov/fnic/foodcomp/search/).

Notes

Hazelnut growers' handbook