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**Rural Industries Research and
Development Corporation**

Hazelnuts

—Variety assessment for South-eastern Australia—

RIRDC Publication No. 09/0178





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Development Corporation**

Hazelnuts

Variety assessment for South-eastern Australia

by

Basil Baldwin

January 2010

RIRDC Publication No 09/178
RIRDC Project No PRJ-000552 (US-125A)

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ISBN 1 74151 974 8
ISSN 1440-6845

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Electronically published by RIRDC in January 2010
Print-on-demand by Union Offset Printing, Canberra at www.rirdc.gov.au
or phone 1300 634 313

Foreword

This report looks at the potential varieties that may support a growing hazelnut industry in Australia, where we currently import more than 2000 tonnes of hazelnut kernels annually.

The report summarises the research which was initiated by the Faculty of Rural Management, the University of Sydney, Orange, which is now the School of Agriculture and Wine Science 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 Inc. This report explains how the research was conducted and outlines the results obtained. The results will be of value to those wishing to invest in hazelnut growing in Australia.

The report provides very useful information on:

- a list of suitable varieties for Australian conditions and the pollinators to plant with them
- the most appropriate soils and climate
- the potential yield of the crop and some observations on potential profitability.

It should be noted that each of the “suitable” varieties listed have pros and cons relating to their growing conditions and end use. While the information presented in this report provides a very useful guide to industry participants, it is naturally a reflection of an interaction between growing conditions at the trial sites, the varieties and specific genetics used. In addition to the quality varying with climate, soils and genetics, potential growers need to be aware that the economics of hazelnut growing will vary depending on a variety of factors outside of the producer’s control, such as market demand, production costs and competition from overseas producers.

In terms of markets, there is no doubt that Australia can produce high quality hazelnuts and deliver them to Australian markets at a quality and freshness that will allow them to compete well and achieve a good price. However, the market for this retail and fresh-market supply of Australian hazelnuts will have a limit. It is also important for the industry to note, that if it looks towards value-adding as an outlet for any excess production, the industry may find that it is difficult for Australian-produced hazelnuts to compete for price with imports, where nuts are being sourced to value-add.

As with all new rural industries, it is up to each individual to weigh the potential benefits with the risks before planning out their pathway through the industry.

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

This report, an addition to RIRDC’s diverse range of over 1900 research publications, forms part of our New Plant Products R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

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Peter O’Brien
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

I wish to acknowledge the financial support provided by the Rural Industries Research and Development Corporation that has enabled this research to be conducted. I 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 supported the on-going work.

The conduct of this research relied heavily on support provided by collaborating parties. In particular, I 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. Particularly, I wish to thank Lester Snare for all his assistance in the operation and management of the Orange research site, his assistance in planting at all the mainland sites and his assistance in harvesting at Myrtleford. The purchase of a Tonutti vacuum harvester by NSW DPI greatly assisted in harvesting at Myrtleford when the trees at that site were in full production.

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.

My 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.

My particular thanks are extended to Karilyn Gilchrist who was employed as a technical assistant to this project, initially by the University of Sydney and subsequently by Charles Sturt University. Karilyn was of immense help in the management of research data, its compilation for statistical analysis, the management of the automatic weather stations; help with the fieldwork and overall support and enthusiasm for the project.

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

I wish to express my appreciation for professional advice and support provided by Professor Shawn Mehlenbacher of the Oregon State University (OSU). I 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.

I wish to thank members of the Management Committee of the Hazelnut Growers of Australia Inc. (HGA) for their support of this project.

Finally I wish to thank Jean Baldwin for editorial assistance in the preparation of this manuscript and Marja Simpson for her very comprehensive peer review of the report.

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Executive Summary

What the report is about

The report provides detailed information on the potential for growing hazelnuts in Australia, possible production areas and the characteristics and productivity of a range of varieties. It is the culmination of twelve years of research.

Who the report is 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.

Background

Hazelnuts are a health food, being high in monounsaturated fats, protein, Vitamin E, calcium and potassium. Although hazelnuts were introduced into Australia more than 150 years ago, the 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 nuts in-shell, compared with a consumption of about 2,000 tonnes of kernels, equivalent to over 4,000 tonnes of nuts in-shell.

Australia imports over \$15m worth of hazelnuts annually. There is an opportunity for import replacement of high quality nuts as well as an opportunity to grow this part of the domestic, fresh nut market. There are opportunities to develop a range of value-added products from Australian grown hazelnuts, wherever they can compete strongly on the basis of freshness and quality, for instance, at the top end of the market. However, we need to be aware that, as Australian production increases in volume, it is likely that prices paid for Australian grown nuts will decline, but it will still be very difficult for Australian nuts to compete with the large quantities of consistent-quality, cheaper, imported product that is currently available to the manufacturing sector.

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 (*Corylus avellana* L.) in Australia.

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. Limited data was obtained on the variety ‘Lewis’, which was bred at the Oregon State University (OSU). All of these 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 variety Ennis produces large attractive nuts, but its kernels did not fill well when it was subject to moisture stress at the time of kernel fill. The key attributes of all the varieties evaluated are reported. The potential pollenisers 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°C, to provide sufficient chill;
- Mean temperature in hottest month < 31°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; and
- Deep, well-drained fertile 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 \$6-8,000 per hectare, established orchards should be capable of providing a gross margin of \$3-5,000 per hectare, depending on yield and price received.

Implications for relevant stakeholder for:

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, the Monbulk area, parts of Gippsland in the northern and southern districts of Tasmania and on the Central Tablelands, Southern Highlands and South Coast of NSW. A concentration of plantings in these areas could lead to a substantial industry. Other possible areas include the Mount Gambier district and parts of the Adelaide Hills in South Australia and the Manjimup district of Western Australia. Global warming and drying in southern Australia will be a challenge for the developing industry, raising questions about the future suitability of localities that currently have potential.

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 (Baldwin and Simpson, 2003), 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 buyers, who 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. At this stage, best potential appears to be in capitalising on the quality end of the market, especially on the fresh, tasty, nutritious aspects of the crop, selling to discerning buyers seeking the fresh nut or perhaps value adding at the premium end of the market.
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. It is suggested that potential growers on the mainland do not buy planting material from Tasmania to minimise the risk of introducing this pest to the mainland.
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. The selection of compact varieties planted at relatively high density and netted during nut development is a potential strategy to consider for new orchards in vulnerable areas.

Recommendations

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

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. However, the ability to place freshly cracked hazelnuts kernels on the Australian market is a major competitive advantage over imported product that invariably lacks freshness.

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 may be achieved through a plant breeding and evaluation program, but at this stage of industry development, such a program could not be justified. Given the genetic improvement program overseas (especially in the USA) is substantial, it may be more effective to look at the outcomes of the work overseas, evaluate new varieties developed there, and make selections from promising genotypes already present in Australia.

- It is recommended that further evaluation of new and promising genotypes from overseas and material already in Australia be conducted. This should involve productivity, quality aspects and 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. This needs to be complemented with field studies on the effectiveness of various types of irrigation systems to meet the water needs of the crop.

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 as young orchards come into production.

- 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.
- It is recommended that hazelnut growers on the mainland do NOT source planting material from Tasmania.

Implementation of the recommendations

1. Industry initiatives

It is recommended that the peak hazelnut industry body, the Hazelnut Growers of Australia (HGA Inc.), 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

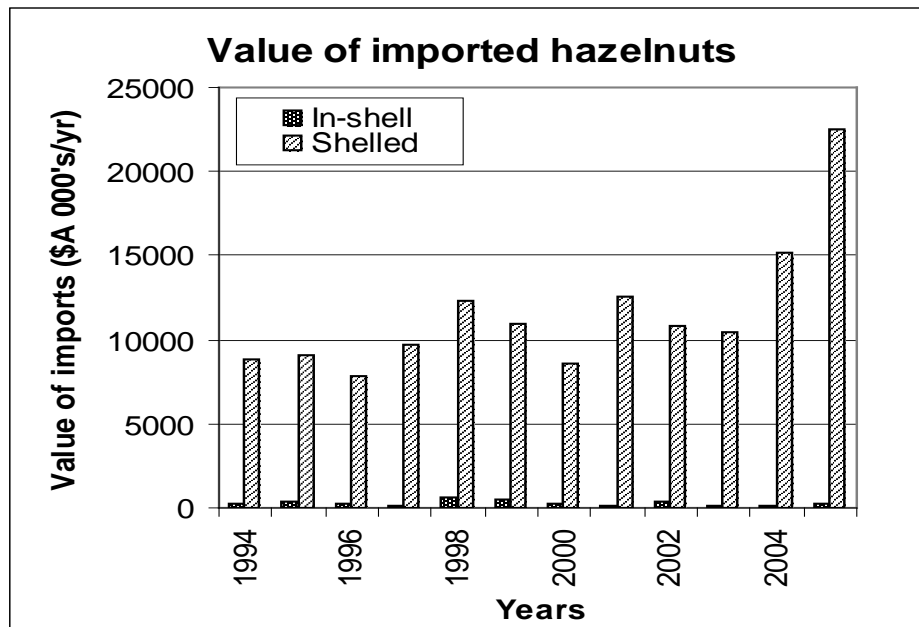
The management or control of Big Bud Mite requires action from government working in collaboration with the industry. It is considered there is a need for action to be taken to mitigate against the spread of this pest, which is a potential threat to the developing industry. A program of action needs 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

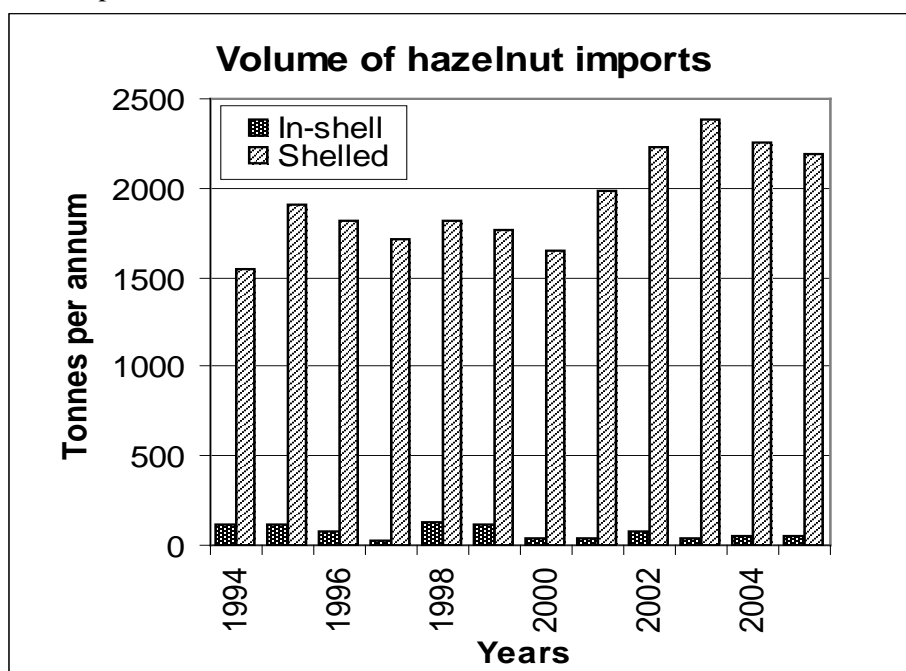
Australia imports an average of approximately \$A15 million worth of hazelnuts per annum (Australian Bureau of Statistics, 2006) (Figure 1). The greatest volume of imports is as kernels rather than as nuts in-shell, (Figure 2). The volume and value of imported kernels has increased over the last 10 years.

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 1920's, 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 1980's and 90's 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°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 have claimed 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 central 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. In Australia, the word "variety" is synonymous with "cultivar" or cultivated variety.

This report finalises the research conducted at the four sites on the Australian mainland, and that in Tasmania.

1.2 Objectives

The objectives of this research were to:

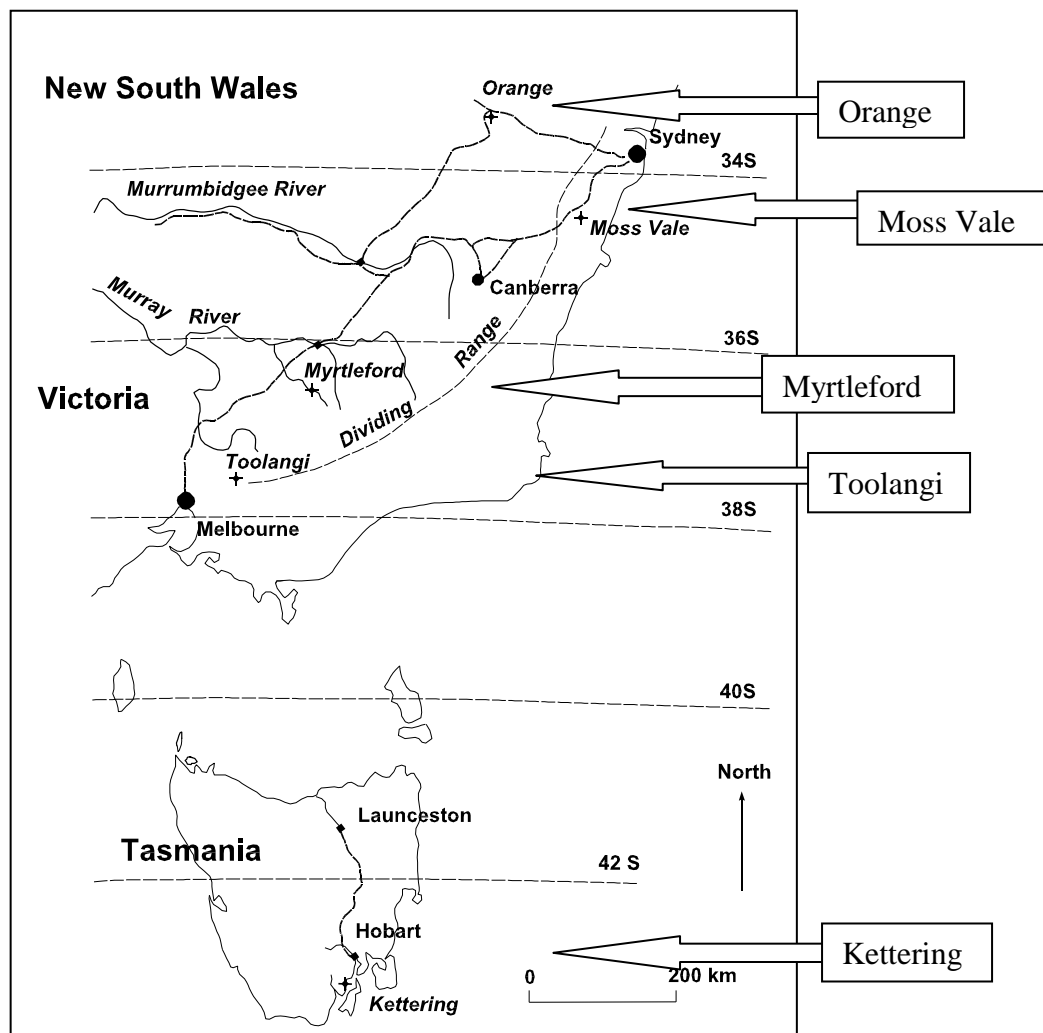
- Determine the most suitable hazelnut varieties that could be used for the establishment of a hazelnut industry in south-eastern Australia;
- Assess the effects of geographical region and climate on hazelnut production and varietal performance;
- Assess the productive potential of hazelnuts (*Corylus 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°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 main production areas in the Northern Hemisphere (Figure 3), 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

Attribute	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 subsequently considered 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 a deep loam, but with some variation in 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 yellow podsol. Podsollic 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 podsollic soils had the poorest drainage, particularly at Kettering which had a relatively heavy clay B horizon.

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 high in organic matter and 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 1.0 - 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 pollenisers (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' ('TBC'). 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	Late 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 varieties ‘Willamette’ and ‘Lewis’ at Orange and Myrtleford, which were relatively recent releases from the breeding program at Oregon State University and had only recently been imported into Australia. However, at Kettering, these two varieties were planted in the same year as all the other varieties evaluated.

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, nut clusters, 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 10 - 15% catkins had started to shed pollen and the date when only about 10 - 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 unclear 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 between 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°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 and 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°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 Soil samples

Samples from the top 0–100mm of soil were collected, in March 2003 and again in March 2006, for the mainland sites and March 2008 for the Kettering site, 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.

2.8 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 evaporation, through the use of the Penman formula and 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 leafing out as discussed in the report.

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 which 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 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 resource 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 (3.4). 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 no longer being used for research

At a tree density of 660 trees per hectare, irrigation levels of 1500 litres per tree are equivalent to one megalitre of water per hectare. It can be seen that, at Myrtleford, water use was up to nearly three 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, for well developed trees, 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® (glyphosate) 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 form 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 also 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 period of the research. 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. 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.

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*)
- hazelnut 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. The hazelnut aphid (*Myzocallias coryli*) was of greatest concern at Kettering, where it seemed more difficult to control than at other sites and caused black sooty mould on the leaves of trees in autumn.

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. No borers were recorded at Myrtleford, Toolangi or Kettering and only a few were recorded at Moss Vale. Borers are a serious pest, as the larvae can kill whole trees by girdling or ring-barking the branches or trunks. Ring-barking of branches occurred on a few trees at Orange.

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 at the trial site at Kettering, but in 2005 some infected trees were found in the commercial orchard adjacent to the research site and subsequently were found in the trial 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 and controlled in Tasmania.

Diseases

The major disease recorded from the 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 site other than Orange. Copper oxychloride as either Kocide ® or Cuprox ® was applied at Orange in May at 50% leaf fall to manage this disease in the young developing trees. It seems that damage to stems caused by hail can present opportunities for bacterial spores to enter the plant and cause infection, the effects of which may not be seen until the following season.

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 in section 3.5. This pest was managed at Moss Vale through the use of bird scaring tactics. Sulphur crested cockatoos seem 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 pollenisers will shed their pollen.

Data was collected on the commencement of pollen shed; that is the date when an estimated 10 - 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 varieties, sites and seasons. The objective of the data analysis was to try to understand the underlying factors that influence 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. A further objective was to determine the suitability or otherwise of different environments for hazelnut production.

Dates of commencement of pollen shed and bloom were markedly different between varieties, sites and seasons. Variation was greater between seasons than sites. For example, at Orange, over the seven years of data collection, commencement of pollen shed for the cultivar 'Barcelona' ranged from Julian Day (JD)146, 25 May, in 2003 to JD198, July 17, in 2005, Table 7. Julian Days for the commencement of bloom for this cultivar ranged from the earliest on JD 181, 30 June, in 2003 to the latest of JD 227, 15 July, in 2005. Similar variations were observed with all other varieties.

Table 7. Julian Days (JD) and chill hours to the commencement of pollen shed (PS) and bloom for the cultivar 'Barcelona' at Orange. Chill hours were calculated from 1 April

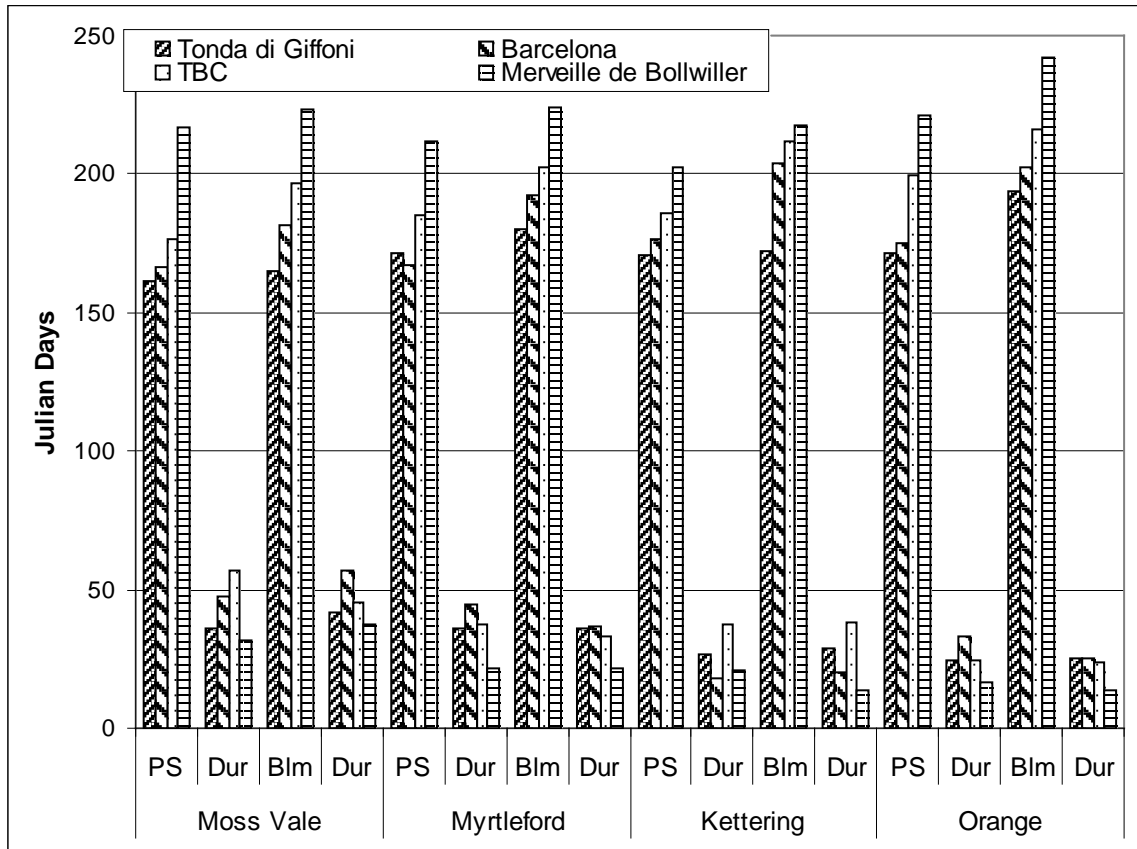
Years	1999	2000	2001	2002	2003	2004	2005
JD PS	158	178	169	175	146	186	198
Chill hours to PS	565	741	632	791	412	945	929
JD bloom	200	199	190	210	181	214	227
Chill hours to bloom	1091	1023	845	1179	826	1305	1470

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 January plus 1 day in February). Similarly, April 1 is Julian Day 91 in a non leap year (Jan 31 + Feb 28 + Mar 31 + April 1). Julian Day 151 is May 31, Julian Day 181 is 30 June.

Differences between sites in the dates when pollen shed and bloom commenced were far less than the differences between seasons. It was found that the order in which genotypes commenced flowering was very similar at all sites, as illustrated by four varieties in Figure 5. For example, for the four varieties, 'Tonda di Giffoni', 'Barcelona', 'TBC' and 'Merveille de Bollwiller', the 'Tonda di Giffoni' was always earliest to commence pollen shed and 'Merveille de Bollwiller' was always latest. A similar pattern was found with the date of commencement of female bloom. On average, 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 9). There also appeared to be a trend towards a longer period of pollen shed and bloom at Moss Vale compared with Orange.

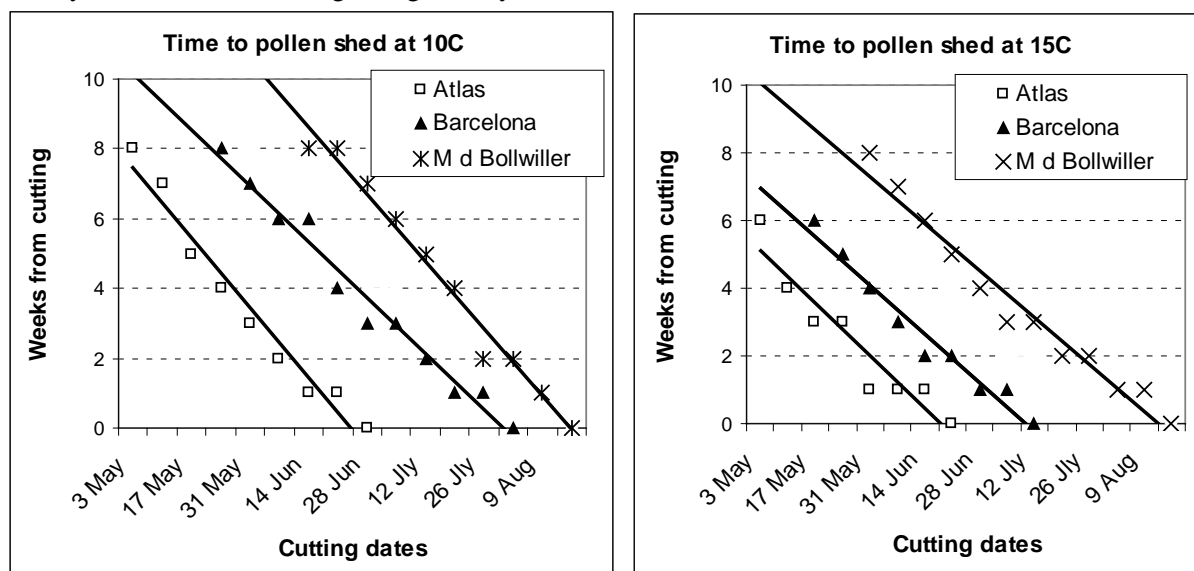
Figure 5. Average Julian Days to the commencement of pollen shed (PS) and bloom (Blm) for four genotypes at four of the field sites, along with their duration (Dur)



It is considered that 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.

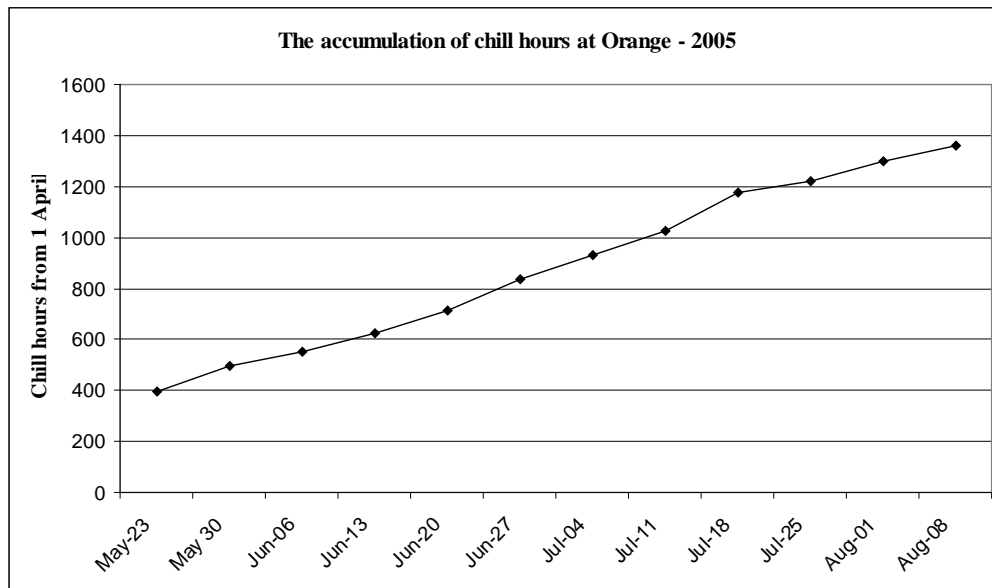
A similar type of experiment was conducted at Orange in 2005, when small branches of several varieties were cut at weekly intervals, starting from 3 May, and placed in temperature controlled cabinets at 10°C and 15°C. After 6 weeks in the 15°C cabinet, the very early variety ‘Atlas’ started shedding pollen. At the lower temperature, 10°C, it took 8 weeks before pollen shed occurred (Figure 6). The early-cut branches of the variety ‘Merveille de Bollwiller’ (syn ‘Halls Giant’), which is always late in pollen shed, did not shed pollen in the cabinets. It was not until branches cut on 31 May were placed in the cabinet at 15°C and those cut on 14 June at 10°C, that pollen shed commenced for this variety. The later the cutting date the more chill that the flowers had received. For each delay in cutting there was an increase in the degree of chilling of the flowers in the field (Figure 7). This amounted to about 80 hours of chill per week.

Figure 6. Effect of temperature on the date of pollen shed for branches cut from three varieties at weekly intervals from the beginning of May 2005



There appeared to be two factors affecting flowers in the field, these being an accumulation of chill and warmth. 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 well documented for hazelnuts.

Figure 7. Accumulation of chill hours from 1 April at Orange during May and June 2005



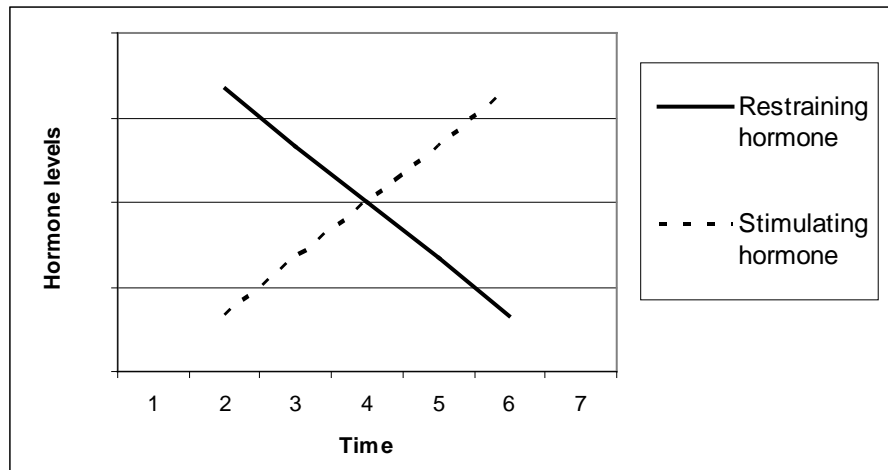
It is hypothesised that two growth regulating substances affect catkin extension and pollen shed (Figure 8), namely:

- a *restraining* substance – the effect of which declines with chilling
- a *stimulating* substance – causing catkin extension and requiring warmth for its activity

The restraining substance is like a brake in a car whilst the stimulating substance is more like an accelerator. When the brake is fully depressed, the accelerator will not move the car, but as the brake is

released, the accelerator will cause the car to move. That is, a variety requires a minimum level of chilling before catkin extension can occur through post-chill warmth. But as chilling increases, less warmth is required. In seasons or locations where the winter is relatively mild but sufficiently cool to meet the required minimum amount of chilling, the mild temperatures can stimulate pollen shedding. Where winter temperatures are relatively mild, such as at Moss Vale, compared with the lower winter temperatures of Orange with its higher altitude, pollen shed occurs earlier at Moss Vale than at Orange. Thus the variation in autumn and winter temperatures between years, with the consequent different levels of chilling and post chill warmth, accounts for differences in dates when pollen shed commences, as shown for all the varieties in table 8.

Figure 8. Concept of levels of growth regulators influencing flowering in hazelnuts



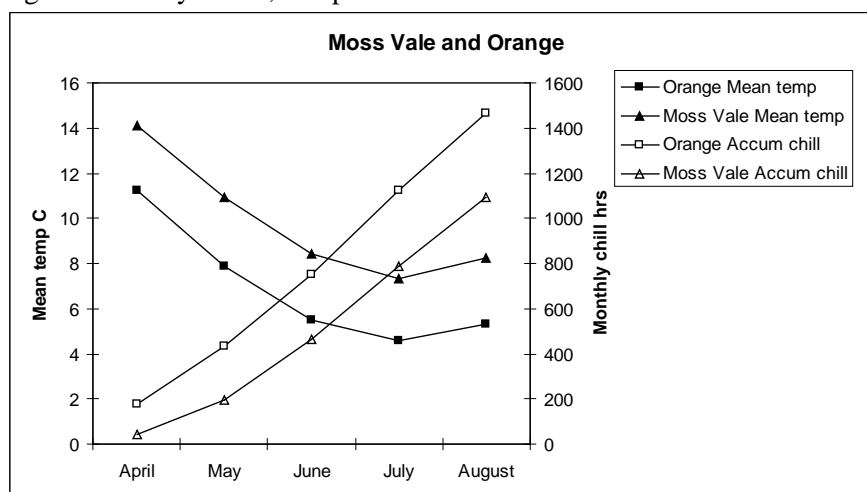
It seems that female flowers behave slightly differently from catkins as the female flowers could not be forced by warmth in the growth cabinets. It appears the female flowers require chilling but seem to require less post-chill warmth. That is, they require less of the stimulating hormone to promote the emergence of stigmas. This theory on the effects of chilling and post-chill warmth could explain why some varieties seem to be protandrous in locations with mild winters, but are reported to be protogynous in locations with very cold winters such as in Poland (Piskornik et al, 2001). Similarly, the effect of different temperature regimes between years in Romania was reported to influence whether a variety exhibited protandrous or protogynous characteristics (Turcu et al 2001). In Australia, with our relatively mild winter temperatures, there is sufficient post-chill warmth for catkin extension and in general varieties behave in a protandrous manner; that is pollen shed occurs before female bloom. However female bloom in the varieties 'Wanliss Pride' and 'Lewis' have been observed to occur at the same time as pollen shed in some seasons.

In this report, the degree of chilling was based on the accumulation of chill hours in the range 0-7°C from the end of March. Studies were undertaken on the development of pollen mother cells and microspores in catkins of nine cultivars in Oregon by Tiyayon and Azarenko (2005). They found that the degree of pollen development in late summer was correlated with flowering time. Microspores were seen in all nine cultivars by the end of September. Although the end of March in the Southern Hemisphere is considered to be equivalent to the end of September in the Northern Hemisphere, the research of Tiyayon raises the questions: when are catkins fully developed, at what stage are they dormant, from which date should chill hours be accumulated and is this a common date for all genotypes and years?

When the pattern of mean monthly temperatures and chill hours are compared between Moss Vale and Orange (Figure 9), it can be seen that the mean monthly temperatures at Orange were lower than those at Moss Vale. 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 432, compared with only 194 chill hours for Moss Vale.

Figure 9. Pattern of mean temperatures and chill hours at Orange and Moss Vale. Average chill hours (0-7°C) at Orange to end May = 432, compared with Moss Vale = 194



When the average Julian Days for the commencement of both pollen shed and bloom are compared between Orange and Moss Vale (Figure 5), it can be seen that on average, pollen shed and bloom commenced earlier at the warmer site, Moss Vale, than at Orange.

The level of chilling required at Moss Vale seemed to be very much lower for all varieties, compared with Orange. For example, on average, the variety ‘Barcelona’ commenced pollen shed on Julian Day 166 (15 May) when, on average, less than 200 chill hours had been recorded from the end of March, contrasting with an average of nine days later at Orange (Julian Day 175) when on average about 400 chill hours had been recorded. However, it should be noted that the mean temperatures in May were 10.9°C for Moss Vale compared with 7.9°C for Orange. Thus at Moss Vale, in winter, there was less chill but more warmth compared with Orange, supporting the concept of the need for both chilling and post chill warmth.

It is possible 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. 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 8). 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 is possible that these temperatures might have similar chilling effects on hazelnuts.

Table 8. 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

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 of 1°C 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 critical for chilling. If they are above the average, which in our data set was 7°C, less chill is accumulated and flowering is delayed, again supporting the concept that chilling is required to overcome a restraining hormone before pollen shed and bloom can commence.

Despite seasonal variations in the dates when pollen shed and bloom commenced, 'Atlas' and 'TGDL', were always the first varieties to commence pollen shed. 'Hall's Giant', 'Jemtgaard #5', 'Kentish Cob' and the Australian selection 'Woodnut', were always the latest to shed pollen. In Table 9, the average dates for the commencement of pollen shed and female bloom have been compiled. This is the mean date from Orange and Myrtleford for the eight years 1998-2005. The varieties have been ranked from the earliest to shed pollen (lowest chill requirement), to the latest (highest chill requirement). Data from some varieties that were only in the buffer rows has also been included.

Table 9. Average Julian Days (JD) 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	JD to start of pollen shed	Av.date to start of pollen shed	Duration of pollen shed (days)	JD to start of female bloom	Av.date to start of female bloom	Duration of female bloom (days)
TGDL	152	1 June	25	182	1 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
Hall's Giant ³	218	6 Aug	17	231	19 Aug	18
Kentish Cob	220	8 Aug	14	230	18 Aug	14
Jemtegaard #5 ²	223	11 Aug	19	238	26 Aug	16
Woodnut ²	223	“	14	235	23 Aug	21

Footnotes: ¹ ‘Tonda Romana’ provided by Ferrero, considered true to type. ² less than eight years of data. ³ ‘Hall’s Giant’ syn ‘Merveille de Bollwiller’

3.2 Catkin numbers

Observations were made of the relative number of catkins produced by the varieties being studied (Table 10). 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 drop catkins in a dry autumn and ‘Hall’s Giant’/‘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 the appearance of 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 10. Relative number of catkins (1=few - 5=many) produced on average at each site for the 5-6 year period

Varieties	Mean	Orange	Myrtleford	Moss Vale	Kettering	Toolangi
Kentish Cob	5.0				5.0	
TBC	4.6	4.0	4.0	4.8	4.8	4.8
Hall's Giant ¹	4.2	3.7	4.0	4.1	4.7	4.5
Woodnut	4.2		3.1		5.0	
Victoria	4.0	4.3	4.3	3.3	4.8	4.5
Square Shield	3.6	4.1	3.9	2.5	4.7	4.8
Jemtegaard # 5	3.6		3.7			
"Sicilian"	3.4	2.5	3.6	4.0	4.5	4.3
Eclipse	3.2	3.4	3.8	1.5	4.5	3.8
Lewis	3.2	3.0	3.7	2.7	3.2	
Willamette	3.2	3.3	3.2	4.3	2.8	
Ennis	3.1	2.8	4.1	4.0	3.3	1.5
Segorbe	3.1	3.8	3.8	3.5	1.5	1.8
Tonda di Giffoni	3.1	2.5	3.3	3.0	2.7	3.5
Casina	3.0	3.1	3.4	4.3		2.0
Montebello	3.0	2.6	0.0	0.0	4.2	
Tonda Romana(Ferrero)	3.0		3.0			
Hammond 17	2.9	1.5	2.5		4.3	
Royal	2.9	3.0	3.7		4.2	
Daviana	2.7	1.0	4.0			
Riccio di Tallancio (Ferrero)	2.7		2.7			
Barcelona	2.6	2.1	3.0	3.8	2.2	1.8
Atlas	2.5	1.8	3.0	1.8	0.0	4.3
Tonollo	2.3	1.5	2.5			
Negret	2.2	2.6	2.3			2.3
Whiteheart	2.2		1.7		2.8	
Butler	2.1	1.2	2.9	2.8		2.5
TGDL	1.9	1.0	2.0	1.3	2.3	3.8
Wanliss Pride	1.8	1.0	1.4	3.5	1.8	2.3

Note: ¹ ‘Hall’s Giant’ syn ‘Merveille de Bollwiller’. 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 11. 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 10). 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.

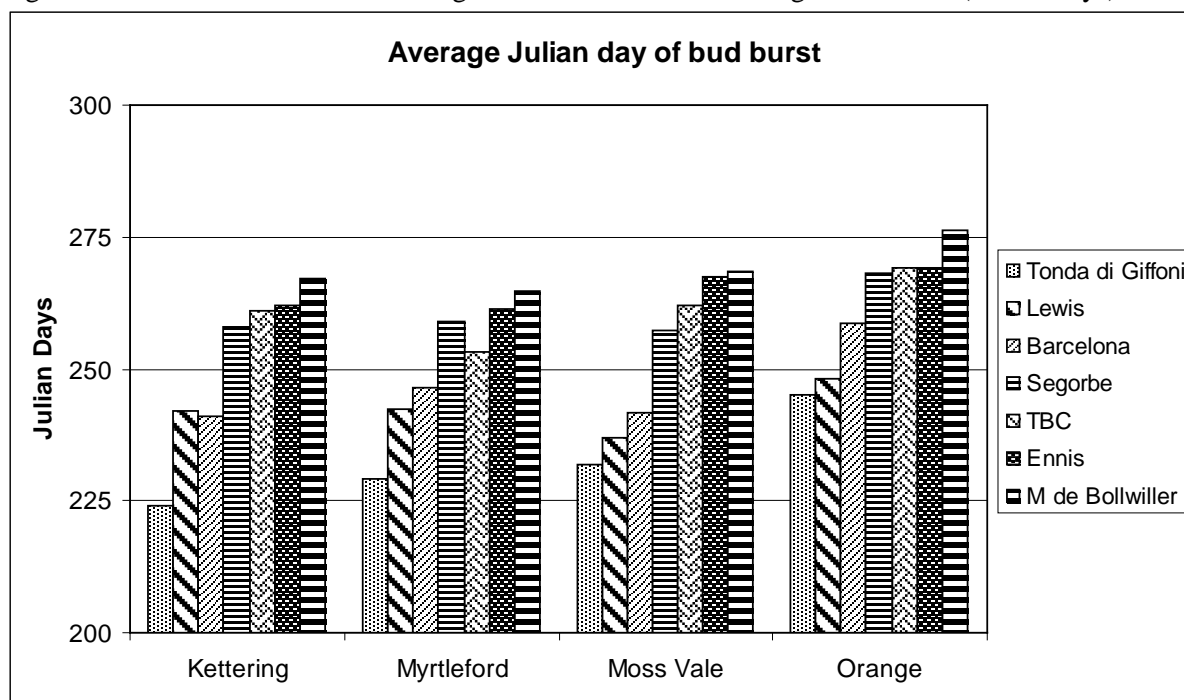
The date of bud burst observed in Australia generally fits into a similar pattern to that observed in Oregon. Similarly, the order of bud burst fits into a similar pattern as the estimated chilling hour requirements, as calculated by Mehlenbacher (1991). It appears that once chilling has been completed,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

Table 11. 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	“
Atlas	238	26 August “		
Royal	238			
Lewis	242	30 August		
Wanliss Pride	242	“		
Montebello	243	31 August	990-1040	26 February
“Sicilian”	243	“		
Barcelona	247	4 September	990-1040	“
Willamette	247	“	860-990	5 March
Tonollo	253	10 September		
Whiteheart	253	“		
Negret	256	13 September	760-860	5 March
Victoria	260	17 September		
Segorbe	261	18 September	1170-1255	12 March
TBC	261	“		
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	“		
Daviana	267	24 September		
Woodnut ⁽²⁾	267	“		
Hammond 17	268	25 September		
Hall's Giant	269	26 September	990-1040	19 March
Kentish Cob ⁽²⁾	273	30 September		

(1) Mehlenbacher, 1991 (2) Limited data (3) ‘Hall’s Giant’ syn ‘Merveille de Bollwiller’.

Figure 10. Site differences in the average date of bud burst for a range of varieties (Julian Days)



3.4 Tree growth

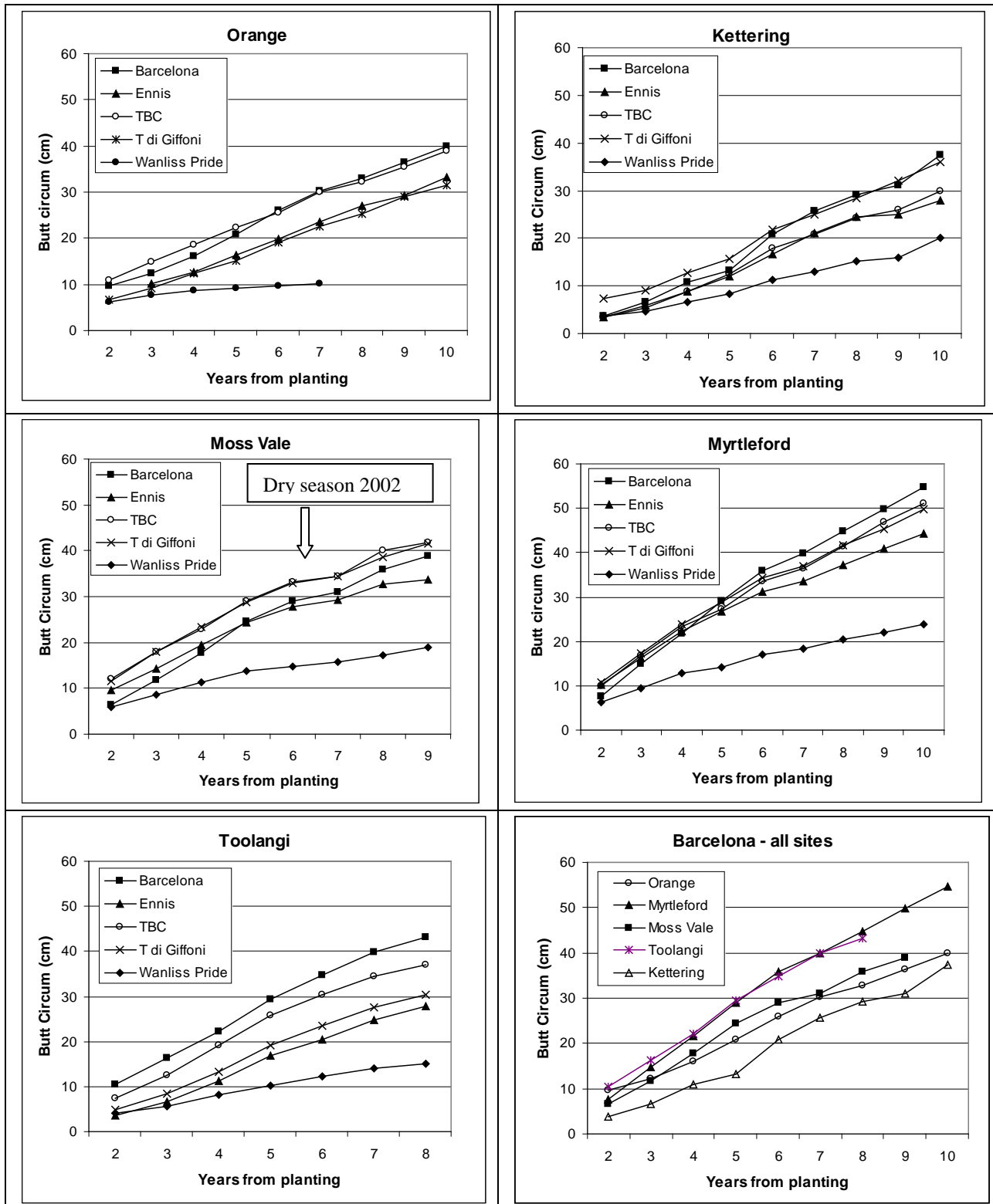
Differences were observed and measured in tree growth between varieties and sites. At Orange, the growth of ‘Wanliss Pride’, ‘TGDL’ and ‘Negret’ was extremely poor, with many plants dying and requiring replanting. Some of the replanted trees also died and again had to be replaced. ‘Wanliss Pride’ was the worst variety in this regard, with none of the original trees remaining, all having been replaced at some stage. When the variety ‘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’ appeared to be identical to ‘Wanliss Pride’. In 2001, all the trees of ‘White American’ were removed to make room for ‘Lewis’. ‘Wanliss Pride’ was generally the weakest growing cultivar at all sites (Figure 11). It grew best at Myrtleford, as did all other varieties.

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’. ‘Ennis’ also made good growth at all sites but was generally a little less vigorous than the aforementioned varieties, as can be seen in Figure 11. ‘Tonollo’ and ‘Butler’ demonstrated a high level of vigour at Myrtleford. ‘Butler’ and ‘Hammond 17’ also grew vigorously at Kettering.

The main differences in the growth of the trees were between sites and varieties, some with minor differences between seasons. The growth of most varieties at Moss Vale was adversely affected by the very dry season of 2002 (Figure 11), 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.

Figure 11. Relative tree growth as assessed by annual butt circumference measurements and calculations of cross-section area



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, following more than 100mm of rain in each of the previous two months, causing the poorly drained soil to become saturated (Figure 12). In the following year, 2001, high rainfall was also recorded in October (Figure 12) and again the soil became very wet, however, no crop damage was noted. This may have been because September had been relatively dry and slow release fertilisers had been applied from 2001 onwards.

Figure 12. Monthly rainfall and evaporation at Kettering from May 2000 to October 2002

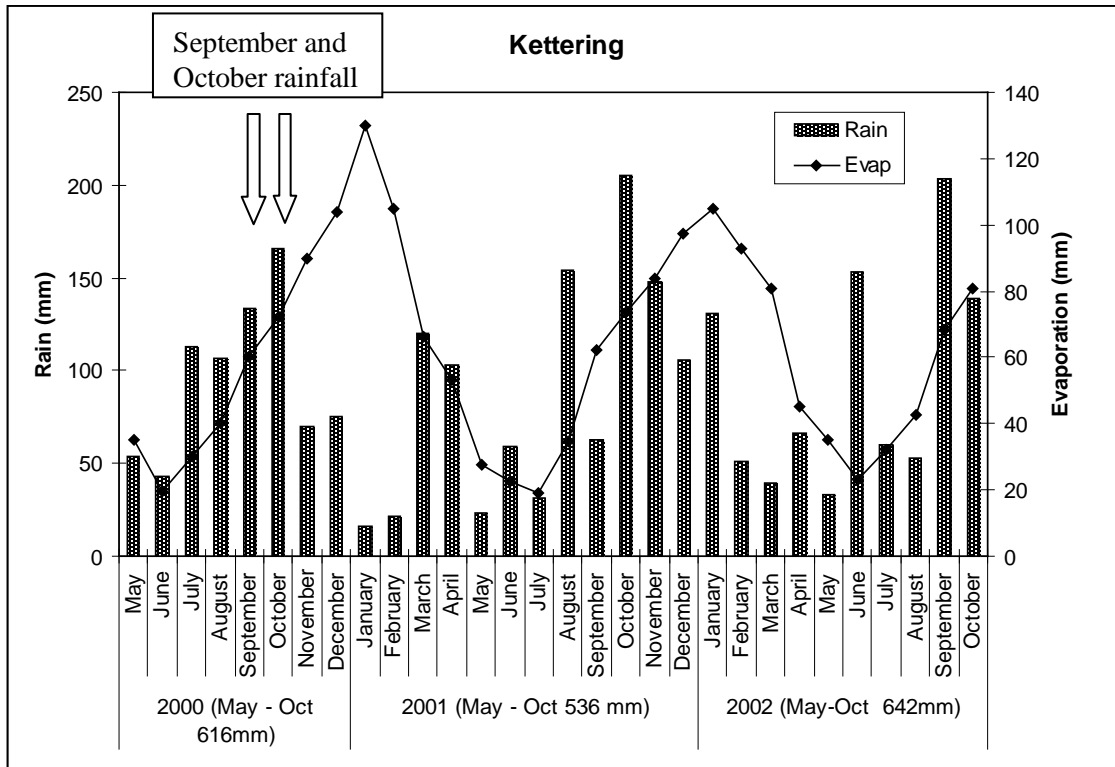
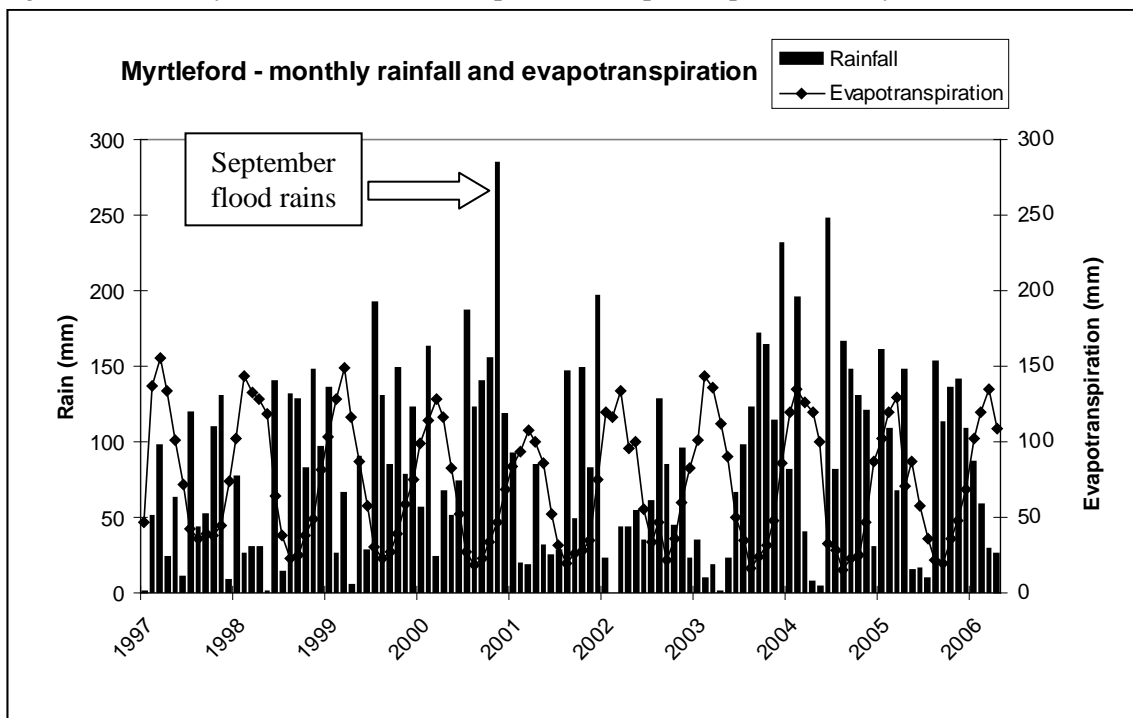


Figure 13. Monthly rainfall and estimated potential evapotranspiration at Myrtleford



The wet conditions experienced in September 2000 at the Myrtleford site (Figure 13), which was flooded for about two days with the trees standing in about 500mm of water, did not appear to have any adverse effect on tree growth nor did the 628mm of rainfall at Moss Vale in August 1998. It appears that damage occurs when there is an extended period of saturated soils due to characteristics of poor drainage such as with poorly structured clay soils, as was the case at Kettering. It is also likely that young trees are more susceptible to the effects of water logging than are older trees. The use of nitrogen fertilisers might have been an additional factor.

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 11).

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 soil factors. 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 well drained.

At Orange, the soil was a clay loam in the A horizon, overlying a light clay. It was generally well structured, well drained and relatively deep. It appeared to have a suitable texture and structure, although the texture was heavier than the ideal. The pH_{Ca} was 5.7 at the time of planting and was one of the least acid of the trial 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. These are also indicative of seasonal waterlogging.

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 12), suggesting that there were no major deficiencies affecting plant growth.

Table 12. Chemical composition of leaves taken from the five hazelnut variety trial sites from 1997 to the final year of study at each site

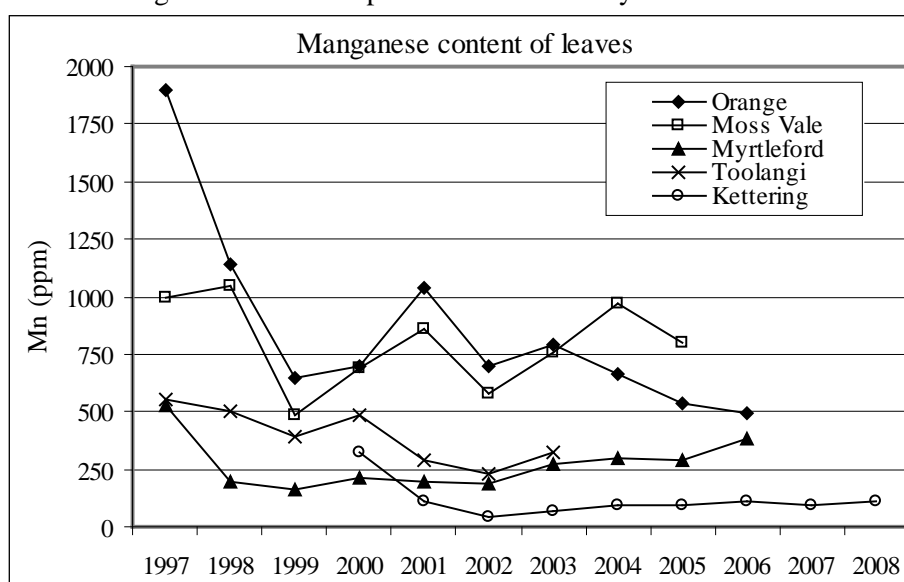
Elements	Sites					Desirable Range ⁽¹⁾
	Orange	Moss Vale	Myrtleford	Toolangi	Kettering	
	Site ranges, lowest –highest					
Nitrogen %	2.4-3.17	2.3-2.92	2.5-2.9	2.7-3.1	2.2-3.49	2.2–2.5
Phosphorus %	0.12-0.17	0.12-0.19	0.12-0.38	0.13-0.29	0.31-0.45	0.14–0.45
Calcium %	1.25-1.9	1.04-1.60	0.94-2.1	1.15-1.8	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	0.04-0.12	<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	30-75
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 14), where trees had made least growth. Manganese levels were low at Myrtleford, where trees had generally grown best, but were lowest at Kettering where trees had grown less well.

Figure 14. Levels of manganese in leaf samples collected annually from all sites



It seems possible that high levels of soil manganese may have had an adverse effect on the growth of hazelnut trees at Orange, 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 also have been due to high levels of manganese. It is 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

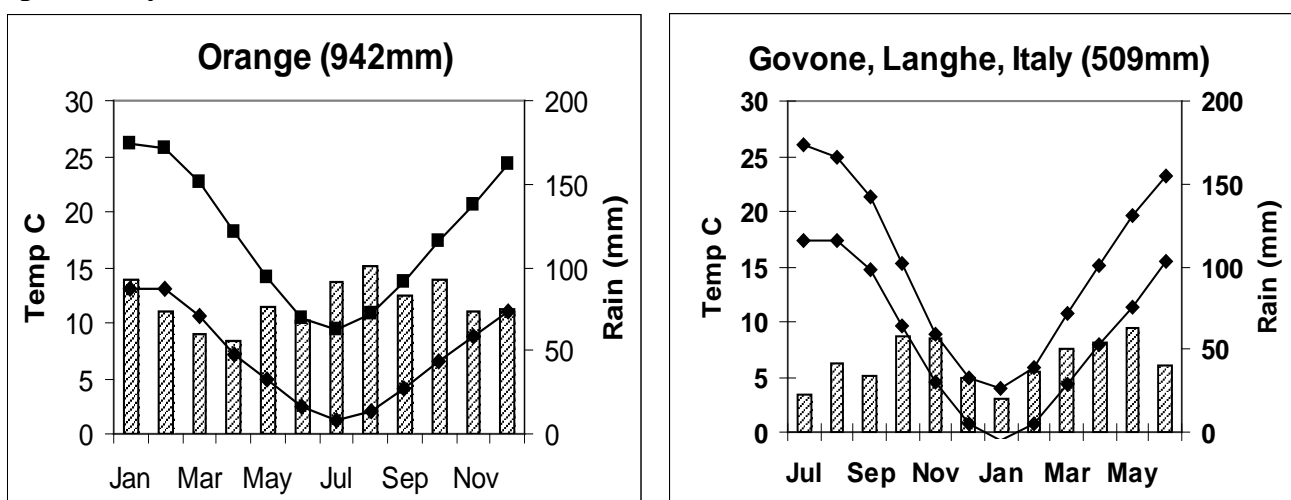
phalaris being particularly sensitive (Glendinning, 1999). Differential cultivar tolerance to soil manganese has also been reported for some crops (Sale et al., 1993; Gonzalez and Lynch, 1999).

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 14) is probably due to the effects of liming and the consequent rise in soil pH.

A small sand culture experiment was conducted at Orange, in which ‘Barcelona’ and ‘Wanliss Pride’ trees were grown in pots that were watered weekly with a Manutec Hydroponic Nutrient Solution® to provide all the basic elements required for normal growth. Some pots were provided with additional manganese to ascertain the effects of the higher levels of this element on their growth. No adverse effects were recorded on any trees during the growing period.

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 (Figure 15) that the temperature patterns are not greatly different. The climate of the Langhe is influenced by the Mediterranean Sea and has less diurnal temperature variation than the inland district of Orange, but both regions have mild summers and cool to cold winters. The Langhe area has a lower annual rainfall than Orange, but probably higher humidity. The soils in the Langhe region are of a sandy texture. The similarity in the temperature patterns for Orange and the Langhe 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 at Orange and the high level of available manganese, or both, rather than the influence of climate. There has been considerable interest in growing ‘TGDL’ in Chile, where growth has also been poor (Grau and Bastias, 2005).

Figure 15. 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, with final samples being taken at Kettering in 2008 (Table 13). 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, even with the use of Roundup® down the tree rows to suppress weeds, which is where the soil samples were collected.

Table 13. Soil analysis data for each of the hazelnut trial sites (Desirable levels are in Table 3)

Site	Orange			Moss Vale		Myrtleford			Toolangi		Kettering		
	1995	2003	2006	1996	2003	1996	2003	2006	1995	2003	1999	2006	2008
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	5.6
Phosphorus (P) Bray (mg/kg)	21	61	76	9	18	7	10	12	3	4	141	120	110
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	4.0
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	1.3
Calcium (Ca) meq/100g	6.8	12	12	3.9	8.4	5.6	10	9.8	3.8	11	12.6	13	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	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	<0.1
Total exch cations (mg/kg)	8.1	14	14	6.4	9.9	8.8	13	13	6.6	15	16.2	17.3	17.4
Ca/Mg ratio	9.7	12	12.2	2.8	8.4	2.4	4	4	4.8	6.1	5	4.2	4.2

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 was good at all sites, being greater than 2.0 indicating a stable surface soil structure.

A comparison of the vigour of growth of 'Barcelona' across all sites is shown in Figure 11. 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 less 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, evaporation and wind run were determined for each site for the period of each experiment (Table 14). 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 14. Average annual rainfall, evapotranspiration and wind run measured at each site

Sites	Average annual rainfall (mm)	Estimated annual evaporation (mm)	Average annual wind run (km)
Toolangi	1181	1008	33773
Moss Vale	1087	899	31243
Myrtleford	1030	865	28975
Orange	939	999	30483
Kettering	904	917	24652

It seems likely that, at Kettering, the lower rainfall and the poorly drained subsoil combined to limit tree growth. The trees at Kettering had a rather stunted appearance (Figure 24) when compared with those at Myrtleford (Figure 19). It seems likely that at Orange and Moss Vale there was some soil factor, such as heavy soil texture in the B horizon, that had a greater detrimental effect on growth than the limitation of rainfall, apart from in the very dry season of 2002.

3.5 Nut yields

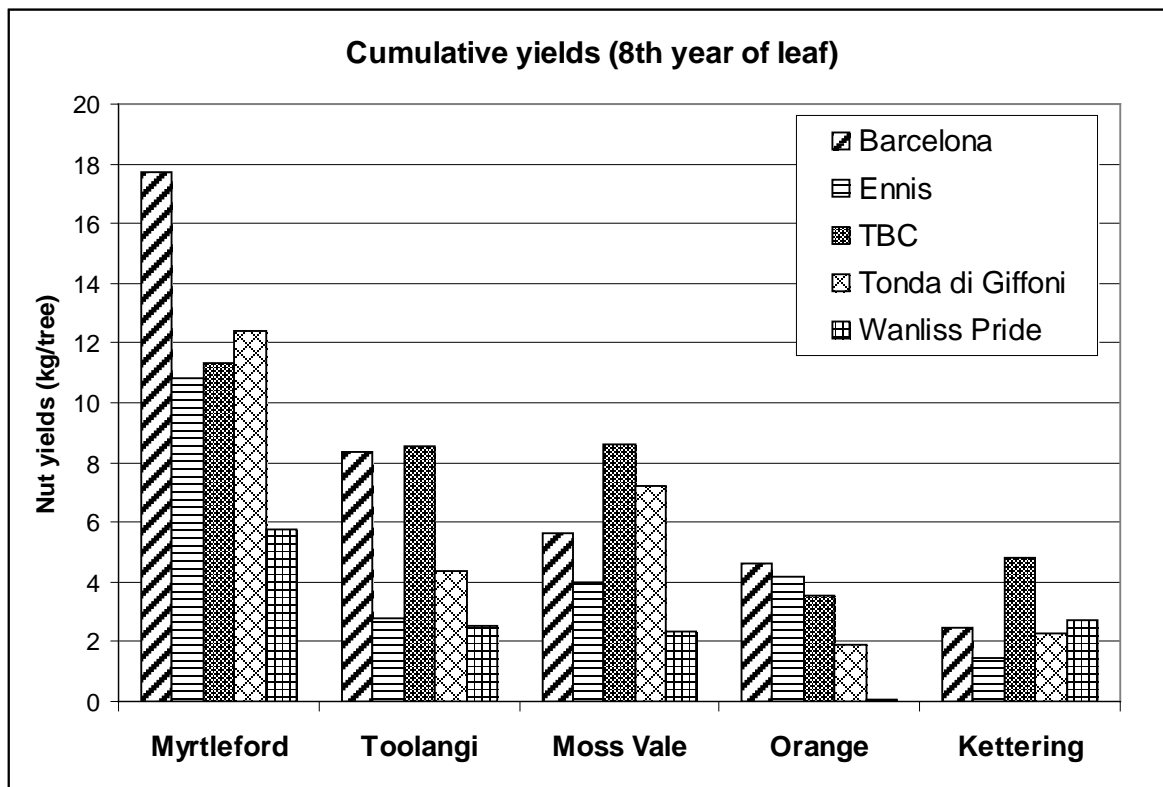
Valuable yield data was obtained from all sites, particularly from the Moss Vale, Kettering and Myrtleford sites, although at Myrtleford sulphur crested cockatoos caused some yield losses in 2006 and 2007. Yield losses from cockatoos were substantial at Toolangi in 2003 and high at Orange in 2002. From 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 assumed 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. However, 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 was no single cultivar that out-yielded all others at all sites in all seasons (Figure 16 and Tables 15-19). However, there are two varieties that have yielded well at most sites, these being 'Barcelona' and 'TBC'.

'Barcelona' was the highest yielding variety at Myrtleford, and was one of the highest yielding varieties at Toolangi and Orange. It performed well at Moss Vale, but did not yield well at Kettering.

TBC yielded very well at Moss Vale, Toolangi and Kettering. It yielded well at Orange and Myrtleford.

Figure 16. Cumulative nut yields (kg/tree) for five key varieties during their first eight years of growth at the five sites



‘Tonda di Giffoni’ yielded well at Myrtleford and Moss Vale, but was not so productive at the other sites. ‘Ennis’ performed well at Orange and Myrtleford, but only produced moderate yields at the other sites. ‘Wanliss Pride’ did best at Kettering but production at the other sites was poor in comparison with other varieties, especially at Orange where it made very poor growth.

‘Butler’ and ‘Tonollo’ yielded very well at Myrtleford (Table 15) but ‘Tonollo’ was not included for yield comparisons at other sites. ‘Tonollo’ was reported as the highest yielding variety 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.

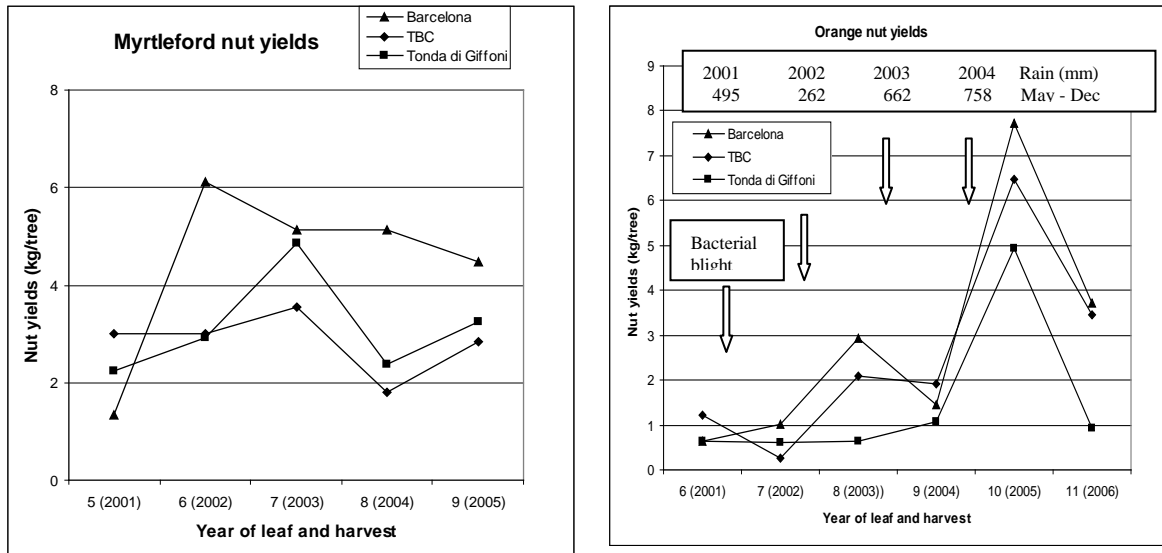
‘Atlas’ only produced mediocre yields and did not perform as well as had been reported in previous studies. High yields were recorded for this variety by Snare at Orange (Department of Agriculture NSW, 1982) and later by Sample (1993) at Myrtleford. ‘Segorbe’ grew well at all sites, giving moderately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

Table 15. Annual and cumulative nut yields (kg/tree) for the varieties planted in 1996 at Myrtleford. 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	0.45	0.41	0.32	0.27	1.48
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

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 17); 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. 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 alternate 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.

Figure 17. 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 at Orange.

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 18. 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 19. Growth of trees at Orange in March 2005, their ninth year of leaf. The trees seemed to lack vigour compared with those at Myrtleford.



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 11). However, it was not until the tenth season of growth that the variety 'Barcelona' exceeded a yield of 6kg/tree (Figure 17). 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. 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 the 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.)

Table 16. Estimates of annual and cumulative nut yields (kg/tree) recorded at Orange (2000–2006)

Variety	Year of harvest and (leaf)							Cumulative yields to 2006
	2000 (5)	2001 (6)	2002 (7)	2003 (8)	2004 (9)	2005 (10)	2006 (11)	
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

At Moss Vale, although the trees made better growth than at Orange (Figure 11) their yields were rather poor. They did not exceed 4kg/tree until their ninth season of growth in 2005, (Table 17 and Figure 20). 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 21) and lack of water for irrigation. The relatively low yields in the following season were attributed to the limited growth in the 2002-03. ‘TBC’ and ‘Tonda di Giffoni’ produced the highest yields at this site.

Table 17. Annual and cumulative nut yields at ninth year of leaf (kg/tree) recorded for the highest yielding varieties planted in 1996 at Moss Vale

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.

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

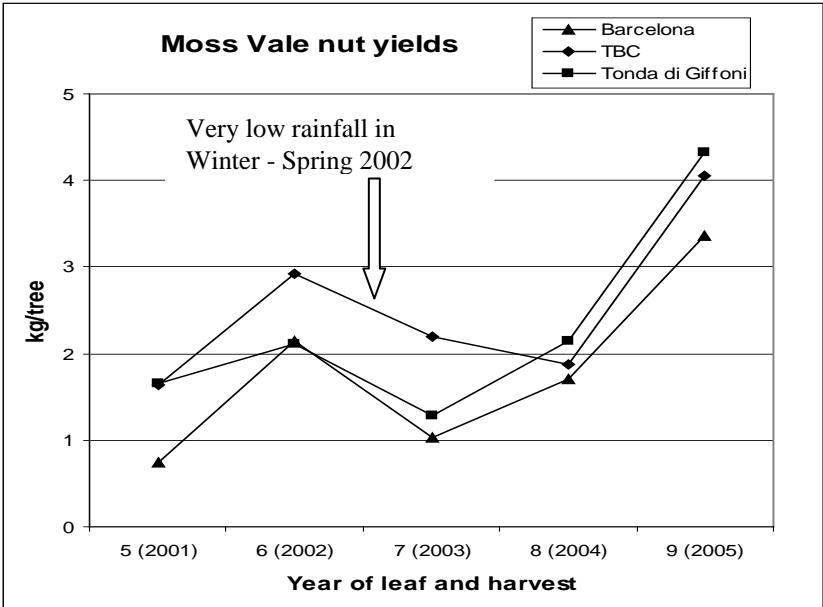
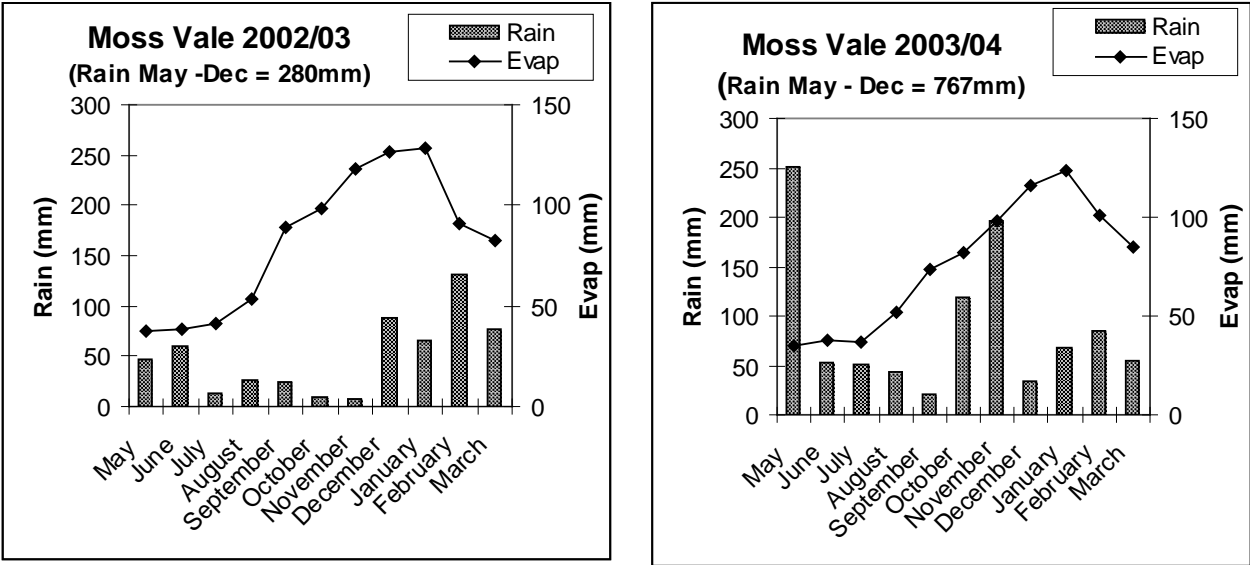


Figure 21. Growing season rainfall (mm) and evaporation at Moss Vale



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 21) with growth (Figure 11), yield (Figure 20) and kernel quality (Figure 28) seeming to be adversely affected by the moisture stress.

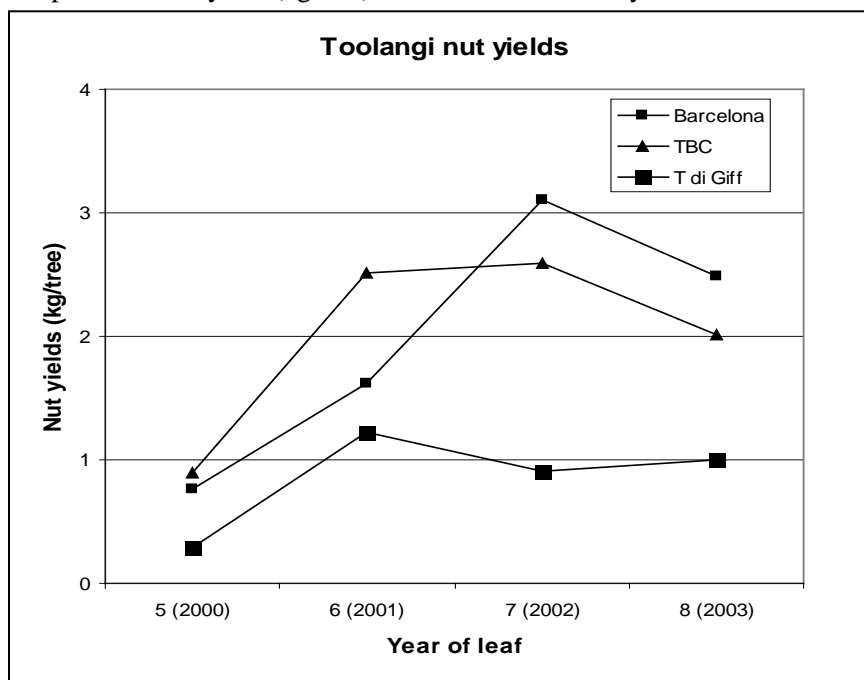
At Toolangi ‘Barcelona’ and ‘TBC’ were the highest yielding varieties, ‘Segorbe’, ‘Tonda di Giffoni’ and the “Sicilian” type produced similar yields, but yields were less than ‘Barcelona’ and ‘TBC’. ‘Wanliss Pride’ and ‘Ennis’ were lower again (Table 18).

Table 18. Estimates of annual and cumulative nut yields (kg/tree) for key varieties grown at Toolangi (2000–2003)

Variety	Year of harvest and (leaf)				Cumulative yields
	2000 (5)	2001 (6)	2002 (7)	2003 (8)	
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”	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

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 22). As with other sites, this peak yield coincided with the stage of growth when the trees had achieved a butt cross-sectional area of 80-100cm² and were meeting down the rows.

Figure 22. Development of nut yield (kg/tree) with time for three key varieties at Toolangi



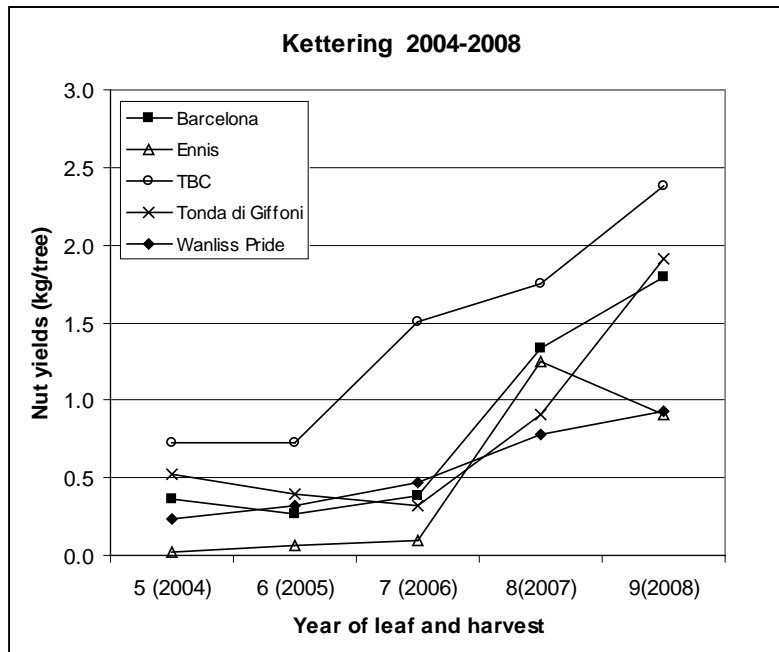
At Kettering, ‘Victoria’ was the most productive variety, followed by ‘TBC’ and ‘Hammond 17’, with cumulative yields to 2008 of 10-11kg/tree (Table 19). Nine other varieties, including ‘Barcelona’, ‘Tonda di Giffoni’, ‘Montebello’ and the “Sicilian” type produced cumulative yields in the range 5-6.5 kg/tree. ‘Ennis’ and ‘Wanliss Pride’ were of relatively low productivity, with cumulative yields in the range 3.7 -4.5kg/tree.

Table 19. Annual and cumulative nut yields (kg/tree) at Kettering (2004-2008)

Variety	Year of harvest and (leaf)					Cumulative nut yields
	2004 (5)	2005 (6)	2006 (7)	2007 (8)	2008 (9)	
Barcelona	0.37	0.27	0.38	1.34	1.79	6.50
Eclipse	0.22	0.42	0.47	0.99	1.74	5.94
Ennis	0.02	0.06	0.10	1.25	0.91	3.76
Hammond #17	0.48	0.47	0.75	2.03	2.83	10.29
Lewis	nil	0.09	0.19	1.70	0.93	4.89
Merveille de Bollwiller	0.04	0.05	0.07	0.02	0.22	0.57
Montebello	0.23	0.32	0.13	0.86	2.07	5.14
Royal	0.13	0.59	0.58	1.01	1.01	5.65
Segorbe	0.10	0.24	0.36	0.74	1.76	4.62
“Sicilian”	0.46	0.37	0.22	1.17	2.03	6.47
Square Shield	0.26	0.24	0.35	0.95	1.57	5.17
TBC	0.73	0.73	1.51	1.75	2.38	11.82
T.G.D.L	nil	nil	0.07	0.08	0.27	0.59
Tonda di Giffoni	0.53	0.39	0.32	0.91	1.91	6.20
Victoria	1.51	0.72	1.21	3.00	1.81	14.68
Wanliss Pride	0.24	0.32	0.47	0.78	0.93	4.55
Whiteheart	0.00	0.03	0.04	0.63	0.58	1.98
Willamette	0.48	0.25	0.11	0.82	1.84	5.16

The development of yield over time was very slow at Kettering (Figure 23) compared with other sites, with yields of only 2kg/tree having been achieved by the ninth year of leaf compared with the fifth year at Myrtleford (Figure 17) and Moss Vale (Figure 20), but it was similar to Orange.

Figure 23. Development of nut yield (kg/tree) with time for three key varieties at Kettering



Although ‘Barcelona’ had made reasonable growth and had achieved a butt cross-section area of 111cm² by the ninth year of leaf, compared with 71cm² for ‘TBC’, nut yields for ‘Barcelona’ were relatively low. Although ‘Barcelona’ produced good shoot growth it did not seem to produce many female flowers, compared with ‘TBC’. Pollination did not seem to be an issue, with a high percentage of flowers on tagged branches in the winters of 2006 and 2007 producing nut clusters. As there was a wide range of compatible polleniser varieties at this site, as with all the other sites, pollination was not considered to be an issue for most varieties, except for those very late into female bloom, such as ‘Merveille de Bollwiller’ (‘Hall’s Giant’). This variety was one of the latest at all sites to come into female bloom and gave low yields at all sites. ‘Whiteheart’ was another very late flowering variety, which might account for its low yields, although it was also a variety of low vigour.

The mean monthly temperatures in the months of November – March are lower at Kettering compared with the mainland sites. This may possibly have affected 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.

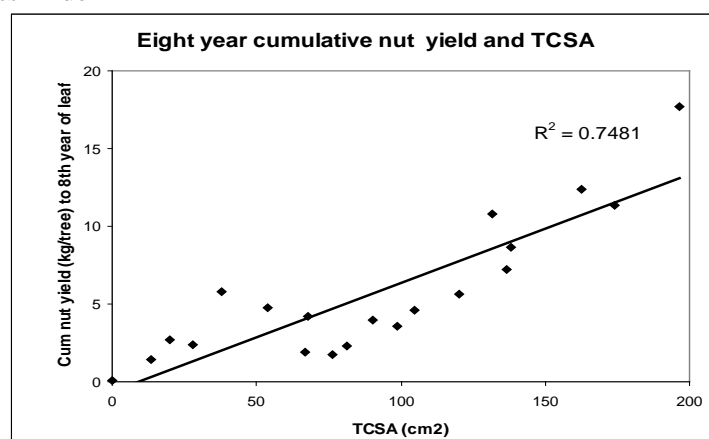
Figure 24. Tree growth at the Kettering site in the sixth year of leaf, March 2005. The trees generally lacked the vigour of growth that occurred at Myrtleford, Figure 15.



In general, nut yields appear to have been strongly influenced by tree growth. A significant relationship ($P=0.01$) was found to occur between vigour in the growth of five key varieties and their accumulated nut yields for the first eight (8) years of leaf (Figure 25) over the four sites, Kettering, Moss Vale, Myrtleford and Orange. This suggests that to obtain good yields, under Australian conditions, at sites that might not be ideal for hazelnut production due to soil type or marginal rainfall, there is a need to plant varieties that have high vigour in order to obtain early production. Some of the weaker growing varieties, such as 'Whiteheart' or 'Wanliss Pride', might perform well over a very much longer time frame, such as 20 years, but with the relatively high costs of orchard establishment and income foregone in the early years, the economics of such slow growing varieties are questionable.

At Kallista in the Dandenong area of Victoria, 'Wanliss Pride' trees, that were at least 40 years old and had been planted at a spacing of 7m x 5m, are reported to have given yields of 20kg/tree or 6 tonne/ha. (Merry, Anthony HGA field visit, 19 October, 2008). The site was one with a krasnozem soil that appeared similar to the Toolangi site and with high annual rainfall, about 1000mm per annum.

Figure 25. The relationship between cumulative nut yield (kg/tree) and tree growth, expressed as trunk cross-section area (cm²) (TCSA) for the cultivars ‘Barcelona’, ‘Ennis’, ‘TBC’, ‘Tonda di Giffoni’ and ‘Wanliss Pride’



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.

Table 20. 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.

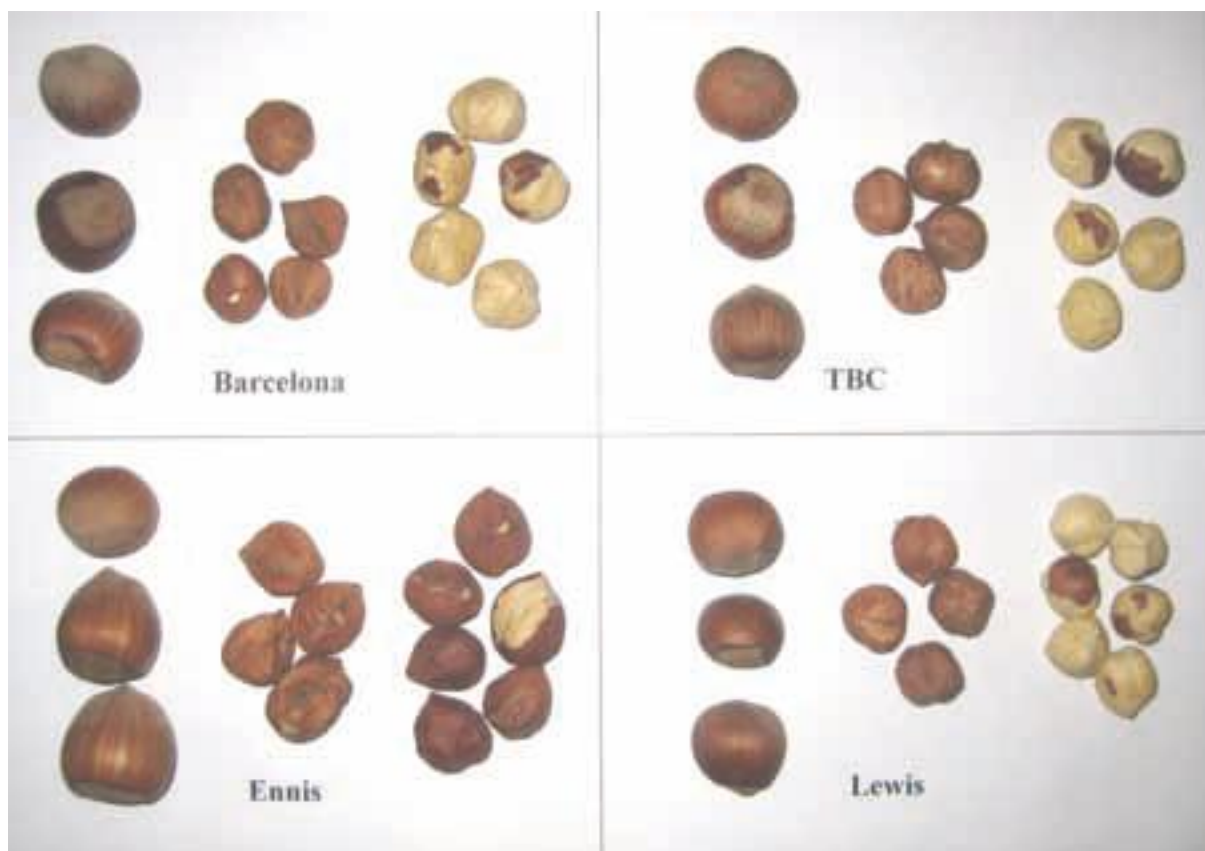
Variety	Nut wt (g)	Nut shape (length/width)	Kernel wt (g)	Kernel/nut wt (%)	Kernel fibre	Relative blanching
Atlas	3.10	0.92	1.26	41%	2.5	4.1
Barcelona	3.25	0.97	1.29	40%	3	3.3
Butler	3.35	1.1	1.41	42%	2	6.3
Casina	1.91	1.08	0.98	51%	1.5	5.7
Daviana	2.75	1.18	1.40	51%	2	5.4
Eclipse	2.71	0.92	1.25	46%	3.3	3.1
Ennis	3.92	1.12	1.62	41%	1.5	6.6
Halls Giant	3.42	1.1	1.41	41%	1.3	3.4
Hammond 17	3.29	1.1	1.36	41%	2	5.7
Lewis	2.40	0.97	1.15	48%	1.8	2.6
Montebello	3.02	0.92	1.09	36%	2.5	2.7
Negret	0.86	1.15	0.42	49%	2	1.7
Royal	4.07	1.2	1.61	40%	1.7	4.8
Segorbe	2.37	1.04	0.96	40%	1.7	4.1
“Sicilian”	3.15	0.96	1.09	35%	2	3.1
Square Shield	2.96	0.96	1.19	40%	2	5.1
TBC	2.98	1	1.27	43%	2.5	2.6
TGDL	2.46	0.97	1.10	45%	2	2.8
T. di Giffoni	2.62	0.94	1.12	43%	2	3.1
Tonollo	3.26	0.98	1.41	43%	3	3.8
Victoria	2.94	1.05	1.18	40%	1.3	5.5
Wanliss Pride	3.23	0.85	1.45	45%	2	2.4
Whiteheart	2.68	1.00	1.25	47%	1	1.0
Willamette	2.12	0.96	0.96	45%	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).

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’, ‘Daviana’, ‘Lewis’ and ‘Negret’ all gave kernel yields over 48% whereas the “Sicilian” type and ‘Montebello’ with their thick shells gave yields of less than 40% (Table 20). ‘Daviana’ is mainly grown as a polleniser variety as it has a fairly long nut and is relatively low yielding.

Kernels were assessed for their blanching characteristic by heating them in an oven at 130-150°C for 15 minutes, followed by rubbing them in a cloth to remove any loose skins. The blanched kernels were scored for their degree of blanching on a 1-7 scale. A rating of 1 was given to kernels that had lost all their skin and 7 to those that had their skins still intact. A limitation of this technique was that under commercial conditions, there might be more abrasion applied to remove the skins, resulting in a better blanching rating (lower score). It was noted that poorly filled kernels were more likely to retain their skins, thereby receiving a poorer rating (higher blanching score). Some seasonal differences, related to kernel fill, were noted in blanching. It is generally considered that ‘TGDL’ blanches very well, but, in our experiments, the kernels of ‘TGDL’ did not fill well and consequently did not blanch well.

Figure 26. Nuts, unblanched and blanched kernels of the varieties ‘Barcelona’, ‘TBC’, ‘Ennis’ and ‘Lewis’. Ranging from the largest nut, ‘Ennis’, to the smallest, ‘Lewis’. ‘Lewis’ blanched the best and ‘Ennis’ the poorest.



‘Ennis’ and ‘Royal’ consistently produced the largest nuts (Table 20). The nut yield from ‘Royal’ was generally lower than ‘Ennis’, except at Kettering. The large size of the ‘Ennis’ and ‘Royal’ nuts make them attractive for the in-shell market. In the USA and Europe, ‘Ennis’ has received a premium price for the in-shell market. ‘Ennis’ kernels are relatively large and, in some situations, did not fill well (Figures 27 and 28). They do not blanch (Table 20 and Figure 26). 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. There is a potential market for them in China, where they are roasted in shell (Michael Waring, pers comm. HGA Conference, 2008). ‘Hall’s Giant’, which is synonymous with ‘Merveille de Bollwiller’, also produced large nuts. The kernels blanched moderately well, 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 20). Apart from ‘Segorbe’, these varieties blanch moderately well, that is, removal of the pellicle after blanching is in the order of 75–90%. Although ‘Segorbe’ blanches less well, it has a thin pellicle and may be well suited to some sectors of the kernel market seeking raw, 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.

Uniformity of nut size was assessed on the nuts of most varieties from the 2008 harvest at Kettering. The nuts were put through a rotating drum, size grader with hole sizes varying by 1mm from 16 - 21mm, to assess size grades. Unfortunately, several varieties had nuts that were more than 21mm in diameter (Table 21) so it was not possible to obtain the proportion of nuts in each 1mm size grade above 21mm. More than 90% of the nuts of the varieties ‘Ennis’ and ‘Royal’ were over 21mm.

Table 21. Proportion of nuts in each size grade from 16mm to above 21mm for a range of varieties

Variety	Size grade (mm)						
	16	17	18	19	20	21	22+
Barcelona				2%	7%	27%	64%
Butler			2%	7%	18%	27%	45%
Ennis						6%	93%
Lewis			4%	28%	41%	21%	5%
Hall’s Giant				1%	5%	18%	75%
Montebello			3%	15%	38%	32%	12%
Royal					1%	3%	97%
Segorbe		1%	7%	23%	32%	24%	13%
TBC				2%	14%	39%	44%
Tonda di Giffoni			2%	14%	36%	34%	14%
TGDL	1%	6%	23%	43%	22%	4%	2%
Victoria			1%	3%	11%	29%	56%
Willamette		2%	8%	25%	38%	21%	5%
Wanliss Pride				2%	4%	11%	83%

Assessments of kernel size were undertaken 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 as was the degree of variation between the sizes of the kernels. 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.

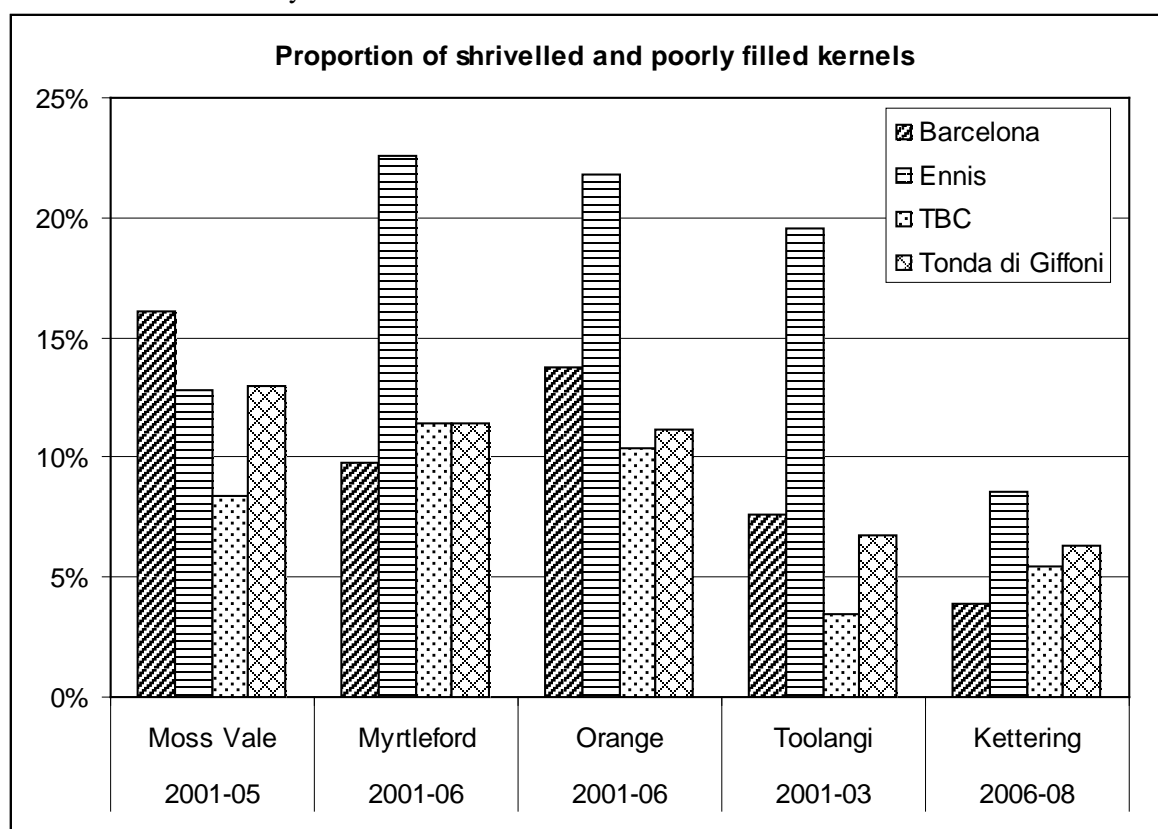
Table 22. Mean size of kernels from the Myrtleford site in 2002

Variety	Mean kernel size (mm)	Co-efficient of variation %
Kernels 13-15mm		
Negret	13.4	5.78
<i>Casina</i>	13.5	5.70
Segorbe	13.7	5.47
Montebello	14.2	4.99
“Sicilian”	14.4	5.75
TGDL	14.4	6.79
<i>Tonda di Giffoni</i>	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
<i>Wanliss Pride</i>	17.0	6.99

Note: A high value for the coefficient of variation indicates high variability in kernel size.

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 several seasons at all the research sites, is shown in Figure 27 for some of the key varieties. In general, ‘Ennis’ produced more poorly filled kernels than the other varieties.

Figure 27. Proportion of inferior quality kernels (i.e. poorly filled and shrivelled) obtained from cracked nuts from four key varieties



At Moss Vale, the proportion of inferior quality kernels was very high for the 2003 harvest year, particularly when compared with 2002 (Figure 28). It is considered that the shortage of water during kernel fill due to very low rainfall in 2002 (Figure 29) was the main factor. In 2002 the trees were under considerable stress which reduced growth, yield and kernel size. A decrease in 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, compared with the other varieties.

Figure 28. Variation between seasons at Moss Vale in the proportion of shrivelled and poorly filled kernels

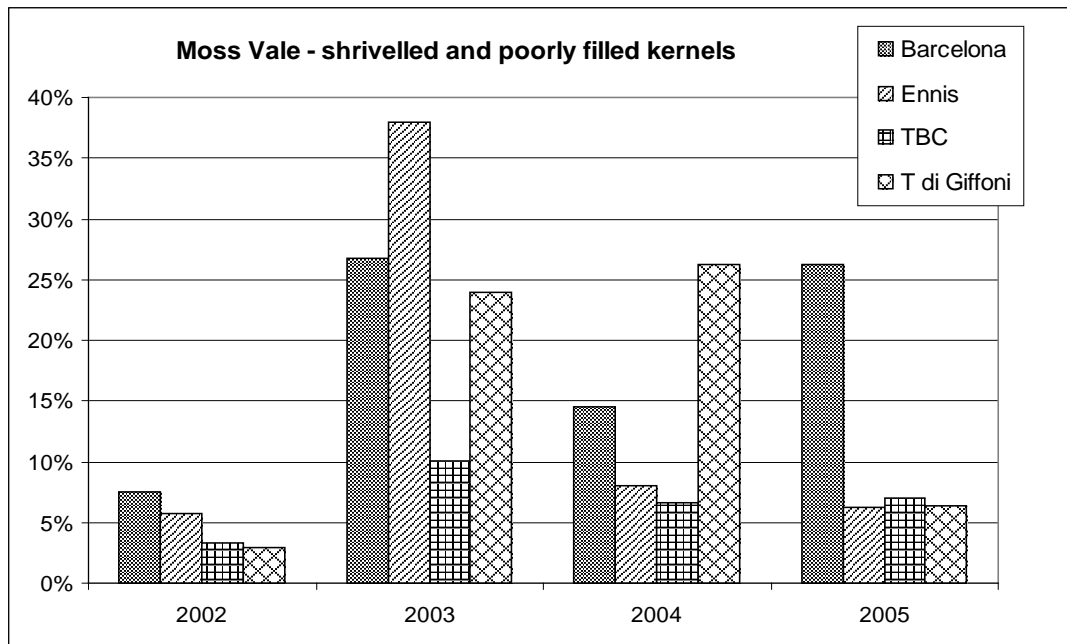
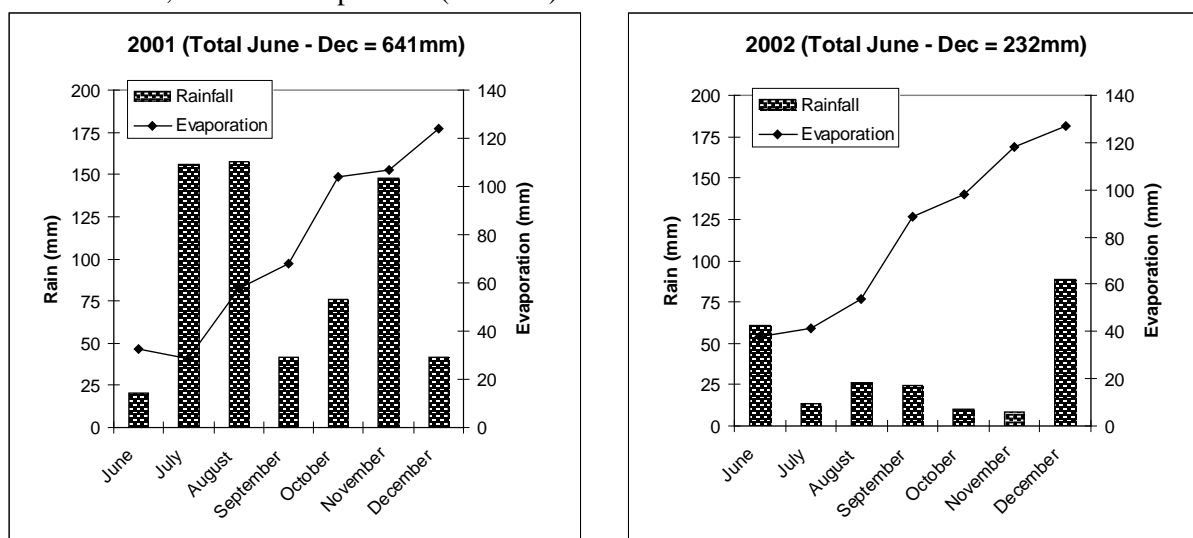


Figure 29. Pattern of rainfall (mm) and evaporation (mm) at Moss Vale for seasons of good rainfall and kernel fill, 2001-02 and poor fill (2002-03)



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 30). In the harvest year of 2003, poor kernel fill was again associated with dry weather conditions

(Figure 31), 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 31), except for the month of January, a critical time for kernel fill. Supplementary irrigation was applied to reduce this deficit.

Figure 30. Variation between seasons at Myrtleford in the proportion of shrivelled and poorly filled kernels

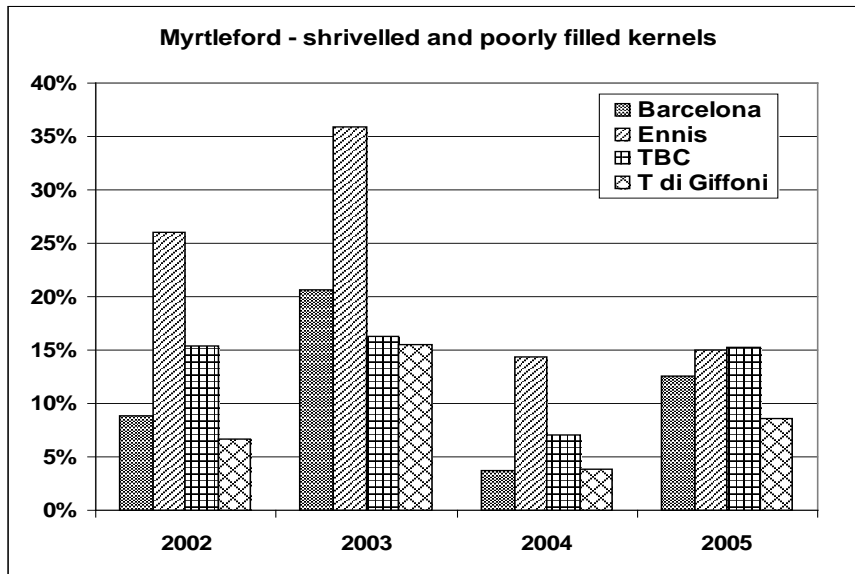
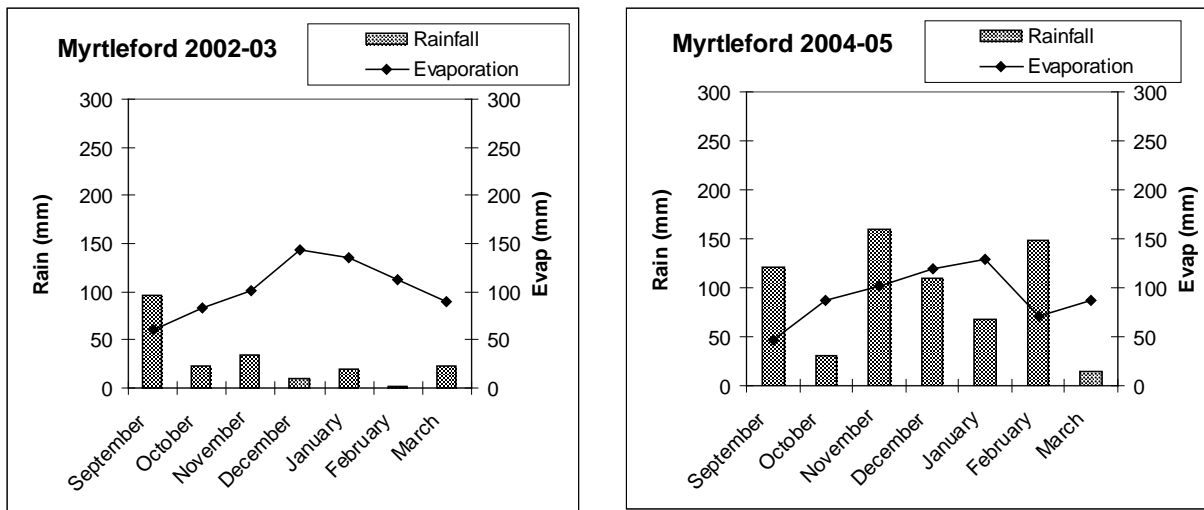


Figure 31. Pattern of rainfall (mm) and estimated evaporation (mm) at Myrtleford for the dry season of 2002-03 and the favourable rainfall season of 2004-05



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.

At Kettering, in the dry summer of 2008 (Figure 33), there was a significant relationship ($P=0.01$) between nut size and kernel fill across all varieties grown at that site. The proportion of poorly filled kernels in the cultivars ‘Ennis’ and ‘Royal’ was high, 11%, compared with only 1- 2% in the varieties ‘Casina’ and ‘Whiteheart’, which produce small nuts (Figure 32). In Australia, the period of kernel fill is in January and February, when temperatures are relatively high. Some moisture stress probably occurs in many circumstances, resulting in poorly filled kernels. The moisture stress in this critical

period may reduce photosynthesis and the production of sugars, which are vital building blocks for the developing kernels. When cereal and oil seed crops are under moisture stress during grain fill, grain size and yields are reduced. It is hypothesised that it is easier to fill small kernels during this critical phase. It would appear that varieties that have large nuts and kernels such as ‘Ennis’ and ‘Royal’ are therefore more vulnerable to poor fill.

Figure 32. Relationship between the proportion of shrivelled and poorly filled kernels and nut weight

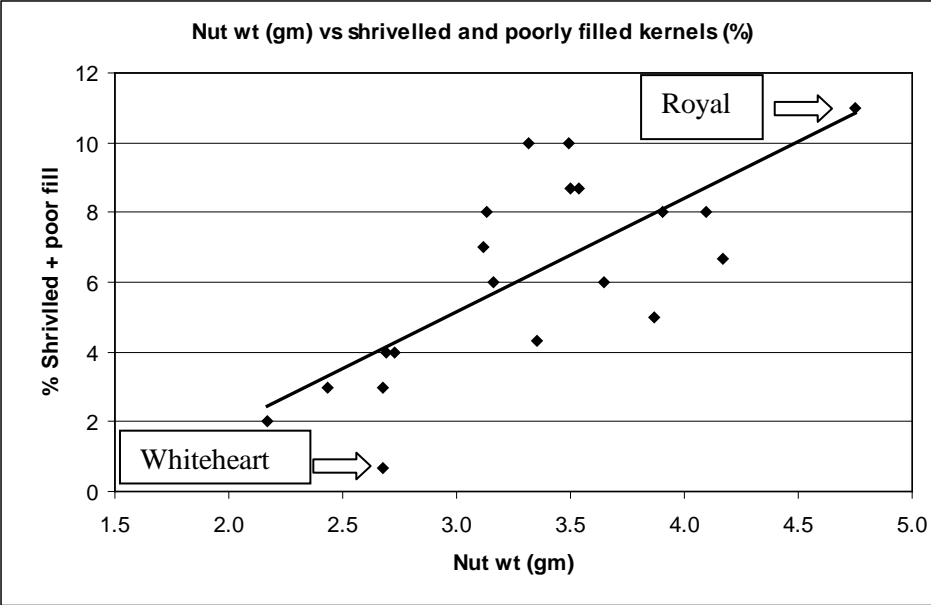
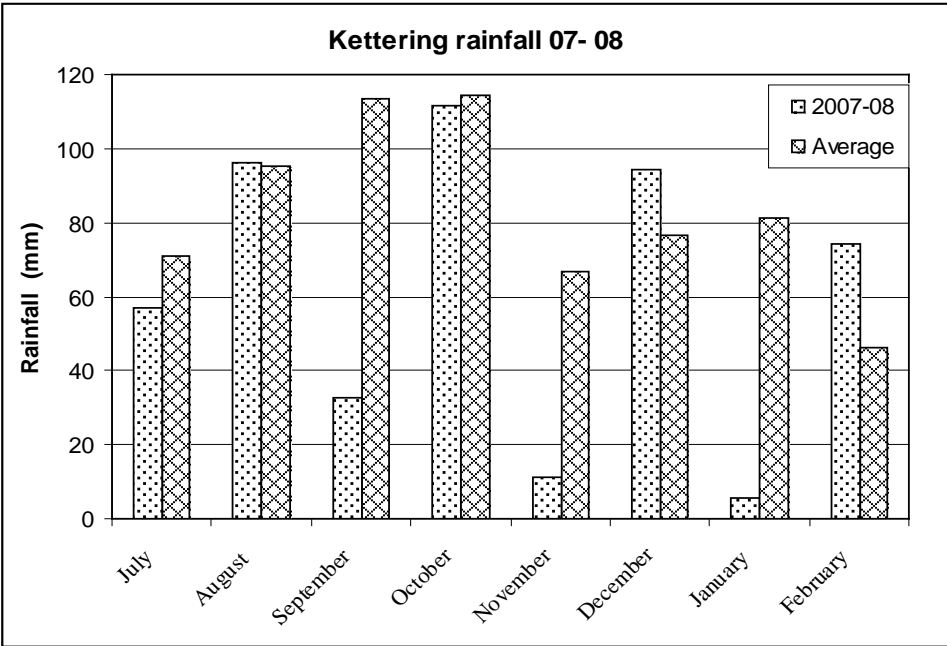


Figure 33. Total monthly rainfall at Kettering in the growing season and period of nut development and kernel fill in 2007-08



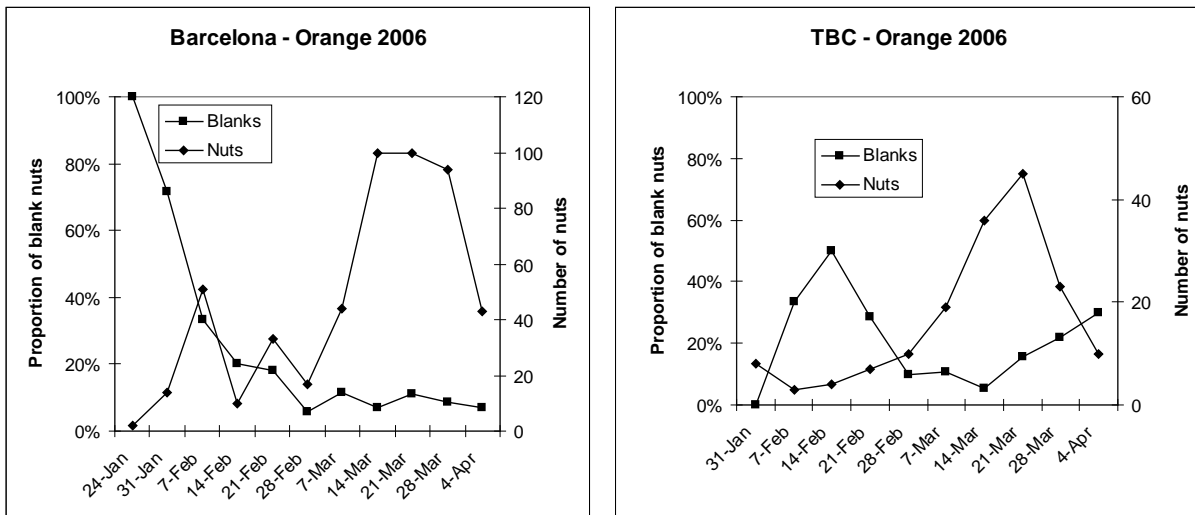
Note: Both January and February were dry, with very little rain falling until 23 February.

A study of blank nuts was also undertaken. 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 situations, nut fall was over a period of about four weeks for each variety. Most of the early falling nuts of 'Barcelona' were blank (Figure 34). 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 34. Pattern of nut fall and blank nuts at Orange in 2006 for the varieties 'Barcelona' and 'TBC'



Assessments were undertaken on nutritional value of kernels. Samples of kernels from the 2002, 2005, 2006, and 2008 harvests were assessed for their oil content, their fatty acid composition and vitamin E content. There appeared to be some differences between varieties (Table 23), 'Ennis' appeared to have a lower oil content (52.6-59.4%) than most of the other varieties which averaged about 62%.

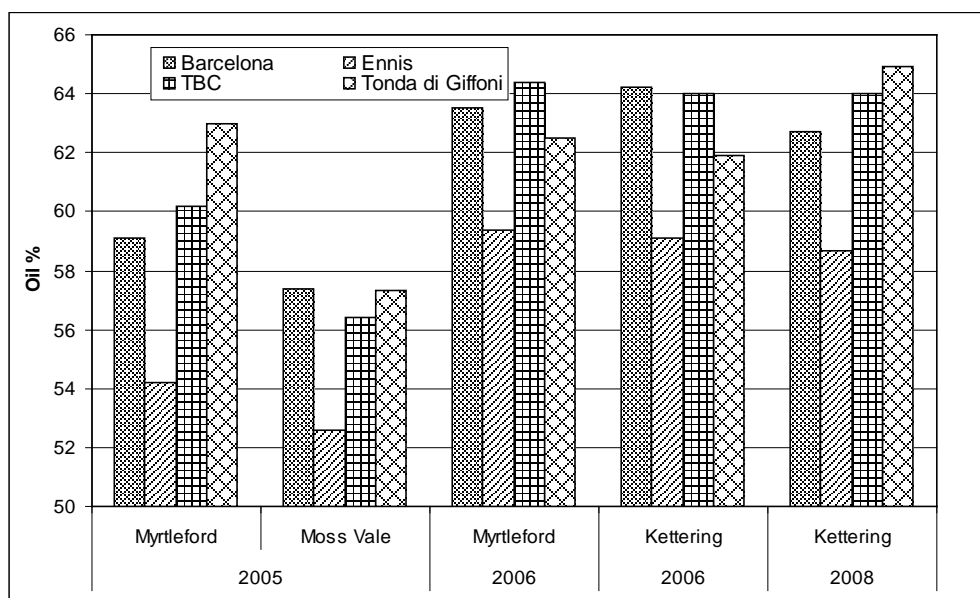
Table 23. Oil content (%) of hazelnut varieties from Australian research sites compared with Oregon (Ebrahim et al, 1994)

	2002	2005		2006		2008	Oregon	
	Myrtleford	Myrtleford	Moss Vale	Myrtleford	Kettering	Kettering	Ebrahim	Richardson
Barcelona	62.0	59.1	57.4	63.5	64.2	62.7	62.8	61.8
Butler		56.3						
Ennis		54.2	52.6	59.4		58.7		
Lewis		61.0		64.7	62.4	64.8		
Segorbe		56.6						
“Sicilian”	61.1	59.3	58.2					
TBC	60.1	60.2	56.4	64.4	64.0	64		
Tonda di Giffoni	63.6	63.0	57.3	62.5	61.9	64.9	62.9	63.1
Tonollo	60.2	56.1						
Wanliss Pride	57.5	55.5				62.2		
Whiteheart						64.2		

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

There appeared to be differences between seasons (Figure 35). It is presumed they are related to the conditions during the period of kernel fill, as Ebrahim et al. (1994) showed that oil content steadily rose to a peak towards the end of kernel development. The oil content obtained under Australian conditions does not seem to vary markedly from that obtained by Ebrahim et al. (1994) and Richardson and Ebrahim (1996).

Figure 35. Seasonal and site variations in the oil content of four 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 vitamin E content seemed to vary between situations, the mean vitamin E levels for the varieties tested were in the range 327-423µg/g. The levels of vitamin E appeared to be lower for ‘Ennis’, as was the oil content. Across varieties and seasons there was no significant correlation between oil content and vitamin E levels.

Table 24. Oil content (%), Vitamin E ($\mu\text{g/g}$) and proportion of mono-unsaturated fatty acids (MUFA) for five hazelnut varieties in two seasons and at two sites

		Barcelona	Ennis	Lewis	TBC	Tonda di Giffoni
Myrtleford 2005	Oil	59.1	54.2	61	60.2	59.3
	Vitamin E	388	293	387	419	396
	MUFA	80	80	81	81	82
Myrtleford 2006	Oil	63.5	59.4	64.7	64.4	62.5
	Vitamin E	295	224	262	274	351
	MUFA	83	82	84	83	82
Kettering 2006	Oil	64.2	59.1	62.4	64	61.9
	Vitamin E	400	364	378	475	383
	MUFA	76	76	79	79	80
Kettering 2008	Oil	62.7	58.7	64.8	64	64.9
	Vitamin E	526	428	430	525	474
	MUFA	77	74	79	79	80
Mean values	Oil	62.4	57.9	63.2	63.2	62.2
	Vitamin E	402	327	364	423	401
	MUFA	79	78	81	81	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%.

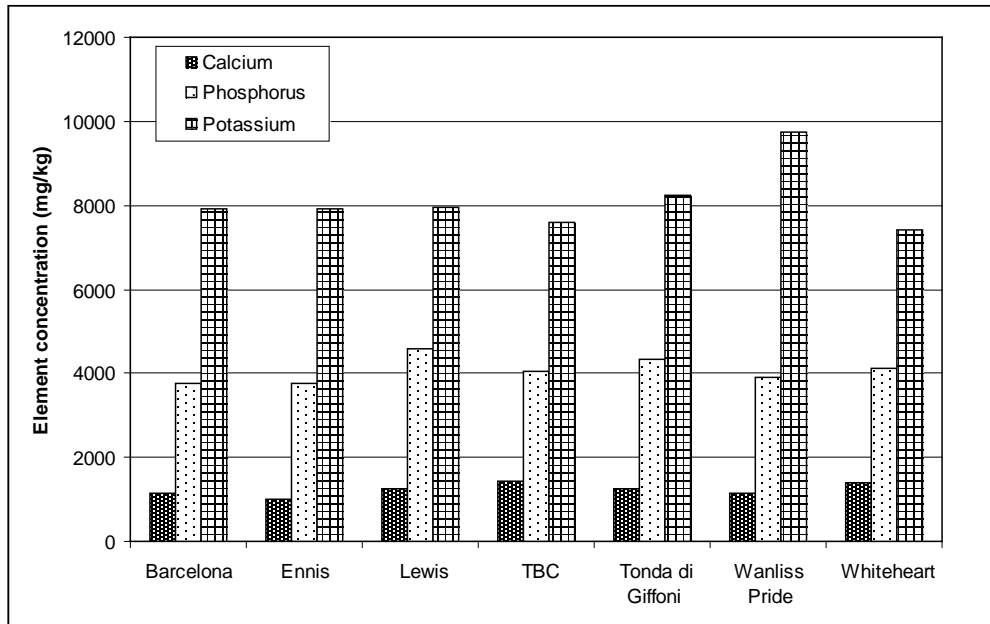
Kernels from seven varieties harvested at Kettering in 2008 were sent to NSW DPI for an analysis of their water soluble carbohydrate and nitrogen content (Table 25). As with previous analyses on sugar content (Baldwin and Simpson, 2003), 'Wanliss Pride' was found to have a high level of water soluble carbohydrates. It appears that 'Ennis' also has a high level of water soluble carbohydrates (sugars), which aligns with the sweet taste commonly associated with its kernels.

Table 25. Water soluble carbohydrates and nitrogen contents of kernels from seven hazelnut varieties from Kettering 2008

Variety	Water soluble carbohydrates %	Nitrogen %
Barcelona	15.9	6.38
Ennis	21.4	5.9
Lewis	14.2	7.47
TBC	15.7	5.87
Tonda di Giffoni	17	6.11
Wanliss Pride	19.5	5.82
Whiteheart	16	6.81

The kernels from seven varieties harvested at Kettering in 2008 were sent to NSW DPI for an analysis of three key elements. The analyses show very high levels of potassium (average 8110mg/kg), this was about twice the concentration of phosphorus (average 4069 ng/kg) and nearly eight times the average levels of calcium (average 1231 mg/kg), Figure 36. There appeared to be little difference between the varieties in the concentration of the individual elements, except for potassium, where 'Wanliss Pride' appeared to have a higher concentration than any other variety.

Figure 36. Concentration levels of some key elements in hazelnut kernels from Kettering 2008



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; and
- Assess the productive potential of hazelnuts (*Corylus avellana* L.) in Australia.

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

4.1 Suitability of hazelnut varieties for the Australian hazelnut industry

Hazelnut production has two basic purposes, 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 26). Some products require varieties that have a thin skin or pellicle, such as for snack foods; others such as gelati 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.

Table 26. 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. gelati 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 also used in bakery products
Praline	A paste made from meal	A flavouring product 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

Before discussing the attributes of the varieties, it was important to consider whether the varieties provided were true to type. A detailed study of the characteristics of the varieties used in this research was undertaken and was presented in a separate report, (Baldwin, 2007). In that study it was concluded that all the varieties supplied for this research were true to type except for "Tonda Romana",

which appears to be a Sicilian type similar to Montebello. However, the 'Tonda Romana', imported by Ferrero Australia Ltd. at a late stage in the research, was considered to be true to type.

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 Big Bud Mite and to Eastern Filbert Blight which is a major threat to the Oregon industry. 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 particularly for that State. An additional attribute is adaptation to a wide range of soil and climatic conditions.

In this research, two of the highest yielding varieties were 'Barcelona' and 'TBC'. Two other varieties that performed well and showed potential were 'Tonda di Giffoni' and 'Lewis'. The relative attributes of these varieties are given in Table 27.

Table 27. Potential kernel varieties

	Highest yielding varieties		Other 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.
Average percentage kernel weight (Table 20)	40% Relatively thick shells	43%	43%	48% Thinner shells
Kernel defects (shrivelled and poor fill) (Figure 23)	Commonly some poor filled and shrivelled also some twin kernels.	Generally low proportion of shrivel or poorly filled.	Generally well filled.	Generally well filled
Blanching (1 excellent – 7 none) (Table 20)	3.3	2.6	3.1	2.6
Pellicle fibre 1(low) – 5 (high)	3	2.6	2	1.8
Nut shape (l/w)	0.97	1.0	0.9 Distinct indents on the sides	0.97
Average kernel size	14-16 mm	14-16mm	12-14mm	12-14mm

‘Barcelona’

This variety has been 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 was obtained.

‘Barcelona’ is a versatile variety that appears to adapt to a wide range of conditions. However, it did not yield well at Kettering, suggesting it may be less well suited to cooler summer 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 pollenisers 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’ produces 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 has a slight tendency to fall in husk and may require 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 would suggest 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 polleniser for many varieties. Apart from the potential polleniser 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. 'Lewis' 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. Nut clusters can contain eight or more nuts, some of these nuts are misshapen and do not develop completely. In some seasons nut fall is protracted with some nuts hanging on the tree.

The potential of Lewis was not 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 not only be genetically compatible with the trees of the main variety that is to be pollinated but must shed pollen when the female flowers of the main variety are receptive. Ideally pollinisers should 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 28. For example, in 'Barcelona' (S_1S_2), only the dominant allele S_1 is expressed, whereas in 'Hall's Giant' (S_5S_{15}) the S-alleles are co-dominant, therefore both are expressed.

Table 28. Example of some cultivars that are compatible with ‘Barcelona’ and can be used as pollenisers, compared with an incompatible variety, ‘Montebello’

Example:			<u>S-alleles</u>	
Nut producing variety	-	‘Barcelona’	<u>1</u>	2
Polleniser varieties	-	‘Butler’	2	<u>3</u>
	-	‘Casina’	<u>10</u>	<u>21</u>
	-	‘Hall’s Giant’	<u>5</u>	<u>15</u>
BUT NOT	-	‘Montebello’	<u>1</u>	2

In Table 28 it can be seen that the dominant allele is underlined in each case. The dominant allele of ‘Butler’ is the S_3 allele, so although ‘Butler’ has an S_2 allele, this is recessive in the pollen and therefore cross-pollination with ‘Barcelona’ can occur. ‘Casina’ and ‘Hall’s Giant’ have co-dominant S-alleles, but they are different from the S_1S_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_1 allele of ‘Montebello’ is also dominant in ‘Barcelona’.

Recommended pollenisers for ‘Barcelona’, ‘TBC’, ‘Lewis’ and ‘Tonda di Giffoni’ are given in Table 29. These recommendations are based on timing of pollen shed and their genetic compatibility.

Table 29. Potential pollenisers for the most promising varieties in the field studies

Variety	S - alleles	Early	Mid-season	Late
‘Barcelona’	<u>1</u> 2	‘Segorbe’	‘TBC’ ‘Lewis’	‘Hall’s Giant’
‘TBC’	<u>5</u> 23	‘Barcelona’	‘Lewis’	‘Jemtegaard #5’
‘Tonda di Giffoni’	<u>2</u> 23	‘Barcelona’ ‘Segorbe’	‘Lewis’	‘Hall’s Giant’
‘Lewis’	<u>3</u> <u>8</u>	‘Tonda di Giffoni’	‘TBC’	‘Hall’s Giant’

‘Hall’s Giant’ and ‘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 those produced by the varieties ‘Ennis’ and ‘Royal’ usually have a higher buyer appeal than small nuts. At Orange, ‘Ennis’ yielded well (Table 18), at Myrtleford and Moss Vale (Tables 16 and 17) ‘Ennis’ also gave reasonable yields. Although ‘Royal’ was not evaluated at all sites, at Myrtleford it yielded less than ‘Ennis’, whereas at Kettering, yields were 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 both ‘Ennis’ and ‘Royal’ 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. Neither ‘Ennis’ nor ‘Royal’ are considered very suitable for the kernel market, due to poor kernel fill, uneven kernel shape and poor blanching. It appears that there is currently an emerging market in China for ‘Ennis’ nuts. As the kernels seem to have a higher water content than other varieties, they require some specialised storage treatment to reduce shrivelling of the kernel when drying.

Comments on other varieties

- ‘Atlas’** was generally a vigorous growing variety at the sites where it was grown 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 sometimes fell 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 under Australian conditions ‘TBC’ is far better. ‘Daviana’ has a long shaped nut and kernel. Yields are low. It often loses catkins in a dry autumn when it is under moisture stress.
- ‘Eclipse’** sheds pollen late and may be a useful polliniser. Growth was poor at Orange.
- ‘Hall’s Giant’** or **‘Merveille de Bollwiller’** (Syn.) are valuable late pollinisers and are compatible with many varieties. 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 variety. The trees had almost identical characteristics.
- ‘Hammond 17’** appears to be a variant of ‘Butler’ but 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 was limited at that site. At Kettering, yields were modest. As it grows as a small, compact tree, it has the potential to be planted at a higher density than ‘Barcelona’ and ‘TBC’ and, if covered with netting during nut and kernel development in areas where sulphur crested cockatoos are a pest, could be a useful variety. A potential spacing would be 3m between trees in the row and 5m between rows. The kernel has a pleasant taste, but the nut has a 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’** grew well at all sites; but only produced modest yields of small nuts and kernels. Despite this, it has produced a high kernel percentage 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 are not a marketing issue if ‘Segorbe’ is in mixture with ‘Barcelona’.
- “Sicilian” type** was 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 this 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 limitations are its thick shell and low kernel percentage.

‘TGDL’ is recognised as a superior kernel variety in Italy. It lacked vigour and productivity at all sites. It was particularly poor at Orange, as was the ‘TGDL’ in the Ferrero Australia collection at that site. ‘TGDL’ did not produce very well filled kernels and did not blanch very well at any of the sites.

‘Tonda Romana’ 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 that 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 kernel percentage.

‘Victoria’ is a vigorous variety that produces large nuts. It was the highest yielding variety at Kettering. The kernels do not blanch. The variety appears to have limited value due principally to its inferior kernel quality, although it demonstrated reasonable yield potential.

‘Wanliss Pride’ has been widely planted in Australia 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, particularly in the Monbulk area, where yields of up to 20kg/tree have been reported from 40-50 year old trees grown at a spacing of 5m x 7m (Merry, 2008 pers comm). Wanliss Pride produces an attractive large nut and has a nice flavoured kernel. In these studies, the growth and yield of Wanliss Pride was generally lower than most varieties. It performed best at Kettering and poorest at Orange. It is generally a weak, slow growing variety. It may be best suited to maritime environments. It has the characteristics of the Turkish variety ‘Kargalak’, (Syn ‘Imperial de Trebizonde’) and probably originates from the Black Sea Coast. It appears to perform best as a multi stemmed tree. The S alleles are 2 10.

‘Whiteheart’ was one of the latest additions to the trials and was only included in yield testing at Kettering. It exhibited weak growth at Kettering and in the buffer rows at Orange. Yields at Kettering were very low, but kernel quality was excellent, with a high kernel percentage. It is very late in female bloom. This variety appears to be very susceptible to Big Bud Mite. It is widely grown in New Zealand, particularly on the South Island.

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 30. Alleles of ‘Tonollo’ are as for ‘Barcelona’ and those of ‘Wanliss Pride’ are considered to be as for ‘Imperial de Trezbionde’ (S 2 10).

Table 30. Incompatibility S-alleles of some hazelnut cultivars introduced into Australia.

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

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 climate with a maritime influence. The research sites were chosen to represent a range of agro-climatic conditions. Contrasting temperature patterns were recorded from these sites (Figure 37), 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.

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 31, along with the mean temperature for the coldest month. Kettering 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 -7⁰C. Note the mean temperature for the coldest month, July, at Kettering was 8.5⁰C. Although it was the most southerly site, winter temperatures are buffered by the effects of the sea. It is suggested that when selecting suitable sites for hazelnut production, the mean temperature for the coldest month should be less than 10⁰C, unless varieties with low chill requirements are being grown, when a mean temperature of 11-12⁰C might be suitable. Summer temperatures are also highly significant as hazelnuts do not like extremes of heat as discussed later.

Figure 37. Average maximum and minimum temperatures and rainfall recorded at four of the field sites during the conduct of the experiments

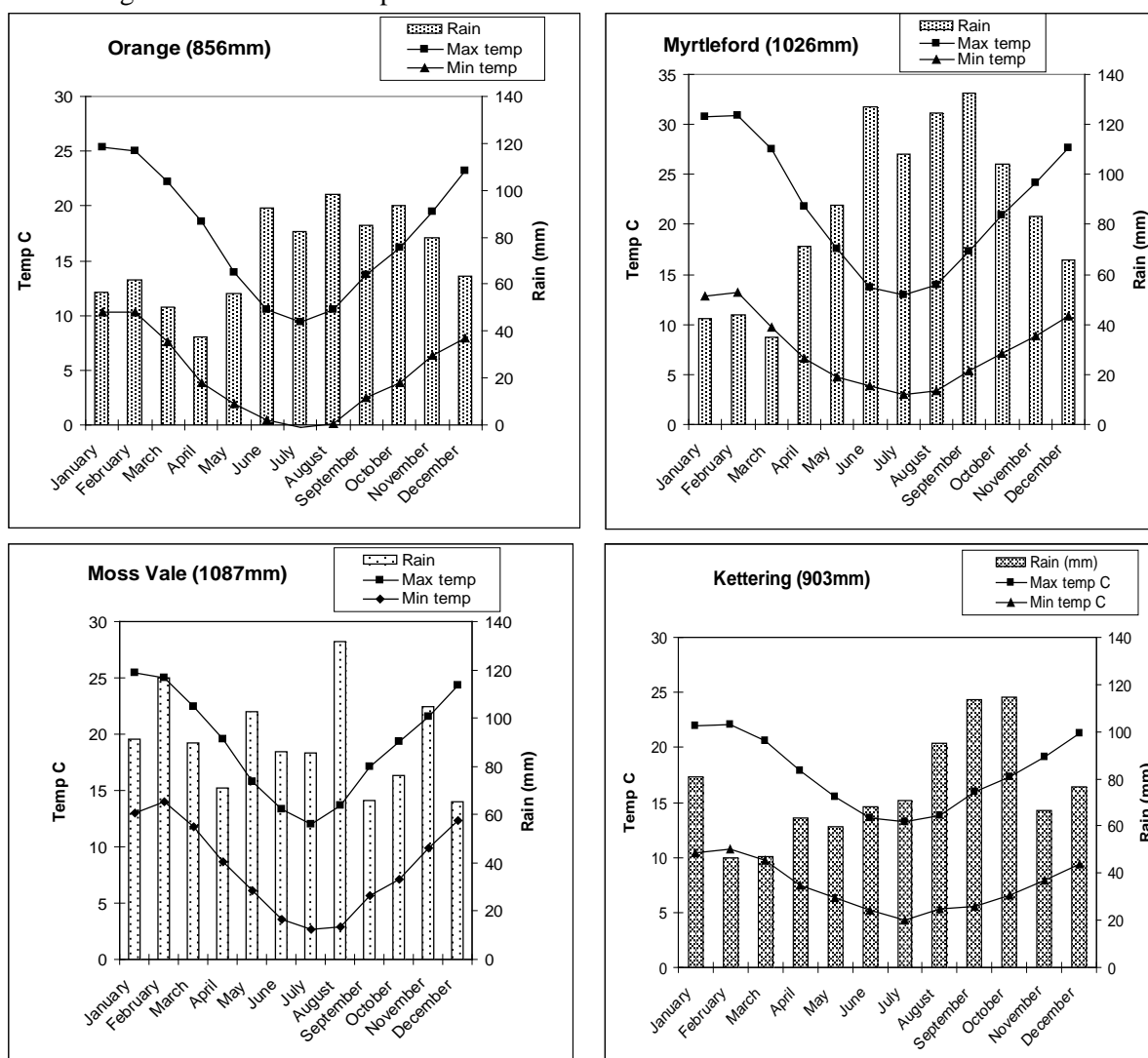


Table 31. Relationship between total chill hours (0-7°C) for the period April – August, inclusive, and mean temperatures recorded in the coldest month, July, for the five sites

	Kettering	Moss Vale	Myrtleford	Toolangi	Orange
Total chill hours (0-7°C) April – August (incl.)	1088	1072	1370	1430	1467
Mean max temp July °C	12.8	12.3	12.9	9.0	9.4
Mean min temp July °C	4.2	2.8	2.9	4.2	-0.2
Mean temp July °C	8.5	7.6	7.9	6.6	4.6
Mean max temp Jan °C	21.9	25.4	30.7	23.4	25.3

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°C (Westwood, 1988). Although radiation frosts are common in inland areas of Victoria and NSW, particularly at high elevations, temperatures below -10°C are uncommon. During the trial temperatures as low as -7.6°C at Orange and -5°C at Myrtleford were recorded. At Glen Innes, on the Northern

Tablelands of NSW, a minimum of -11°C had 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 the 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°C. This is generally hotter than most other major overseas centres of hazelnut production, Table 32.

Table 32. Mean maximum temperatures (°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 °C for the hottest month	27.2	28.5	26.3	30.4	30.8	21.7
Mean annual rainfall (mm)	1084	518	831	939	1026	903

Most of the overseas centres have mean maximum temperatures for the warmest month of over 25°C, whereas at Kettering the mean maximum in January and February was about 22°C. This lower temperature seemed to be adequate for nut development. However, it delayed maturity, with nuts not ripening until April for most varieties, 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°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 was 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 520mm, 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 700mm, 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, but higher where annual rainfall is less than 700mm.

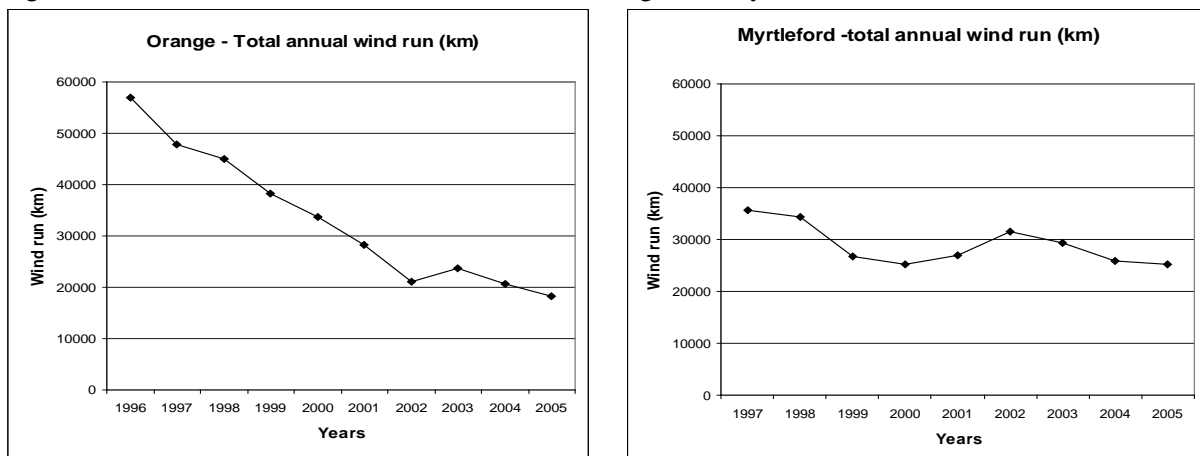
Areas that have winter–spring rainfall dominance appear to be more suitable than areas with summer–autumn rainfall dominance, as late summer rains can hamper harvest and may have an adverse effect on nut quality, causing moulds to develop.

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 attributed to wind, as that site was initially very open to wind (Figure 38) 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 themselves.

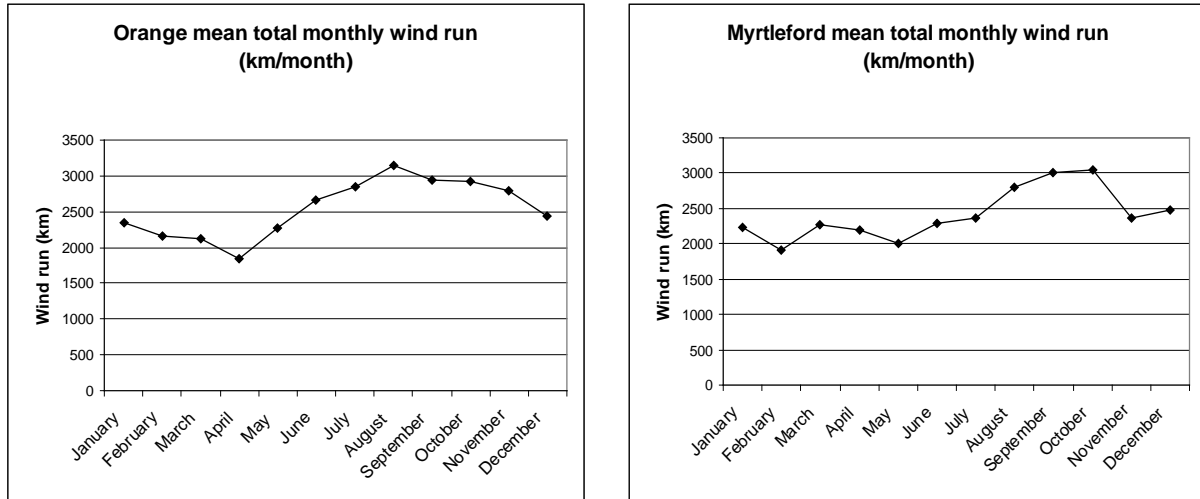
Winds in spring and summer have been observed to cause damage to both leaves and developing shoots. Hazelnut trees can have fairly large leaves, which are quite soft until late November to December. Hot dry winds can cause leaf scorch in summer.

Figure 38. 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 39), 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. Selection of suitable species that do not subsequently compete with the hazelnut trees is important. Late summer and autumn is commonly the calmest period of the year.

Figure 39. 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 well-drained 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. It was considered that 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 and may indicate seasonal waterlogging.

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 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.

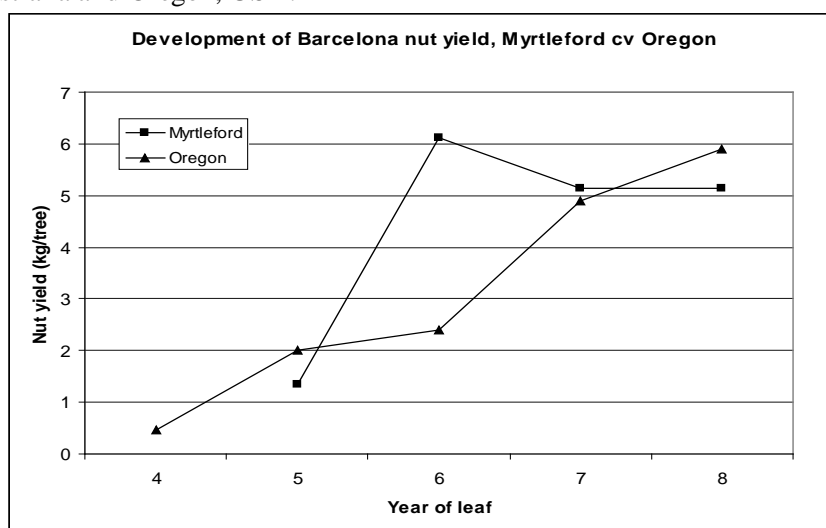
4.3 The productive potential of hazelnuts (*Corylus avellana* L.) in Australia

Productive potential

The site at Myrtleford provided a good indication of 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 40), 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.

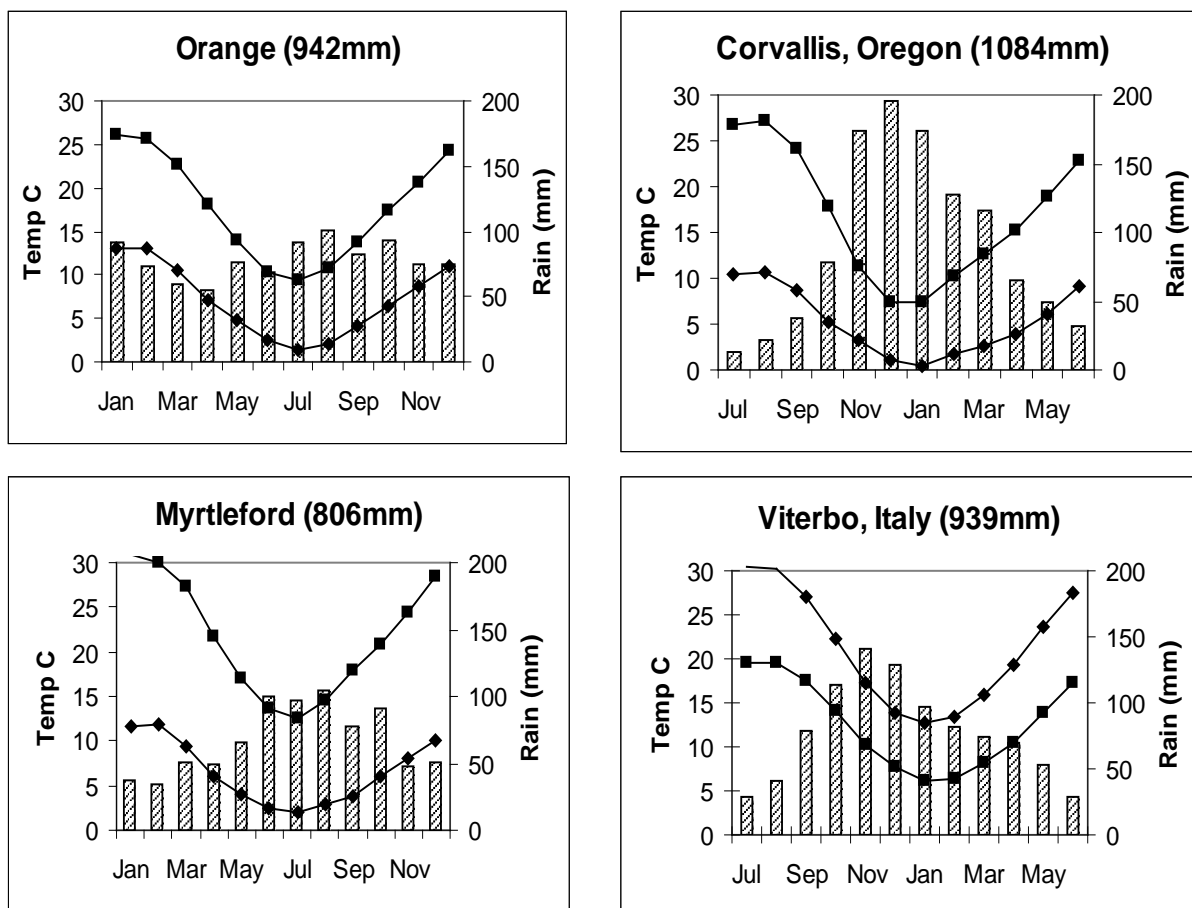
The trees at Corvallis were grown at a wider spacing (4.5 x 5.5m) than those at Myrtleford (3 x 5m). It is considered that the difference in density would have had little effect on tree growth and yields before the seventh year of leaf. Thereafter, it is very likely there was inter-tree competition from 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 40. 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 41). 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.

Figure 41. Comparison of mean monthly temperature and rainfall for Myrtleford and Orange compared with two centres of hazelnut production, Corvallis, Oregon, USA and Viterbo, Italy



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’ is grown on volcanic soils in the Monti Cimini area. 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. The Monti Cimini area in Italy is influenced by the tempering effects of the Mediterranean Sea, which also increases levels of humidity.

There appears to be great scope for growing hazelnuts in parts of Tasmania, such as in the Deloraine and Meander Valley area in the north, 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). Big Bud Mite is wide spread in Tasmania and has probably been there for many years. It can have a very damaging effect on susceptible varieties; the best strategy for control being to plant resistant varieties.

The apple growing areas such as Manjimup in the south-west of Western Australia are also suitable for hazelnut growing.

World production of hazelnuts is static or slightly declining in the northern hemisphere (Table 33) 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). The health benefits from including nuts in the diet have been strongly promoted to health professionals through the Nuts for Life program and in recent years, nut consumption in Australia has increased.

Australian production of hazelnuts is estimated to be 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 4kg/tree is achievable at a spacing of 3x5m or about 650 trees/ha. This is equivalent to 2.5tonnes/ha. Such yields are comparable to those achieved with good management in Italy, Spain, Oregon and France (Table 33), 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 5,000 hectares have been planted in recent years, with an additional 1,000 hectares being planted annually. (Chase –Lansdale and Perry, 2008).

Table 33. World hazelnut situation, total areas planted, average annual production and average size of orchards

Country	Av. annual production (t)	Approximate total area (ha)	Approximate average yields (t/ha) ⁽¹⁾	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, rainfed, highly mechanised
France	5,300	2,500	2-2.5	14 - 20	Slight growth, highly mechanised, some irrigation

Footnote (1) Yields from unirrigated 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 ground 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 34).

Table 34. 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 and manual operation of the system..	<u>2,400</u>
Total materials costs	5,950

The data from the research sites indicates it may take from 6-10 years to achieve peak yields from an 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 35. 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 35. 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	150	
Sucker spraying (4 times per year)	100	
Mowing (4 times/year)	150	
Weed control, (eg Roundup down the tree rows)	100	
Irrigation (application costs)	100	
Harvesting (suction machine @ \$1/kg)	<u>2000</u>	
Total direct costs		<u>2600</u>
Gross margin (\$ per hectare)		4400

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

Price received (\$/kg)	Yield of nuts in-shell (t/ha)			
	1.0	1.5	2.0	2.5
3.00	400	1900	3400	4900
3.50	900	2650	4400	6150
4.00	1400	3400	5400	7400

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. A source of supplementary irrigation is highly desirable, particularly where annual rainfall is less than 1000mm.

Shelter

Select sites that are sheltered from strong winds or plant windbreak trees before planting the orchard. Avoid planting trees like wattles that may harbour borers. Some native species, eg Callistemons, Hakeas and Casuarinas give good wind protection without competing with the adjacent orchard row.

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 one year-old trees that are well grown (4-6 cm butt circumference) with good root systems. Select appropriate pollenisers.

Planting distances

Based on the experience gained from the research, it is suggested that commercial orchards 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 less 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 37. 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 nine months after planting.

Table 37. Typical target figures of stem (butt) circumference (cm) and nut yields (kg/tree)

	Year of leaf								
	1	2	3	4	5	6	7	8	9
Butt circumference (cm)	8	14	19	24	29	33	37	41	45
Nut yields (kg/tree)				0.2	0.9	1.8	2.8	3.7	4.5

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, dried 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, the Monbulk area, parts of Gippsland, in northern and southern districts of Tasmania and, in NSW, on the Central Tablelands, Southern Highlands and South Coast. A concentration of plantings in these areas could lead to a substantial industry. Other possible areas include the Mount Gambier district and parts of the Adelaide Hills in South Australia and the Manjimup district of Western Australia. Global warming and drying in southern Australia will be challenging for the developing industry, raising questions about the future suitability of localities that currently have potential.
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 (Baldwin and Simpson, 2003), 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 buyers, who 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. While considering this, it is important to remember that it will be difficult for Australian hazelnuts to compete on price in the ingredient market. At this stage, best potential appears to be in capitalising on the quality end of the market, especially on the fresh, tasty, nutritious aspects of the crop, selling to discerning buyers seeking the fresh nut or perhaps value adding at the premium end of the market.
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. It is suggested that potential growers on the mainland should not buy planting material from Tasmania, in order to minimise the risk of introducing this pest to the mainland.

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 for the crop to be grown 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. The selection of compact varieties planted at relatively high density and netted during nut development is a potential strategy to consider for new orchards in vulnerable areas.

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. However, the ability to place freshly-cracked hazelnut kernels on the Australian market is a major competitive advantage over imported product that invariably lacks freshness.

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. However, it is feasible to evaluate new varieties developed overseas and to make selections from genotypes already present in Australia.

- It is recommended that further evaluation of new and promising genotypes from overseas and material already in Australia is conducted; this should involve productivity, quality aspects and 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. This needs to be complemented with field studies on the effectiveness of various types of irrigation systems to meet the water needs of the crop.

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 as young orchards come into production.

- 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 areas in regions suited to hazelnut production, such as Northern Tasmania, North-eastern Victoria and the Central Tablelands of 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.
- It is recommended that hazelnut growers on the mainland do NOT source planting material from Tasmania.

Implementation of the recommendations

1. Industry initiatives

It is recommended that the peak hazelnut industry body, the Hazelnut Growers of Australia (HGA Inc.), 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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8. Appendix

Report on the 7th International Congress on Hazelnut

Basil Baldwin – Charles Sturt University

This international congress was held in June 2008 and was organised jointly by the Hazelnut Research Centre, the University of Tuscia and CeFAS on behalf of the International Society for Horticultural Science (ISHS).

The congress was attended by over 150 delegates from more than 30 countries. Thanks to funding provided by the Rural Industries Research and Development Corporation (RIRDC), the author of this report was able to attend the congress. He had the opportunity to present two oral papers, one entitled “The effects of site and seasonal conditions on nut yield and kernel quality of hazelnut genotypes grown in Australia”, the other was “Field and controlled temperature studies on the flowering of hazelnuts in Australia”. The data presented in these two papers was drawn from the research presented in this report.

The author and his wife were the only delegates from Australia. The congress was conducted over five days and included six oral sessions and six poster sessions, along with a full-day tour. The congress was held in the old city of Viterbo at the University of Tuscia, about 100km north of Rome in the hazelnut growing district of Monti Cimini in the Latium region of Italy.

Congress sessions included a presentation on breeding of hazelnut varieties with the main breeding program being that conducted by Professor Shaun Mehlenbacher of Oregon State University (OSU). The main focus of Professor Mehlenbacher’s program has been the breeding of varieties resistant to Eastern Filbert Bight (EFB), a bacterial disease that has devastated the Oregon hazelnut industry. The variety Ennis is particularly susceptible to this disease. The latest release from the OSU breeding program is an EFB resistant variety called ‘Yamhill’, which is a highly productive tree with a more compact shape than ‘Barcelona’. Nuts are slightly smaller than ‘Barcelona’.

Two papers were presented on training systems, vase shape versus multi-stemmed trees. As with previous papers on this topic, there seems to be little difference in productivity from these two systems. However, a single trunk tree is generally considered to be better from a management perspective, especially when trees are mechanically harvested. Posters were presented on summer pruning of old orchards in the Langhe district of Italy. They showed yield benefits for two years after pruning, but a yield loss in the year of pruning.

Studies presented on irrigation confirmed the sensitivity of hazelnuts to water stress. Key periods to avoid water stress are from nut development to kernel fill (December to February in Australia). It was reported that if trees are irrigated to at least 75% of evapotranspiration levels throughout this period, there were no adverse effects on yield or kernel quality.

Conflicting reports were presented on foliar nutrition. One study indicated the value of foliar applications of calcium and boron at the time of shell development, (November in Australia). The other study showed no value was obtained from foliar treatments at this time, however, it was suggested that this was because the trees in the study were growing under favourable conditions of soil nutrition.

The value of Indole Butyric Acid (IBA) treatments to aid rooting in stool beds was again reported. Benefits from substances that help retain moisture (Hydroretenteur) in the mounded stool beds were obtained.

There were several interesting presentations on post-harvest handling and kernel quality. It was reported that high temperature roasting could result in the formation of some carcinogenic substances. Beneficial health effects were reported from some phenolic antioxidants in hazelnuts. The concentration of the antioxidant ellagic acid varied considerably between the varieties studied, from a low level of 0.56mg/kg to a high level of 18.5mg/kg in a Portuguese variety known as Purpurea.

There was a very interesting demonstration of hazelnut harvesting equipment. The FACMA Company produces a range of suction or vacuum harvesters from a small machine with hand-held hoses to a self-propelled suction harvester that sweeps, collects and cleans at a rate of about one hectare per hour in a productive orchard.



Self-propelled FACMA harvester

The Jolly Company demonstrated a pick-up harvester that also collected and cleaned nuts. It did not use suction technology but removed weeds and trash very efficiently via two counter-rotating rollers, with rough surfaces, at the front of the machine, behind the pick-up mechanism.



Front mounted Jolly pick-up harvester, with side sweeper



Counter-rotating rollers remove leaves and husks. Auger moves nuts laterally over sieve bars to secondary cleaning mechanism

Front of the Super Jolly harvester, showing the primary cleaning mechanism of two counter-rotating rollers that remove leaves, husks and small sticks from the nuts that have been collected.

A visit to the Stelliferi processing plant showed how hazelnuts could be processed very efficiently on a large scale with a relatively small labour force. However, there was still a need for a final quality assessment on sorting tables before the product was despatched.



Final sorting of kernels at the Stelliferi hazelnut processing plant

The on-going issue of support to the Turkish industry was discussed and the need for liberalisation before Turkey could enter the European Union. There is a growing interest in hazelnut growing in the Southern Hemisphere with representatives from Chile, New Zealand and South Africa attending the congress. The main developments are in Chile where over 5,000 hectares of hazelnut trees have been planted, with an additional 1,000 hectares being planted each year.

The next International Congress on Hazelnut will be held in Chile in 2012.

Following on from the Congress, the author of this report was invited to review the papers presented in the session on Biology and Physiology of Hazelnuts and to edit all papers written by those who do not have English as their first language. This is for the Congress Proceedings which will be presented in an edition of *Acta Horticulturae*.

Hazelnuts

—Variety assessment for South-eastern Australia—

by Basil Baldwin

Publication No. 09/178

This report looks at the potential varieties that may support a growing hazelnut industry in Australia, where we currently import more than 2000 tonnes of hazelnut kernels annually.

The report summarises the research which was initiated by the Faculty of Rural Management, the University of Sydney, Orange, which is now the School of Agriculture and Wine Science 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 Inc. This report explains how the research was conducted and outlines the results obtained.

The results will be of value to those wishing to invest in hazelnut growing in Australia.

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