Australian Government

Rural Industries Research and Development Corporation

# Hazelnut variety assessment

## for South-eastern Australia

**An interim report for the Rural Industries Research and Development Corporation**

by

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April 2007

RIRDC Publication No 07/062
RIRDC Project No US-125A

ISBN 1 74151 459 2
ISSN 1440-6845

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*Publication No. 07/ 062*
Project No. US 125A



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Published in April 2007

# Foreword

Hazelnuts are a highly nutritious food that can be consumed in many ways, either raw or roasted or incorporated into a wide range of food products. Hazelnuts are relatively small, shrub-like trees that are wind pollinated. The nuts are formed during the summer and ripen in late summer to early autumn. In most European varieties, the ripe nuts fall to the ground and are then collected by sweeping or suction harvesters. Nuts are dried and can be kept in shell for many months prior to cracking.

The kernels can be eaten either raw or roasted. They are rich in protein and oil. The oil is mainly comprised of monounsaturated fatty acids, chiefly oleic acid. The nuts are considered to be “heart friendly” and are purported to lower blood cholesterol levels. They are also high in vitamin E. The kernels have a thin skin or pellicle which can be removed by heating for 15 minutes at 130-150$^{o}$C. The process of pellicle removal is known as blanching. Some varieties blanch more readily than others; those that blanch well are highly prized in the confectionery trade. Hazelnuts are often roasted to bring out their flavour. The duration and temperature of roasting differs with variety, kernel size and the desired flavour.

Although hazelnuts were introduced into Australia more than 100 years ago, to date they have only been grown on a small scale. The major centres of hazelnut production in the world are Northern Turkey, Italy, Spain and Oregon in the USA. These locations lie in the latitude range 40–45$^{0}$N and have a Mediterranean-type climate with mild winters and warm summers. Parts of Australia have a similar climate; there would therefore appear to be a potential to grow hazelnuts in these parts of Australia. Currently, Australia imports more than 2000 tonnes of hazelnut kernels annually, valued at over $15 million.

A program of research has been conducted in NSW, Victoria and Tasmania, to evaluate the potential of this crop. The key outcomes provide information on:

- the yield potential of this crop
- the best varieties to grow and the pollinators to plant with them
- the most appropriate soils and climate, and
- the potential profitability of the crop

This report summarises the research which was initiated by the Faculty of Rural Management, the University of Sydney, Orange, which is now the School of Rural Management in the Faculty of Science at Charles Sturt University. The research has been conducted in collaboration with the Departments of Primary Industries in NSW and Victoria, along with individual hazelnut growers and the Hazelnut Growers of Australia Ltd. This report explains how the research was conducted and outlines the results obtained. The results will be of great value to those wishing to invest in hazelnut growing in Australia.

This project was funded from RIRDC Core Funds which are provided by the Australian Government.

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**Peter O’Brien**
Managing Director
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# Acknowledgments

We wish to acknowledge the financial support provided by the Rural Industries Research and Development Corporation that has enabled this research to be conducted. We also wish to thank the Dean of the Faculty of Rural Management, the University of Sydney, for the support that has been provided by the university. The University of Sydney was the principal researcher's employer during the time of conducting this research; however, the Orange campus has now been transferred to Charles Sturt University who support the on-going work.

The conduct of this research relied heavily on support provided by collaborating parties. In particular, we wish to thank NSW Department of Primary Industries (NSW DPI) for the provision of a trial site in Orange and the infrastructure support at the Orange Agricultural Institute.

Thanks are also extended to Agriculture Victoria for the provision of trial sites and support from staff at the Horticultural Research Institute, Toolangi and the Ovens Research Station, Myrtleford.

The help and support of the hazelnut growers who have collaborated in the provision of field sites is greatly appreciated. The growers are Jim and Lauren Gleeson at Moss Vale, NSW and John and Connie Zito at Kettering, Tasmania.

Our thanks are also extended to Milan Paskas, Richard Salt, Janet Brown, Jim Beattie, Lyn and Colin McRae, Bruce West and Simon Hammond for the provision of planting material.

Helen Nicol provided advice on experimental design and conducted statistical analyses of some data. Our appreciation is extended to her for the advice and analyses conducted.

We wish to express our appreciation for professional advice and support provided by Professors Shawn Mehlenbacher and Anita Azarenko of the Oregon State University (OSU). We also thank Rebecca (Becky) McCluskey of OSU who spent sabbatical leave at the University of Sydney, Orange and helped us in many aspects of the field studies, including the establishment of testing for kernel evaluation.

Thanks are also extended to Danuta Knihinicki of NSW DPI, who helped with the identification of Big Bud Mite. Our appreciation is extended to other researchers in NSW DPI who assisted in the identification of other pests and diseases.

We wish to thank members of the board of the Hazelnut Growers of Australia Ltd for their support during the duration of this project.

Finally we wish to thank Jean Baldwin for editorial assistance in the preparation of the manuscript.

Basil Baldwin, Karilyn Gilchrist and Lester Snare

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## What the report is about

The report provides detailed information on the potential for growing hazelnuts (*Corylus avellana* L.) in Australia, possible production areas and the characteristics and productivity of a range of varieties. It is the culmination of ten years of research.

## Who is the report targeted at

It is intended to provide valuable information for existing hazelnut growers, those planning to grow hazelnuts, potential investors in the hazelnut industry, individual advisers and policy makers.

## Aims/Objectives

The principal aims/ objectives of this research were to:

- Determine the most suitable hazelnut varieties that could be used for the establishment of a hazelnut industry in south-eastern Australia.
- Assess the effects of geographical region and climate on hazelnut production and varietal performance.
- Assess the productive potential of hazelnuts in Australia.

## Background

Australia imports over $15m of hazelnuts annually. There are opportunities for both import replacement and the development of a range of hazelnut products from Australian grown hazelnuts. Hazelnuts are a health food, being high in monounsaturated fats, vitamin E, calcium and potassium.

Although hazelnuts were introduced into Australia more than 150 years ago, an industry has not developed, yet we have many significant nut and tree fruit industries. Currently, production of hazelnuts in Australia is very small, only about 20-50 tonnes per annum of in-shell nuts, compared with a consumption of about 2,000 tonnes of kernels, equivalent to over 4,000 tonnes of in-shell nuts.

## Methods used

Five field sites were established in NSW, Victoria and Tasmania to study the potential of 25 hazelnut varieties. The research included observations of the flowering characteristics of the varieties, measurements of tree growth, nut yields and assessments of kernel quality. Automatic weather stations were used to monitor climatic conditions at all sites. Plant tissue testing was used to monitor the nutrient levels of the trees annually at all sites. The physical and chemical status of the soils at all sites was also assessed.

## Results/Key findings

### Varietal performance

No single variety gave the highest yield at all sites. The two best yielding varieties were Barcelona and Tokolyi/Brownfield Cosford (TBC). The Italian variety, Tonda di Giffoni, also performed well. The variety Lewis, which was bred at the Oregon State University (OSU), also showed considerable promise. These four varieties are suited to the kernel market. The choice of variety for planting is strongly influenced by the grower's target market. The largest market is the kernel market. Many buyers or processors require specific kernel attributes, such as taste, size, ease of blanching and pellicle thickness. The key attributes of the varieties evaluated are reported. The potential pollinisers for the most promising varieties are given.

### The effects of climate and soils on site selection for hazelnut production

The climatic data recorded at the sites was analysed and compared with key centres of hazelnut production overseas. Generally, hazelnuts require a relatively cool climate with moderate rainfall.

Characteristics of suitable sites:

- Mean temperature in coldest month < $10^{o}$C, to provide sufficient chill
- Mean temperature in hottest month < $31^{o}$C
- Mean average annual rainfall > 750mm, along with supplementary irrigation
- Rainfall pattern dominant in winter and spring, with dry autumn for harvest
- Relatively sheltered sites, with suitable windbreaks if required.
- Deep, well-drained soils with loamy texture and pH 6.0.

### Productive potential

The growth of trees and the nut yields obtained from the Myrtleford site, for the variety Barcelona, were found to be comparable to those obtained from similar experiments in Oregon, USA. The nut yields obtained from the established trees at all the mainland sites were equivalent to 2-2.5 tonnes/ha, which are comparable to yields obtained from productive commercial orchards in Italy, Spain, Oregon, USA and France.

Although establishment costs for hazelnuts are estimated to be $6,000-$8,000 per hectare, established orchards should be capable of providing a gross margin of $3,000-$5,000 per hectare, depending on yield and price received.

## Implications for stakeholders

### Production and product quality aspects

1. There appears to be great potential for hazelnut production in the cooler parts of Australia, such as on the alluvial soils of the river valleys in north-eastern Victoria, in parts of Tasmania and on the Central Tablelands of NSW. Plantings in these areas could lead to a substantial industry.
2. The varieties TBC and Barcelona appear to be well adapted to a range of agro-climatic and soil conditions in South-eastern Australia, with Lewis and Tonda di Giffoni also showing promise.
3. Care needs to be taken in site selection and site management, as hazelnut trees require deep well-drained soils of low acidity with shelter from damaging winds.
4. Supplementary irrigation is required to minimise the effects of erratic rainfall, to ensure adequate growth in spring and to avoid moisture stress in late spring and summer, during the periods of fertilisation, nut development and kernel fill.

### Pest management issues

1. The pest, Big Bud Mite, is present in Tasmania. Some strategies need to be set in place to prevent the spread of this pest to the mainland, where it does not appear to exist at present.
2. There do not appear to be any serious insect pests or diseases of hazelnuts in Australia, apart from Big Bud Mite in Tasmania, giving potential to grow the crop organically and to capitalise on this market opportunity.
3. Sulphur crested cockatoos can be a major pest at the later stages of nut development and during nut fall. Growers need to be prepared for the management of this pest, which appears to be relatively easily scared when flocks first enter an orchard. Regular surveillance of this pest is required to prevent it from feeding in orchards. It is a particular problem in small orchards when landholders are absent. The birds can consume the entire crop if left uncontrolled.

# Recommendations

Recommendations to facilitate the successful and long-term development of the hazelnut industry are:

## Productivity and market acceptance

The experiments conducted indicate that there are four varieties –
Barcelona, TBC, Lewis and Tonda di Giffoni - that have good yield potential and have acceptance for particular niches in the kernel market. At this stage of industry development, these are recommended as the most suitable varieties to grow for that market.

Each of these varieties has its own limitations and there is no ideal variety. If the industry seeks to expand to meet all of Australia's hazelnut needs, other varieties would be required to give higher yields and superior quality kernels. This would probably require a plant breeding and evaluation program, but at this stage of industry development such a program could not be justified.

- It is recommended that further evaluation of new and promising varieties be conducted. This research should involve productivity and quality aspects as well as market acceptance.

It is generally recommended that irrigation systems be established to supplement rainfall deficiencies at key stages in tree and nut development. Micro-sprinklers were used at Myrtleford, Moss Vale and Orange with drip irrigation at Kettering and Toolangi. In France, Spain and, to a lesser extent, in Italy, drip irrigation is used in hazelnut orchards. Many studies on irrigation have been conducted overseas; there is a need to review the literature on irrigation and develop guidelines for growers and identify areas where further research might be needed so that scarce water resources can be used efficiently.

- It is recommended that a review of the literature on irrigation of hazelnuts be conducted and guidelines on irrigation be developed for growers

At Myrtleford, a complete foliage canopy was achieved about seven years after planting. The nut yields reached a plateau at this stage. It is possible that higher yields might have been obtained by removal of trees or some form of pruning to manage the canopy. There will be a need for research on this matter in due course.

- It is recommended that research on plant spacing and canopy management (pruning) be conducted at some future date.

## Industry development and extension

If the hazelnut industry is to develop, it is considered desirable to establish a concentration of growers and plantations in regions suited to hazelnut production such as Northern Tasmania, North-eastern Victoria and the Central Tablelands in NSW.

- It is recommended that groups of growers in these areas work in collaboration, to share knowledge and support any contractors or parties that invest in harvesting and processing equipment to maximise economies of scale.

- It is recommended that funding be made available to facilitate the development of the industry in such areas

## Pest management

Big Bud Mite was identified as a pest of hazelnuts in Tasmania; to date this pest has not been found on the mainland.

- It is recommended that strategies for the control of Big Bud Mite be evaluated and controls be implemented to prevent the spread of this pest to newly planted areas in Tasmania and to the mainland.

## Implementation of the recommendations

1. Industry initiatives.

It is recommended that the peak hazelnut industry body, the Hazelnut Growers of Australia (HGA), develop a strategic plan for industry development that includes priorities for research and that further funding be sought to undertake studies on the topics identified in the section on "Productivity and market acceptance".

2. Community and government support

A key ingredient of industry development will be initiatives taken by growers or groups of growers. They will require support from local communities, such as local councils and funding from state or federal government sources, for regional development initiatives. Such funds will be required to assist with the costs of travel to study production methods, mechanisation and marketing as well as for the development of infrastructure, such as harvesting equipment and processing facilities.

3. Policy development

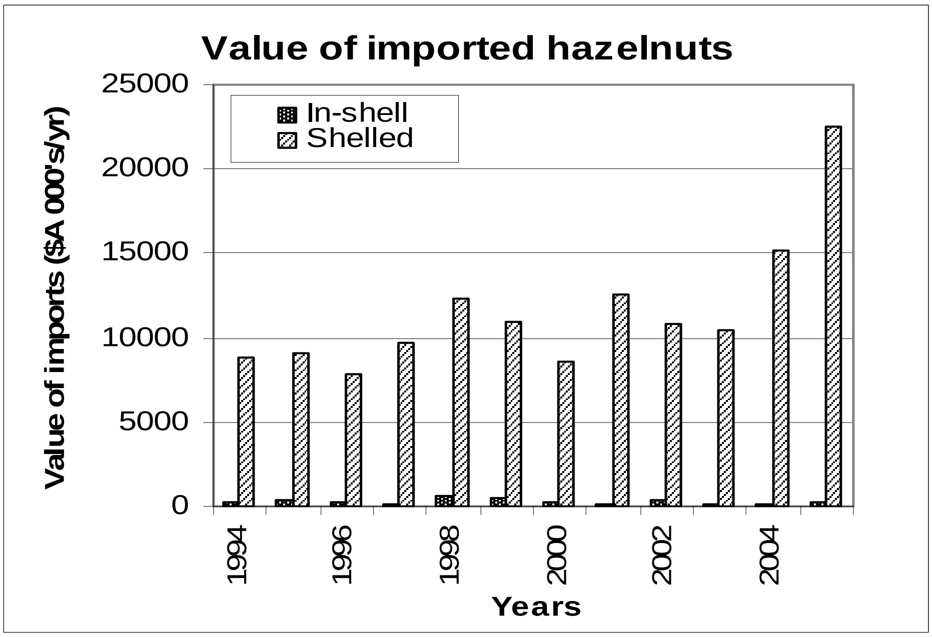
The management or control of Big Bud Mite requires action from government working in collaboration with the industry. It is considered there is a need for action to be taken to mitigate against the spread of this pest, which is a potential threat to the developing industry. A program of action needs to be developed by the industry in conjunction with state government authorities with legislation to support any recommendations that are developed for the management of this pest.

# 1. Introduction

## 1.1 Background

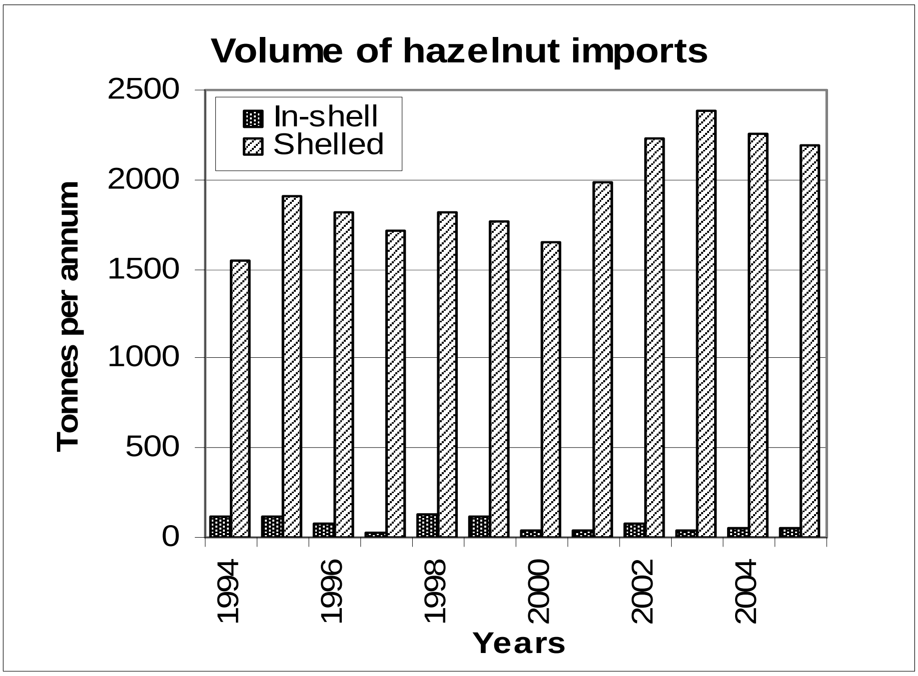
Australia imports an average of approximately $A15 million worth of hazelnuts per annum (Australian Bureau of Statistics, 2006) (Figure 1). The greatest volume of imports is as kernels rather than as nuts in-shell, (Figure 2). The volume and value of imported kernels has increased over the last 10 years.

Figure 1. Annual value of imports of hazelnut kernels and nuts in-shell 1994–2005.




Source: Australian Bureau of Statistics (ABS), 2006

Figure 2. Annual imports of hazelnuts as kernels and nuts in-shell 1994–2005.




Source: ABS, 2006

Although hazelnuts were introduced into Australia more than 150 years ago, to date they have not become established as a significant crop. Although a small industry was established in North-eastern Victoria in the 1920s, most of these plantings were removed to make way for crops giving a higher return, such as tobacco. Currently, there are about 100 hazelnut growers, mainly in Victoria and NSW. Total annual production is estimated to be less than 50 tonnes of nut in-shell. Early introductions of hazelnuts into Australia were probably as plants from England. The names of varieties were listed in early nursery catalogues in Tasmania (Dickinson, 1845) and Victoria (Law Sommer and Co., 1887). Some cultivar evaluation appears to have taken place at Grove in the Huon Valley, but this is not well documented. In 1937, a hazelnut variety trial was commenced at Glen Innes on the Northern Tablelands of NSW. The highest yielding variety was Tonollo, with trees producing up to 7.5kg/tree (Trimmer, 1965). Tonollo does not appear to be a recognised cultivar, but has several characteristics similar to the cultivar Barcelona and is probably closely related. Although many cultivars had been imported in the 1980s and 90s no scientific evaluation of these had been undertaken for Australian conditions prior to the commencement of this research (Baldwin, 1997).

There is limited information available on varietal performance upon which new growers can base their investment decisions. The cost of establishing a hazelnut grove is estimated to be up to $8,000 per hectare for trees, irrigation and land preparation, including liming (Baldwin, 1998). This does not include the establishment of infrastructure such as dams or bores for irrigation. A newly planted hazelnut orchard takes many years to come into full production and provide a return on invested capital. If the Australian hazelnut industry is to progress, it is essential that growers have reliable data on the reproductive characteristics, yield, kernel quality and market acceptance of hazelnut varieties grown under Australian conditions, so that productive and profitable plantations can be established.

Major hazelnut production areas in the Northern Hemisphere lie in the latitude range 40–45$^{o}$N (Alvisi, 1994; Lagerstedt, 1979). These areas are situated in Northern Turkey, Italy, Spain and Oregon, USA, generally within 100km of the coast, with a Mediterranean climate of cool winter and warm summer temperatures.

Australian growers claim that varieties grown in one place may not be suited to another locality, suggesting that there may be some interaction between climate and/or soils and varietal performance. There appear to be differences overseas between varieties, in their adaptation to Mediterranean and continental climates. In Italy, for example, the cultivars which are grown in the mid and southern parts of the country appear to have lower vernalisation requirements for flowering and bud burst, compared with some varieties grown in more continental climates with colder winters, such as Oregon.

The research reported herein is on tree growth, flowering periods, nut yields and kernel quality of a range of hazelnut varieties grown under varying soil and climatic conditions. The word ‘variety’ is commonly used in this report rather than the more technically correct word ‘genotype’, because ‘variety’ is more commonly used in everyday language. Also, most of the genotypes or genetic plant types evaluated were recognised varieties. The word variety is synonymous with the word cultivar or cultivated variety.

This report finalises the research conducted at the four sites on the Australian mainland, but funding has been provided for a further two years for the Tasmanian site, as this site was planted later than the mainland sites.

## 1.2 Objectives

The objectives of this research were to:

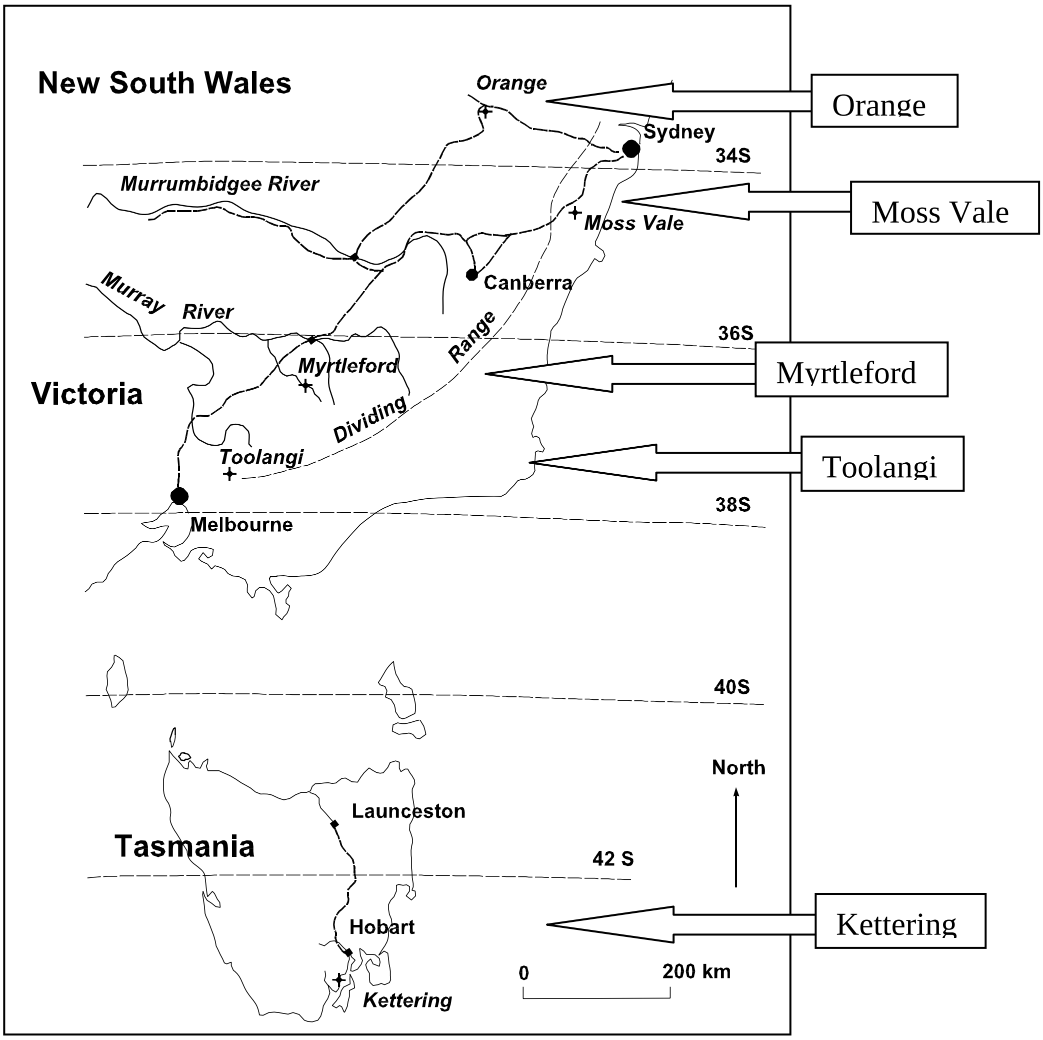
- Determine the most suitable hazelnut varieties that could be used for the establishment of a hazelnut industry in south-eastern Australia.
- Assess the effects of geographical region and climate on hazelnut production and varietal performance.
- Assess the productive potential of hazelnuts (*Corylus avellana* L.) in Australia.

# 2. Methodology

## 2.1 The trial sites

Five variety trials were established in South-eastern Australia at locations where it was considered that hazelnuts could be grown. The five sites were selected to represent different rainfall and temperature patterns as well as different soil types. Two sites were in NSW, at Orange and Moss Vale, two in Victoria, at Myrtleford and Toolangi and one in Tasmania, at Kettering (Figure 3).

Figure 3. Location of the five hazelnut variety sites in South-eastern Australia.




(Note: in the Northern Hemisphere, main production areas lie in the latitude range 40–45$^{o}$N).

Three sites were on land owned and managed by State Government authorities, two were on private land. The mainland sites were situated at lower latitude than the Northern Hemisphere production areas, but had similar temperature patterns (Baldwin and Snare, 1996). The general climatic characteristics of the districts where the sites were established are shown in Table 1.

Table 1. Climatic characteristics of the localities where the hazelnut variety trial sites were established.

| Atribute | ORANGE (Orange Ag. Inst.) | MOSS VALE (Hoskins Street) | MYRTLEFORD (Post Office) | TOOLANGI (Mount St Leonard) | KETTERING (Kingston) |
|---|---|---|---|---|---|
| Distance from coast (km) | 200 | 40 | 200 | 60 | 2 |
| Altitude (m) | 920 | 690 | 300 | 600 | 50 |
| Latitude | 33° 19’ S | 34° 29’ S | 36° 44’ S | 37° 34’ S | 43° 57’ S |
| Mean temp °C hottest month (Feb) | 19.4 | 18.9 | 20.9 | 17.5 | 16.3 |
| Mean temp °C coldest month (July) | 5.2 | 6.6 | 7.3 | 6.1 | 7.5 |
| General rainfall pattern | Winter – spring dominance, erratic in summer | Summer – autumn rain, dry spring | Winter – spring rain, dry summer | Rain all months, winter – spring dominance | Erratic summer rainfall, spring dominance |
| Mean annual rainfall (mm) | 949 | 981 | 905 | 1390 | 677 |
| Growing period rain (Sept – Feb) (mm) | 493 | 945 | 387 | 686 | 341 |
| Three wettest months in succession | July – Sept | Jan – Mar | June – Aug | Aug – Oct | Oct – Dec |
| Mean rainfall March (mm) | 55 | 93 | 60 | 88 | 52 |
| Mean number of rain days in March | 6.8 | 11 | 6 | 12.9 | 9.3 |
| Annual rainfall variability | 0.68 | 0.7 | 0.66 | 0.49 | 0.7 |
| Mean annual evaporation (mm) | 1460 | 1500 | 1460 | 1020 | 985 |
| Soil type | Krasnozem | Red podsol | Alluvial | Krasnozem | Yellow podsol |

Source of climatic data: Commonwealth Bureau of Meteorology, 2002.

The principal objective of selecting the range of site locations was to ascertain whether there were any interactions between variety and climate. It is recognised that, in addition to climatic variation, the sites differed with respect to soil, which was found to be a very significant factor. The soil differences were assessed and monitored. Standard procedures for site management were implemented, as much as it was feasible, to minimise variation due to management.

## 2.2 Soils of the trial sites

The soil profile at each site was described from soil samples taken down to 600mm depth from four sampling points within each site. The soils at both Orange and Toolangi were volcanic in origin, having been developed from basaltic lava flows. The basaltic rock had been weathered over millions of years to form deep, red krasnozem soils (Table 2). The soil at Myrtleford was alluvial and was situated on a relatively recent floodplain or terrace. This soil was deep, with varying texture down the profile, due to the changing deposits of material that had been spread across the floor of the Ovens Valley, over time. Generally, this alluvial soil had a coarser texture than the krasnozems. The Moss Vale site was on a red podsol derived from sedimentary rock. The Kettering site was on a podsolic soil derived from fine sandstone. Podsolic soils typically have a duplex profile with a heavier textured, more clayey subsoil or B horizon, which can have poor drainage characteristics. The sites with podsolic soils had the poorest drainage.

Table 2. General description of soil profiles at the five field sites. Soil pH values were prior to liming.

| Location | Soil type | Characteristics |
|---|---|---|
| Orange | Krasnozem | 0–300mm A horizon, red brown clay loam, pH 5.5; overlying red light clay, pH 6.0. Both A and B horizons were well structured. |
| Moss Vale | Red podsol | 0–200mm A horizon, dark reddish brown sandy loam, pH 4.5 – 5.0; overlying reddish brown sandy clay loam, pH 5.5 |
| Myrtleford | Alluvial | Brown sandy loam, undifferentiated profile, pH 4.5 – 5.0; well drained. |
| Toolangi | Krasnozem | 0–300mm A horizon, brown clay loam, pH 5.0; overlying red brown light clay, pH 5.5. Both A and B horizons were well structured. |
| Kettering | Yellow podsol | 0–250mm A horizon, grey brown fine sandy loam, pH 5.0; overlying yellow brown clay. |

## 2.3 Soil sampling and analysis

Prior to planting, soil samples were taken across each of the sites from the top 10cm of soil and combined to produce a composite sample of about 500g for each site. The composite samples were analysed for their nutrient availability (Table 3).

Table 3. Soil analysis data for each of the hazelnut variety trial sites, prior to liming and planting.

| Attributes | SITES | | | | | Minimum Desirable Levels [1] |
|---|---|---|---|---|---|---|
| | Orange | Moss Vale | Myrtleford | Toolangi | Kettering | |
| $pH_{Ca}$ (1:5 soil $CaCl_2$) | 5.7 | 4.3 | 4.5 | 4.5 | 5.5 | $pH_w$ 5.0 |
| Phosphorus (P) Bray test (mg/kg) | 21.0 | 9.0 | 7.0 | 3.0 | 141.0 | N/A |
| Total carbon ( %) | 2.0 | 3.8 | 3.3 | 6.6 | 3.5 | N/A |
| Potassium (K) meq/100g | 0.6 | 0.3 | 0.6 | 0.5 | 1.0 | 0.2 |
| Calcium (Ca) meq/100g | 6.8 | 3.9 | 5.6 | 3.8 | 12.6 | 5.0 |
| Magnesium (Mg) meq/100g | 0.7 | 1.4 | 2.3 | 0.8 | 2.7 | 0.5 |
| Sodium (Na) meq/100g | <0.1 | 0.2 | <0.1 | 0.1 | 0.11 | <5 |
| Aluminium meq/100g | <0.1 | 0.6 | 0.2 | 1.4 | <0.1 | <5 [(2)] |
| Total exchangeable cations (mg/kg)[2] | 8.1 | 6.4 | 8.8 | 6.6 | 4 | N/A |
| Ca/Mg ratio | 9.7 | 2.8 | 2.4 | 4.8 | 4.8 | 2.0 |
| Boron (B) (mg/kg) | <2 | <2 | <2 | <2 | <2 | N/A |

Source: [1] Olsen, 1995 [2] Aluminium sensitive crops. Peverill et al., 1999. N/A Not available

The soil pH and nutrient data was used to determine lime and fertiliser requirements for the sites. All sites were limed before planting to reduce any potential adverse effects of soil acidity. Olsen (1995) considered that $pH_w$ 5.0 (1:10 soil: water) is the minimum that is suitable for hazelnut growing in Oregon. In Australia, pH is generally measured in a 1:10 calcium chloride solution ($pH_{Ca}$). Values for $pH_{Ca}$ are generally 0.5 units lower than those for water, indicating that the sites were close to the minimum desirable pH level before liming. Five tonnes/ha of ground limestone were applied before planting at all sites, except Myrtleford, where 7 tonnes/ha was applied. A further 7 tonnes/ha of lime was applied at Orange in 2001 with an additional 2 tonnes/ha being applied at Orange in 2004.

The available phosphorus level varied considerably from low levels, less than 10mg/kg, as recorded at Toolangi, Myrtleford and Moss Vale to a very high level of 141 mg/kg at Kettering. This very high level was probably due to previous applications of chicken manure to the site. The desirable minimum level of phosphorus for hazelnuts is unclear. Olsen (1995) recorded no response to phosphorus fertilisers in Oregon. Possibly Oregon soils may be relatively high in this element. In Australia, temperate pasture species generally respond to applied phosphorus, when soil levels are below 8mg/kg (Abbott and Vimpany, 1986).

Potassium and calcium levels were generally considered adequate, with an appropriate Ca/Mg ratio. Sodium levels were low indicating that soils were neither sodic nor saline.

Available aluminium was extremely high at Toolangi and relatively high at Moss Vale, being 20% and 9%, respectively, of the total exchangeable cations. No data has been found on the sensitivity of hazelnuts to aluminium. However, when soil $pH_{Ca}$ levels are above 5.0, aluminium toxicity is not usually considered to be a problem (Abbott and Vimpany, 1986). As the growth of hazelnuts is favoured by soils that are not very acid, it is possible that hazelnut trees could be sensitive to aluminium and hence the recommendation to apply lime before planting (Olsen, 2001).

## 2.4 Varieties

A total of 25 hazelnut varieties were evaluated for growth and productivity, with data on flowering also being obtained on several additional varieties that were included in the trees surrounding the treatment plots. The varieties evaluated were mainly those suited to the kernel market, but also included varieties suited to the in-shell trade and others whose main role was as pollinisers (Table 4).

The varieties included in the trials were mainly named cultivars of European and North American origin, but also included some Australian selections or varieties, that have been given names such as Atlas, Tonollo and Tokolyi/Brownfield Cosford. The planting material was obtained chiefly from specialist hazelnut propagators, but some material was also obtained from growers. Most varieties were bare rooted, but a few had been grafted onto rootstocks of other varieties of the European hazelnut (*Corylus avellana* L.). These grafted plants had a metal tie placed above the graft and were planted with the graft below the ground to encourage them to be self-rooting - that is, to form roots on the scion wood.

As most sites had limited space and not all varieties were available at the beginning of the research, not all 25 varieties were planted at all sites. Moss Vale was the smallest trial site, where only 12 varieties were planted. These 12 varieties were common to all sites. At Orange and Toolangi, an additional four varieties were planted, with a further eight varieties added at Myrtleford. There were 20 varieties planted at Kettering. The four mainland sites were planted first, as initially it had not been possible to find a suitable site in Tasmania. Each of the mainland sites comprised four replicates of the varietal treatments in a randomised block design. At Orange and Toolangi there were four trees of each variety in each replicate, whereas at Moss Vale and Myrtleford there were only two trees per variety per replicate. Planting at the Orange and Toolangi sites was commenced in July 1995 while planting commenced at Myrtleford and Moss Vale in July 1996. Planting did not commence at Kettering until 1999. At Kettering, it was decided to use only three replicates of 20 varieties with two trees per replicate, due to limited space.

The reason for changing from the initial plan of planting four trees per varietal plot to only two trees arose from the difficulty of obtaining sufficient planting material as well as the limitations of space. At the Oregon State University, an experimental design is favoured in which single tree replicates are used in the evaluation of varieties and new selections (McCluskey et al., 1997).

Table 4. Varieties planted at the five hazelnut variety field sites.

| Varieties | Potential use | Country of origin | Original source of material [1] | Supplier of planting material [2] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | OR | MV | MY | TL | KT |
| Atlas | Kernel/ In-shell | Australia | NSW Agriculture, Orange | MP | MP | MP | MP | |
| Barcelona | Kernel/ In-shell | USA | Oregon USA | RS | RS | RS | RS | MP |
| Butler | Polliniser /In-shell | USA | Oregon USA | RS & MP | RS | RS | MP | MP |
| Casina | Kernel | Spain | Oregon USA | CO | CO | CO | CO | MP |
| Daviana | Polliniser | England | Oregon USA | | | RS | | |
| Eclipse | Kernel | Australia | Milan Paskas, Victoria | MP | | MP | MP | MP |
| Ennis | In-shell | USA | Oregon USA | RS | RS | RS | RS | MP |
| Hall's Giant | Late polliniser | Germany | Oregon USA | RS | RS | RS MP | RS | |
| Hammond 17 | Kernel/ In-shell | Australia | S. Hammond, Orange NSW | | | SH | | SH |
| Lewis | Kernel | USA | Oregon USA | BW | | BW | | MP |
| Merveille de Bollwilller | Polliniser | France | Knoxfield Victoria | | | MP | | MP |
| Montebello | Kernel | Italy | Knoxfield Victoria | | | MP | | MP |
| Negret | Kernel | Spain | Knoxfield Victoria | RS | | RS | RS | |
| Royal | In-shell | USA | Oregon USA | | | RS | | MP |
| Segorbe | Kernel | France | Knoxfield Victoria | MP | MP | MP | MP | MP |
| Square Shield | Kernel | Australia | Milan Paskas, Victoria | MP | | MP | MP | MP |
| Tonda Gentile delle Langhe (TGDL) | Kernel | Italy | Knoxfield Victoria | MP | | MP | MP | MP |
| Tokolyi/Brownfield Cosford (TBC) | Kernel | Australia | I Tokolyi/ J. Brown, Victoria | JBr | JBr | JBr | JBr | MP |
| Tonda di Giffoni | Kernel | Italy | Italy | JBe | JBe | JBe | JBe | JBe |
| Sicilian type "Tonda Romana" | Kernel | Italy | Knoxfield Victoria | MP | MP | MP | MP | MP |
| Tonollo | Kernel/ In-shell | Australia | NSW Agriculture | | | NSW Ag | | |
| Victoria | In-shell | Australia | T. Baxter, Knoxfield Victoria | MP | MP | MP | MP | MP |
| Wanliss Pride | Kernel/ In-shell | Australia/ Turkey | T. Cerra, Victoria | JG & MP | JG | JG | JG | MP |
| Whiteheart | Kernel | New Zealand | New Zealand | | | | | MP |
| Willamette | Kernel | USA | Oregon USA | BW | | RS & MP | | MP |

Footnote:

1. As most varieties were imported, an attempt was made to identify the source of the original imports or, where this was unknown, the main importer or point of entry into Australia.
2. Key to suppliers of planting material: MP – Milan Paskas, RS – Richard Salt, BW – Bruce West, CO – Chris Offner, SH – Simon Hammond, JBr – Janet Brown, JBe – Jim Beattie, JG – Jim Gleeson, NSW Ag – NSW Department of Primary Industries.

At least one buffer row was used to surround the treatment trees at all sites. These buffer rows included a wide range of hazelnut polliniser varieties. This design was used to reduce any edge effects on the treatment trees and also to maximise the period and diversity of pollen shed throughout the block, thereby minimising yield limitations from inadequate pollination.

It was not possible to plant all variety treatments in the main year of planting due to the unavailability of some varietal planting material. This applied particularly to the cultivars Willamette and Lewis, which were relatively recent releases from the breeding program at Oregon State University and had only recently been imported into Australia.

All sites were planted with rows five metres apart and trees three metres apart down the rows, equivalent to a density of 660 trees per hectare. Trees were planted in July or August when they were dormant.

Observations on characteristics of tree shape, fruits, nuts, kernels, time of pollen shed, female bloom and bud burst were all used to verify whether the imported varieties were true to type. Nut samples were sent to Professor Shawn Mehlenbacher of Oregon State University to obtain his views on whether the imported, named varieties were true to type. The only variety that it was considered was incorrectly named was that provided as “Tonda Romana”. It was not possible to provide the specific identity of this variety, but the variety shows the characteristics of Sicilian types and is probably closely related to Montebello. In this report it has been referred to as “Sicilian”.

## 2.5 Measurements and recordings

Periods of pollen shed and female bloom were recorded annually. These were first recorded in the second winter after planting, for most trees. Although pollen shed was considered to have commenced when a few catkins were shedding pollen, the main period of pollen shed was recorded as the time between the date when about 15% catkins had started to shed pollen until only about 15% of the catkins were still shedding. These records provided information on the commencement and duration of pollen shed.

Figure 4. Extended catkins, mid pollen shed, and small female flowers in early bloom

The relative number of catkins per variety was recorded. This was based on a relative 1–5 score with 5 being the rating for the variety that appeared to have the greatest number of catkins at that site in the year of recording; these figures are therefore relative between varieties, at the given site, for the year of recording. Records were also kept of the date when several fully opened female blooms were first observed on the trees; this date was considered to be the beginning of bloom. The end of bloom was recorded as the date when few blooms were remaining. This end point tended to be vague as, towards the end of bloom, stigmas had a withered, dark purple appearance. The recorded dates provided an estimate of the commencement and duration of female bloom.

The dates when the vegetative buds started to open, indicating bud burst, were also recorded. The observations on pollen shed, female bloom and bud burst were taken on a weekly basis.

General observations of tree growth were made throughout the period of the experiment. In April of each year, the butt circumferences of all treatment trees were measured 10-15 cm above the ground. These measurements were used to make comparisons of tree growth between years and varieties.

Nut yields were generally obtained by collecting all of the fallen nuts from under the trees in late summer to early autumn. The nuts were dried at 30$^{o}$C for two to three days, then cleaned and any husks removed before weighing. For the higher yielding varieties, samples of 100 nuts from each pair of treatment trees were weighed and cracked. For lower yielding varieties, generally only one composite sample from trees across all replicates was cracked out. All the kernels were weighed to obtain an average kernel weight, the number of blank nuts and kernels with defects were counted and recorded. Kernel defects included shrivelled, poor fill, black tips, mouldy, brown stain and twin kernels.

Blanching characteristics were assessed by heating samples of whole kernels in an oven at a temperature of 130–150$^{o}$C for 15 minutes, followed by rubbing the blanched kernels in a cloth to remove any loose skin or pellicle. Ratings of the degree of blanching were made using the 1–7 rating scale that has been used in the Oregon State University cultivar evaluation programme (McCluskey et al, 2001), where 1= 100% removal and 7= nil removal of the pellicle.

## 2.6 Leaf analysis

During February of each year, from the second year of leaf, composite samples of at least 100 leaves were obtained from each site. These samples were collected at random across each site and analysed for the total content of selected elements. This data was used to assess the general nutrient status of the experimental trees and to determine fertiliser requirements at each site.

## 2.7 Automatic weather stations

Automatic weather stations were purchased from the Queensland company “Environdata” and were installed at each site. These weather stations collected data on temperature, relative humidity, wind run, wind direction, solar radiation and rainfall on a continuous basis. The units were programmed to calculate estimates of potential evapotranspiration loss, through the use of the Penman formula. Potential evapotranspiration is the loss of water due to evaporation from the soil and transpiration from plants, when plants are growing in soil that is near field capacity. The potential water loss may be higher than actual loss when soils dry out and plants reduce transpiration rates due to the closure of stomata in their leaves. Figures 9 and 10 show the records of monthly rainfall and estimated potential evapotranspiration for the sites at Kettering and Myrtleford, respectively. The relatively even seasonal pattern of low evapotranspiration in winter rising to a maximum in summer contrasts markedly with the erratic rainfall. The very high spring rainfall in 2000 is apparent at both sites. In 2002 and in 2003 there was very little rainfall in January and February at Myrtleford. At Kettering, very little rain fell in the period December, 2005 to April 2006.

The weather stations were programmed to measure the number of chilling hours: that is, the hours when the temperature was in the range 0–7°C. Chilling hours influence the time of pollen shed, female bloom and leaf out as discussed in sections 3.1 and 3.2.

## 2.8 Soil samples

Samples from the top 0–100mm of soil were collected, in March 2003 and again in March 2006, to assess the available nutrients in those years and to compare them with the nutrient status of soil samples taken at the commencement of the experiments.

## 2.9 Fertiliser

No fertiliser was applied to young trees in the year of planting at any of the sites, as the roots of young hazelnut trees are considered to be very sensitive to fertiliser at this early stage.

In subsequent years, Nitram (ammonium nitrate, which contains 34% nitrogen) was sprinkled around the trees in the Spring, at the times and rates shown in Table 5. As trees came into production, an NPK mix of Pivot 400 was used to boost levels of phosphorus (P) and potassium (K) which may have been removed in harvested nuts. Nitrogen fertilisers are the main fertilisers recommended for young developing hazelnut trees (Olsen, 2001). The level of nutrients measured in the leaf samples (Table 13) was used as a basis for determining fertiliser applications to meet the nutrient requirements of the trees. No nutrient deficiencies were observed.

Table 5. Typical rates of fertiliser elements applied per tree at the field sites. The actual fertiliser used varied with sites and circumstances.

| Year from planting | Rate of element (g/tree) | | | |
|---|---|---|---|---|
| | Nitrogen (N) | Phosphorus (P) | Potassium (K) | Sulphur (S) |
| 3 | 10 | | | |
| 4 | 15 | | | |
| 5 | 20 | | | |
| 6 | 25 | | | |
| 7 onwards | 30 | 5 | 8 | 9 |

In Tasmania, a slow release fertiliser was used from 2001 onwards. The slow release fertiliser was used on that site because it was suspected that damage from nitrogen fertiliser had occurred following very high rainfall and saturated soils in September and October, 2000. At Orange Calam ®, a lime coated nitrogen fertiliser, was used. The lime coating was to reduce the acidifying effects of the nitrogen fertiliser.

## 2.10 Irrigation

Micro-sprinkler irrigation systems were installed at all sites except Orange and Kettering, where drip irrigation was initially used. In 2002/03, the irrigation system at Orange that comprised two 4L/hour drippers per tree was changed to a system of a single micro-sprinkler per tree to provide a greater distribution of water within the tree rows. This change was made to try to improve tree growth at Orange.

Tensiometers were used in an attempt to monitor soil moisture levels and as an aid to estimate irrigation requirements. The approximate quantities of irrigation water applied per tree, in the six seasons 2000/01–2005/06, are shown in Table 6. At the Moss Vale and Myrtleford sites, relatively high rates of water were used in 2002/03 in an attempt to compensate for the severe rainfall deficits at those sites. The restricted supply of water at Moss Vale limited water usage to a level lower than desirable, in that season. The effects of this are discussed later, in the section on tree growth. At Toolangi, the water supplies were limited and were in greater demand for other research programs, making it impossible to irrigate the hazelnut research site in 2002/03, despite the incredibly dry season. The summer of 2005/06 was very dry at Kettering, hence the high level of irrigation.

Table 6. Approximate quantities of irrigation water applied as litres (L) per tree at the five sites on a per season basis.

| Sites | Growing seasons | | | | | |
|---|---|---|---|---|---|---|
| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 |
| Kettering | 100 | 100 | 250 | 870 | 790 | 1800 |
| Orange | 650 | 1120 | 1220 | 3000 | 1560 | 2450 |
| Moss Vale | 268 | 737 | 2820 | 2950 | 3150 | N/A |
| Myrtleford | 252 | 2650 | 4240 | 1170 | 900 | 2800 |
| Toolangi | 250 | nil | nil | N/A | N/A | N/A |

Note: N/A Not applicable as site not being used for research

At a tree density of 660 trees per hectare, irrigation levels of 1500 litres per tree are equivalent to 1 megalitre of water per hectare. It can be seen that, at Myrtleford, water use was up to nearly 3 megalitres per hectare in the very dry season of 2002/03. Studies of water use by fully developed hazelnut trees in Bordeaux, France, by Mingeau and Rousseau (1994), indicated a daily usage of 50L per tree in mid-summer or 4500L per tree for the three summer months, which is similar to the amount of water applied at Myrtleford in 2002/03.

## 2.11 Orchard management

After planting, the young trees were mulched to minimise moisture loss from the soil around the trees. Straw and old hay were used for this purpose. The stems of the trees were painted with a dilute mixture of white acrylic paint to minimise sunburn. The weeds in the tree rows were sprayed with Roundup and hand weeded as necessary. The strips between the trees were mown to encourage a short grass and clover sward.

Suckers were removed from the base of each tree by hand in the first two to three years. In subsequent years, Sprayseed, a paraquat-diquat herbicide mixture, was used at regular intervals to kill young suckers in the spring and early summer. This was supplemented by hand cutting, as required.

Pruning of trees was undertaken from about the third year of planting to shape trees into an open vase type and to remove any limbs that affected orchard operations. At Myrtleford, it was necessary to do significant pruning each winter from the seventh year of leaf to minimise limbs crossing within the rows between varieties and across the rows. This was necessary to minimise the mixing of nuts from adjacent varieties at nut fall and to facilitate mechanical harvesting.

## 2.12 Pests and diseases

Site managers made observations of pests and diseases throughout the experimental period and took action to manage any pest and disease problems.

### Pests

A number of pests were recorded from the trial sites over the funding period. Collected specimens were identified by the Australian Scientific Collections Unit, NSW Department of Primary Industries in Orange. These recordings have been incorporated into Biolink, an Australian database, and place hazelnuts alongside other major traditional and developing crops. This data is relevant to quarantine issues, biosecurity and potential market protection for a developing industry. Nearly all of the accessions in the collection relating to hazelnuts have been sourced over the duration of this research project.

Many of the pests have a limited impact, with aphids and borers being the most destructive to date.

Recorded pests include:

- painted apple moth (*Teia anartoides*)
- cerambycid borer, a longicorn beetle (*Pachydissus sp.*)
- fruit tree borer (*Cryptophasa melanostigma*)
- green peach aphid (*Myzus persicae*)
- black aphid (*Myzocallias coryli*)

Infestations of aphids were controlled at some sites with the insecticide Pirimor. This insecticide was only used when aphids were considered to be at damaging levels.

Borers generally affected trees with a poor health status. The Orange site, where the trees had made relatively poor growth, had relatively high borer counts, with none being recorded at Myrtleford. Borers are a serious pest, as the larvae can kill whole trees by girdling or ring-barking the branches or trunks.

Big Bud Mite (*Phytoptus avellanae*), a serious pest of hazelnuts in Europe and North America, was observed on old collections of hazelnut trees in Tasmania. Infected trees were found in the Hobart Botanical Gardens, an old arboretum at Perth, in the Northern Midlands where a plant nursery was once located and at a site adjacent to the North Esk River at Hadspen. It appears this pest is relatively widespread in Tasmania in older plantations and was also seen in one plant nursery. It was not initially present in the trial site at Kettering, but in 2005 some infected trees were found in the commercial orchard adjacent to the research site. It is suspected the pest was introduced in hazelnut stock in the early years of plant introduction into Tasmania. In 1998 and 1999, a number of bud and leaf samples were collected from sites in Tasmania and on the mainland. Big Bud Mite was only found on samples from Tasmania (Snare and Knihinicki, 2000). It is considered important that this common and damaging pest be contained, or preferably destroyed, in Tasmania.

### Diseases

The major disease recorded from trial sites was Hazelnut Blight (*Xanthomonas corylina*). Despite preventative applications of copper, many of the trees at the Orange site were infected by this disease in the spring of 2001. Die-back of twigs was noted in most varieties, with early leafing varieties appearing to be the most affected. Hazelnut blight has not been a serious problem at any of the other sites. Copper oxychloride as either Kocide or Cuprox was applied in May at 50% leaf fall to manage this disease in the young developing trees.

## Other pests

Other pests have included hares, deer and wallabies that have damaged young plants from time to time. An electric fence was erected around the Moss Vale site to supplement the existing rabbit and stock-proof fence, as deer and wallabies were a pest at that site, which abuts a State Forest. Rabbit-netting and electric fencing was erected around the Kettering site where rabbits and wallabies were also a problem.

Sulphur crested cockatoos (*Cacatua galerita*) have been a major pest at harvest time, causing large losses of nuts at Orange, Toolangi and eventually at Myrtleford in 2006, as discussed under nut yields. This pest was managed at Moss Vale through the use of bird scaring tactics. It seems to be less common in Tasmania.

# 3. Results

## 3.1 Flowering

Hazelnuts are wind pollinated. The pollen from the catkins drifts through the orchard on warm dry days in winter and is caught by the stigmas of open female flowers. For pollination to be successful, the male pollen donor variety must be genetically compatible with the female receptor variety. The keys to successful pollination are:

- Good supplies of viable pollen
- Synchronous flowering of genetically compatible varieties

Effective pollination is an essential component of high productivity. When planting a hazelnut orchard, it is important to know which varieties will pollinate the selected nut-bearing, main crop varieties and when these pollinisers will shed their pollen.

Data was collected on the commencement of pollen shed, that is the date when an estimated 15% of the catkins on trees of a given variety had commenced shedding pollen. The duration of shed was from that date until only a few catkins were still shedding pollen. Similarly, the dates of commencement of female bloom and the periods of bloom were recorded. This data was tabulated in spreadsheets to determine the variation in time when pollen shed and bloom commenced between sites and within sites. The objective of the data analysis was to try to understand the underlying factors that influenced flowering and to attempt to develop a formula that could be used to predict dates when pollen shed and bloom would be likely to commence and the suitability or otherwise of different environments for hazelnut production.

Differences were found between seasons and between sites in the dates when varieties commenced both pollen shed and female bloom. For example, at Orange, Barcelona was on average, over the 8 year period 1998 – 2005, found to commence pollen shed on Julian day 175 and to commence female bloom on Julian day 203. However, in the winter of 2002, Barcelona started to shed pollen much later (Julian day 189) and started later into bloom (Julian day 217), about 2 weeks later than average in each case. In the following winter of 2003, it was more than 22 days earlier in pollen shed and was 22 days earlier in bloom, Julian days 146 and 181 respectively. Similar variations were observed with other varieties when a range of early to late flowering varieties was compared in those years (Table 7).

Table 7. Variation in dates (Julian days) of commencement of pollen shed and female bloom for six varieties at Orange, the eight (8) year mean compared with Julian days in 2002 and 2003.

| | Mean | | 2002 | | 2003 | |
|---|---|---|---|---|---|---|
| | Pollen shed | Bloom | Pollen shed | Bloom | Pollen shed | Bloom |
| Tonda di Giffoni | 171 | 194 | 182 | 217 | 146 | 181 |
| Barcelona | 175 | 203 | 189 | 217 | 146 | 181 |
| Ennis | 184 | 240 | 189 | 245 | 160 | 237 |
| TBC | 199 | 216 | 210 | 231 | 167 | 216 |
| Daviana | 208 | 230 | 210 | 231 | 195 | 230 |
| Hall's Giant | 226 | 238 | 224 | 245 | 209 | 230 |
| Means | 194 | 220 | 201 | 231 | 171 | 213 |

Note: "Julian days" are the number of days that have elapsed in a year since the first of January. There are 365 Julian days in the year. The Julian day for any given calendar date is calculated by adding all the days from the beginning of January. For example, February 1 is Julian day 32 (31 days in Jan plus 1 day in February). Similarly, April 1$^{st}$ is Julian day 91 in a non leap year (Jan 31 + Feb 28 + Mar 31 + April 1).

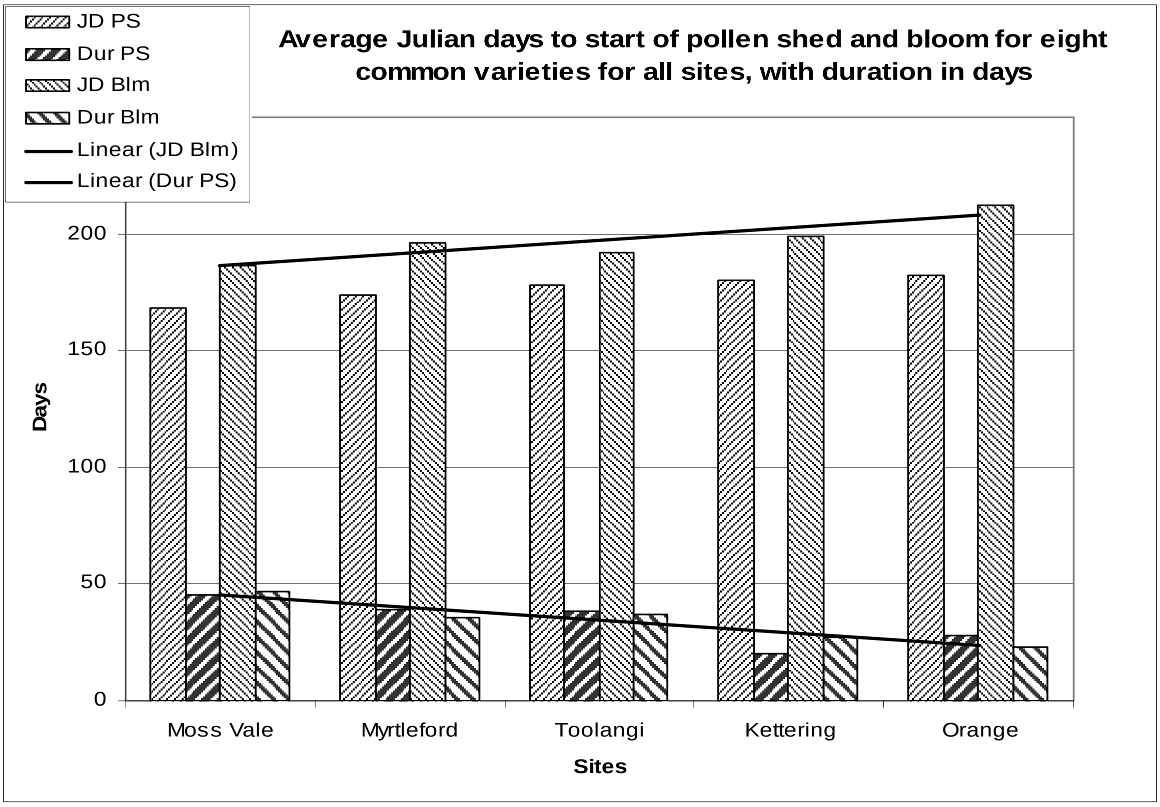
Differences between sites were also found in the dates when pollen shed and bloom commenced. Comparing Orange with Myrtleford, the 8 year average date for the commencement of pollen shed and bloom for a set of eight (8) varieties at Orange was Julian days 182 and 212, compared with Julian days 174 and 197 for Myrtleford (Table 8). That is, pollen shed and bloom occurred on average one to two weeks earlier at Myrtleford.

Table 8. The average Julian days for the commencement of pollen shed and female bloom for eight varieties grown at Orange and Myrtleford.

| | Orange | | Myrtleford | |
|---|---|---|---|---|
| Variety | Pollen shed | Bloom | Pollen shed | Bloom |
| Barcelona | 175 | 203 | 165 | 190 |
| Ennis | 184 | 240 | 175 | 212 |
| Segorbe | 173 | 219 | 168 | 212 |
| TBC | 199 | 216 | 185 | 204 |
| Tonda di Giffoni | 171 | 194 | 170 | 182 |
| Sicilian | 172 | 198 | 164 | 181 |
| Victoria | 184 | 230 | 182 | 205 |
| Wanliss Pride | 198 | 198 | 183 | 188 |
| Means | 182 | 212 | 174 | 197 |

When the same eight varieties were compared across all five field sites, it was found that, in general, the varieties commenced both pollen shed and female bloom earliest at Moss Vale, the site with the mildest winter temperatures, and latest at Orange, the site with the coldest winter temperatures (Figure 5). There also appeared to be a trend towards a shorter period of pollen shed and bloom, the later the varieties came into pollen shed or bloom.

Figure 5. The average number of Julian days to the commencement of pollen shed and bloom for a set of eight varieties grown at the five field sites, along with the duration (days) of pollen shed and bloom.

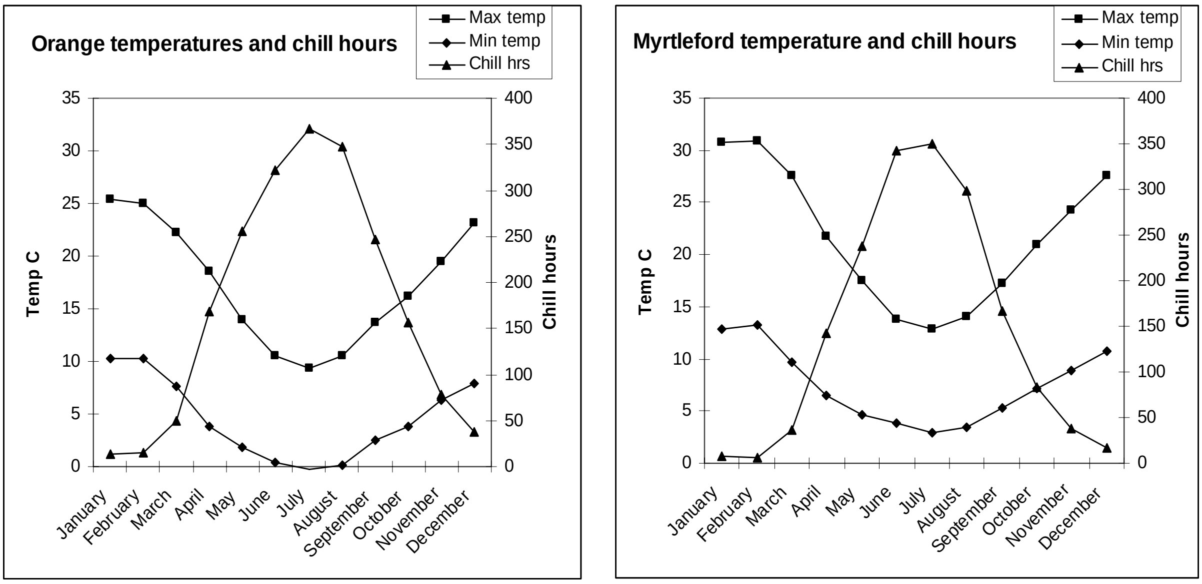



Note: JD PS = Julian day of commencement of pollen shed. Dur PS = Duration (days) of pollen shed. Blm = Female bloom. Linear is the statistical relationship between days and site, a temperature effect.

Catkins and female flowers require specific levels of chilling to break their dormancy. Chilling needs to be followed by warmth to enable the catkins and female flowers to develop. An experiment was conducted by Mehlenbacher (1991) to estimate the chill hour requirements for both catkins and female flowers in Oregon. This was done, during the winter, by cutting small branches from a range of cultivars at weekly intervals in the field and placing them in a glasshouse at 20°C. The chill hours were considered to be the number of hours in the range 0–7°C that were recorded in the field, to the date when material was cut and transferred to the glasshouse. The chill hour requirements for catkin development or female bloom were the number of chill hours that had been accumulated to the week of cutting when pollen shed or female bloom was first observed in the glasshouse.

When the pattern of mean monthly temperatures and chill hours are compared between Orange and Myrtleford (Figure 6), it can be seen that the mean monthly temperatures at Orange were lower than those at Myrtleford. The lower mean temperatures at Orange were associated with higher monthly chill hours at that site, assuming that chilling occurs in the temperature range 0-7°C. On this basis, average chill hours at Orange to the end of May were 482, compared with 415 chill hours for Myrtleford.

Figure 6. Pattern of mean temperatures and chill hours at Orange and Myrtleford. Average chill hours (0-7°C) at Orange to end May = 482, compared with Myrtleford = 415.




When the average Julian days for the commencement of both pollen shed and bloom are compared between Orange and Myrtleford (Figure 6), it can be seen that on average, pollen shed and bloom commenced earlier at the warmer site, Myrtleford, than at Orange. This seems contrary to the concept that chill is needed to overcome the dormancy of the flowers. There are two possible explanations for this:

One is that although chill was overcome earlier at Orange, any post-chill warmth requirements were accumulated more slowly at Orange, due to the lower mean temperatures in June and July at that site (5°C at Orange, compared with 8°C at Myrtleford). The need for warmth after chilling is well documented for many deciduous fruit crops such as almonds (Rattigan and Hill, 1986; Egea et al 2003) peaches (Richardson et al, 1975; Couvillon and Erez, 1985) and cherries (Felker and Robitaille 1985), but is not documented for hazelnuts.

An alternative explanation is that the temperature range 0-7°C is not the best indication of chilling. Richardson et al (1974) found that in studies conducted on the chill requirements of peach flowers, some temperatures were more effective than others for chilling. It was found that temperatures in the range 2.5–9.1°C were the optimum for that species. A model was developed that related temperature to chill units, in which temperatures of 2.5-9.1°C were optimal and were given a chill unit value of 1. Less chilling was attributed to temperatures below 2.5°C and above 9.2°C. As these were less effective, they were given a lower effective chill unit value (Table 9). Temperatures below 1.4°C and in the range 12.5-15.9°C were considered to be ineffective, whereas above 16°C temperature was found to have a negative effect on chilling. It seems possible that these temperatures might have similar chilling effects on hazelnuts. In order to obtain a better understanding of the effects of chill and warmth on pollen shed and bloom, studies are being undertaken in controlled temperature environments at the Charles Sturt University campus at Orange.

Table 9. The relationship between temperature and effective units of chill (Richardson et al 1974)

| Temperature range (°C) | Effective chill units |
|---|---|
| <1.4 | 0 |
| 1.5 – 2.4 | 0.5 |
| 2.5 – 9.1 | 1.0 |
| 9.2 – 12.4 | 0.5 |
| 12.5 – 15.9 | 0 |
| >16.0 | negative effect |

Based on the Richardson model, it can be seen that, at Orange, minimum temperatures are in the optimum chill range from March onwards, but this does not occur at Myrtleford until April. However, at Orange, minimum temperatures in May start to fall below the optimum for chilling, whereas at Myrtleford they are still in the fully effective range. Thus it is possible that, although chill hour accumulation initially occurs earlier at Orange, it slows as the temperatures of late autumn fall, whereas at Myrtleford there is more effective chilling during late autumn and the rate of chill hour accumulation becomes greater than at Orange. More detailed analysis is required to verify this hypothesis; this is beyond the scope of this report.

The number of chill hours to the date of pollen shed and female bloom for eight varieties over several seasons for all five sites were compiled and analysed. A highly significant positive correlation between the number of chill hours (0-7°C) and the date of pollen shed and bloom was found. This correlation accounted for more than 85% of the variation in the date of flowering. That is, the date of commencement of flowering was highly dependant on the degree of chilling. When the effects of monthly maximum and minimum temperatures were brought into the analysis, minimum temperatures in April were found to have the greatest impact on variation in time of commencement of flowering. An increase in the average minimum temperature for April resulted in a delay of about 2.5 days for both pollen shed and bloom. These analyses indicate that temperatures in April are just moving into the critical range for chilling. If they are above the average, which in our data set was 7°C, less chill is accumulated and flowering is delayed.

Considerable variation between seasons was observed in the date when flowering commenced, ranging from 10–12 days either side of the mean date. The earliest recorded date for the commencement of pollen shed, for the early cultivar Atlas, was 20 May 2001 at both Moss Vale and Myrtleford, whilst the latest date was 26 June at Toolangi in 2000. These variations are considered to be associated with variations in seasonal temperatures, as discussed.

Despite seasonal variations, Atlas and TGDL, with their low chill requirements, were always the first cultivars to commence pollen shed. Hall's Giant, Jemtegaard #5, Kentish Cob and the Australian selections Woodnut and Werai 1, with their high chill requirements, were the latest to shed pollen. In these experiments the cultivars were generally protandrous, that is, they shed pollen before they came into female bloom.

In Table 10, the average dates for the commencement of pollen shed and female bloom have been listed. This data is the average of the mean dates from both Orange and Myrtleford for the eight years 1998-2005. The varieties have been ranked from the earliest to shed pollen to the latest. Data from some varieties that were planted only in the buffer rows has also been included. All varieties were found to be protandrous, that is they shed pollen before coming into female bloom.

Table 10. Average Julian days to the commencement of pollen shed and female bloom, with duration of flowering for Myrtleford and Orange, along with estimates of floral chill requirements.

| **Variety** | **Average Julian day to start of pollen shed** | **Average calendar date to start of pollen shed** | **Average duration of pollen shed (days)** | **Average Julian day to start of female bloom** | **Average calendar date to start of female bloom** | **Average duration of female bloom (days)** |
|---|---|---|---|---|---|---|
| TGDL | 152 | 1 June | 25 | 182 | I July | 28 |
| Atlas | 160 | 9 June | 37 | 175 | 24 June | 50 |
| Tonollo | 167 | 16 June | 34 | 199 | 18 July | 25 |
| Sicilian | 168 | 17 June | 32 | 189 | 8 July | 32 |
| Montebello | 170 | 19 June | 34 | 181 | 30 June | 37 |
| Segorbe | 170 | " | 38 | 215 | 3 Aug | 25 |
| Tonda di Giffoni | 171 | 20 June | 30 | 188 | 7 July | 31 |
| Barcelona | 171 | " | 39 | 196 | 15 July | 32 |
| Royal | 178 | 27 June | 33 | 217 | 5 Aug | 28 |
| Riccio de Tallanica [1] | 179 | 28 June | 19 | 210 | 29 July | 12 |
| Ennis | 180 | 29 June | 38 | 226 | 14 Aug | 27 |
| Victoria | 183 | 2 July | 36 | 217 | 5 Aug | 25 |
| Willamette | 183 | " | 29 | 201 | 20 July | 33 |
| Butler | 186 | 5 July | 28 | 226 | 14 Aug | 30 |
| Negret | 190 | 9 July | 23 | 195 | 14 July | 36 |
| Wanliss Pride | 191 | 10 July | 24 | 193 | 12 July | 35 |
| Lewis | 192 | 11 July | 28 | 205 | 24 July | 32 |
| TBC | 192 | " | 31 | 210 | 29 July | 28 |
| Turkish Cosford [2] | 193 | 12 July | 21 | 228 | 16 Aug | 7 |
| Tonda Romana (Ferrero) [1] | 193 | " | 19 | 219 | 7 Aug | 19 |
| Casina | 195 | 14 July | 25 | 228 | 16 Aug | 22 |
| Hammond 17 | 196 | 15 July | 29 | 229 | 17 Aug | 29 |
| Square Shield | 200 | 19 July | 27 | 223 | 11 Aug | 30 |
| Daviana | 200 | " | 21 | 227 | 15 Aug | 24 |
| Du Provence [2] | 200 | " | 21 | 228 | 16 Aug | 28 |
| Eclipse | 205 | 24 July | 23 | 227 | 15 Aug | 22 |
| Wandiligong (NE Barcelona) [2] | 210 | 29 July | 16 | 233 | 21 Aug | 23 |
| Whiteheart [2] | 214 | 2 Aug | 12 | 240 | 28 Aug | 19 |
| Merveille de Bollwiller | 216 | " | 19 | 233 | 21 Aug | 18 |
| Hall's Giant | 220 | 8 Aug | 16 | 230 | 18 Aug | 18 |
| Kentish Cob | 220 | " | 14 | 230 | 18 Aug | 14 |
| Jemtegaard #5 [2] | 223 | 11 Aug | 19 | 238 | 26 Aug | 16 |
| Woodnut [2] | 223 | " | 14 | 235 | 23 Aug | 21 |
| Werai 1 [2] | 223 | " | 14 | 238 | 26 Aug | 19 |

Footnotes

[1] Trees growing at the Orange site provided by Ferrero, this Tonda Romana is considered to be true to type.

[2] Buffer trees at Orange, less than eight years of records

## 3.2 Catkin numbers

Observations were made of the relative number of catkins produced by the varieties being studied (Table 11). Varieties that seemed to consistently have a very high number of catkins across sites and seasons included Hall’s Giant/Merveille de Bollwiller (syn.), TBC (Tokolyi/Brownfield Cosford), Victoria, Woodnut and Square Shield. These scored an average of more than four (4), out of a maximum of five (5). However, there were many varieties that scored greater than three out of five. There was generally little difference in the relative number of catkins for a given variety between seasons and sites. Although in some years some varieties dropped their catkins, Daviana tended to do this in a dry autumn and Hall’s Giant and Merveille de Bollwiller (syn.) did this to some extent in the dry autumn of 2005.

Unfortunately, the scores on the relative number of catkins only provide an estimate of the apparent potential pollen producing qualities of a variety; they do not give information on the total production of pollen or pollen viability. Differences in catkins were observed; TBC, Segorbe and Lewis had large catkins at the time of pollen shed and appeared to produce large quantities of pollen, whereas Tonda di Giffoni had relatively small, thin catkins at the time of pollen shed.

Table 11. Relative number of catkins (1=few - 5=many) produced on average at each site for the period 2001-05.

| **Varieties** | **Average** | **Orange** | **Myrtleford** | **Moss Vale** | **Kettering** | **Toolangi** |
|---|---|---|---|---|---|---|
| Kentish Cob | 5.0 | | | | 5.0 | |
| TBC | 4.5 | 4.0 | 4.0 | 4.8 | 5.0 | 4.8 |
| Victoria | 4.1 | 4.3 | 4.3 | 3.3 | 4.8 | 4.5 |
| Woodnut | 4.1 | 3.1 | | | 5.0 | |
| Hall’s Giant | 4.0 | 4.2 | 3.6 | 4.3 | | 4.5 |
| M. de Bollwiller | 4.0 | 3.7 | 3.8 | | 4.5 | |
| Square Shield | 4.0 | 3.9 | 4.1 | 2.5 | 4.5 | 4.8 |
| Jemtegaard #5 | 3.7 | 3.7 | | | | |
| Sicilian | 3.7 | 3.6 | 2.5 | 4.0 | 4.3 | 4.3 |
| Eclipse | 3.4 | 3.8 | 3.4 | 1.5 | 4.3 | 3.8 |
| Willamette | 3.4 | 3.2 | 3.3 | 4.3 | 2.7 | |
| Ennis | 3.2 | 4.1 | 2.8 | 4.0 | 3.0 | 1.5 |
| Montebello | 3.2 | | 2.6 | | 3.8 | |
| Royal | 3.2 | 3.7 | 3.0 | | 3.5 | |
| Segorbe | 3.1 | 3.8 | 3.8 | 3.5 | 1.8 | 1.8 |
| Casina | 3.1 | 3.4 | 2.8 | 4.3 | | 2.0 |
| Tonda di Giffoni | 3.0 | 3.3 | 2.5 | 3.0 | 2.8 | 3.5 |
| Tonda Romana (Ferrero) | 3.0 | 3.0 | | | | |
| Hammond 17 | 3.0 | 2.5 | 1.5 | | 4.5 | |
| Riccio di Tallanico | 2.7 | 2.7 | | | | |
| Lewis | 2.6 | 3.0 | 2.7 | 2.3 | 2.5 | |
| Barcelona | 2.6 | 3.0 | 2.1 | 3.8 | 2.0 | 1.8 |
| Daviana | 2.5 | 4.0 | 1.0 | | | |
| Atlas | 2.5 | 3.0 | 1.8 | 1.8 | | 4.3 |
| Negret | 2.4 | 2.3 | 2.6 | | | 2.3 |
| Butler | 2.3 | 2.9 | 1.2 | 2.8 | | 2.5 |
| Tonollo | 2.2 | 2.5 | 1.5 | | | |
| TGDL | 1.8 | 2.0 | 1.0 | 1.3 | 1.5 | 3.8 |
| Wanliss Pride | 1.7 | 1.4 | 1.0 | 3.5 | 1.5 | 2.3 |
| Whiteheart | 1.4 | 1.7 | | | 1.0 | |

Note: Not all varieties were present at all sites, as indicated by missing values.

## 3.3 Bud burst

Observations were made across all sites of the dates when budburst had commenced. Average dates for this occurrence are shown in Table 12. Seasonal differences of up to five days on either side of the average value were observed for most varieties. Differences between sites were also observed in the average date of bud burst. On average, budburst occurred earliest at Kettering and latest at Orange, with most varieties being 10-15 days earlier at Kettering (Figure 7). The pattern or order in which varieties came into bud burst varied little between sites and seasons, for example Tonda di Giffoni was always early into bud burst and Merveille de Bollwiller was always late, the difference between the two varieties being more than one month.

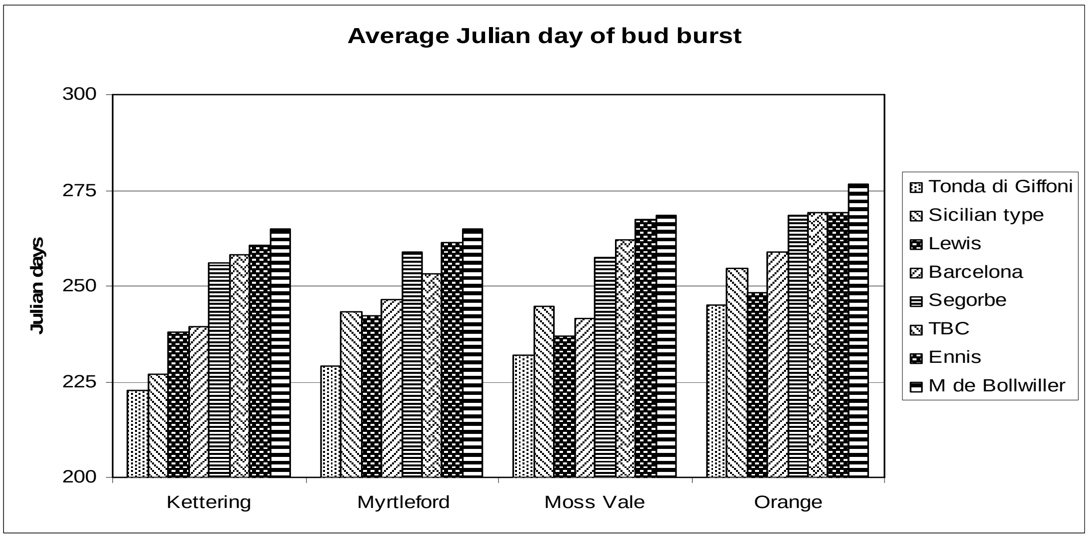
The date of bud burst observed in Australia generally fits into a similar pattern to that observed in Oregon. Similarly, the order of bud burst fits into a similar pattern as the estimated chilling hour requirements, as calculated by Mehlenbacher (1991). It appears that once chilling has been completed, post-chill warmth is the major factor influencing leaf out (Heide, 1993).

Table 12. Average bud burst dates for the varieties being evaluated in the field experiments, compared with the dates on which bud burst was observed in Oregon, USA.

| Varieties | Average Julian days to bud burst | Average date of bud burst | Estimated chill requirements (1) | Oregon dates (1) |
|---|---|---|---|---|
| Tonda di Giffoni | 232 | 20 August | 600-680 | 26 February |
| TGDL | 233 | 21 August | 760-860 | " |
| Royal | 238 | 26 August | | |
| Atlas | 238 | " | | |
| Lewis | 242 | 30 August | | |
| Wanliss Pride | 242 | " | | |
| Sicilian | 242 | " | | |
| Montebello | 243 | 31 August | 990-1040 | 26 February |
| Barcelona | 246 | 3 September | 990-1040 | " |
| Willamette | 247 | 4 September | 860-990 | 5 March |
| Tonollo | 253 | 10 September | | |
| Negret | 256 | 13 September | 760-860 | 5 March |
| Victoria | 260 | 17 September | | |
| Segorbe | 260 | " | 1170-1255 | 12 March |
| Whiteheart (2) | 260 | " | | |
| TBC | 261 | 18 September | | |
| Casina | 264 | 21 September | 1395-1550 | 12 March |
| Ennis | 265 | 22 September | 1040-1170 | 5 March |
| Butler | 266 | 23 September | 1040-1170 | 5 March |
| Square Shield | 266 | " | | |
| Eclipse | 266 | " | | |
| Jemtegaard#5 (2) | 266 | " | | |
| Woodnut (2) | 266 | " | | |
| Daviana | 267 | 24 September | | |
| Hammond 17 | 268 | 25 September | | |
| Merveille de Bollwiller | 269 | 26 September | 990-1040 | |
| Hall's Giant | 270 | 27 September | 990-1040 | 19 March |

(1) Mehlenbacher, 1991 (2) Limited data, based mainly on observations of buffer trees at Orange

Figure 7. Site differences in the average date of bud burst for a range of varieties (Julian days).



## 3.4 Tree growth

Differences were observed and measured in tree growth between cultivars and sites. At Orange, the growth of Wanliss Pride, TGDL and Negret was extremely poor, with many plants dying and requiring replanting. Some of the replanted trees also died and again had to be replaced. Wanliss Pride has been the worst cultivar in this regard, with none of the original trees remaining, all having been replaced at some stage. When the cultivar Willamette became available for planting in 2000, the inner two yield evaluation trees of Negret in each treatment plot at Orange were replaced with Willamette. Similarly, when the cultivar Lewis became available in 2001, the inner two trees of TGDL in all the treatment plots at Orange were replaced with Lewis.

At Myrtleford, Montebello was not planted until 1998, due to unavailability of planting material. Half of the Willamette trees were planted at Myrtleford in 1998, with the remaining Willamette trees being planted in 1999. Spaces had been left for this variety. The variety White American, which was originally planted appeared to be identical to Wanliss Pride. In 2001, all the trees of White American were removed to make room for Lewis.

Differences were noted in tree growth between cultivars and sites. At Orange and Toolangi, the cultivars Wanliss Pride, Negret and TGDL made the poorest growth. Wanliss Pride was generally the weakest growing cultivar at all sites (Figure 8). It grew best at Myrtleford, as did all other cultivars.

Varieties that grew vigorously at all sites, based on visual ratings of tree growth and measurements of butt circumference, included Atlas, Barcelona, Hall's Giant, Tonda di Giffoni, Segorbe and TBC. The growth of Ennis was good at all sites but was generally a little less vigorous than the aforementioned varieties, as can be seen in Figure 8. Tonollo and Butler demonstrated a high level of vigour at Myrtleford.

There appear to be some major differences between sites in the growth of the trees, with minor differences between seasons. The growth of several varieties at Moss Vale was affected by the very dry season of 2002, when only 190mm of rain was recorded for the seven months from May to November, inclusive. Due to the low winter rainfall at that site, the spring for the dam did not run and there was insufficient irrigation water available to make up for the rainfall deficit during the critical growth period of September to December.

The only time that excessive moisture seemed to have an adverse effect on growth was in the spring of 2000, when some young trees died at Kettering. This was thought to have occurred as a result of high rainfall and poor soil drainage, combined with the application of nitrogen fertiliser to young trees two years after planting. A total of 299mm of rainfall was recorded at that site in September and October, 2000, causing the poorly drained soil to become saturated (Figure 9). In the following year, 2001, high rainfall was also recorded in September and October (Figure 9) and again the soil became saturated, however, no crop damage was noted. This may have been because slow release fertilisers were applied from 2001 onwards.

At Moss Vale in August 1998, 628mm of rainfall was recorded. This did not appear to have any adverse effect on tree growth, nor did the wet conditions experienced in September 2000 at the Myrtleford site, which was flooded for about two days with the trees standing in about 500mm of water. It appears that damage occurs when there is an extended period of saturated soils combined with the use of nitrogen fertilisers, as was the case at Kettering. It is also likely that young trees are more susceptible to the effects of water logging and nitrogen fertilisers than are older trees.

Figure 8.  Relative tree growth as assessed by annual butt circumference measurements and calculations of cross-section area.

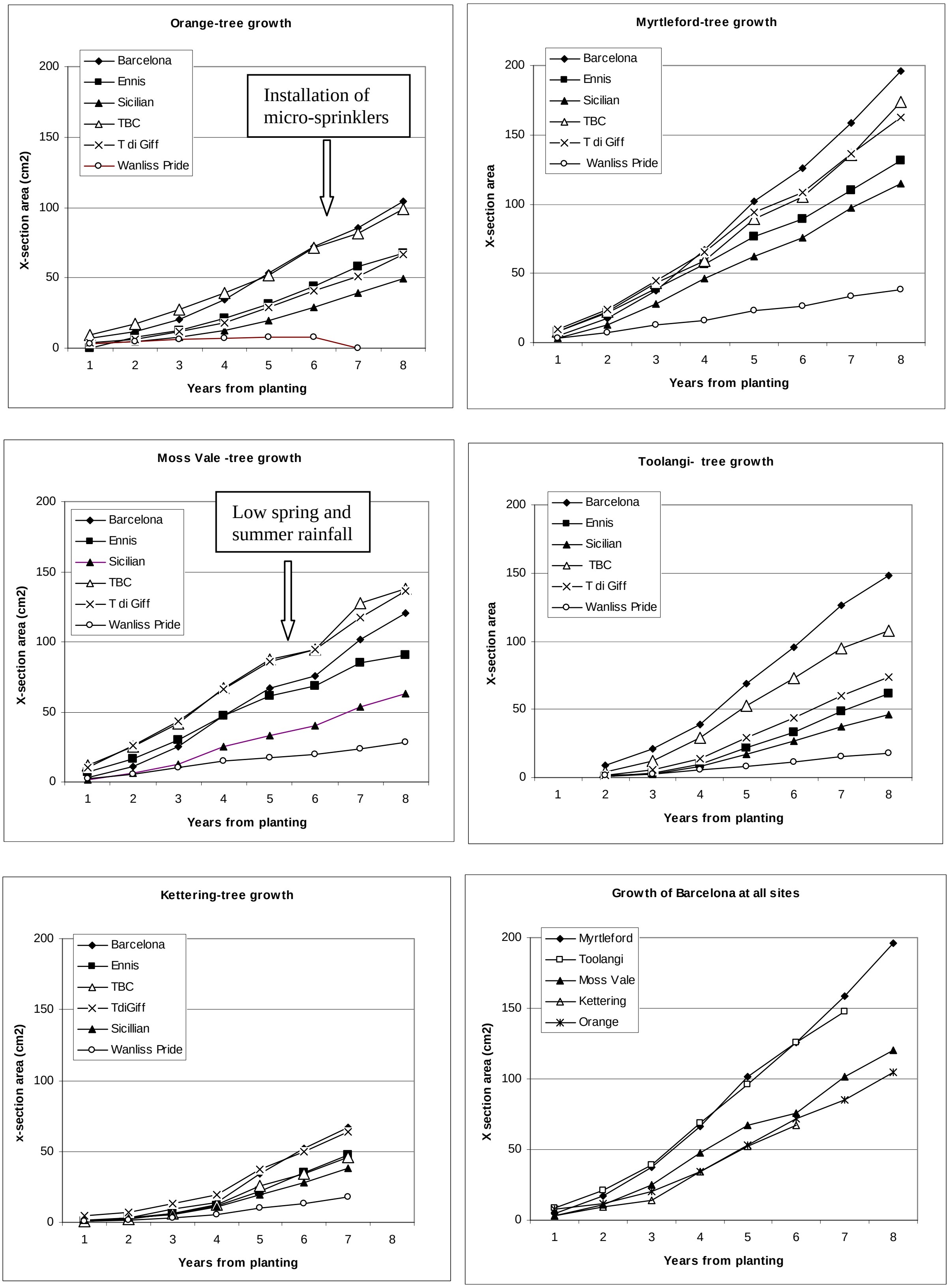


Figure 9. Monthly rainfall and estimated potential evapotranspiration at Kettering.

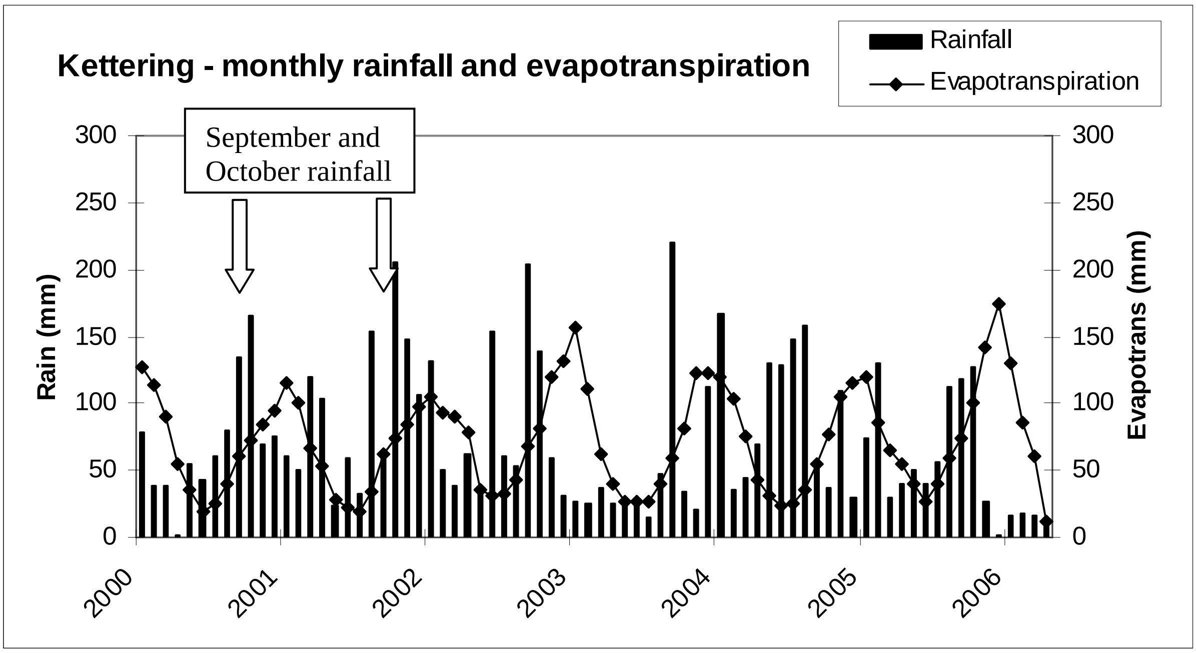
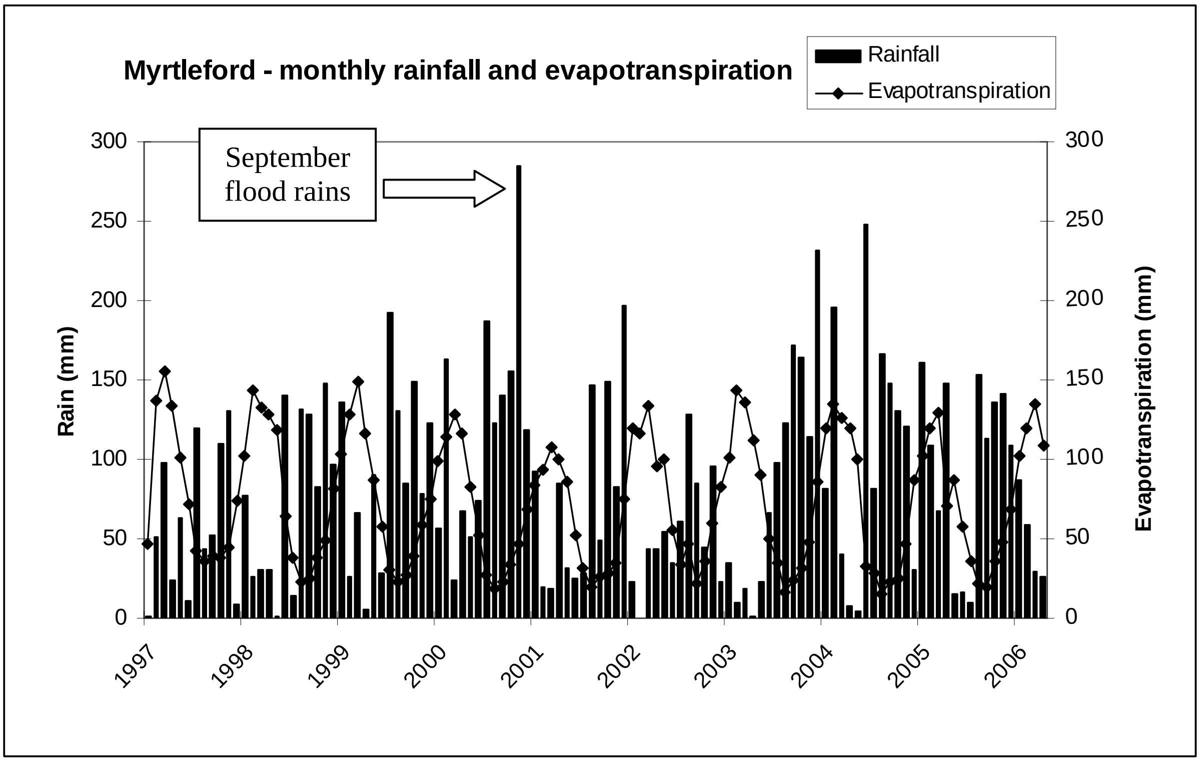



Figure 10. Monthly rainfall and estimated potential evapotranspiration at Myrtleford.




It is generally considered that hazelnut trees do not tolerate poorly drained soils and are less productive when planted on shallow soils. Hazelnut roots are reported to be most active in the top 600mm of soil, but will draw water from greater depths as the soil profile dries out (OSU, 1985). The rainfall pattern in Oregon is one of a wet winter and relatively dry summer. Despite the low summer rainfall, trees are normally grown without irrigation; it is therefore considered that the trees must be able to draw on moisture from considerable depths to fill nuts and kernels in that environment. Roots have been noted to extend down to 3 metres in depth in Oregon.

The change in the irrigation system at Orange in 2002/03, in the seventh year from planting, from two drippers per tree to a single micro-sprinkler per tree did not seem to have any noticeable effect on tree growth (Figure 8).

At Orange, the very poor growth of Wanliss Pride, TGDL and Negret was considered to be related to soil conditions. It is difficult to separate the effects of chemical and physical factors of soil. Soil depth and soil texture appear to be important. In Oregon, hazelnut trees grow best when planted in deep soils and rich, river-bottom loams (Lagerstedt, 1979). In France, Germain and Sarraquigne (2004) considered the ideal soil types for hazelnut production were clay loams, loamy clays and sandy loams that were well structured and with good drainage.

At Orange, the soil is a clay loam in the A horizon, overlying a light clay It is generally well structured, well drained and relatively deep. It would appear to have a suitable texture and structure, although of a heavier texture than the ideal. The $pH_{Ca}$ was 5.7 at the time of planting and was one of the least acid of the sites. However, nodules of manganese were observed in the B horizon or sub soil and may have led to excessively high levels of manganese in this soil.

Plant tissue testing, by leaf analysis, was used to monitor the nutrient status of the trees at all sites. Nutrients generally seemed to be within or close to the desired levels (Table 13) suggesting that there were no major deficiencies affecting plant growth.

Table 13. Chemical composition of leaves taken from the five hazelnut variety trial sites over the period 1997–2006.

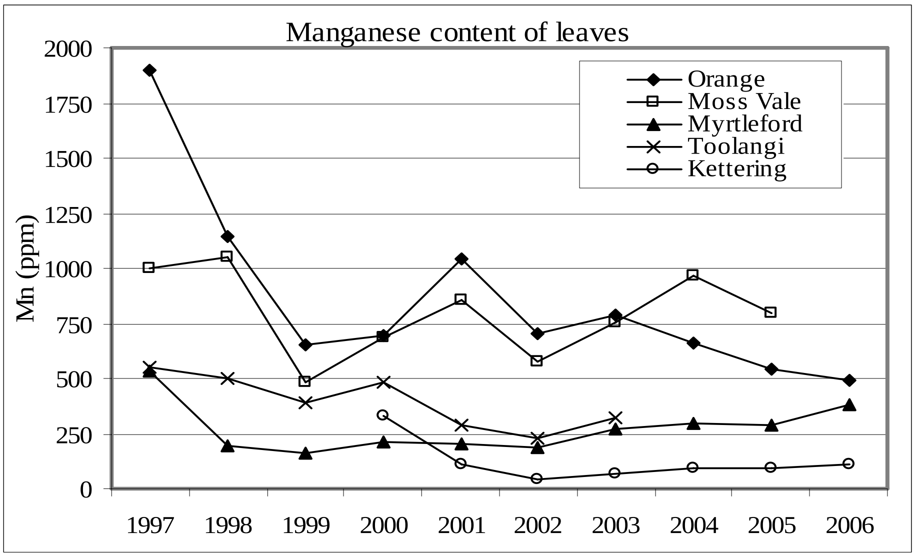
| **Elements** | **Sites** | | | | | **Desirable Range**[(1)] |
|---|---|---|---|---|---|---|
| | **Orange** | **Moss Vale** | **Myrtleford** | **Toolangi** | **Kettering** | |
| | **Site ranges, lowest –highest** | | | | | |
| Nitrogen % | 2.4-3.17 | 2.3-2.92 | 2.5-2.9 | 2.7-3.1 | 2.5-3.49 | 2.2–2.5 |
| Phosphorus % | 0.12-0.17 | 0.12-0.19 | 0.12-0.38 | 0.13-0.29 | 0.31-0.45 | 0.14–0.45 |
| Calcium % | 1.25-1.9 | 1.04-1.60 | 0.94-2.1 | 1.15-1.8 | 1.17-2.0 | 1.0–2.5 |
| Magnesium % | 0.13-0.22 | 0.16-0.33 | 0.14-0.6 | 0.12-0.23 | 0.21-0.3 | 0.25–0.5 |
| Potassium % | 0.65-1.3 | 0.43-1.2 | 0.55-1.3 | 0.63-1.5 | 0.72-1.32 | 0.8–2.0 |
| Sodium % | 0.01-0.05 | .05-0.17 | 0.01-0.24 | 0.02-0.13 | 0.05-0.12 | <0 0.1 [(2)] |
| Manganese ppm | 490-1900 | 484-1050 | 162-530 | 230-550 | 46-327 | 26–650 |
| Sulphur % | 0.1-0.2 | 0.15-0.21 | 0.1-0.23 | 0.1-0.22 | 0.13-0.23 | 0.12 - 0.2% |
| Boron ppm | 38-67 | 25-68 | 20-57 | 44-69 | 20-53 | 1.0–2.5 |
| Copper ppm | 7.3-11 | 5-10 | 3-11 | 6.7-17 | 4.8-9.9 | 0.8–2.0 |
| Zinc ppm | 19-32 | 20-40 | 16-49 | 17-45 | 21-47 | 15 - 60 |

[(1)] Recommended range for hazelnuts (Olsen, 2001). [(2)] Weir and Cresswell, 1993.

Apart from the Kettering site, phosphorus levels were at the lower end of the desirable range, reflecting the low levels of available soil phosphorus identified in the soil tests (Table 3). Potassium and magnesium were also at the lower end of the desirable range at most sites, as was calcium, despite the moderately high levels of lime application.

Manganese (Mn) levels were very high at both Orange and Moss Vale, with levels well above the desirable range reported for most crops. The levels of manganese were consistently high at Orange (Figure 11), where trees had made least growth. Manganese levels were lowest at Myrtleford, where trees had generally grown best.

Figure 11. Levels of manganese in leaf samples collected annually from all sites.

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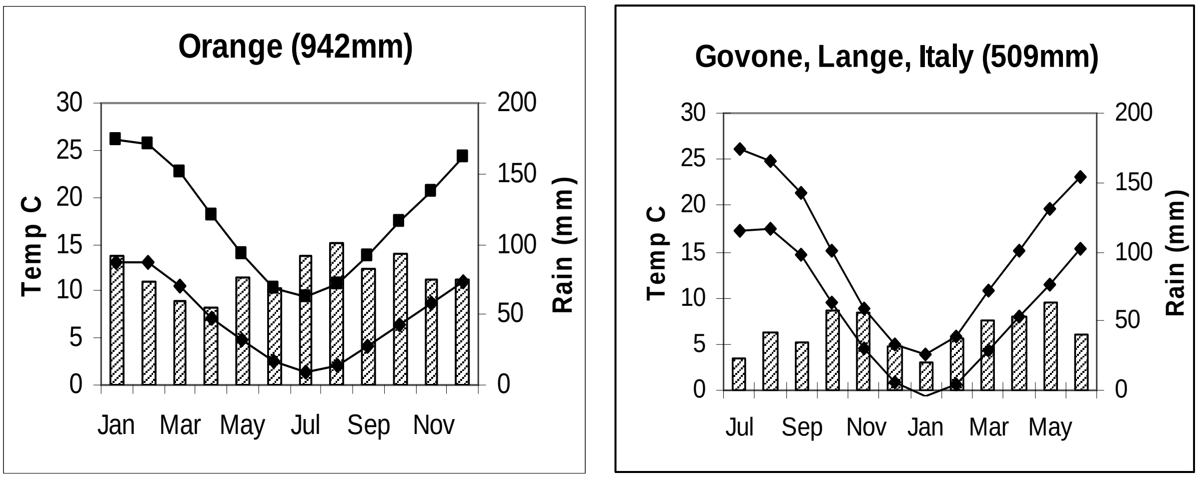
It is possible that high levels of soil manganese may adversely affect the growth of hazelnut trees, although this is not documented in the literature on hazelnut nutrition. However, Grau et al. (2001) considered that poor growth of hazelnuts in Chile may have been due to high levels of manganese. It seems possible that some cultivars such as Barcelona, TBC and Tonda di Giffoni are more tolerant to high levels of soil manganese than are cultivars such as Wanliss Pride, Negret and TGDL. Crops can vary in their tolerance to manganese, with lucerne, canola and phalaris being particularly sensitive (Glendinning, 1999). Differential cultivar tolerance to soil manganese has also been reported for some crops (Sale et al., 1993; Gonzalez and Lynch, 1999).

Manganese availability is influenced by soil type, with krasnozem soils derived from basalt frequently containing high levels of this element (Peverill et al, 1999). The availability of manganese is also affected by soil pH, with manganese becoming less available as soil pH is increased (Uren, 1999). The lime applied pre-planting at all sites raised soil pH by 0.5 to 1 unit (Table 13). The general decline in the levels of manganese (Figure 8) is probably due to the effects of liming and the consequent rise in soil pH.

The reason for the poor growth of Tonda Gentile delle Langhe (TGDL) at Orange is considered to be related to the soil. TGDL is the main variety grown in the Langhe region of Italy. When the temperature and rainfall patterns of Orange and Govone in the Langhe are compared, it can be seen (Figure12 ) that the temperature patterns are not greatly different. The Langhe area has a significant influence from the Mediterranean Sea and has less diurnal variation than the inland district of Orange, but both regions have mild summers and cool to cold winters. The Langhe area is drier than Orange. The soils in the Langhe region are of a sandy texture. This climatic data is presented as further evidence to support the notion that the poor growth of TGDL at Orange was probably due to some soil factor, such as the clayey texture of the soil, or high manganese, or both, rather than climate.

Figure 12. A comparison of mean monthly temperatures and rainfall, between Orange and the Langhe region of Italy.




Soil samples were taken at all sites prior to planting, in 2003 and again in 2006 at Myrtleford, Orange and Kettering (Table 14). At Orange, pH levels rose during the duration of the experiment, reflecting the applications of ground limestone at that site. Soil carbon appears to have remained fairly steady, despite the use of Roundup down the tree rows to suppress weeds, which is where the soil samples were collected. Potassium, calcium and magnesium were generally above the desired minimum. The levels of these elements appear to be relatively stable, indicating that fertiliser applications have matched or exceeded nutrient removal. The Ca/Mg ratio is good, being greater than 2.0 indicating a stable soil structure.

Table 14. Soil analysis data for each of the hazelnut variety trial sites.

| | Orange | | | Moss Vale | | Myrtleford | | | Toolangi | | Kettering | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 2003 | 2006 | 1996 | 2003 | 1996 | 2003 | 2006 | 1995 | 2003 | 1999 | 2006 |
| $pH_{Ca}$ (1:5 soil $CaCl_2$) | 5.7 | 6.7 | 7.3 | 4.3 | 5.2 | 4.5 | 5.6 | 5.2 | 4.5 | 5.2 | 5.5 | 5.8 |
| Phosphorus (P) Bray (mg/kg) | 21 | 61 | 76 | 9 | 18 | 7 | 10 | 12 | 3 | 4 | 141 | 120 |
| Total carbon ( %) | 2 | 1.9 | 1.8 | 3.8 | 3.2 | 3.3 | 2.8 | 3.5 | 6.6 | 6.1 | 3.5 | 3.7 |
| Potassium (K) meq/100g | 0.6 | 0.98 | 0.78 | 0.3 | 0.35 | 0.6 | 0.57 | 0.5 | 0.5 | 1.8 | 1.03 | 1.2 |
| Calcium (Ca) meq/100g | 6.8 | 12 | 12 | 3.9 | 8.4 | 5.6 | 10 | 9.8 | 3.8 | 11 | 12.6 | 13 |
| Magnesium (Mg) meq/100g | 0.7 | 1 | 0.95 | 1.4 | 1 | 2.3 | 2.5 | 2.5 | 0.8 | 1.8 | 2.65 | 3.1 |
| Aluminium meq/100g | <0.1 | <.05 | <.01 | 0.6 | 0.12 | 0.2 | <.05 | <0.1 | 1.4 | 0.31 | <0.1 | <0.1 |
| Total exchangeable cations (mg/kg) | 8.1 | 14 | 14 | 6.4 | 9.9 | 8.8 | 13 | 13 | 6.6 | 15 | 16.2 | 17.3 |
| Ca/Mg ratio | 9.7 | 12 | 12.2 | 2.8 | 8.4 | 2.4 | 4 | 4 | 4.8 | 6.1 | 5 | 4.2 |
| Mn | | | 1.7 | | | | | 1.4 | | | | 0.36 |

Note: Desirable levels are shown in Table 3.

A comparison of the vigour of growth of Barcelona across all sites is shown in Figure 8. It can be seen that growth rates at Myrtleford and Toolangi were similar for this variety, and were the highest for all sites. An average butt circumference of 38cm was achieved at both sites by the end of the seventh year of leaf. This occurred in 2002 at Toolangi and 2003 at Myrtleford. Growth rates at Moss Vale, Orange and Kettering were similar, but much poorer than at Myrtleford and Toolangi. It appears that Barcelona grew slightly better at Moss Vale than the other two sites, except for the very dry season of 2002 when only 190mm of rain was recorded from May to November.

Although soil type appears to have affected tree growth, there also appear to have been rainfall effects. Average annual rainfall, evapotranspiration and wind run were determined for each site for the period of each experiment (Table 15). It appears that the relatively high rainfall of Toolangi may have had a bearing on the good growth of Barcelona at that site. Although the rainfall at Myrtleford was not as high, it seems likely that the good growth of the trees generally at that site was a combination of good rainfall and excellent soil quality.

Table 15. Average annual rainfall, evapotranspiration and wind run measured at each site.

| **Sites** | **Average annual rainfall (mm)** | **Estimated annual evapotranspiration (mm)** | **Average annual wind run (km)** |
|---|---|---|---|
| Toolangi | 1181 | 1008 | 33773 |
| Moss Vale | 1087 | 899 | 31243 |
| Myrtleford | 1030 | 865 | 28975 |
| Kettering | 895 | 853 | 26955 |
| Orange | 857 | 999 | 30483 |

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It seems likely that, at Kettering, the lower rainfall and the poorly drained subsoil at that site, combined to limit tree growth. The trees at Kettering have a rather stunted appearance (Figure 21) when compared with those at Myrtleford (Figure 15).

It seems likely that at Orange and Moss Vale there was some soil factor, such as high levels of soil manganese or heavy soil texture, that had a greater detrimental effect on growth than the limitation of rainfall, apart from the very dry season of 2002. The Orange site was very windy, particularly in the earlier years of the research (Figure 32), the wind may have had a detrimental effect on growth.

## 3.5 Nut yields

The most reliable yield data has been obtained from the Moss Vale site where there were no nut losses from sulphur crested cockatoos. Reliable data had been obtained from Myrtleford until 2006 when cockatoos were a major problem. Yield losses from cockatoos were substantial at Toolangi in 2003 and high at Orange in 2002. From 2003 to 2006, immature nuts were picked at Orange, to minimise loss from birds. The nut yields were estimated from the numbers of green nuts, picked in January, multiplied by average nut weights from mature nuts, collected later in that season.

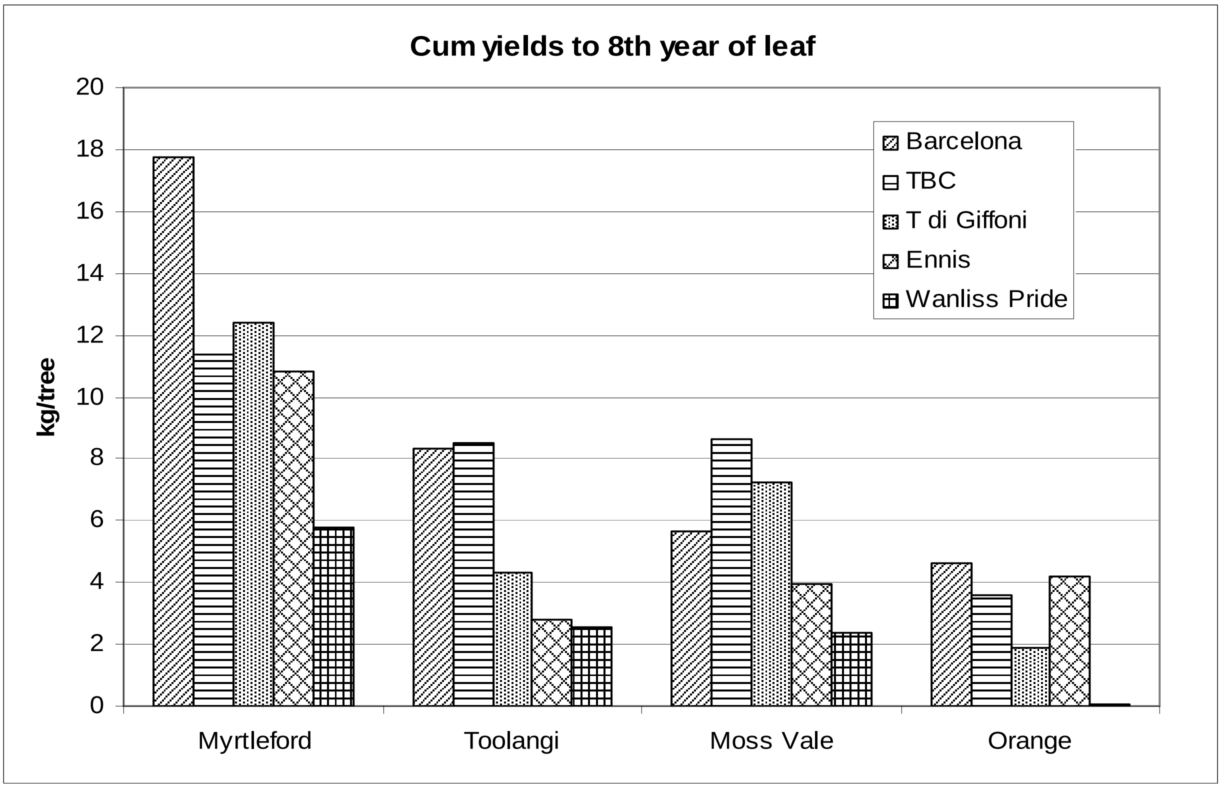
One of the problems with this technique was that it assumes that green nuts would develop into mature nuts, which is not necessarily the case. It is therefore possible that there has been a slight overestimation of yield using this technique, particularly with the variety Ennis, as that variety had several clusters of two nuts in which one was large and the other was small; there was some doubt as to whether the small nuts would develop. Any small nuts that appeared yellow or slightly shrivelled were excluded from the nut count.

Bearing in mind the limitations to some of the data, there is no single cultivar that has out-yielded all others at all sites in all seasons (Figure 13 and Tables 16-20). However, there are two cultivars that have yielded well at most sites, these being Barcelona and TBC.

Barcelona was one of the highest yielding varieties at Myrtleford, Toolangi and Orange. It also did well at Moss Vale, but so far has not yielded well at Kettering.

TBC yielded very well at Moss Vale, Toolangi and Kettering. It yielded well at Orange, but was not in the highest yielding group at Myrtleford.

Figure 13. Cumulative nut yields (kg/tree) for five key varieties during their first eight years of growth at the four mainland sites.




Tonda di Giffoni yielded well at Moss Vale and Myrtleford, but was not so productive at the other sites. Ennis was outstanding at Orange, but only produced moderate yields at the other sites. The Sicilian type was outstanding at Myrtleford, did well at Moss Vale, but was not so good at the other sites.

Table 16. Annual and cumulative nut yields (kg/tree) recorded for the highest yielding trees planted in 1996 at Moss Vale (2001–05).

| Variety | Year of harvest | | | | | Cumulative yields |
|---|---|---|---|---|---|---|
| | 2001 | 2002 | 2003 | 2004 | 2005 | |
| Atlas | 0.29 | 0.48 | 0.15 | 0.17 | NA | |
| Barcelona | 0.75 | 2.15 | 1.03 | 1.70 | 3.36 | 8.99 |
| Ennis | 0.49 | 1.83 | 1.47 | 0.17 | 2.78 | 6.74 |
| Hall's Giant | 0.03 | 0.10 | 0.06 | 0.02 | NA | |
| Segorbe | 0.47 | 2.08 | 0.64 | 0.16 | NA | |
| Sicilian | 0.34 | 1.74 | 0.88 | 2.27 | 2.95 | 8.17 |
| TBC | 1.64 | 2.92 | 2.19 | 1.88 | 4.05 | 12.67 |
| Tonda di Giffoni | 1.66 | 2.12 | 1.28 | 2.15 | 4.33 | 11.54 |
| Victoria | 0.92 | 1.50 | 1.33 | 0.23 | NA | |
| Wanliss Pride | 0.37 | 0.47 | 0.26 | 1.27 | NA | |

Note: Only five varieties were harvested in 2005, these are the only varieties with five year cumulative yields.

Butler and Tonollo yielded very well at Myrtleford (Table 17) but Tonollo was not included for yield comparisons at other sites. Tonollo was reported as the highest yielding genotype in the field evaluation planted at Glen Innes in 1937 (Trimmer, 1965). Snare (Department of Agriculture NSW, 1982) also reported good yields for Tonollo in the varietal collection at Orange. The origin of Tonollo is unknown, but it seems likely that it is related to Barcelona as it has many similar characteristics to that variety.

Table 17. Annual and cumulative nut yields (kg/tree) for the varieties planted in 1996 at Myrtleford (2001-05). This excludes the later planted varieties of Casina, Montebello, Lewis and Willamette.

| Variety | Year of harvest | | | | | Cumulative yield |
|---|---|---|---|---|---|---|
| | **2001** | **2002** | **2003** | **2004** | **2005** | |
| Atlas | 1.53 | 2.36 | 4.29 | 2.02 | 1.99 | 12.19 |
| Barcelona | 1.35 | 6.12 | 5.14 | 5.13 | 4.47 | 22.20 |
| Butler | 1.11 | 5.59 | 5.46 | 5.72 | 5.29 | 23.17 |
| Daviana | 0.19 | 0.75 | 0.83 | 0.86 | 0.33 | 2.96 |
| Eclipse | 0.41 | 2.50 | 2.31 | 2.78 | 1.60 | 9.60 |
| Ennis | 0.89 | 3.54 | 3.66 | 2.73 | 3.08 | 13.89 |
| Hall's Giant | 0.03 | 0.36 | 0.41 | 0.26 | 0.22 | 1.27 |
| M. de Bollwiller | 0.04 | 0.66 | 0.44 | 0.40 | 0.34 | 1.88 |
| Negret | 0.48 | 2.33 | 2.01 | 3.11 | 1.66 | 9.60 |
| Royal | 0.61 | 1.85 | 2.33 | 1.53 | 2.04 | 8.37 |
| Segorbe | 1.02 | 4.67 | 3.73 | 2.43 | 2.16 | 14.00 |
| Sicilian | 2.15 | 5.31 | 4.10 | 4.82 | 5.36 | 21.74 |
| Square Shield | 0.18 | 1.12 | 1.95 | 1.26 | 1.19 | 5.72 |
| TBC | 1.80 | 3.01 | 3.54 | 1.80 | 2.85 | 12.99 |
| T.G.D.L. | 0.59 | 1.60 | 2.30 | 1.55 | 0.70 | 6.74 |
| Tonda di Giffoni | 2.25 | 2.91 | 4.86 | 2.37 | 3.24 | 15.63 |
| Tonollo | 0.92 | 4.87 | 4.68 | 4.15 | 4.00 | 18.62 |
| Victoria | 0.89 | 2.59 | 2.77 | 1.21 | 1.66 | 9.11 |
| Wanliss Pride | 1.48 | 0.95 | 2.00 | 1.34 | 0.96 | 6.74 |

Atlas only produced mediocre yields and did not perform as well as had been reported in previous studies. High yields were recorded for this variety by Snare at Orange (Department of Agriculture NSW, 1982) and later by Sample (1993) at Myrtleford. Segorbe grew well at all sites, giving moderately good yields, producing cumulative yields at Myrtleford that were not significantly different from those of TBC. All the cultivars discussed above yielded higher than Wanliss Pride, which had been the most widely grown cultivar in Australia until the early 1990s. At that time, this cultivar was viewed as the industry standard or benchmark cultivar in Australia.

Table 18. Estimates of annual and cumulative nut yields (kg/tree) recorded at Orange (2000–2006).

| Variety | Year of harvest | | | | | | | Cumulative yield |
|---|---|---|---|---|---|---|---|---|
| | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | |
| Atlas | 0.38 | 0.38 | 0.34 | 1.81 | 0.71 | 4.93 | 2.02 | 10.57 |
| Barcelona | 0.34 | 0.64 | 1.02 | 2.93 | 1.46 | 7.73 | 3.73 | 17.86 |
| Ennis | 1.02 | 0.55 | 1.38 | 2.24 | 2.29 | 7.98 | 3.57 | 19.03 |
| Segorbe | 1.38 | 0.24 | 0.33 | 1.20 | 1.63 | 4.13 | 2.21 | 11.12 |
| Sicilian | 0.60 | 0.52 | 0.14 | 1.62 | 1.12 | 6.31 | 1.87 | 12.18 |
| TBC | 0.33 | 1.23 | 0.26 | 2.08 | 1.93 | 6.47 | 3.47 | 15.77 |
| Tonda di Giffoni | 0.26 | 0.64 | 0.60 | 0.64 | 1.07 | 4.94 | 0.93 | 9.08 |
| Victoria | 0.14 | 0.29 | 0.24 | 0.89 | 1.10 | 6.29 | 0.31 | 9.25 |
| Wanliss Pride | 0.24 | 0.05 | 0.00 | 0.01 | 0.05 | 0.03 | 0.06 | 0.44 |

Table 19. Estimates of annual nut yields (kg/tree) for key varieties grown at Toolangi (2000–2003).

| Variety | Year of harvest | | | | Cumulative yields |
|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | |
| Atlas | NA | 0.30 | NA | NA | NA |
| Barcelona | 0.76 | 1.62 | 3.11 | 2.49 | 7.98 |
| Ennis | 0.02 | 0.36 | 0.87 | 0.67 | 1.92 |
| Segorbe | 0.34 | 1.22 | 1.68 | 0.91 | 4.15 |
| Sicilian type | 0.1 | 0.52 | 1.28 | 1.15 | 3.06 |
| TBC | 0.89 | 2.51 | 2.59 | 2.02 | 8.00 |
| Tonda di Giffoni | 0.29 | 1.22 | 0.91 | 0.99 | 3.41 |
| Victoria | NA | 1.15 | NA | NA | NA |
| Wanliss Pride | 0.09 | 0.65 | 0.59 | 0.67 | 2.00 |

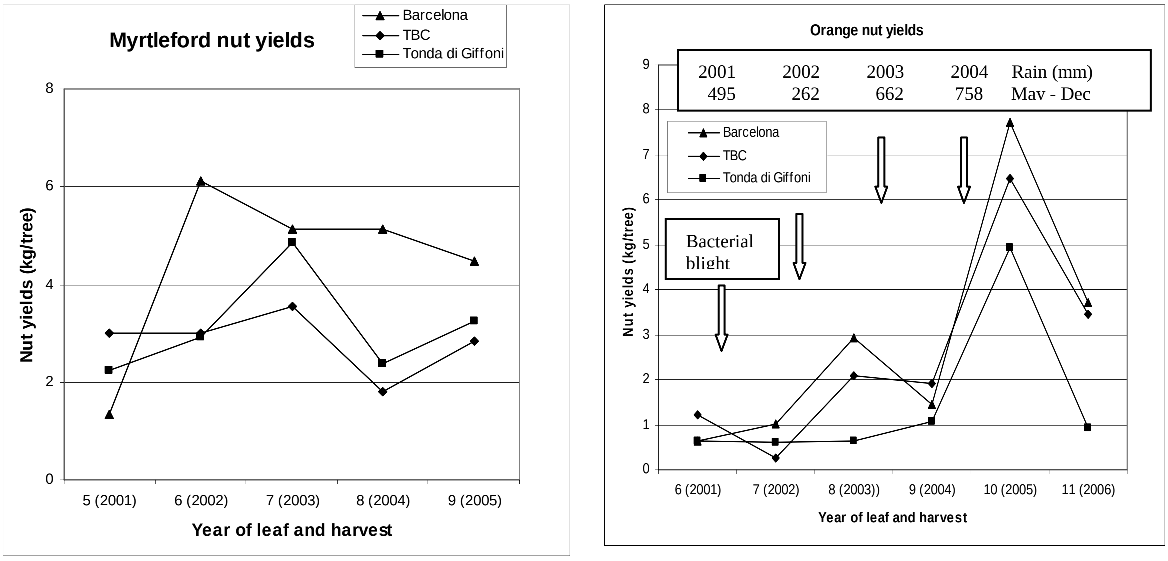
Table 20. Annual and cumulative nut yields (kg/tree) at Kettering (2004-2006)

| Variety | Year of harvest | | | Cumulative nut yields |
|---|---|---|---|---|
| | 2004 | 2005 | 2006 | |
| Barcelona | 0.37 | 0.27 | 0.38 | 1.02 |
| Eclipse | 0.22 | 0.42 | 0.47 | 1.11 |
| Ennis | 0.02 | 0.06 | 0.10 | 0.18 |
| Hammond 17 | 0.48 | 0.47 | 0.75 | 1.71 |
| Lewis | 0.00 | 0.09 | 0.19 | 0.28 |
| M. de Bollwiller | 0.04 | 0.05 | 0.07 | 0.15 |
| Montebello | 0.23 | 0.32 | 0.13 | 0.68 |
| Royal | 0.13 | 0.59 | 0.58 | 1.30 |
| Segorbe | 0.10 | 0.24 | 0.36 | 0.69 |
| Sicilian | 0.46 | 0.37 | 0.22 | 1.04 |
| Square Shield | 0.26 | 0.24 | 0.35 | 0.85 |
| TBC | 0.73 | 0.73 | 1.51 | 2.97 |
| TGDL | 0.00 | 0.00 | 0.07 | 0.08 |
| Tonda di Giffoni | 0.53 | 0.39 | 0.32 | 1.24 |
| Victoria | 1.51 | 0.72 | 1.21 | 3.43 |
| Wanliss Pride | 0.24 | 0.32 | 0.47 | 1.03 |
| Whiteheart | 0.00 | 0.03 | 0.04 | 0.07 |
| Willamette | 0.48 | 0.25 | 0.11 | 0.84 |

The trees at Myrtleford made very good growth with the variety Barcelona producing more than 5kg nuts per tree by the sixth season of growth (Figure 14); thereafter there was a slight decline in production. Tonda di Giffoni and TBC peaked a year later, also followed by a decline in yields. By the seventh season of growth, the branches of the trees had met within the rows and were very close to meeting between the rows. Pruning had been carried out annually to maintain vigour and maximise an open tree structure. However, at the high density planting used at all sites, 3m within the rows and 5m between rows, the trees were becoming over-crowded by years seven and eight and ideally should have been thinned. This was despite regular annual pruning of branches with the objective of maintaining an open vase structure. Pruning was not undertaken to shorten branches or reduce the height of the trees. By the eighth year of leaf it was realised that there was probably a need for severe pruning to reduce the competition for light, either by cutting back the limbs of the trees or removing alternative trees in the row. It was considered that such treatments would be relatively expensive and would be likely to have a short term reduction in yield with little gain from a research point of view as the experiment was nearing completion. Such actions were, therefore, not taken.

At Myrtleford, the varieties Casina and Montebello were planted in 1998, two years after the initial planting. Half of the Willamette trees were planted in 1998 with the remainder being planted in 1999. Lewis trees were not planted until 2001, five years after the initial planting. The later planted varieties initially appeared to benefit from the wind shelter created by the earlier planted varieties, but in time, competition for light seemed to limit their growth, particularly that of Lewis. It was, therefore, not possible to make a fair assessment of the yield of these later planted varieties.

Figure 14. Development of nut yields (kg/tree) for three key varieties at Myrtleford and Orange.




Note: Rainfall attributed to the previous growing period (May-Dec) is shown above the nut yields.

Figure 15. Excellent growth of trees in their fifth year of leaf at Myrtleford, November 2001; peak nut yields were achieved with Barcelona the following year. At this stage tree canopies were just meeting down the rows.

Figure 16. Growth of trees at Orange in March 2005, their ninth year of leaf. The trees seem to lack vigour compared with those at Myrtleford, see previous figure (Figure 15).

At Orange, growth of the trees was very much slower, as has been discussed already. The trees took eight seasons of growth to achieve about the same butt circumference as that achieved by the trees at Myrtleford in five seasons (Figure 8). However, it was not until the tenth season of growth that the variety Barcelona exceeded a yield of 6kg/tree. There was very little new shoot growth in the very dry spring of 2002, which it is considered reduced nut yields the following year, 2003/04 (Figure 14). This is because hazelnuts fruit on the previous season's growth. In 2003, the rainfall in the May – December period was above average; this stimulated good shoot growth in that year and resulted in good yields the following season, 2004/05. Although the May – December rainfall was even higher in 2004, this did not result in higher yields. It is postulated that this was because the tree was using much of its assimilates from photosynthesis to produce the high nut yield of the 2004/05 season. This phenomenon of competition for assimilates between shoot growth and nut development has been observed by several authors as documented by Germain (1994). The biennial bearing pattern that appeared to commence in 2004 is common in hazelnuts and can occur across a whole district. In Oregon, crop yields fluctuate considerably on a biennial pattern (Olsen and Goodwin, 2005.)

At Moss Vale, although the trees made better growth than at Orange (Figure 8) their yields were rather poor. They did not exceed 4kg/tree until their ninth season of growth (Figure 17). The general decline in yield in 2003 was almost certainly due to moisture stress at that site, owing to the very dry seasonal conditions in the 2002-03 growing season (Figure 18) and lack of water for irrigation. The relatively low yields in the following season were attributed to the limited growth in the 2002-03 season. Very good rainfall was recorded in October and November 2003; this produced good new growth which resulted in the good yields of 3-4 kg/tree in the 2004-05 season.

Figure 17.  Development of nut yield (kg/tree) with time for three key varieties at Moss Vale

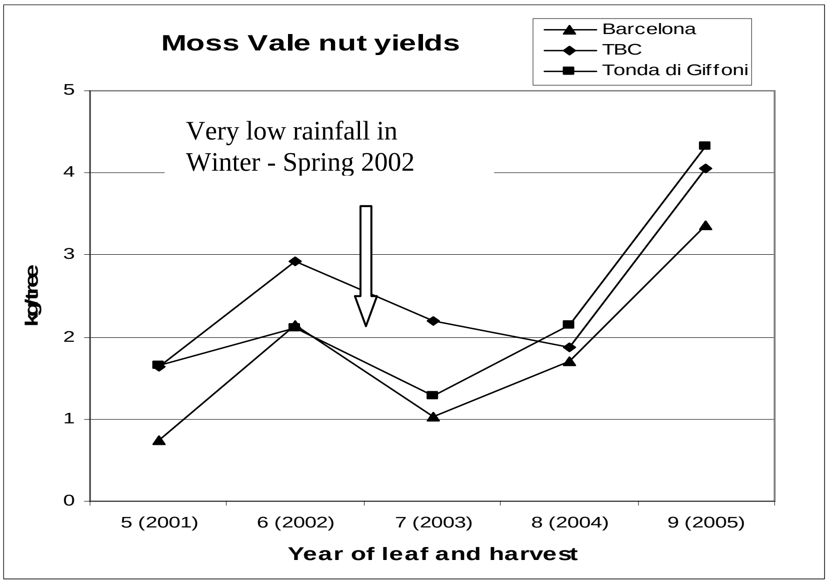
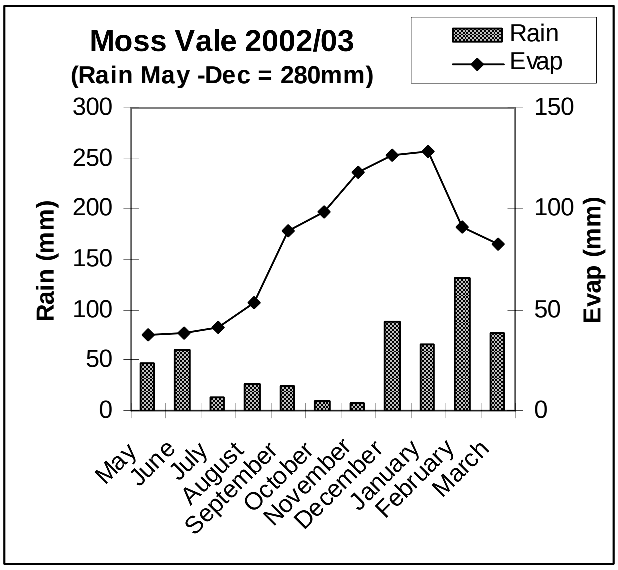
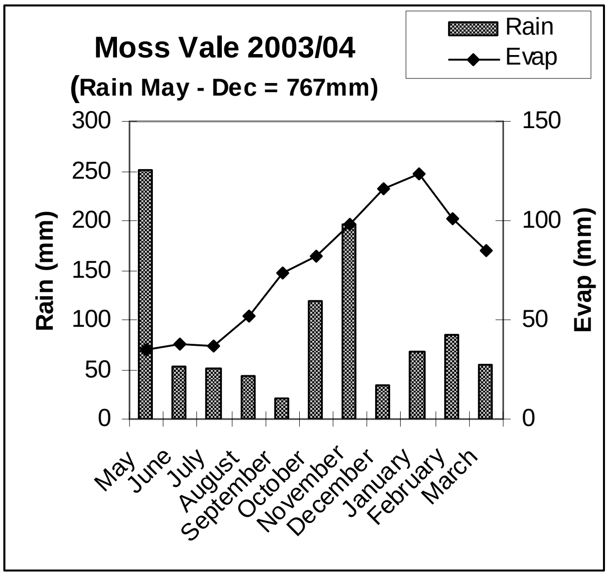



Figure 18. Growing season rainfall (mm) and estimated water loss (evapotranspiration) at Moss Vale



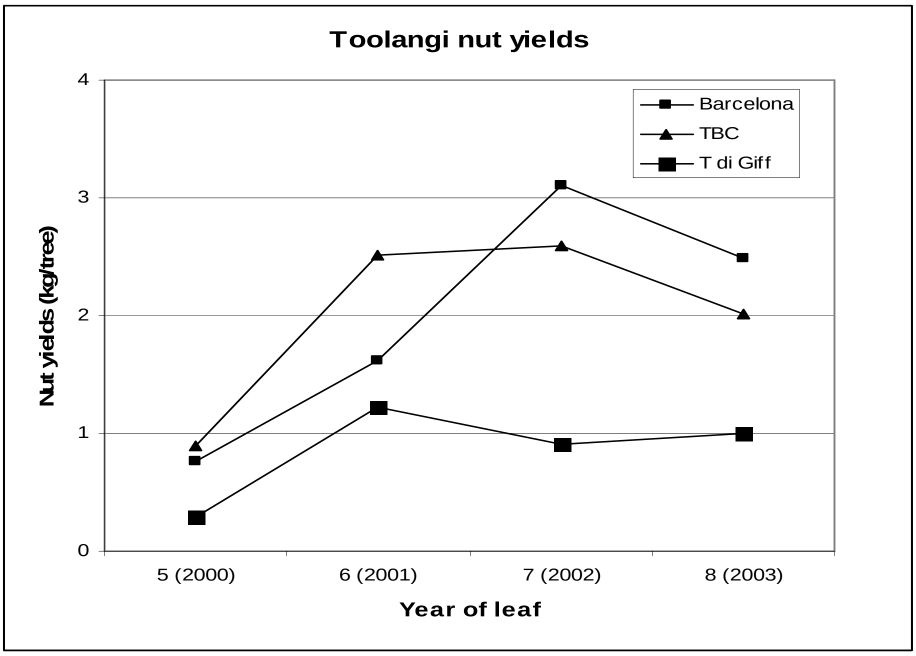




Irrigation water was applied at all sites, with quantities varying both with seasonal conditions and available water supplies. In the very dry growing season of 2002–03, water supplies at Moss Vale became very limited and it was only possible to apply 2820L/tree. Although this seems to be a high figure, the trees appeared to become moisture stressed in late spring and summer in that incredibly dry year (Figure 18) with growth (Figure 8), yield (Figure 17) and kernel quality (Figure 25) seeming to be adversely affected by the moisture stress.

It should be noted that in Figure 18, the term ‘evapotranspiration’ refers to an estimate of potential water loss from the orchard, which is likely to be higher than actual moisture loss when available soil moisture becomes limiting.

At Toolangi, peak nut yields occurred in the sixth year of leaf for TBC and Barcelona and the seventh year of leaf for Tonda di Giffoni (Figure 19). As with other sites, this peak yield coincided with the stage of growth when the trees had achieved a butt cross-sectional area of 80-100cm$^2$ and were meeting down the rows.

Figure 19. Development of nut yield (kg/tree) with time for three key varieties at Toolangi.




The trees at Kettering are still in the early stages of production. To date, TBC and Victoria have given the highest yields (Table 21). Although Barcelona has made reasonable growth and had achieved a butt cross-section area of nearly 50cm$^2$ by the sixth year of leaf, nut yields in that year - 2005 - and again in 2006 were less than 0.5kg/tree. The reason for these low yields is unclear, but the low rainfall of October and November, following a very wet September in 2003, may have restricted shoot growth that year and limited yield development in 2005. The soils at Kettering are not well drained and, as discussed previously, plant growth was adversely affected in the very wet spring of 2000. Although rainfall was better in the spring of 2004, nut yields the following year were still poor, except for TBC and Victoria. Pollination is unlikely to be an issue, as there was a wide range of compatible varieties at this site, as with all the other sites, and the trial trees are situated in an orchard which also comprises a mix of varieties.

The mean monthly temperatures in the months of November – March are lower at Kettering compared with the mainland sites. This may possibly be affecting the development of floral buds with some genotype temperature interaction. Possibly Barcelona may require more warmth in this period compared with TBC for floral bud initiation. The trees at this site are still quite young; data will be collected for a further two years, until 2008.

In general, nut yields appear to have been strongly influenced by tree growth. The best growth and nut yields were obtained at Myrtleford.

Figure 20. Development of nut yield (kg/tree) with time for three key varieties at Kettering .

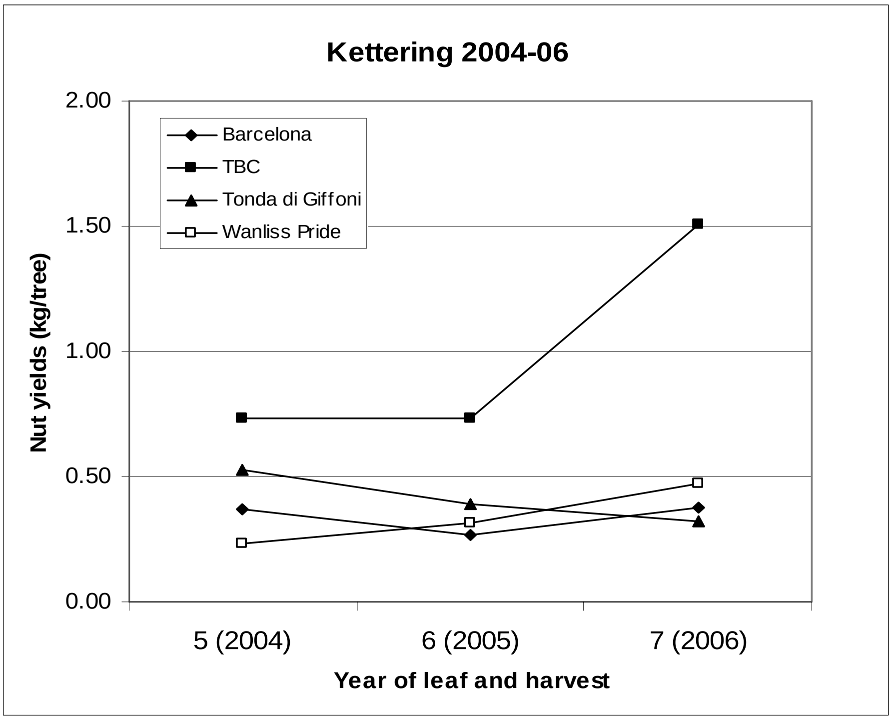



Figure 21. Tree growth at the Kettering site in the sixth year of leaf, March 2005. Some trees required supporting stakes due to the strong winds experienced at this site. Although very healthy looking, the trees generally lacked the vigour of growth that occurred at Myrtleford, Figure 15.

## 3.6 Nut size and kernel quality

After harvest, samples of 100 nuts of each variety were weighed and cracked to determine the proportion of blanks, defective kernels, the number of good kernels and the mean kernel weight.

Ennis consistently produced the largest nuts (Table 21). Although the nuts of Royal were nearly as large, the nut yield from Royal was generally lower, except at Kettering. The large size of the Ennis nuts makes them attractive for the in-shell market. In the USA and Europe, Ennis receives a premium price for the in-shell market. Ennis kernels are relatively large and, in some situations, did not seem to fill well (Figures 24 and 25) and do not blanch (Table 21 and Figure 22). The kernels are larger than the general size preference for kernels in the confectionery trade, but may be readily marketed as kernels in snack foods. Hall's Giant, which is synonymous with Merveille de Bollwiller, also produced large nuts, but the yields were low.

The higher yielding varieties, Barcelona, Tonollo and TBC, produced medium sized nuts and kernels. Those of the Sicilian type, Tonda di Giffoni and Segorbe were slightly smaller (Table 22). Apart from Segorbe, these varieties blanch moderately well, that is, removal of the pellicle after blanching is in the order of 75–90%.

Table 21. Mean nut and kernel weights with nut shape and kernel characteristics of the varieties being evaluated. The varieties are ranked for kernel/nut weight, an indication of kernel yield after cracking.

| Variety | Nut wt (g) | Nut shape (length/width) | Kernel wt (g) | Kernel/nut wt % | Kernel fibre | Relative blanching |
|---|---|---|---|---|---|---|
| Atlas | 3.1 | 0.92 | 1.26 | 41% | 2.5 | 4.1 |
| Barcelona | 3.14 | 0.97 | 1.32 | 42% | 3 | 3.6 |
| Butler | 3.25 | 1.1 | 1.52 | 47% | 2 | 6.3 |
| Casina | 1.76 | 1.08 | 0.98 | 56% | 1.5 | 5.7 |
| Daviana | 2.75 | 1.18 | 1.4 | 51% | 2 | 5.4 |
| Eclipse | 2.56 | 0.92 | 1.24 | 48% | 3.3 | 3.5 |
| Ennis | 3.97 | 1.12 | 1.65 | 42% | 1.5 | 6.6 |
| Halls Giant | 3.42 | 1.1 | 1.41 | 41% | 1.3 | 3.4 |
| Hammond 17 | 3.33 | 1.1 | 1.44 | 43% | 2 | 5.5 |
| Lewis | 2.45 | 0.97 | 1.27 | 52% | 1.8 | 3 |
| M. de Bollwiller | 3.42 | 1.1 | 1.34 | 39% | 1.3 | 3.5 |
| Montebello | 2.93 | 0.92 | 1.13 | 39% | 2.5 | 2.7 |
| Negret | 1.71 | 1.15 | 0.83 | 49% | 2 | 1.7 |
| Royal | 3.87 | 1.2 | 1.6 | 41% | 1.7 | 4.5 |
| Segorbe | 2.33 | 1.04 | 1 | 43% | 1.7 | 4.1 |
| Sicilian type | 2.99 | 0.96 | 1.12 | 37% | 2 | 3.1 |
| Sq Shield | 2.95 | 0.96 | 1.25 | 42% | 2 | 5.1 |
| TBC | 2.97 | 1 | 1.33 | 45% | 2.5 | 3.3 |
| TGDL | 2.07 | 0.97 | 1.07 | 52% | 2 | 3.2 |
| Tonda di Giffoni | 2.59 | 0.94 | 1.18 | 46% | 2 | 3.1 |
| Tonollo | 3.26 | 0.98 | 1.41 | 42% | 3 | 3.8 |
| Victoria | 2.99 | 1.05 | 1.27 | 42% | 1.3 | 5.3 |
| Wanliss Pride | 3.09 | 0.85 | 1.43 | 46% | 2 | 2.7 |
| Willamette | 1.93 | 0.96 | 0.88 | 46% | 2.5 | 2.8 |

Notes: Kernel fibre was rated on a 1(low) - 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).

Although Segorbe blanches less well, it has a thin pellicle and may be well suited to some sectors of the kernel market seeking unblanched kernels, such as snack foods or muesli.  Tonollo has a very thick fibrous pellicle, which makes it unattractive unless blanched.  It is likely there may be buyer resistance to kernels with a thick pellicle.

Figure 22. Nuts and kernels of the varieties Ennis, Barcelona, TBC and  Lewis. Ranging from the largest nut, Ennis to the smallest, Lewis.


Barcelona


TBC


Ennis


Lewis

In-shell nuts


Barcelona


TBC


Ennis


Lewis

Kernels showing degree of blanching

In some varieties, kernels vary considerably in size whereas with others the kernels are very even in size. In 2002, samples of 50 nuts were taken for a range of varieties grown at Myrtleford, the nuts were cracked to obtain the kernels. The diameter of the individual kernels was measured by passing them through a plastic gauge that had a range of hole sizes to see which was the closest fit. The mean size was determined and the degree of variation. The variation was compared with the mean and expressed as the co-efficient of variation (Table 22), the larger the figure, the greater the variability.   The kernel size of Wanliss Pride varied considerably, compared with the very even kernel size of Willamette and Tonda di Giffoni.

Table 22. The mean size of kernels (mm) from the Myrtleford site in 2002

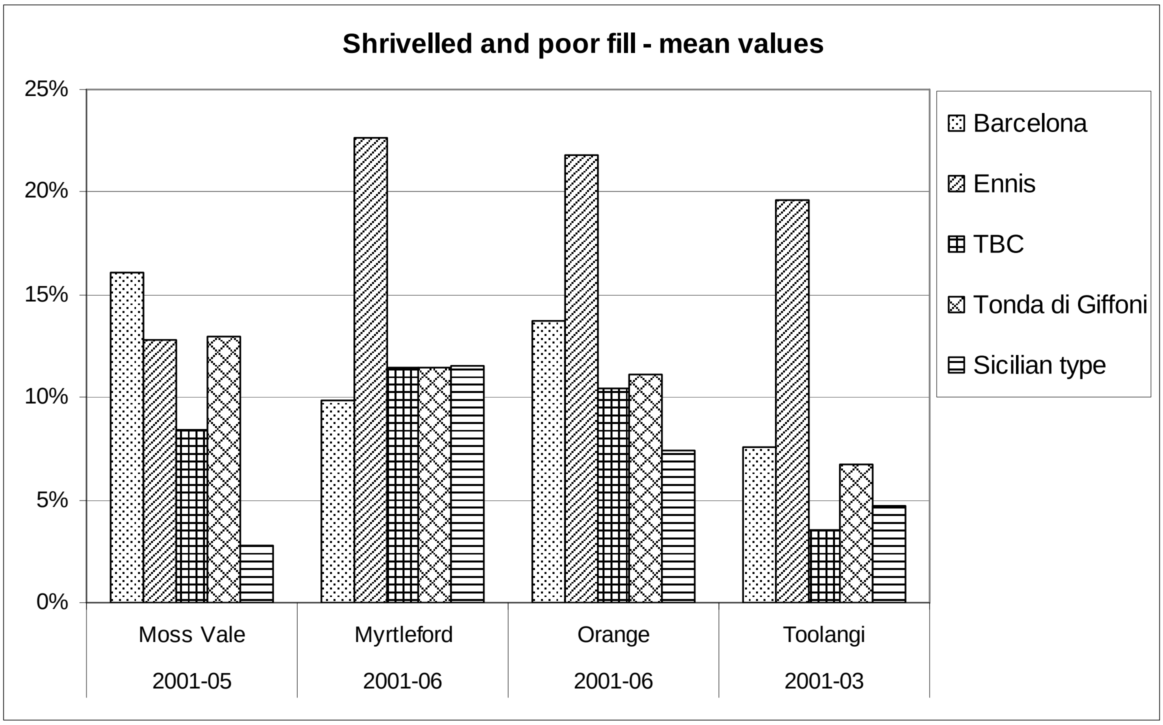
| Variety | Mean kernel size (mm) | Co-efficient of variation % |
|---|---|---|
| | Kernels 13-15mm | |
| Negret | 13.4 | 5.78 |
| Casina | 13.5 | 5.70 |
| Segorbe | 13.7 | 5.47 |
| Montebello | 14.2 | 4.99 |
| Sicilian type | 14.4 | 5.75 |
| TGDL | 14.4 | 6.79 |
| Tonda di Giffoni | 14.6 | 4.34 |
| | Kernels 15-17 mm | |
| Willamette | 15.1 | 4.37 |
| Atlas | 15.3 | 5.58 |
| TBC | 15.8 | 5.31 |
| Barcelona | 15.7 | 5.96 |
| Tonollo | 16.3 | 5.20 |
| Wanliss Pride | 17.0 | 6.99 |

Note: The coefficient of variation indicates the variability in kernel size.

Kernel quality is an important issue for those selling into the kernel trade. The ideal variety has a plump kernel in every nut. The nut shell is thin so a high crack-out is achieved, that is the weight of kernels per kilogram of nuts cracked is high. Casina, Lewis and TGDL all gave kernel yields over 50% whereas the Sicilian type and Montebello gave yields of less than 40% (Table 21).

Data obtained from cracking 100 nut samples showed that the main defects were shrivelled and poorly filled kernels. Generally, few kernels were downgraded due to mould, brown stain or black tips.
The proportion of inferior quality kernels (i.e. poorly filled and shrivelled) obtained for five seasons at four mainland sites is shown in Figure 23 for some of the key varieties. In general, Ennis produced more poorly filled kernels than the other varieties.

Figure 23. The proportion of inferior quality kernels (i.e. poorly filled and shrivelled) obtained from cracked nuts for five key varieties harvested in the years 2001–2006.



At Moss Vale, the proportion of inferior quality kernels was very high for the 2003 harvest year, particularly when compared with 2002 (Figure 24). It is considered that the shortage of water during kernel fill in January and February (Figure 25) may have reduced photosynthesis at this critical time, resulting in poor fill. A decrease in photosynthesis, nut and kernel size was reported by Tombesi and Rosati (1997) in studies they undertook on the effects of water availability during nut growth and kernel fill in Italy.

There were relatively few shrivelled kernels for the variety TBC even in the dry year of 2002- 03. A defect noted with the variety Barcelona was the relatively high number of nuts that had twin kernels; at Myrtleford this ranged from 5 – 15%. Tonollo also tended to have a relatively high proportion of twin kernels.

Figure 24. Variation between seasons at Moss Vale in the proportion of shrivelled and poorly filled kernels

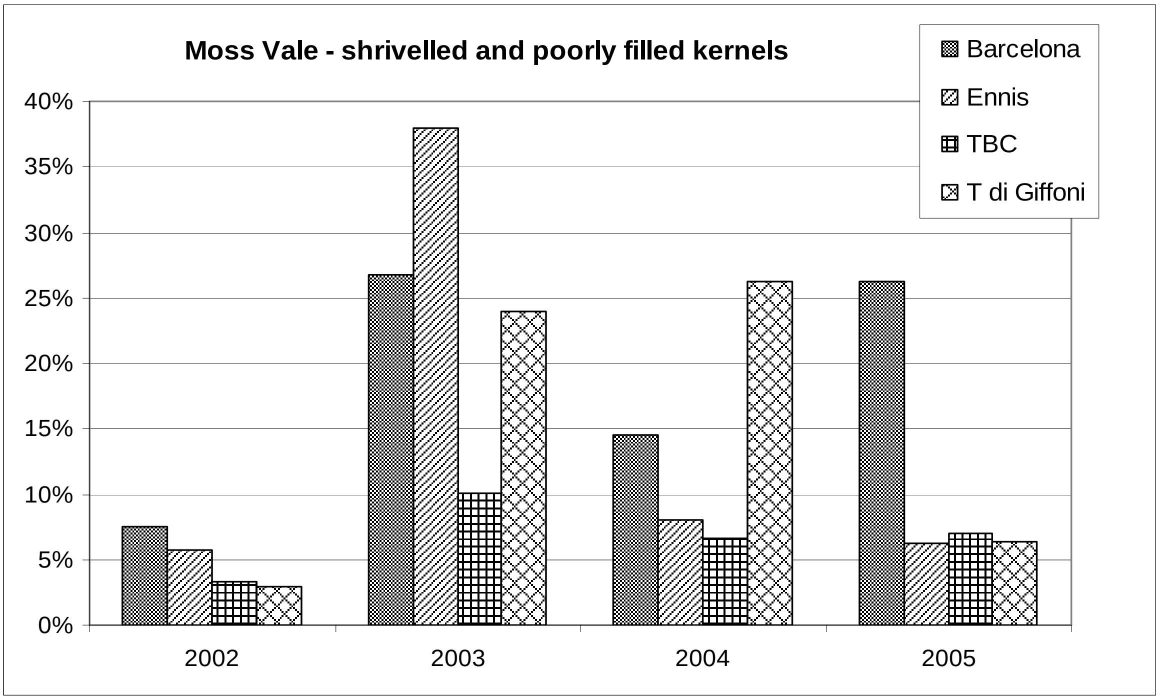
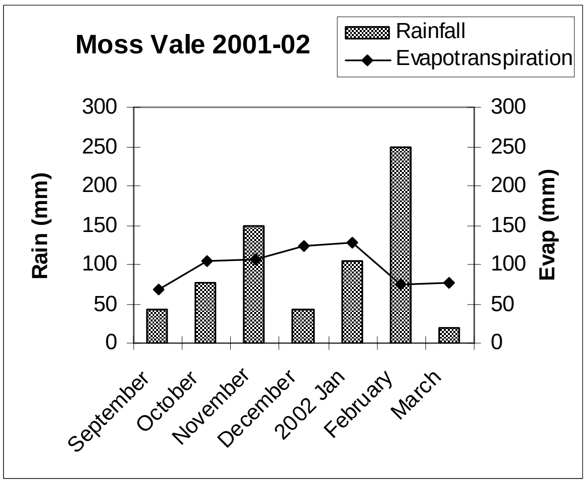
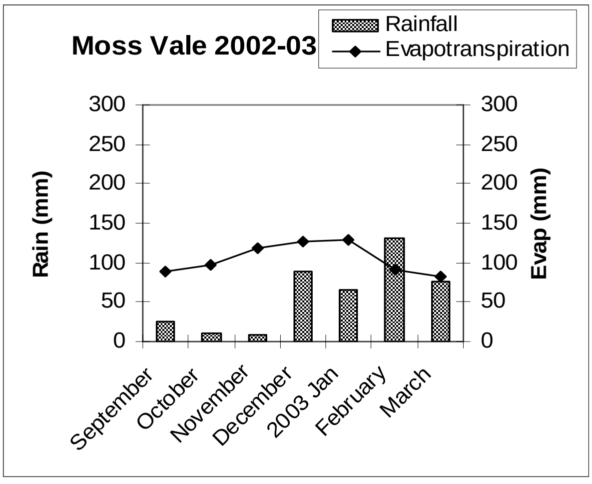



Figure 25, The pattern of rainfall (mm) and estimated water loss (mm) (evapotranspiration) at Moss Vale for seasons of good kernel fill, 2001-02 and poor fill (2002-03).



At Myrtleford, there was also considerable variation in kernel fill between seasons and varieties. Kernel fill of Ennis was generally inferior to the varieties Barcelona, TBC and Tonda di Giffoni, (Figure 26). In the harvest year of 2003, poor kernel fill was again associated with dry weather conditions (Figure 27), despite the application of over 4000L of water per tree during the growing season (Table 6). In 2002-03, rainfall was low throughout the whole growing season. In contrast, rainfall was generally very favourable in the 2004-05 season (Figure 27), except for the month of January, a critical time for kernel fill. Supplementary irrigation was applied to reduce this deficit.

Figure 26. Variation between seasons at Myrtleford in the proportion of shrivelled and poorly filled kernels.

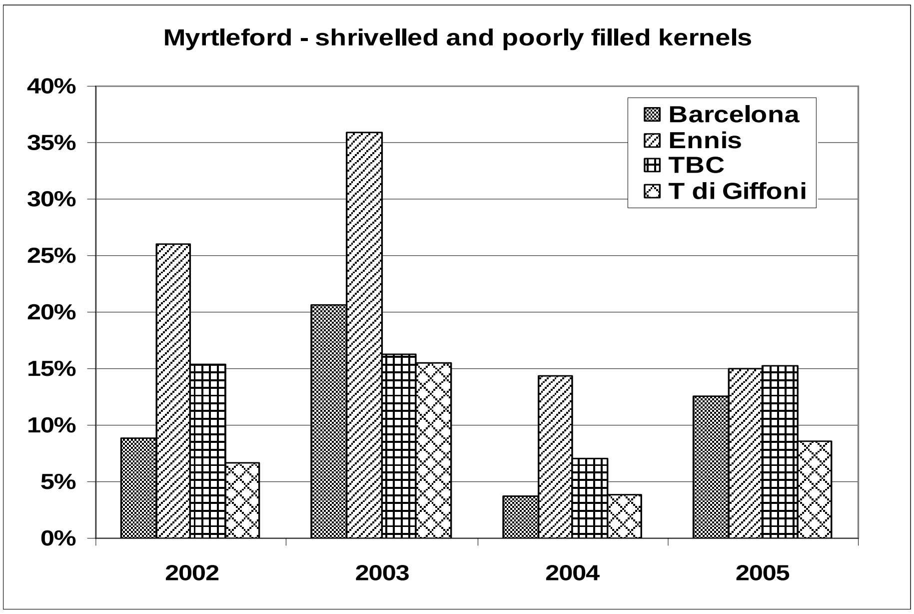
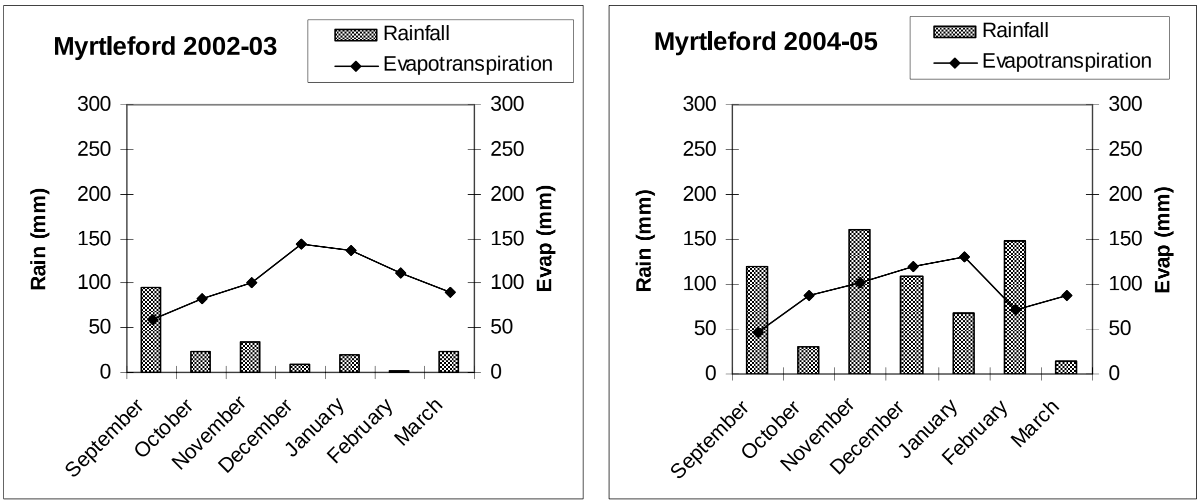



Figure 27. The pattern of rainfall (mm) and estimated water loss or evapotranspiration (mm) at Myrtleford for the dry season of 2002-03 and the favourable rainfall season of 2004-05.



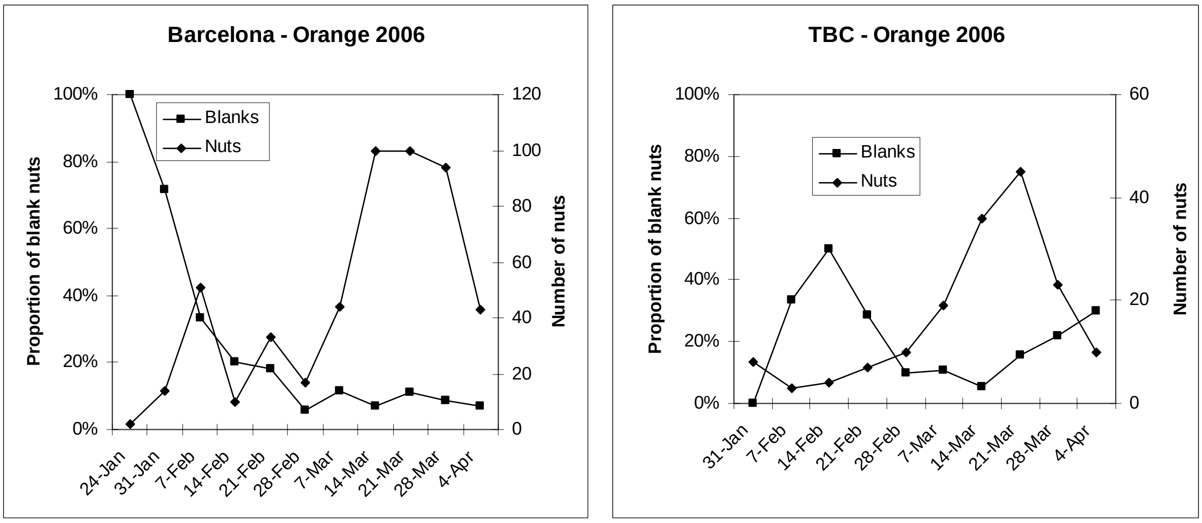

In 2001, nuts were gathered weekly from under the trees at Myrtleford for all varieties and kept separately in their weekly batches. The number of nuts that had fallen each week was counted and the nuts cracked out to assess the pattern of nut fall and the proportion of blank nuts.

In 2006, the trees of some varieties at Orange were covered with nets to protect them from the ravages of sulphur crested cockatoos. Mature nuts that had fallen were harvested weekly from these trees, then counted and cracked out as they had been at Myrtleford in 2001. In both seasons, nut fall was over a period of about four weeks for each variety. Most of the early falling nuts of Barcelona were blank

(Figure 28). However, the time at which the blank nuts of the variety TBC fell was slightly different. Many of the early falling nuts were blanks, but some blank nuts also seemed to hang on the trees to fall later.

The peak of nut fall varied a little between seasons; this was considered to be related to the accumulation of heat units from the beginning of December, when nut development generally occurs. An analysis of the temperature data and days to nut fall for the variety Barcelona showed that the warmer the season, the quicker the nuts developed and the earlier they fell (Baldwin and Gilchrist, 2005).

Figure 28. The pattern of nut fall and blank nuts at Orange in 2006 for the varieties Barcelona and TBC.




Samples of nuts from the 2005 and 2006 harvests were assessed for their oil content, their fatty acid composition and vitamin E content. Although there were differences between varieties (Table 23) the most marked differences were between seasons (Figure 29). The reasons for this are unclear. It is presumed they are related to the time period of kernel fill, as Ebraham et al (1994) showed that oil content steadily rose to a peak towards the end of kernel development.

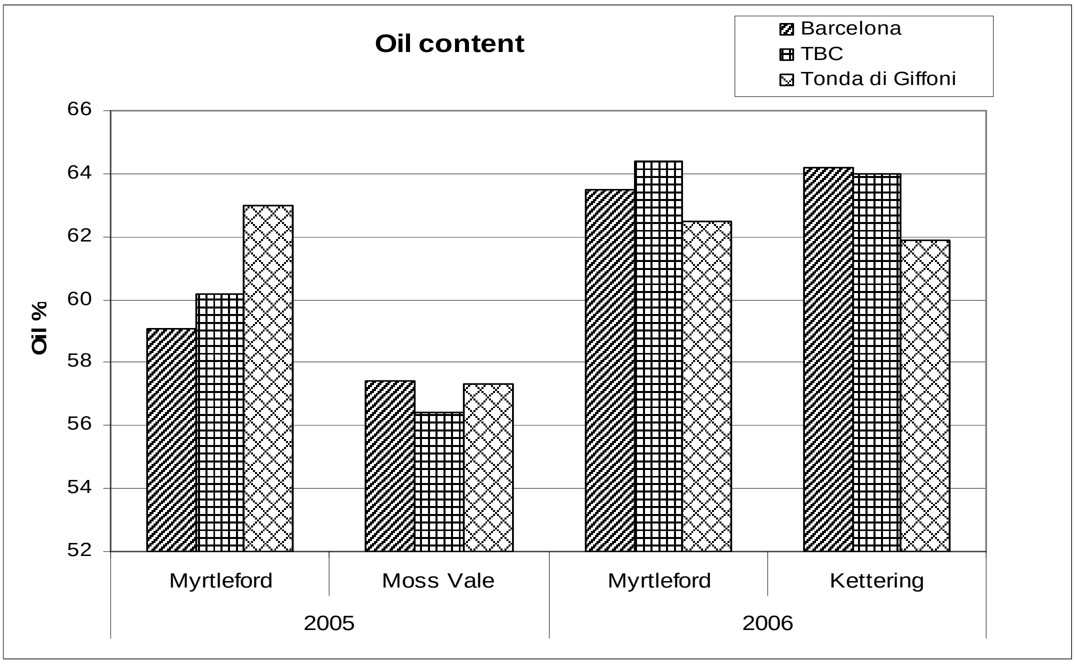
Table 23. Oil content (%) of hazelnut varieties from Australian research sites compared with Oregon (Ebraham et al, 1994).

| | 2002 | 2005 | | 2006 | | Oregon | |
|---|---|---|---|---|---|---|---|
| | Myrtleford | Myrtleford | Moss Vale | Myrtleford | Kettering | Ebraham | Richardson |
| Barcelona | 62.0 | 59.1 | 57.4 | 63.5 | 64.2 | 62.8 | 61.8 |
| Butler | N.A. | 56.3 | | | | | |
| Ennis | N.A | 54.2 | 52.6 | 59.4 | | | |
| Lewis | N.A | 61.0 | | 64.7 | 62.4 | | |
| Segorbe | 61.0 | 56.6 | | | | | |
| Sicilian | 61.1 | 59.3 | 58.2 | | | | |
| TBC | 60.1 | 60.2 | 56.4 | 64.4 | 64.0 | | |
| Tonda di Giffoni | 63.6 | 63.0 | 57.3 | 62.5 | 61.9 | 62.9 | 63.1 |
| Tonollo | 60.2 | 56.1 | | | | | |
| Wanliss Pride | 57.5 | 55.5 | | | | | |

Source of Oregon data: Ebraham et al, 1994. Richardson and Ebraham, 1996

The oil content obtained under Australian conditions does not seem to vary markedly from those obtained by Ebraham et al (1994) and Richardson and Ebraham (1996). Ennis and Wanliss Pride appear to have a relatively low oil content compared to Tonda di Giffoni and Lewis (Table 23).

Figure 29. Seasonal and site variations in the oil content of three hazelnut varieties.




The fatty acid profile and vitamin E content of five varieties was assessed. The proportion of monounsaturated fatty acids varied very little between varieties and situations; it was generally about 80% (Table 24). The main fatty acid was oleic acid with a proportion of about 85% of the monounsaturated acids. Although the vitamin E content seemed to vary between situations, the mean vitamin E levels for most varieties tested were in the range 325-365µg/g, although the levels for Ennis appeared to be lower, as was the oil content.

Table 24. The oil content (%), Vitamin E (µg/g) and proportion of monounsaturated fatty acids for five hazelnut varieties in two seasons and at two sites.

| | Myrtleford 2005 | | | Myrtleford 2006 | | | Kettering | | | Means | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oil | Vit E | Mono | Oil | Vit E | Mono | Oil | Vit E | Mono | Oil | Vit E | Mono |
| Barcelona | 59.1 | 388 | 80 | 63.5 | 295 | 83 | 64.2 | 400 | 76 | 62.3 | 361 | 80 |
| Ennis | 54.2 | 293 | 80 | 59.4 | 224 | 82 | 62.4 | 378 | 79 | 58.7 | 298 | 80 |
| Lewis | 61 | 387 | 81 | 64.7 | 262 | 84 | | | | 62.9 | 325 | 83 |
| TBC | 60.2 | 419 | 81 | 64.4 | 274 | 83 | 64 | 475 | 79 | 62.2 | 359 | 81 |
| T di Giffoni | | | | 62.5 | 351 | 82 | 61.9 | 383 | 80 | 62.2 | 367 | 81 |

Samples of hazelnut kernels from nuts harvested at Myrtleford in 2002 were assessed for oil and sugar content in a market research study undertaken by Baldwin and Simpson (2003). The varieties Barcelona, TBC, Tonda di Giffoni, and Segorbe all had oil content of at least 60% and sugar content of 4–6%. Wanliss Pride was found to have the highest sugar content at 6.9%, with TBC the next highest at 5.6%.

# 4. Discussion

## Objectives

The research had three key objectives, these were to:

- Determine the most suitable hazelnut varieties that could be used for the establishment of a hazelnut industry in south-eastern Australia.
- Assess the effects of geographical region and climate on hazelnut production and varietal performance.
- Assess the productive potential of hazelnuts (*Corylus avellana* L.) in Australia.

This section of the report will examine the research data and how it relates to these objectives.

## 4.1 Suitability of hazelnut varieties for the Australian hazelnut industry.

Hazelnut production has to meet two basic needs, to meet the needs of the market and to be profitable for the grower. As discussed in the introduction, the main market opportunities are in the kernel market. Hazelnut kernels have a wide range of uses, both in the raw and roasted form (Table 25). Some products require varieties that have a thin skin or pellicle, such as for snack foods; others such as gelato require varieties that blanch well. Manufacturers of chocolate often specify that they require kernels in the 9-11mm or 13-15 mm size range. In general, the ideal variety has a high kernel crack-out, is round and preferably has a thin skin that can be removed when blanched or roasted. The required size will vary with specific market outlets. Some buyers also have specific texture and flavour requirements. These were not assessed in this research, but were examined to some degree in a market research study conducted by Baldwin and Simpson, 2003.

Growers seek a high yield to maximise income, but the variety must meet market needs. Varietal type might influence price, for example some buyers pay a premium for the Italian variety TGDL as its kernels are highly prized by Italian manufacturers.

Table25. Key products derived from hazelnut kernels

| Hazelnut product | Description | Common usage |
|---|---|---|
| Raw kernels | Whole nut, pieces and diced | Snack food, muesli and in a wide range of food products. |
| Blanched kernels | Skins removed by heating | Ingredient in many foods. Some foods e.g. gelato require varieties that blanch well. |
| Roasted kernels | Dry roasted to bring out the flavour | Confectionery and bakery products |
| Meal | Raw or roasted hazelnuts that have been finely chopped or ground | Food ingredient, flavouring product such as praline, a paste which is used in a wide range of products. |
| Oil | Obtained from cold pressed raw kernels | Salad dressing, cooking, high in vitamin E and monounsaturated fatty acids. |
| Flour | Residual meal after oil extraction | Flour substitute, gluten free. |

Desirable characteristics for a grower to consider when selecting hazelnut varieties are:

- High yield
- High percentage kernel weight
- Few kernel defects
- Kernel blanching ability/thin skin or pellicle
- Round nut and kernel shape
- Free falling nuts for ease of harvest

Other considerations are:

- Early maturity
- Early bearing
- Resistance to pests and diseases

In the hazelnut breeding program at Oregon State University (OSU), Mehlenbacher (1995) has included the above attributes along with resistance to Eastern Filbert Blight, a major threat to the Oregon industry, and the pest Big Bud Mite. The main aim of the OSU breeding program is to develop varieties for the kernel market.

These attributes are also desirable in the Australian situation and should be considered when evaluating the material grown in these field studies. Eastern Filbert Blight is not present in Australia, but the pest Big Bud Mite occurs in Tasmania and resistance to that disease should be a consideration when selecting varieties for that State. An additional attribute is adaptation to a wide range of soil and climatic conditions.

In this research, the two highest yielding varieties were Barcelona and TBC. Two other varieties that performed well and show potential are Tonda di Giffoni and Lewis. The relative attributes of these varieties are given in Table 26.

Table 26. Potential kernel varieties

| | **Highest yielding varieties** | | **Potential varieties** | |
|---|---|---|---|---|
| | **Barcelona** | **TBC** | **Tonda di Giffoni** | **Lewis** |
| Nut yield, based on cumulative 8-year yields, (Figures 9 and 14) | Outstanding at Myrtleford, good at Toolangi and Orange, poor at Kettering | Fairly even across all sites, highest at Moss Vale and Kettering. | Good yields at Moss Vale, less well at other sites. | Promising yields, but planted later with limited data. |
| Average percentage kernel weight | 42%<br>Relatively thick shells | 45% | 46% | 52%<br>Thinner shells |
| Kernel defects (shrivelled and poor fill)<br>(Figure 23) | Tendency to poor fill and shrivel (7-15%) also some twin kernels. | Generally low proportion of shrivel or poorly filled (4-12%) | Generally well filled, 7-13% poorly filled | Generally well filled, but limited data |
| Blanching<br>(1 excellent – 7 none) (Table 21) | 3.5 | 3.2 | 3.1 | 3.0<br>(Blanch well) |
| Pellicle fibre<br>1(low) – 5 (high) | 3 | 2.5 | 2 | 1.8 |
| Nut shape (l/w) | 0.97 | 1.0 | 0.9<br>Distinct indents on the sides | 0.97 |
| Average kernel size | 14-16 mm | 14-16mm | 12-14mm | 12-14mm |

**Barcelona**
This variety is the basis of the Oregon industry. It probably originated in Spain and is synonymous with Fertile de Coutard, which is grown in France. Fertile de Coutard was included in the buffer row at Orange. Observations of this cultivar suggest its performance matches Barcelona. Pollen shed and female bloom appeared identical, but no comparative yield data has been obtained.

Barcelona is a versatile variety that appears to adapt to a wide range of conditions. Its kernels have good nutty flavour and blanch quite well. It commonly has some poorly filled kernels which generally have an off-flavour, do not blanch and need to be removed to produce a good quality product. It is well suited to the snack food market, but has been used successfully in a wide range of products. It is a variety with medium chill requirements which blooms in mid-season. Suggested pollinisers for this variety are shown in Table 28. Barcelona has moderate tolerance to Big Bud Mite.

**TBC (Tokolyi / Brownfield Cosford)**
The origin of this variety is unknown; it is possibly an Australian seedling, which was initially selected by Imre Tokolyi. It was planted extensively in the Brownfield orchard at Acheron, in Victoria. It is purported that subsequent selection was made in that orchard.

TBC produced moderate to good nut yields at all sites with kernels generally being well-filled and with good blanching attributes. Its main drawback is that it tends to fall in husk and frequently requires some dehusking in the field. However, it is not uncommon for commercial vacuum harvesters to have in-built dehuskers. The nut is round despite the term ‘Cosford’ in its name, which suggests a long nut.

Scion wood from a TBC tree at Orange was taken to Oregon by Professor Shawn Mehlenbacher who subsequently determined its S-alleles to be 5, 23. As the variety appears to produce good quantities of pollen mid-season, it is a potential polliniser for many varieties. Apart from the potential polliniser varieties shown in Table 28, observations by growers suggest that TBC is also pollinated by the Australian seedling selections known as Turkish Cosford, North-east Barcelona and Woodnut. Shawn Mehlenbacher (Pers. Comm. Oct 2006) reported moderate tolerance to Big Bud Mite.

**Tonda di Giffoni**
Of Italian origin, this variety is a strong-growing tree, described in the Italian literature as being “rustic”. It has relatively low chill requirements for catkins and vegetative buds and may be well suited to areas with mild winters and lower chilling hours. It has grown well at all sites. The kernels generally fill and blanch well and have a good nutty flavour. Nuts have a characteristic indent or groove. It has potential for the confectionery trade and in the manufacture of Nutella. It has good tolerance to Big Bud Mite.

**Lewis**
A variety developed by Oregon State University and released in 1997. It is earlier into bearing than Barcelona, is a smaller tree, nut fall is earlier and it has fewer kernel defects. It has moderate tolerance to Big Bud Mite.

The potential of Lewis has not been fully evaluated in this research as it was not available in the initial years of planting. However, it does seem to have potential as a kernel variety and has a useful role as a polliniser.

**Polliniser varieties**

When selecting varieties to use as pollinisers, they must be genetically compatible with the trees of the main variety that is to be pollinated. The polliniser trees must shed pollen when the female flowers of the main variety are receptive and ideally have kernels that can be used in mixture with the main crop varieties. If the kernels cannot be used in mixture, then the polliniser variety needs to have nuts that can be separated from the main cropping variety by size grading. Apart from Segorbe, all the suggested polliniser varieties shown in Table 28 blanch quite well.

Comprehensive studies on the genetic factors influencing pollination have been conducted overseas. Hazelnuts have been found to be self-incompatible. In their genetic make-up, alleles, known as S-alleles, prevent hazelnut trees from pollinating themselves and other trees of the same variety. More than 20 different S-alleles have now been identified (Mehlenbacher, 1997).

Identification of the S-alleles for each variety enables compatibility relationships between varieties to be determined. Each variety has two S-alleles and both of these are expressed in the female flowers. In the pollen, both alleles may be expressed when they are of equal dominance, that is, they are co-dominant. However, if one allele in the pollen is dominant over the other, only the dominant allele is expressed in the pollen. For varieties to be compatible, the S-alleles of the female must differ from the dominant or co-dominant alleles of the polliniser, see Table 27. For example, in Barcelona ($S_{\underline{1}}S_2$), only the dominant allele $S_{\underline{1}}$ is expressed, whereas in Hall's Giant ($S_{\underline{5}}S_{\underline{15}}$) the S-alleles are co-dominant, therefore both are expressed.

Table 27. Example of some cultivars that are compatible with Barcelona and can be used as pollinisers, compared with an incompatible variety, Montebello.

| | | | | |
|---|---|---|---|---|
| Example: | | | S-alleles | |
| Nut producing variety | - | Barcelona | $\underline{1}$ | 2 |
| Polliniser varieties | - | Butler | 2 | $\underline{3}$ |
| | - | Casina | $\underline{10}$ | $\underline{21}$ |
| | - | Halls Giant | $\underline{5}$ | $\underline{15}$ |
| BUT NOT | - | Montebello | $\underline{1}$ | 2 |

The dominant allele is underlined in each case. The dominant allele of Butler is the $S_{\underline{3}}$ allele. So although Butler has an $S_2$ allele, it is recessive in the pollen, therefore cross-pollination with Barcelona can occur. Casina and Hall's Giant have co-dominant S-alleles, but they are different from the $S_{\underline{1}}S_2$ alleles of Barcelona, therefore Casina and Hall's Giant are compatible with Barcelona. Montebello pollen is not compatible with Barcelona, as the dominant $S_{\underline{1}}$ allele of Montebello is also dominant in Barcelona.

S-alleles for the introduced cultivars included in the field studies are shown in Table 29. The Australian selections TBC, Tonollo and Wanliss Pride are in the United States Department of Agriculture (USDA) germplasm collection at Corvallis. Their alleles have been determined by Mehlenbacher. Those of TBC are shown in Table 28, Tonollo are as for Barcelona and Wanliss Pride are considered to be as for Imperial de Trezbionde (S 2 $\underline{10}$).

Table 28. Potential pollinisers for the most promising varieties in the field studies

| Variety | S - alleles | Early | Mid-season | Late |
|---|---|---|---|---|
| Barcelona | $\underline{1}$ 2 | Segorbe | TBC<br>Lewis | Hall's Giant/<br>Merveille de<br>Bollwiller |
| TBC | $\underline{5}$ 23 | Barcelona | Lewis | Jemtegaard #5 |
| Tonda di Giffoni | $\underline{2}$ 23 | Barcelona<br>Segorbe | Lewis | Hall's Giant |
| Lewis | $\underline{3}$ $\underline{8}$ | Tonda di Giffoni | TBC | Hall's Giant |

Hall's Giant/ Merveille de Bollwiller are different names for the same variety.

**Varieties for the in-shell market (Ennis and Royal)**

There is a small in-shell market, with demand generally being greatest at Christmas. Large, shiny nuts, such as produced by the varieties Ennis and Royal usually have a higher buyer appeal than small nuts. At Orange, Ennis yielded well (Table 18) and at Myrtleford and Moss Vale (Tables 16 and 17) it gave reasonable yields. Although Royal was not evaluated at all sites, at Myrtleford it yielded less than Ennis, whereas at Kettering, yields have so far been superior for Royal. It seems possible that Ennis is more suitable to cold continental climates, with Royal possibly being better suited to more maritime environments.

In many instances, kernels of Ennis were poorly filled or shrivelled (Figures 16, 17 and 19). Although shrivelled kernels are not apparent at the time of selling nuts in-shell, it seems likely that in time buyer resistance might occur if poor quality kernels are found after cracking the nuts. Although there is limited data on the kernel quality of Royal, the data indicates there are similar problems with poor fill of Royal kernels. Neither Ennis nor Royal are considered very suitable for the kernel market, due to poor kernel fill, uneven kernel shape and poor blanching.

**Comments on other varieties**

**Atlas** was generally a vigorous growing variety at all sites but did not yield very well. The kernels have a very coarse fibrous pellicle which is likely to be a disadvantage if used as whole kernels. The kernels blanch moderately well.

**Butler** grew very well and yielded very well at Myrtleford. The medium sized nut is quite attractive, but the kernels do not blanch. They have their own particular flavour.

**Casina** nuts are very small and tended to fall in the husk. Casina regularly produced a mass of catkins with mid-season pollen shed. Its main role is likely to be as a polliniser, as it is compatible with many of the higher yielding cultivars. The kernels do not blanch well.

**Daviana** has been an important polliniser for Barcelona in Oregon, but has been superseded by Butler. It has a long shaped nut and kernel. Yields are low.

**Eclipse** sheds pollen late and may be a useful polliniser. Growth was poor at Orange.

**Hall's Giant** and **Merveille de Bollwiller** (Syn.) are valuable late pollinisers and are compatible with many cultivars. They grew well at all sites and produced many catkins. Their nuts are relatively large, kernels blanch quite well, but yields are low. They are considered to be the same cultivar. The trees had almost identical characteristics.

**Hammond 17** appears to be a variant of Butler; it does not seem to be superior to Butler.

**Montebello** is an early flowering variety. It was planted later than most other varieties at Myrtleford, so yield data is limited. The kernel has a pleasant taste, but the nut has a very thick shell with a low kernel percentage.

**Negret** grew very poorly at Orange and appears to have limited value under Australian conditions. It produces a small nut with a round kernel that blanches well.

**Square Shield** produces a tasty kernel, but did not grow well at Orange. However, its late pollen shed might make it a useful polliniser for a variety such as TBC, but its alleles are not known.

**Segorbe** is one of the better yielding cultivars. Segorbe has grown well at all sites; it has a small nut and kernel. It has produced a high percentage of good nuts with well-filled kernels. It does not blanch well, but has a thin pellicle. It produces large catkins and could be useful as an early polliniser for Barcelona, provided the poor blanching characteristics were not a marketing issue if in mixture with the Barcelona.

**Sicilian type** a variety provided as Tonda Romana. However, its characteristics were found to be very different from the general descriptions for the variety Tonda Romana. It was not possible to identify the variety but it had typical characteristics of some Sicilian varieties and is likely to be closely related to Montebello. Although it only grows into a relatively small tree, it grew well at all sites and yielded particularly well at Myrtleford. The nuts and kernels are relatively small. It blanches quite well and has potential for the kernel market. Its main limitation is its thick shell and low kernel percentage.

**TGDL** produces high quality kernels but it made very poor growth at Orange, as did the TGDL in the Ferrero Australia collection. It lacked vigour and productivity at all sites.

**Tonda Romana** this Italian variety was imported into Australia by Ferrero Australia and was planted adjacent to the main variety assessment block at Orange. At that site, the trees did not grow very vigorously and have not yielded well. The trees show all the attributes of Tonda Romana, with a good kernel percentage, small to medium sized kernels that have excellent flavour but poor blanching. It is considered this variety, which was not included in these studies, is worthy of further evaluation.

**Tonollo** appears to be closely related to Barcelona; it has a thicker shell and lower crackout.

**Victoria** is a vigorous variety that produces large nuts. The kernels do not blanch. The variety appears to have limited value although it demonstrated reasonable yield potential.

**Wanliss Pride** has been widely planted in the past. It was the main variety grown in the Ovens Valley in the 1920s. There are examples of some very productive trees of this variety in parts of Victoria. It produces an attractive large nut and a nice flavoured kernel. Some growers of this variety have reported that it does not keep well. In these studies, the growth and yield of Wanliss Pride was very variable and was generally lower than most varieties. To date, it has performed quite well at Kettering; it may perform best in maritime environments. It has the characteristics of the Turkish variety Kargalak, Imperial de Trebizonde, which has the S alleles 2 10.

**Whiteheart** was one of the latest additions to the trials and was included in yield testing at Kettering only. Trees in the buffer rows at Orange made very poor growth. It was very late in female bloom. More data is required on this variety which produces high quality kernels and a high kernel percentage in New Zealand, where it is a widely grown.

Table 29. The incompatibility S-alleles of some hazelnut cultivars introduced into Australia.

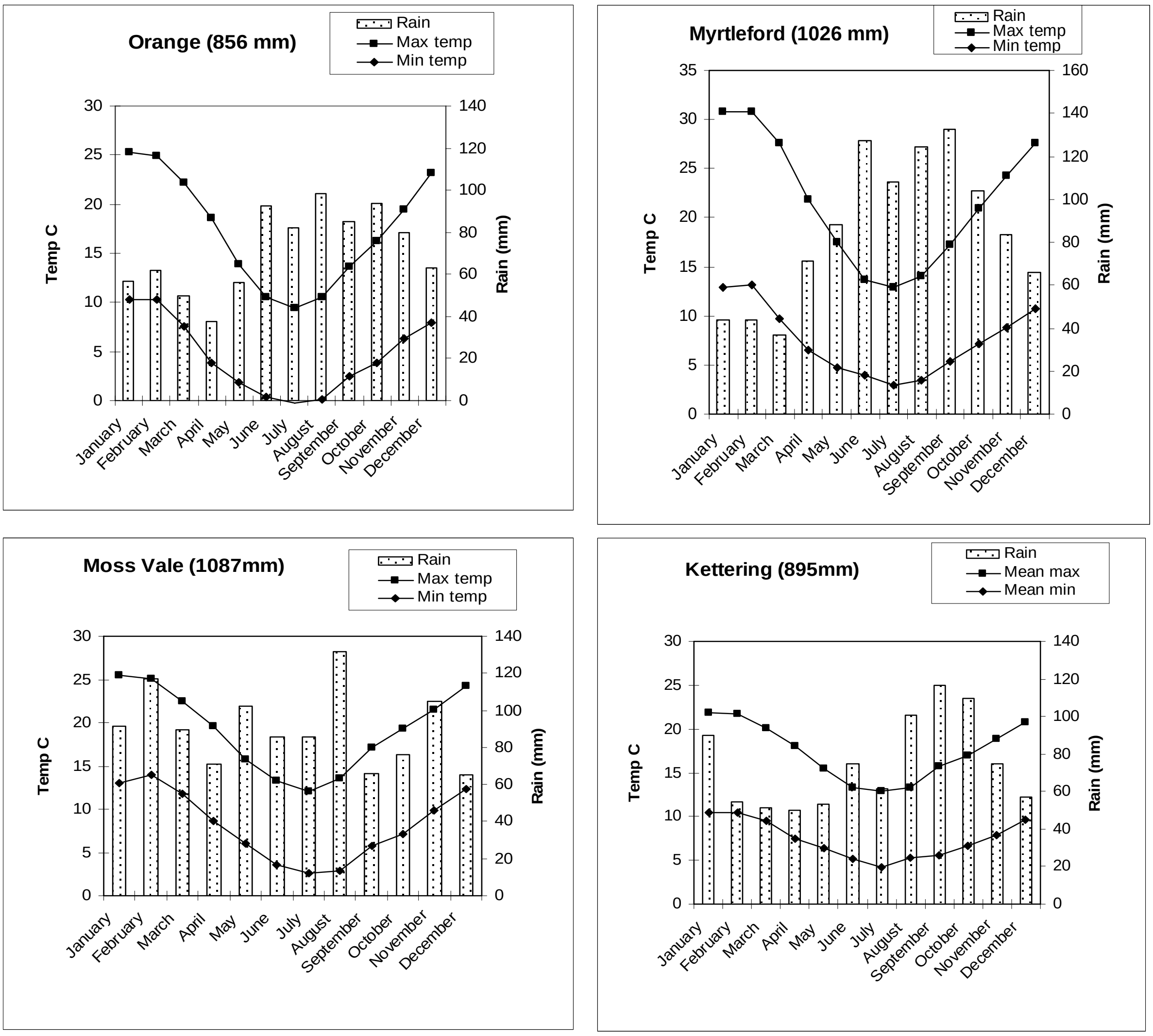
| **Cultivar** | **S alleles** | **Cultivar** | **S Alleles** |
|---|---|---|---|
| Barcelona | 1 2 | Montebello | 1 2 |
| Butler | 2 3 | Negret | 10 22 |
| Casina | 10 21 | Royal | 1 3 |
| Daviana | 3 11 | Segorbe | 9 23 |
| Kentish Cob | 8 14 | TGDL | 2 7 |
| Ennis | 1 11 | Tonda di Giffoni | 2 23 |
| Hall's Giant/ Merveille de Bollwiller | 5 15 | Tonda Romana | 10 20 |
| Jemtegaard #5 (J#5) | 2 3 | Whiteheart (Waterloo) | 2 10 |
| Lewis | 3 8 | Willamette | 1 3 |

Source: Thompson, 1979, Mehlenbacher, 1997 and Mehlenbacher, 1991.

# 4.2 The effects of geographical region and climate on hazelnut production.

The second key objective was to assess the effects of geographical region and climate on hazelnut production and varietal performance. At the outset of these studies, it was considered that climate might play a key role in production. In the Northern Hemisphere, centres of hazelnut production are limited to quite specific locations that have a Mediterranean or maritime climate. The research sites were chosen to represent a range of agro-climatic conditions. Contrasting temperature patterns were recorded from these sites (Figure 30), ranging from continental type patterns of Orange and Myrtleford with their high diurnal variation to the maritime climate of Kettering. The highest average summer temperatures were recorded at Myrtleford with the mildest temperatures at Kettering.

Figure 30. Average maximum and minimum temperatures and rainfall recorded at four of the field sites during the conduct of the experiments.




The data obtained from the experiments can be used to provide guidelines for selecting appropriate sites for growing hazelnuts, in relation to climate and soil type.

**Climate**

Sufficient chill occurred at all sites for pollen shed, female bloom and vegetative bud burst. The total chill hours for the period April – August inclusive are probably the best guide for the minimum requirements for flowering and bud burst. The average figures for this period are given in Table 30, along with the mean temperature for the coldest month. Moss Vale had the lowest chill hours, yet these were sufficient for flowering and bud burst in the variety Hall's Giant (Merveille de Bollwiller syn.). These chill hours are based on the total number of hours in the temperature range 0 -7$^{0}$C. Note the mean temperature for the coldest month, July, at Kettering was 8.5$^{0}$C. It is suggested that when selecting suitable sites for hazelnut production, the mean temperature for the coldest month should be less than 10$^{0}$C, unless varieties with low chill requirements are being grown, when a mean temperature of 11-12$^{0}$C could be suitable.

Table 30. The relationship between the total chill hours (0-7$^{o}$C) for the period April – August, inclusive, and mean temperatures recorded in the coldest month, July, for the five sites.

| | Kettering | Moss Vale | Myrtleford | Toolangi | Orange |
|---|---|---|---|---|---|
| Total chill hours (0-7$^{o}$C) April – August (incl.) | 1088 | 1185 | 1370 | 1430 | 1467 |
| Max temp July $^{o}$C | 12.8 | 12.0 | 12.9 | 9.0 | 9.4 |
| Min temp July $^{o}$C | 4.2 | 2.6 | 2.9 | 4.2 | -0.2 |
| Mean temp July $^{o}$C | 8.5 | 7.3 | 7.9 | 6.6 | 4.6 |

**Frosts**

Winter frosts did not seem to have any detrimental effects in the trials. One of the reasons for the restricted areas of production in Europe and North America is associated with winter cold during flowering. Female flowers with exerted stigmas may be killed at temperatures below -10$^{o}$C (Westwood, 1988). Although radiation frosts are common in inland areas of Victoria and NSW, particularly at high elevations, temperatures below -10$^{o}$C are uncommon. During the trial, temperatures as low as -7.6$^{o}$C at Orange and -5$^{o}$C at Myrtleford were recorded. At Glen Innes, on the Northern Tablelands of NSW, a minimum of -11$^{o}$C has been recorded by the Commonwealth Bureau of Meteorology (2002).

Hazelnut trees appear to have a good tolerance to spring frosts. Late spring frosts that were observed to damage vines and some deciduous fruit trees in the vicinity of the trials did not appear to have any detrimental effects on the trees in our experiments.

**Maximum Temperatures**

The highest maximum temperatures were recorded at the Myrtleford site, where mean maximum temperatures in January and February were just over 30$^{0}$C. This is generally hotter than other major overseas centres of hazelnut production, Table 31.

Table 31. Mean maximum temperatures ($^{0}$C) for the hottest month for three key hazelnut production areas overseas compared with Myrtleford and Kettering

| Location | **Corvallis, Oregon, USA** | **Reus, Spain** | **Samsun, Turkey** | **Viterbo, Italy** | **Myrtleford, Victoria** | **Kettering, Tasmania** |
|---|---|---|---|---|---|---|
| Mean maximum temperature $^{o}$C for the hottest month | 27.2 | 28.5 | 27.0 | 30.4 | 30.8 | 21.7 |

Most of the overseas centres have mean maximum temperatures for the warmest month of over 25$^{0}$C, whereas at Kettering the mean maximum in January and February was about 22$^{0}$C. This lower temperature seemed to be adequate for nut development. However, it delayed maturity, with nuts not ripening until April, compared to March at the mainland sites. It is suggested the mean maximum temperatures in the warmest months, January and February, should not be much greater than 30$^{0}$C. Higher temperatures are likely to be above the optimum and may have an adverse effect on kernel fill, especially if these high temperatures are associated with low relative humidity, high evaporative loss and limited soil moisture. Therefore, areas with high summer temperatures are not recommended for hazelnut production.

**Rainfall**

Rainfall had a major effect on nut yields and kernel quality. In dry seasons, such as that experienced at Moss Vale in 2002/03, tree growth and nut yields in the following year were reduced, with many poorly filled and shrivelled kernels being produced in that dry season. Adequate rainfall in October-November is required to produce wood that will bear the next season's crop. Adequate moisture in December, January and February is required for nut growth and kernel development. This is confirmed by the studies of Mingeau et al (1994) who found that hazelnuts were very sensitive to moisture stress from fertilisation to kernel fill, the most sensitive phase being fertilisation, which, in Australia, generally occurs in November.

Annual rainfall in key centres for hazelnut production overseas is generally in the range 800-1200mm. The mean rainfall recorded at all sites, while these experiments were being conducted, was in this range. However, there was a high degree of variability between years.

Reus in Spain is one of the driest overseas locations where hazelnuts are grown commercially. The average annual rainfall there is about 550mm, but supplementary irrigation is regularly applied. It is suggested that suitable sites for hazelnut growing in Australia should have a mean annual rainfall of at least 750mm, but water supplies for supplementary irrigation are essential to minimise the effect of erratic rainfall commonly experienced in Australia. As a rough guide, this should probably be in the range of 1-2ML/ha.

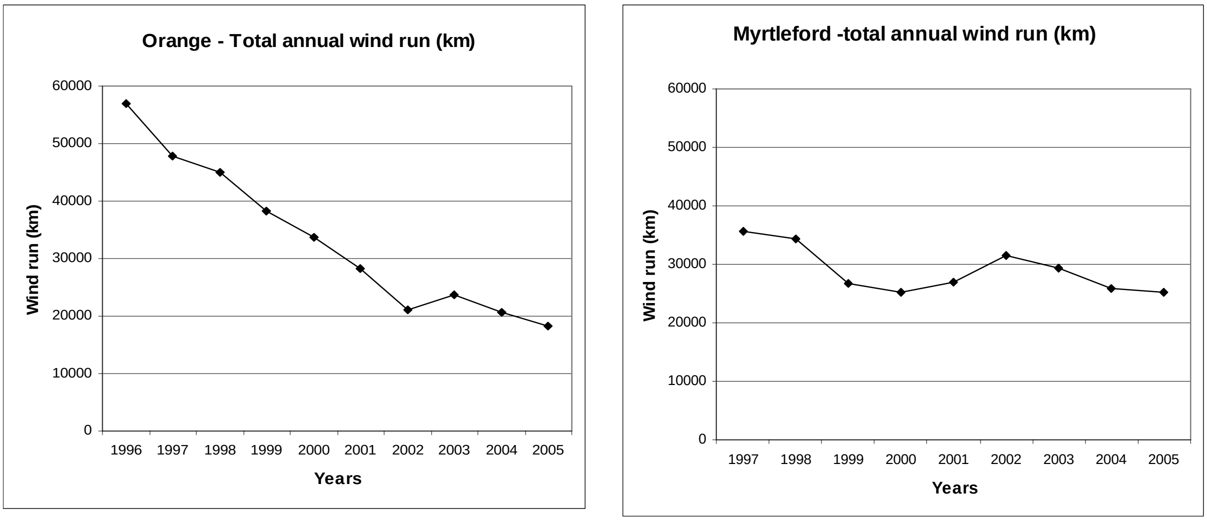
Areas that have winter–spring rainfall dominance appear to be more suitable than areas with summer–autumn rainfall dominance, as late summer rains can hamper harvest and may have an adverse effect on nut quality, causing moulds to develop.

**Wind**

Hazelnut trees are adversely affected by strong and persistent winds, particularly in the spring. This was very obvious at Toolangi, with trees in the top south-western corner of the site being considerably smaller and more bent than those further down the slope, where there was greater wind protection. One of the reasons for poor growth at Orange may be partly attributed to wind, as that site was initially very open to wind (Figure 31) and was 50% windier than the Myrtleford site, at the time of planting, However, eight years after planting, total annual wind run had been reduced by over 60%, due to the combined effects of the casuarinas that had been planted as a wind break and the developing hazelnut trees.

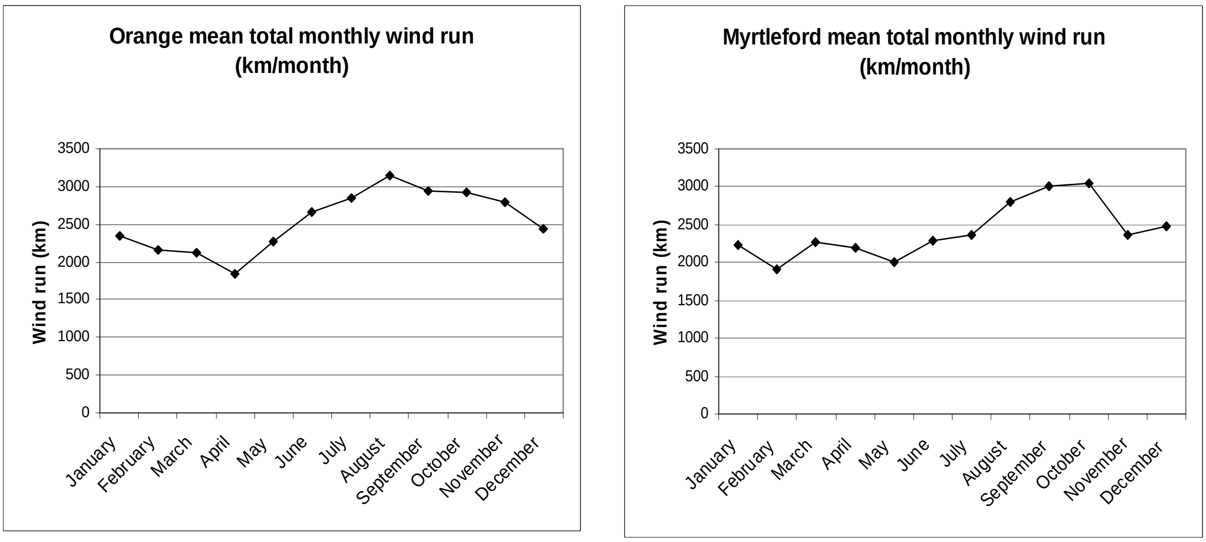
Winds in spring and summer have been observed to cause damage to both leaves and developing shoots. Hazelnut trees can have fairly large leaves, which are quite soft until late November to December. Hot dry winds can cause leaf scorch in summer.

Figure 31. Annual wind run (km) recorded at the Orange and Myrtleford sites.




At most sites, the windiest period of the year was in the spring (Figure 32), when new leaves and soft shoots are developing. These tender new tissues are particularly vulnerable to wind damage. On exposed sites, planting shelter trees in advance of orchard establishment is highly recommended. Late summer and autumn is commonly the calmest period of the year.

Figure 32. The pattern of mean monthly wind run (km) through the year at Orange and Myrtleford.




## Soils

Soil type appears to be a key issue in hazelnut production in Australia. Deep alluvial loams, such as that at the Myrtleford site, appear to be the ideal. It is noteworthy that in Oregon, hazelnut orchards are generally situated on loam soils of alluvial origin and great care appears to be taken in site selection to ensure good tree growth and nut yields. Germain et al, 2004, conducted studies in France on the effects of soil texture on the root growth of hazelnut trees. They considered clay loams and loamy clays that are well structured and well drained were the most suitable soils.

The bulk of root growth is in the top 500-600 mm (Germain et al, 2004) with some roots penetrating down to depths of more than 2 metres. Many Australian soils are old and leached with an A horizon, or surface soil layer, of about 300mm. This commonly lies over a heavier textured B horizon as occurred at Orange, Moss Vale and Kettering. The Orange soil was classified as a krasnozem, which was well structured and well drained, however the B horizon was light clay which is not an ideal texture. Although basaltic krasnozem soils are generally well drained, the high levels of manganese that commonly occur in these soils may be a problem.

At Kettering, the B horizon was also a clay, but in that case it was not well drained, which adversely affected tree growth in the wet year of 2003.

Soil pH, that is the degree of acidity or alkalinity, is considered to be important. The most favourable pH is considered to be about 6.5 (Germain et al, 2004). As many Australian soils are leached, calcium levels and pH values are often lower than pH 6.0. It is considered desirable to test soil pH before planting and apply ground limestone before planting to reduce the acidity and raise the pH.

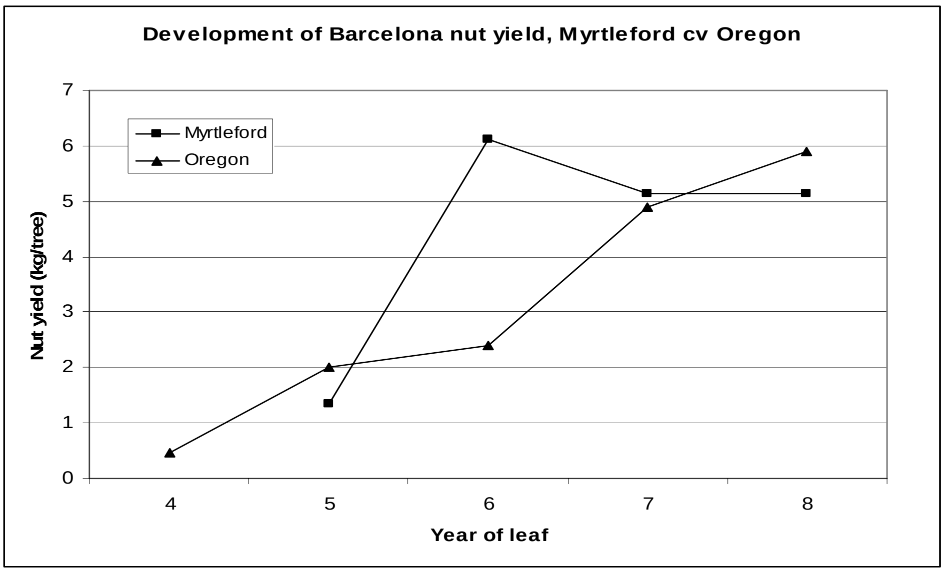
The ideal soil to seek is a deep, well drained alluvial loam. Unfortunately, such soils are not common in Australia. It is recommended that growers undertake a profile analysis of potential orchard sites before planting to ensure they are well drained and have an appropriate loam texture to a depth of at least 500mm, if possible. Heavy clay soils and shallow soils should be avoided.

## 4.3 The productive potential of hazelnuts (*Corylus avellana* L.) in Australia.

### Productive potential

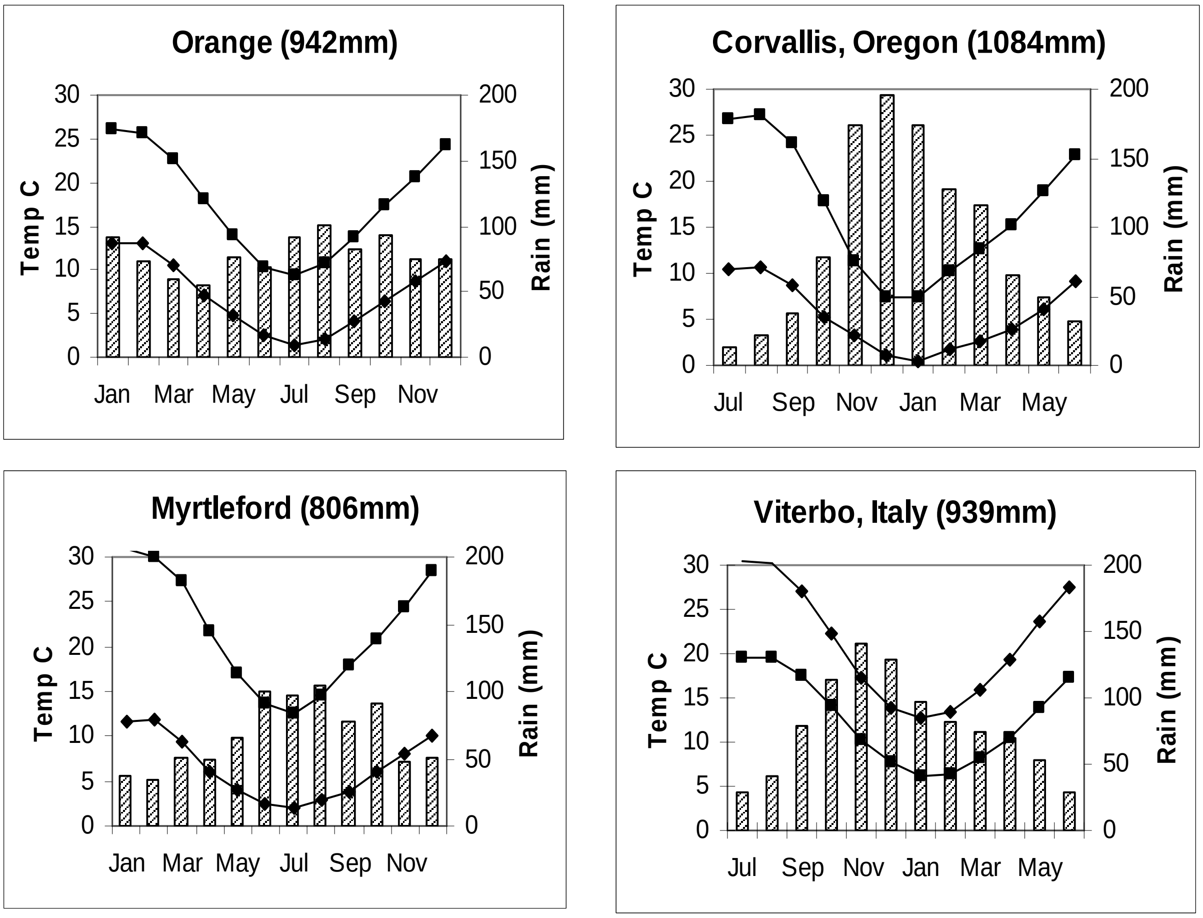
The site at Myrtleford indicates the potential of hazelnuts as a crop. A comparison of nut yields from Myrtleford and Corvallis in Oregon was made for the variety Barcelona (Figure 33), using data from a cultivar evaluation experiment conducted by the Oregon State University research team (McCluskey et al., 2001). The OSU team used one year-old trees compared with the rooted suckers that were planted in our experiments, so the year of leaf for Corvallis was adjusted by one year to compensate for the extra age of those trees. The trees at Corvallis were grown at a wider spacing (4.5 x 5.5m) than those at Myrtleford (3 x 5m). It is considered that the difference in density would have had little effect on tree growth and yields before the seventh year of leaf. Thereafter, it is very likely there was inter-tree competition from the closer planted trees at Myrtleford. The yield from the Barcelona trees grown at Myrtleford compared very favourably with those in Oregon. This data generally suggests great promise for hazelnuts grown in favourable situations in Australia.

Figure 33. Comparisons of the development in nut yield for the cultivar Barcelona grown at Myrtleford, Australia and Oregon, USA.



Although tree growth and productivity at Orange was not as good as at Myrtleford, when the mean monthly temperatures for Orange are compared with those of Corvallis, Oregon, it can be seen that the patterns are quite similar (Figure 34). This suggests that the temperatures at Orange should be just as suitable for hazelnut growing as in Oregon. However, slightly more rainfall is received at Corvallis, with an annual mean of 1084mm compared with an annual mean of 940mm for Orange. The Corvallis rainfall pattern has a very strong winter dominance compared with the rather more even spread at Orange. It is suggested the higher summer rainfall at Orange could be beneficial for nut growth and kernel fill. Myrtleford has a similar rainfall pattern to Corvallis, but is drier and warmer. Viterbo is a major centre for hazelnut production in Italy, where Tonda Romana and Tonda di Giffoni are grown. The mean maximum day temperatures at Myrtleford are similar to Viterbo, but there is more diurnal variation at Myrtleford and the winter temperatures are lower. These climatic comparisons indicate the similarity between the climate in North-eastern Victoria, the Central Tablelands of NSW and two key hazelnut growing areas overseas, supporting the view that parts of Australia have suitable climates for hazelnut production.

Figure 34. A comparison of mean monthly temperature and rainfall for Myrtleford and Orange compared with two centres of hazelnut production, Corvallis, Oregon, USA and Viterbo, Italy.




Although there is limited data from the Tasmanian site, to date the trees have grown well and good yields have been obtained from the variety TBC, indicating the potential for hazelnut production in that State.  As there have been previous attempts at establishing orchards in Tasmania, it appears likely that Big Bud Mite infestations could have been a problem with these plantings.  If Big Bud Mite can be controlled or managed, the indications are that there could be great scope for growing hazelnuts in parts of Tasmania, such as in the Deloraine and Meander Valley area, the old orchard areas of the Tamar Valley and south of Hobart in the Channel and Huon districts. The potential for production in Tasmania has been highlighted previously (Baldwin, 1999).

World production of hazelnuts is static or slightly declining (Table 32) whereas world demand appears to be increasing. The dominant producing country is Turkey, where the orchards are very small and the crop is hand picked. The labour requirements per hectare are around 400-700 hours/year compared with 35-40 hours/year for the large mechanised orchards in Oregon, USA (Tous Marti, 2004). It is argued that there is scope for some import substitution in Australia as well as developing new markets in this country as hazelnuts have nutritional and health benefits. The high oleic acid content has been shown to increase the level of high density lipoprotein (HDL) in blood. HDL in turn lowers blood cholesterol and thus protects against arteriosclerosis. The risk of death from coronary heart disease is reduced by 50% in people consuming hazelnuts at least once per day. (Alphan E, et al. 1997).

Australian production is no more than 50 tonnes of nut in-shell per annum, equivalent to about 20 tonnes of kernels, or about 1% of our imports. These experiments indicate that a yield of about 4kg/tree is achievable at a spacing of 3x5m or about 650 trees/ha, equivalent to about 2.5 tonnes/ha. Such yields are comparable to those achieved with good management in Italy, Spain, Oregon and France (Table 32), indicating that with well selected and managed orchards, Australia has a good potential for production. A potential shortage of hazelnuts has been recognised in Chile, where over 6,000 hectares have been planted in recent years (Rodrigo Cruzat, Pers Comm. Nov. 2006).

Table 32. World hazelnut situation, total areas planted, average annual production and average size of orchards.

| **Country** | **Average annual production (t)** | **Approximate total area (ha)** | **Approximate average [(1)] yields (t/ha)** | **Approximate average orchard size (ha)** | **Comments** |
|---|---|---|---|---|---|
| Turkey | 550,000 | 555,000 | 0.8 - 1 | 0.5 – 1.5 | Area static, mainly hand picked |
| Italy | 110,000 | 70,000 | 1.2 – 2.5 | 5 - 10 | Static production. |
| Spain | 22,000 | 22,500 | 2 – 2.5 | 2 - 4 | Declining area of production, most orchards are irrigated |
| Oregon | 27,000 | 12,000 | 1.7 - 2.5 | 15 - 30 | Static production, dryland, highly mechanised |
| France | 5,300 | 2,500 | 2-2.5 | 14 - 20 | Slight growth, highly mechanised, use of supplementary irrigation |

Footnote (1) Yields from dryland crops in Turkey, Italy and Oregon vary greatly from year to year.

## Potential profitability

It is difficult to be precise about the profitability of hazelnut growing, as this depends on the situation in which the crop is grown, the yields obtained, the market opportunities, and the growers' management skills. However, an attempt has been made to present an approximation of the economics based on the activities carried out to establish the trial sites, the typical management program used to maintain them and current costs of inputs and contractors' rates. The approximate establishment costs are about $6,000/ha, based on the need to apply limestone before planting to raise soil pH levels, the availability of a contractor to prepare the land, and the grower planting the trees.  It is assumed that whips or young trees will be purchased at a cost of about $10 per tree and that the grower has a water supply and irrigation licence for the property. Irrigation costs are for materials only in the orchard and assume the grower will install the irrigation system.  It also assumes a tree spacing of 6m between rows with the trees spaced 5m down the rows. The two major cost items are the purchase of the planting material and the irrigation system (Table 33).

Table 33. Estimate of approximate material costs of establishment per hectare, excluding labour.

| **Item** | **Aproximate cost $/ha** |
|---|---|
| Lime 5t/ha @ $65/t applied by contractor | 325 |
| Land preparation, spraying, ripping, cultivation and levelling | 225 |
| 300 trees @ $10/tree (Spacing 6m x 5m) | 3,000 |
| Irrigation system (Irrigation mains, sub-mains, drip lines and 4 emitters/tree). Assumes water to site. | 2,350 |
| Total materials costs | 5,900 |

The data from the research sites indicates it may take from 6-10 years to achieve peak yields from the orchard. This will depend on the quality of the planting material, the site and the growers' management skills. Estimates of gross margins for orchards in full production are shown in Table 34. The major single cost item is harvesting; the cost given is based on the time taken to harvest a well-managed orchard using a manually operated vacuum harvester that is supplied by a contractor. The grower would be responsible for assisting with the harvest, carting the crop from the orchard and drying as required. Based on these assumptions, the approximate direct costs, excluding labour, are estimated to be nearly $2,500. This also assumes relatively small orchards, less than 5 ha, that can be harvested with a manually operated vacuum harvester. If several growers worked in collaboration to have an aggregate area of 50–100 ha, it would be possible to justify a mechanical sweeping machine and the harvesting cost could probably be reduced substantially.

Table 34. An estimate of the gross margin per hectare for a well managed, productive orchard, assuming harvesting by contractor with a suction harvester with assistance from the grower.

| | **Expenses ($/ha)** | **Income ($/ha)** |
|---|---|---|
| **Income** | | |
| Hazelnuts in-shell, 2 tonnes/ha @ $3.50/kg | | 7000 |
| **Direct costs** | | |
| Fertilisers | 120 | |
| Sucker spraying (4 times per year) | 80 | |
| Mowing (4 times/year) | 100 | |
| Weed control, (eg Roundup down the tree rows) | 50 | |
| Irrigation (application costs) | 100 | |
| Harvesting (suction machine @ $1/kg) | 2000 | |
| Total direct costs | | 2450 |
| Gross margin ($ per hectare) | | 4550 |

Two key factors influencing the profitability of hazelnut growing are the price received for the crop and the yield obtained. An analysis of the effects of grower returns and crop yields (Table 35) shows how much these can vary and the need to obtain yields of at least 1.5 t/ha and $3/kg to obtain a gross margin of over $2,000/ha, based on the costs given in the gross margin analysis.

Table 35. Sensitivity analysis of gross margin ($/ha) to price received and yield (assuming direct costs are constant).

| | Yield of nuts in-shell (t/ha) | | | |
|---|---|---|---|---|
| Price received ($/kg) | 1.0 | 1.5 | 2.0 | 2.5 |
| 3.00 | 550 | 2050 | 3550 | 5050 |
| 3.50 | 1050 | 2800 | 4550 | 6300 |
| 4.00 | 1550 | 3550 | 5550 | 7550 |

**Guidelines for successful hazelnut production**

Site selection
Select sites with deep well-drained loam soils and a cool temperate climate, ideally with an annual rainfall greater than 750mm, with a winter–spring dominance and dry autumn for harvesting. Avoid areas with high average maximum January temperatures much greater than 30°C and mean July minimum temperatures above 10°C.

Shelter
Select sites that are sheltered from strong winds or plant windbreak trees before planting.

Pre-planting
Apply ground limestone before planting to raise soil pH as appropriate. Deep ripping of tree rows is probably beneficial. Cultivate soils pre-planting and prepare a level surface for mowing and nut collection.

Planting stock
Plant whips or 1 year-old trees that are well grown (4-6 cm butt circumference) with good root systems. Select appropriate pollinisers.

Planting distances
Based on the experience gained from the research, it is suggested that commercial orcahrds be planted in rows 6 meters apart to ensure there is good access for harvesting and other mechanised activities within the orchard when the trees are well grown. On sites with deep loamy soils and good rainfall, where good vigorous tree growth is likely to be experienced, it is suggested that trees be planted at 6 metres down the row. However, if cheap planting material is available an initial planting of 3 metres down the row could be considered to obtain higher early yields. At this high density planting, growers need to be prepared to either prune fairly heavily or remove alternate trees to obtain a final spacing of 6 metres down the row. On sites where les vigorous growth is expected a spacing of 4 or 5 meters down the row might be suitable.

Orchard management
Mulch young trees if possible and keep weed free. Establish drip irrigation. Control suckers and any pests or diseases.

Monitoring progress
Monitor tree growth by measuring butt circumference at 100 mm above the ground and nut yields of 20 typical plants to assess performance. Ideal targets are shown in Table 36. The first year of leaf refers to the first year of growth after planting and the butt circumferences for that year are those measured in the autumn of the year following planting, ie. about 9 months after planting.

Table 36. Typical target figures of stem (butt) circumference (cm) and nut yields (kg/tree).

| | Year of leaf | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Stem circumference (cm) | 8 | 14 | 19 | 24 | 29 | 33 | 37 | 40 |
| Nut yields (kg/tree) | | | | 0.5 | 1.5 | 2.5 | 4.0 | 5.0 |

Irrigation
Supplementary irrigation is likely to be necessary at most sites. Rainfall and soil moisture status need to be monitored so irrigation can be applied at critical stages of growth and development.

Harvesting and post harvest handling
Nuts should be harvested promptly when ripe and dry and stored under dry, vermin proof conditions.

# 5. Implications

This report examines the overall yield potential of hazelnuts in Australia and identifies productive varieties that have appropriate quality attributes to meet a range of market opportunities.

The implications of the work show:

## Production and product quality aspects

1. There appears to be great potential for hazelnut production in cooler parts of Australia, such as on the alluvial soils of the river valleys in north-eastern Victoria, in parts of Tasmania and on the Central Tablelands of NSW. A concentration of plantings in these areas could lead to a substantial industry.
   Other possible areas could include parts of Gippsland in Victoria, the Mount Gambier area and parts of the Adelaide Hills in South Australia.
2. The varieties TBC and Barcelona appear to adapt well to a range of agro-climatic and soil conditions in South-eastern Australia, with Lewis and Tonda di Giffoni also showing promise.
3. Care needs to be taken in site selection and site management, as hazelnut trees require deep well-drained soils of low acidity with shelter from damaging winds.
4. Supplementary irrigation is required to minimise the effects of erratic rainfall, to ensure adequate growth in spring and to avoid moisture stress in summer, during the period of fertilisation, nut development and kernel fill.
5. Manganese toxicity may be a concern on red basaltic, krasnozem soils, but soil testing and liming well in advance of planting should overcome this problem.
6. In a separate study, a wide range of Australian buyers, processors of hazelnut kernels and manufacturers of hazelnut products considered that the samples of kernels provided from the research sites were acceptable by many and the buyers indicated a desire to purchase Australian-grown kernels. However, there are some companies that import hazelnuts and have specific requirements that did not match the Australian grown material. Additional collaborative work needs to be undertaken with hazelnut processors and manufacturers to further assess the market acceptance of Australian-grown hazelnuts and any particular varietal preferences.
7. Limited data was obtained on the effects of high summer temperatures on hazelnut production; however, it is likely that there are risks of damage from excessive summer heat; particularly the adverse effects of heat and moisture stress on kernel fill. It is suggested that planting in such areas is risky, especially when consideration is given to the issue of global warming.

## Pest management issues

1. The pest, Big Bud Mite, is present in Tasmania. Some strategies need to be set in place to prevent the spread of this pest to the mainland, where it does not appear to exist at present.
2. There do not appear to be any serious insect pests or diseases of hazelnuts in Australia, apart from Big Bud Mite in Tasmania, giving potential to grow the crop organically and to capitalise on this market opportunity.
3. Sulphur crested cockatoos can be a major pest at the later stages of nut development and during nut fall. Growers need to be prepared for the management of this pest, which appears to be relatively easily scared when flocks first enter an orchard. Regular surveillance of this pest is required to prevent it from feeding in orchards. It is a particular problem in small orchards when landholders are absent.  The birds can consume the entire crop if left uncontrolled.

# 6. Recommendations

The key recommendations to facilitate the successful and long-term development of the hazelnut industry are aligned to the following:

### Productivity and market acceptance

The experiments conducted indicate that there are four varieties –
Barcelona, TBC, Lewis and Tonda di Giffoni - that have good yield potential and have acceptance for particular niches in the kernel market. At this stage of industry development, these are recommended as the most suitable varieties to grow for that market.

Each of these varieties has its own limitations and there is no ideal variety. If the industry seeks to expand to meet all of Australia's hazelnut needs, other varieties would be required to give higher yields and superior quality kernels. This would probably require a plant breeding and evaluation program, but at this stage of industry development such a program could not be justified.

- It is recommended that further evaluation of new and promising varieties be conducted. This research should involve productivity and quality aspects as well as market acceptance.

It is generally recommended that irrigation systems be established to supplement rainfall deficiencies at key stages in tree and nut development. Micro-sprinklers were used at Myrtleford, Moss Vale and Orange with drip irrigation at Kettering and Toolangi. In France, Spain and, to a lesser extent, in Italy, drip irrigation is used in hazelnut orchards. Many studies on irrigation have been conducted overseas; there is a need to review the literature on irrigation and develop guidelines for growers and identify areas where further research might be needed so that scarce water resources can be used efficiently.

- It is recommended that a review of the literature on irrigation of hazelnuts be conducted and guidelines on irrigation be developed for growers

At Myrtleford, a complete foliage canopy was achieved about seven years after planting. The nut yields reached a plateau at this stage. It is possible that higher yields might have been obtained by removal of trees or some form of pruning to manage the canopy. There will be a need for research on this matter in due course.

- It is recommended that research on plant spacing and canopy management (pruning) be conducted at some future date.

### Industry development and extension

If the hazelnut industry is to develop, it is considered desirable to establish a concentration of growers and crop area in regions suited to hazelnut production such as Northern Tasmania, North-eastern Victoria and the Central Tablelands in NSW.

- It is recommended that groups of growers in these areas work in collaboration, to share knowledge and support any contractors or parties that invest in harvesting and processing equipment to maximise economies of scale.
- It is recommended that funding be made available to facilitate the development of the industry in such areas

## Pest management

Big Bud Mite was identified as a pest of hazelnuts in Tasmania, to date this pest has not been found on the mainland.

- It is recommended that strategies for the control of Big Bud Mite be evaluated and controls be implemented to prevent the spread of this pest to newly planted areas in Tasmania and to the mainland.

## Implementation of the recommendations

1. Industry initiatives.

It is recommended that the peak hazelnut industry body, the Hazelnut Growers of Australia (HGA), develop a strategic plan for industry development that includes priorities for research and that further funding be sought to undertake studies on the topics identified in the section on "Productivity and market acceptance".

2. Community and government support

A key ingredient of industry development will be initiatives taken by growers or groups of growers. They will require support from local communities, such as local councils and funding from state or federal government sources, for regional development initiatives. Such funds will be required to assist with the costs of travel to study production methods, mechanisation and marketing as well as for the development of infrastructure, such as harvesting equipment and processing facilities.

3. Policy development

The management or control of Big Bud Mite requires action from government working in collaboration with the industry. It is considered there is a need for action to be taken to mitigate against the spread of this pest, which is a potential threat to the developing industry. A program of action needs to be developed by the industry in conjunction with state government authorities with legislation to support any recommendations that are developed for the management of this pest.

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