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Rural Industries Research and
Development Corporation

Hazelnut Variety Assessment

for South-eastern Australia

A report for the Rural Industries Research and Development Corporation

by Basil Baldwin, Karilyn Gilchrist and Lester Snare

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Researcher Contact Details

Basil Baldwin
Faculty of Rural Management
The University of Sydney
PO Box 883
Orange
NSW 2800

Phone: 02 6360 5562
Fax: 02 6360 5590
Email: bbaldwin@orange.usyd.edu.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone: 02 6272 4819
Fax: 02 6272 5877
Email: rirdc@rirdc.gov.au
Website: http://www.rirdc.gov.au

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Foreword

Hazelnuts are a highly nutritious food that can be consumed in many ways, either raw, roasted or incorporated into a wide range of food products. Hazelnuts are relatively small, shrub-like trees that are wind pollinated. The nuts are formed during the summer and ripen in late summer to early autumn. In most European varieties, the ripe nuts fall to the ground and are then collected by sweeping or suction harvesters. Nuts are dried and can be kept in shell for many months. The nuts have relatively thin shells which are easy to crack. The kernels have a skin or pellicle of varying thickness, depending on the variety. This pellicle can be removed by heating in an oven at 130–150^{0}C, which causes the pellicle to become loose. It can then be readily removed by rubbing. This process of pellicle removing is known as blanching. Some varieties blanch more readily than others. Hazelnuts are often roasted at 150–180^{0}C to bring out their flavour. The period of roasting time will depend on variety, kernel size and the desired flavour.

Although hazelnuts were introduced into Australia more than 100 years ago, to date they have only been grown on a small scale. The major centres of hazelnut production in the world are northern Turkey, Italy, Spain and Oregon in the USA. These locations lie in the latitude range 40–45^{0}N and have a Mediterranean type climate with mild winters and warm summers. Parts of Australia have a similar climate; there would therefore appear to be a potential to grow hazelnuts in these parts of Australia. Currently, Australia imports more than 1800 tonnes of hazelnut kernels annually. A program of field research is being conducted in NSW, Victoria and Tasmania, in potentially favourable areas to answer the questions:

- Can hazelnuts be grown in Australia?
- Where in Australia might hazelnuts be grown?
- What are the best varieties to grow and what pollinisers should be planted with them?
- How profitable might this crop be?

This report summarises the research which is being conducted by the Faculty of Rural Management, the University of Sydney, Orange, in collaboration with NSW Agriculture, Agriculture Victoria and hazelnut growers. This report explains how the research is being conducted and outlines the results to date.

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

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Simon Hearn
Managing Director
Rural Industries Research and Development Corporation

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Basil Baldwin

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Executive Summary

Australia imports approximately $A12 million of hazelnut kernels per year. Although hazelnuts were introduced into Australia more than 100 years ago, production is still very small, less than 50 tonnes per annum. This research is aimed at determining whether hazelnuts can be grown commercially in Australia and, if so, which are the best commercial varieties and the most suitable localities.

Five field trials have been established to evaluate a total of 25 hazelnut varieties. Most of these originate from Europe or the USA, although some Australian seedling types with potential have also been included. Two of the trials are sited in NSW, at Orange and Moss Vale, two are in Victoria, at Myrtleford and Toolangi, with the fifth trial being at Kettering in southern Tasmania. The sites have been selected to test the varieties under different climatic and soil conditions. Each site comprises a randomised block design with four replicates of each variety at each of the mainland sites and three replicates at Kettering.

Planting commenced at Orange and Toolangi in 1995, at Moss Vale and Myrtleford in 1996 and at Kettering in 2000. Data has been collected on the periods of pollen shed, female bloom and leaf out annually at each site. The order in which varieties commence pollen shed and female bloom was found to be consistent across sites and years, although the actual commencement dates varied with seasonal conditions. Chill hour requirements of catkins and female flowers appear to be the key factors in determining the date when pollen shed and female bloom commence.

Automatic weather stations were installed at each of the five sites to record climatic data, including chill hours, that is the number of hours when the temperature is in the range 0-7^{o}C.

Soil samples were taken at all sites before planting, to obtain base data on soil fertility. Leaf samples have been taken annually to measure the nutritional level of the trees. The nutritional levels appear to be adequate at all sites, although high levels of manganese have been recorded at Orange where tree growth has been poorest. It is considered that high levels of manganese may be detrimental to the growth of hazelnuts.

Nuts were harvested from all varieties at Moss Vale and Myrtleford in 2001, 2002 and 2003. Sulphur crested cockatoos have been a major problem at Toolangi and Orange, necessitating the harvest of green, immature nuts in order to provide yield estimates, based on nut numbers. Nut weights were calculated using samples of mature nuts, harvested later.

The combined characteristics of nuts and kernels, periods of pollen shed and female bloom, along with tree shape, have been used to ascertain whether the genetic material evaluated is true to cultivar name. There is a possibility that two cultivars in this study are not true to type.

Samples of nuts from Moss Vale and Myrtleford were used to determine characteristics of kernel quality.

No single variety gave the highest yield at all sites. However, the varieties, Barcelona, Tokolyi/Brownfield Cosford (TBC), Tonda di Giffoni, Tonda Romana and Segorbe, which have potential for use in the kernel market, performed well at all sites. The variety Ennis, which is better suited to the in-shell market, yielded well at Orange.

The variety Tonollo yielded very well at Myrtleford, but was not evaluated at the other sites.

Growth and yields of the Barcelona trees at Myrtleford were comparable with those obtained in Oregon, showing the potential for hazelnut production in Australia.

The only specific hazelnut pest found in Australia is big bud mite, which is restricted to Tasmania. It is recommended that this pest be contained or eradicated in that State. The freedom from major pests and diseases provides enormous potential for organic or pesticide-free production.

Sulphur crested cockatoos were a problem at two of the study sites; this bird has also been a pest in orchards where landholders have been absent at the time of nut maturity. However, if appropriate management strategies are put in place, economic losses from this pest can be minimised.

Potential areas for production are considered to be the alluvial soils of the river valleys in north-eastern Victoria, the Central Tablelands of NSW and parts of Tasmania.

Further data is required on nut and kernel yields to develop economic models on the profitability of this crop.

Further studies need to be undertaken in collaboration with major buyers of hazelnut kernels to gain further information on the acceptability and suitability of hazelnut varieties to Australian processors.

Funding has been provided by RIRDC to continue this work for a further three years to provide further yield data that can be used for economic modelling and to work with processors to determine the suitability of Australian grown hazelnuts for their needs.

Recommendations

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

Product quality, market acceptance and economic viability

- To gain further yield data over the next three years and to use this data to develop an economic model on the profitability of hazelnut production
- To further assess aspects relating to nut and kernel quality for the higher yielding cultivars, including assessment of any environmental or management factors that may influence kernel quality
- To liaise with potential buyers of hazelnut kernels to gain their views on the acceptability of kernels from the higher yielding cultivars

Productivity

- To determine which varieties will pollinate TBC
- To evaluate the factors limiting growth and production of hazelnuts on krasnozem soils, with an emphasis on studying the effects of manganese on tree growth and production and how any adverse effects can be managed

Industry development and extension

- To conduct field days in collaboration with the Hazelnut Growers of Australia Ltd (HGA), agricultural advisors, consultants and buyers of hazelnuts, to disseminate the outcomes of the research and share experiences of growers.
- To develop a final report on the outcome of these studies, including aspects of production, kernel quality, market acceptability and economic feasibility for potential investors in hazelnut growing

Pest management

- Develop strategies to manage or prevent the spread of big bud mite in Australia, if this is not already being done.

1. Introduction

1.1 Background

Australia imports an average of about 1800 tonnes of hazelnut kernels per annum with a total value of about $A12 million (ABS, 2002) (Figure 1). The greatest volume of imports is as kernels rather than as nuts in-shell (Figure 2).

Figure 1. Annual value of imports of hazelnut kernels and nuts in-shell 1994–2001.

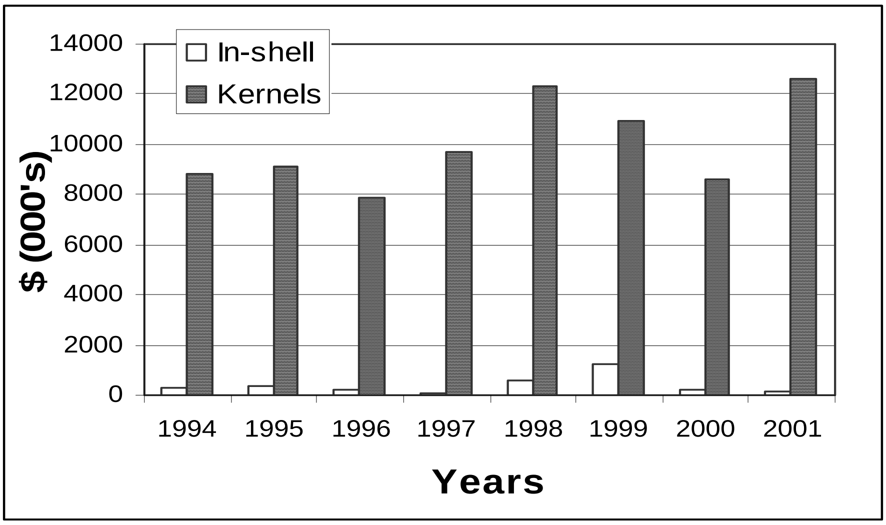


Figure 2. Annual imports of hazelnuts as kernels and nuts in-shell 1994–2001.

Although hazelnuts were introduced into Australia at least 100 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 with a higher return, such as tobacco. Currently, there are about 100 hazelnut growers, mainly in Victoria and NSW. Total production is less than 50 tonnes of nut in-shell. Early introductions of hazelnuts into Tasmania were probably as plants from England. 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 and is considered to be of seedling origin. Although a range of cultivars has been imported in recent years, 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, on which new growers can base their investment decisions. The cost of establishing a hazelnut grove is estimated to be about $8000 per hectare for trees, irrigation and land preparation, including liming (Baldwin, 1998). A newly planted hazelnut orchard takes many years to come into full production and to provide a return on invested capital. If the Australian hazelnut industry is to progress, it is essential that growers have reliable data on the reproductive characteristics, yield, kernel quality and market acceptance of hazelnut varieties grown under Australian conditions, so that productive and profitable plantations can be established.

Major hazelnut production areas in the Northern Hemisphere lie in the latitude range 40–45^{o}N (Alvisi, 1994; Lagerstedt, 1979). They are situated in northern Turkey, Italy, Spain and Oregon, USA, generally within 100km of the coast with Mediterranean climates of cool winters and warm summers.

Australian growers claim that varieties grown in one place may not be suited to another locality, suggesting that there may be some interaction between climate and/or soils and varietal performance. There appear to be differences overseas between varieties, in their adaptation to Mediterranean and continental climates. In Italy, for example, the cultivars grown appear to have lower vernalisation requirements for flowers to open and buds to leaf out, compared with the varieties grown in more continental climates with colder winters, such as Oregon in the USA.

The research reported herein is on tree growth, flowering periods, nut and kernel yields of young trees of varieties grown under varying soil and climatic conditions, along with data on kernel quality. Funding has been provided for a further three years, by which time it is anticipated that the trees should be in full production and valuable data will be available for economic modelling.

1.2 Objectives

The objectives of this research are to:

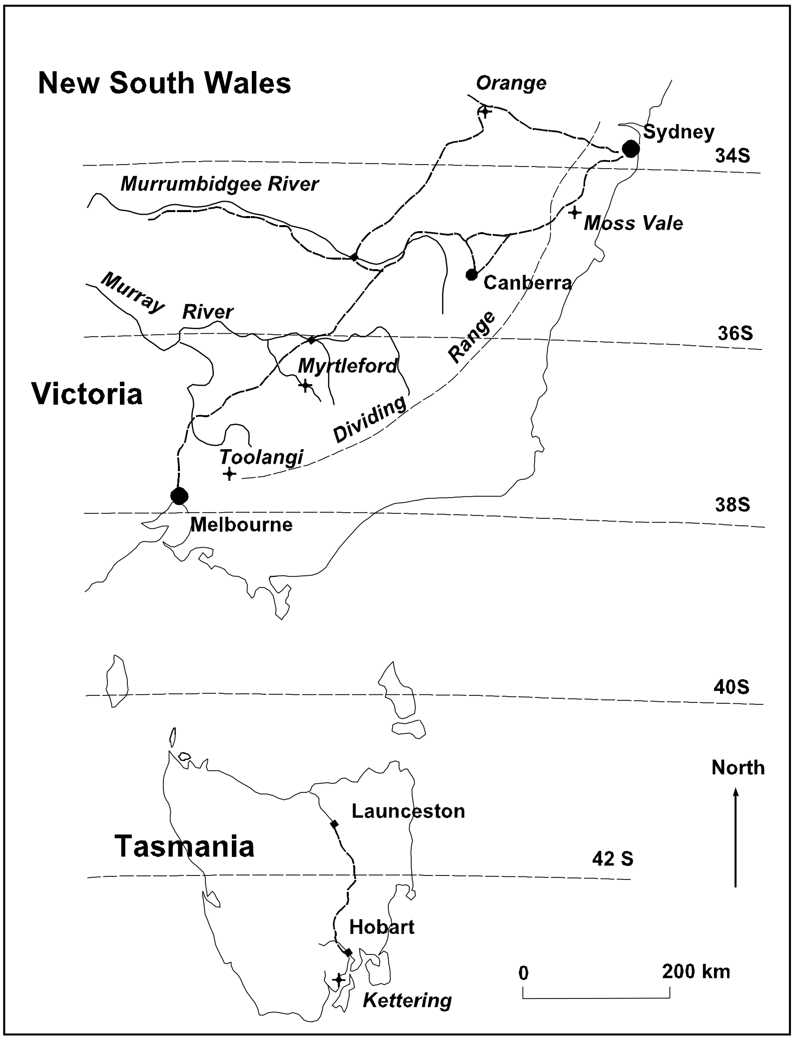
- Determine the most suitable hazelnut varieties that could be used for the establishment of a hazelnut industry in south-eastern Australia.
- Assess the effects of geographical region and climate on hazelnut production and varietal performance.
- Assess the productive potential of hazelnuts (*Corylus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

2. Methodology

2.1 The trial sites

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

Figure 3. Locations of the five hazelnut variety sites in south-eastern Australia. In the Northern Hemisphere, main production areas lie in the latitude range 40–45°N.



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

Table 1. Climatic characteristics of the localities where the hazelnut variety trial sites have been 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: 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 differ with respect to soil, which may compound climatic effects. 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 are volcanic in origin, having been developed from basaltic lava flows. The basaltic rock has been weathered over millions of years to form deep, red krasnozem soils (Table 2). The soil at Myrtleford is alluvial and is situated on a relatively recent floodplain or terrace. This soil is deep, with varying texture down the profile, due to the changing deposits of material that have, over time, been spread across the floor of the Ovens Valley. Generally, this alluvial soil has a coarser texture than the krasnozem. The Moss Vale site is on a red podsol derived from sedimentary rock. The Kettering site is also on a podsolic soil. Podsolic soils typically have a duplex profile with a heavier textured subsoil or B horizon which can have poor drainage characteristics. The sites with podsolic soils have the poorest drainage.

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

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

2.3 Soil sampling and analysis

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 were used to determine lime and fertiliser requirements for the sites. All sites were limed before planting to reduce any potential adverse effects of soil acidity. Olsen (1995) considered that pH_w 5.0 (1:10 soil: water) is the minimum that is suitable for hazelnut growing in Oregon. In Australia, pH is generally measured in a 1:10 calcium chloride solution (pH_{Ca}). Values for pH_{Ca} are generally 0.5 units lower than those for water, indicating that the sites were close to the minimum desirable pH level before liming. 5 tonnes/ha of ground limestone was applied at all sites, except Myrtleford, where 7 tonnes/ha was applied. A further 7 tonnes/ha of lime was applied at Orange in 2001.

The available phosphorus level varied considerably with low levels, less than 10mg/kg, being recorded for Toolangi, Myrtleford and Moss Vale. 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 are under evaluation for growth and productivity, with data on flowering also being obtained on several additional varieties that are included in the trees surrounding the treatment plots. The varieties being evaluated are mainly those suited to the kernel market, but also include varieties suited to the in-shell trade and others whose main role is as pollinisers (Table 4).

The varieties included in the trials are mainly named cultivars of European and North American origin, but also include some Australian seedling types that have been given names, such as Atlas. 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 is the smallest trial site, where 12 varieties have been planted. These 12 varieties are common to all sites. At Orange and Toolangi, an additional four varieties have been planted, with a further eight varieties having been added at Myrtleford. There are 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 comprises four replicates of the varietal treatments in a randomised block design. At Orange and Toolangi there are four trees of each variety in each replicate, whereas at Moss Vale and Myrtleford there are only two trees per variety per replicate. Planting at the Orange and Toolangi sites was commenced in July 1995. Planting commenced at Myrtleford and Moss Vale in July 1996. The reason for changing from four to two trees per treatment in each replicate arose from the difficulty of obtaining sufficient planting material as well as limitations of space. Trials conducted at Oregon State University have single tree replicates (McCluskey et al., 1997). At Kettering, it was decided to use only three replicates of 20 varieties with two trees per replicate, due to limited space.

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

Varieties	Potential use	Country of origin	Location of germplasm repository	Supplier of planting material				
				OR	MV	MY	TL	KT
Atlas	Kernel/ In-shell	Australia	NSW Agriculture Orange	MP	MP	MP	MP	
Barcelona	Kernel/ In-shell	USA	Oregon USA	RS	RS	RS	RS	MP
Butler	Polliniser/ In-shell	USA	Oregon USA	RS & MP	RS	RS	MP	MP
Casina	Kernel	Spain	Oregon USA	CO	CO	CO	CO	MP
Daviana	Polliniser	England	Oregon USA			RS		
Eclipse	Kernel	Australia	Milan Paskas, Victoria	MP		MP	MP	MP
Ennis	In-shell	USA	Oregon USA	RS	RS	RS	RS	MP
Hall's Giant	Late polliniser	Germany	Oregon USA	RS	RS	RS MP	RS	
Hammond 17	Kernel/ In-shell	Australia	S. Hammond, Orange NSW			SH		SH
Lewis	Kernel	USA	Oregon USA	BW		BW		MP
Merveille de Bollwilller	Polliniser	France	Knoxfield Victoria			MP		MP
Montebello	Kernel	Italy	Knoxfield Victoria			MP		MP
Negret	Kernel	Spain	Knoxfield Victoria	RS		RS	RS	
Royal	In-shell	USA	Oregon USA			RS		MP
Segorbe	Kernel	France	Knoxfield Victoria	MP	MP	MP	MP	MP
Square Shield	Kernel	Australia	Milan Paskas, Victoria	MP		MP	MP	MP
Tonda Gentile delle Langhe (TGDL)	Kernel	Italy	Knoxfield Victoria	MP		MP	MP	MP
Tokolyi/Brownfield Cosford (TBC)	Kernel	Australia	J. Brown, Acheron Victoria	JBr	JBr	JBr	JBr	MP
Tonda di Giffoni	Kernel	Italy	Italy	JBe	JBe	JBe	JBe	JBe
Tonda Romana	Kernel	Italy	Knoxfield Victoria	MP	MP	MP	MP	MP
Tonollo	Kernel/ In-shell	Australia	NSW Agriculture			NsA		
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

Key: MP – Milan Paskas, RS – Richard Salt, BW – Bruce West, CO – Chris Offner, SH – Simon Hammond, JBr – Janet Brown, JBe – Jim Beattie, JG – Jim Gleeson, NsA – NSW Agriculture

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

It was not possible to plant all variety treatments in the main year of planting due to the unavailability of some varietal planting material. This applied particularly to the cultivars Willamette and Lewis, which are recent releases from the breeding program at Oregon State University. When analysing yield data, a co-variate statistical technique has been used in some instances to make adjustments for year of planting.

All sites have been planted with rows five metres apart and trees three metres down the row. Trees were planted in July or August when they were dormant.

2.5 Measurements and recordings

Periods of pollen shed and female bloom have been 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 shed was recorded as the date from which about 15% catkins were shedding pollen until only about 15% were still shedding. These records provided information on the commencement and duration of pollen shed.

Relative numbers of catkins per variety was recorded based on a relative 1–5 score with 5 being the rating for the variety that appeared to have the greatest number of catkins. Records were also kept of the date when a few fully open female blooms were first observed on the trees; this date was considered to be the beginning of bloom. The end of bloom was recorded as the date when few blooms were remaining. This end point tended to be vague as towards the end of bloom, stigmas had a withered, dark purple appearance. The recorded dates provided the commencement and duration of female bloom.

The dates when the vegetative buds started to open, indicating the start of leafing out, were also recorded. The observations on pollen shed, female bloom and leaf out 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 15 cm above the ground. These measurements were used to make comparisons of tree growth between years and varieties.

Nut yields were generally obtained by collecting all 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. Samples of 100 nuts from each pair of treatment trees were weighed and cracked. Kernels were weighed to determine kernel yields. These cracked samples were used to determine the number of blank nuts, kernels with defects and whole kernels. 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 tea towel to remove any loose skin or pellicle. Ratings of the degree of blanching were made using a 1–7 rating scale (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 analysed for the total content of selected elements. This data was used to assess the general nutrient status of the experimental trees and to determine fertiliser requirements at each site.

2.7 Automatic weather stations

Automatic weather stations were purchased from the Queensland company “Environdata” and have been installed at each site. These weather stations collect data on temperature, relative humidity, wind run, wind direction, solar radiation and rainfall on a continuous basis. This data is used to calculate potential evapotranspiration loss, through the use of the Penman formula. Evapotranspiration is the loss of water from both evaporation from the soil and transpiration from plants. The potential water loss may be higher than actual loss when soils dry out and plants reduce transpiration rates due to the closure of stomata in their leaves. Figure 6 shows a trace of monthly rainfall and estimated potential evapotranspiration for the four mainland sites. The low rainfall in the later part of 2002 and early 2003 is very noticeable at all sites.

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

2.8 Soil samples

Samples from the top 0–100mm of soil were collected, in March 2003, to assess the available nutrients at that time and to compare these with soil samples taken at the commencement of the experiments.

2.9 Fertiliser

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

In subsequent years, Nitram (ammonium nitrate, which contains 34% nitrogen) was sprinkled around the trees in the spring, at the times and rates shown in Table 5. As trees came into production, an NPK mix of Pivot 400 was used to boost levels of phosphorus (P) and potassium (K) that might 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 12) was used as a basis for determining fertiliser applications to meet the nutrient requirements of the trees.

Table 5. Fertilisers applied at the field sites.

Year from planting	**September**		**November**		**Rate of elements (g/tree)**			
	Fertiliser	Rate (g/tree)	Fertiliser	Rate (g/tree)	N	P	K	**S**
1	Nitram	20	Nitram	20	14			
2	Nitram	40	Nitram	20	21			
3	Nitram	40	Nitram	40	28			
4	Nitram	50	Nitram	50	34			
5 onwards	Pivot 400	100	Nitram	50	40	5	8	9

In Tasmania, a slow release fertiliser was used from 2001 onwards at equivalent rates of nitrogen to the scheduled rates shown in Table 5. The slow release fertiliser was used on this site because it was suspected that damage from nitrogen fertiliser had occurred in the previous spring when high spring rainfall had coincided with the application of nitrogen fertiliser.

2.10 Irrigation

Micro-sprinkler irrigation systems were installed at all sites except Orange and Kettering where drip irrigation has been used. In 2002/03, the irrigation system at Orange was changed to micro-sprinklers to provide a greater distribution of water within the tree rows. Tensiometers have been used as a guide to irrigation requirements. The approximate quantities of irrigation water applied per tree in the three seasons 2000/01–2002/3 are shown in Table 6. At the Moss Vale and Myrtleford sites, very high rates of water were used in 2002/03 in an attempt to compensate for the severe rainfall deficits at those sites. The restricted supply of water at Moss Vale limited water usage to a level lower than that desired. The effects of this are discussed later in the section on tree growth. At Toolangi, the limited water supplies were required for other research programs, making it impossible to irrigate that site in 2002/03, despite the incredibly dry season.

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

Sites	Growing seasons		
	2000/01	2001/02	2002/03
Orange	650	1120	1220
Moss Vale	268	737	2820
Myrtleford	252	2650	4240
Toolangi	250	nil	nil

Studies of water use by hazelnut tees in Bordeaux, France, by Mingeau and Roussseau (1994), indicated a daily usage of 50L per tree in mid-summer. The peak water needs at Myrtleford appeared to be similar to that figure.

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 white acrylic paint to minimise sunburn. The weeds in the tree rows were sprayed with Roundup and hand weeded as necessary. The strips between the trees were mown to encourage a short grass and clover sward.

Suckers were removed by hand in the first two to three years. In subsequent years, Sprayseed ^{R}, 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.

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

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

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

Borers generally affect trees with poor health status. Current control methods are time consuming. The Orange site has relatively high borer counts, with none being recorded at Myrtleford. Borers are a serious pest as the larvae can kill whole trees by girdling or ring-barking the branches or trunks.

Big bud mite (*Phytoptus avellanae*), a serious pest of hazelnuts in Europe and North America, was observed on old trees in Tasmania, a notable example being in the Hobart Botanical Gardens. Infected trees were also found in 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 Hagley. It appears this pest is relatively widespread in Tasmania in older plantations and was seen in one plant nursery. It is not present in the trial site at Kettering. It is suspected the pest was introduced in hazelnut stock in the early years of plant introduction into Tasmania. In 1998 and 1999, a number of bud and leaf samples were collected from sites in Tasmania and on the mainland. Big bud mite was only found on samples from Tasmania (Snare and Knihinicki, 2000). It is considered important that this common and damaging pest be contained, or preferably destroyed, in Tasmania.

Diseases

The major disease recorded from trial plots has been 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. However, Ennis appeared to be less affected. Hazelnut blight has not been a problem at any of the other sites.

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-proof and electric fencing was erected around the Kettering site where rabbits and wallabies were a problem.

Sulphur crested cockatoos (*Cacatua galerita*) have been the major pest at harvest, causing large losses of nuts at Orange and Toolangi, as discussed under nut yields. This pest was managed at Moss Vale through the use of bird scaring tactics.

3. Results

3.1 Flowering

Hazelnuts are wind pollinated. The pollen from the catkins drifts through the orchard on warm dry days and is caught by the styles 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.

When planting a hazelnut orchard, it is important to know which varieties will pollinate the selected nut-bearing, main crop varieties and when these pollinisers will shed their pollen.

The data collected on the dates when pollen shed was observed to commence and the duration of pollen shed, was tabulated for the four mainland sites. Julian days (day of the year) were used to determine average dates for commencement of pollen shed and the mean periods of pollen shed. The data on dates to the commencement of female bloom, that is, when stigmas were first exerted, and the duration of female bloom was similarly averaged. A summary of this data is presented in Table 7.

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. Mehlenbacher (1991) conducted an experiment 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 in the field, at weekly intervals, and placing these 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 hours that had been accumulated to the week of cutting when pollen shed or female bloom was first observed in the glasshouse. The chilling requirements estimated by Mehlenbacher have been included in Table 7.

In Table 7, the cultivars in the trials have been ranked from the earliest to shed pollen to the latest. Apart from the cultivar Butler, the ranking of chill requirements, as estimated by Mehlenbacher, generally parallels the order of pollen shed and female bloom found in the Australian trials.

Considerable variation between seasons was observed in the date when flowering commenced, ranging from 10–12 days either side of the mean date. The earliest recorded date for the commencement of pollen shed, for the cultivar Atlas, was 20 May 2001 at both Moss Vale and Myrtleford, whilst the latest date was 26 June at Toolangi in 2000. Atlas was always the first cultivar to commence pollen shed and Hall’s Giant was always the last. Limited observations are available on the cultivars Jemtegaard#5, Woodnut and Kentish Cob, which are planted in the buffer rows and were observed to shed pollen later than Hall’s Giant. The cultivars that were earliest to produce pollen were often also the earliest into female bloom. Cultivars were generally protandrous, that is, they shed pollen before they came into female bloom.

Table 7. Average dates to the commencement of pollen shed and female bloom, with duration of flowering for the four mainland sites, along with estimates of floral chill requirements.

Variety	**Average date of start of pollen shed**	**Average duration of pollen shed (days)**	**Est. of chill hours for catkins[1]**	**Average date of start of female bloom**	**Average duration female bloom (days)**	**Est. of chill hours for female flowers[1]**
Atlas	1 June	36		11 June	54	
TGDL	1 June	35	<100	1 July	30	760–860
Tonda Romana	7 June	37	100–170	23 June	36	760–860
Tonda di Giffoni	7 June	38	170–240	17 June	36	600–680
Tonollo	9 June	35		23 June	38	
Barcelona	11 June	42	240–290	27 June	42	600–680
Montebello	13 June	35		20 June	39	
Victoria	18 June	44		11 July	41	
Royal	18 June	35		8 July	42	
Segorbe	18 June	41	240–290	18 July	30	600–680
Ennis	20 June	42	290–365	26 July	32	1170–1255
Butler	22 June	36	100–170	25 July	32	860–990
Wanliss Pride	25 June	31		26 June	40	
Negret	28 June	28	240–290	3 July	34	480–600
TBC	29 June	39		9 July	40	
Casina	3 July	32	240–290	21 July	29	1170–1255
Willamette	4 July	25	290–365	10 July	35	680–760
Square Shield	7 July	27		23 July	31	
Eclipse	13 July	26		29 July	24	
Hammond 17	14 July	26		31 July	36	
Daviana	15 July	20		1 August	29	
Hall's Giant	26 July	24	290–365	2 August	22	600–680
Jemtegaard #5	4 August	18		14 August	14	

[1] Mehlenbacher, 1991.

The total chill hours (0–7°C) recorded at each site for the months of April–August (inclusive) were determined at each site (Table 8).

Table 8. Total annual chill hours (hours 0–7°C) for the period April–August for the five field sites.

Years	Sites				
	Orange	Moss Vale	Myrtleford	Toolangi	Kettering
1997	1547	1118		1775	
1998	1512	890	1148	1621	
1999	1563	1003	1331	1292	
2000	1699	1387	1380	1555	919
2001	1612	1080	1345	1133	898
2002	1493	1093	1227	1405	910
Mean	1571	1095	1286	1464	909

On average, Orange has the highest number of chill hours and Kettering the least. This reflects the cold continental climate of the Central Tablelands of NSW compared with the mild winter maritime climate of coastal Tasmania (Table 1 and Figure 3).

It is interesting to note that the Kettering site only records about 900 chill hours in the winter, which, according to Mehlenbacher's studies, would be insufficient for breaking the dormancy of the female flowers of Casina and Ennis. However, these cultivars were observed to bloom during August at this site.

In studies conducted on the chill requirements of peach flowers, Richardson et al. (1974) reported that some temperatures were more effective for chilling than others. They found that 6°C was the optimum for that species, and that temperatures of 3°C and 8°C were 90% as effective and that 10°C was only 50% as effective. Observations of female bloom for high chill hazelnut cultivars suggest that chilling occurs above 7°C, as with peaches.

Limited observations of the cultivar Lewis indicate the period of pollen shed is similar to Casina, with the period of female bloom being similar to Barcelona. The trees were too young and small in 2002 to obtain meaningful data on relative catkins numbers, but did provide data on leaf out (Table 9).

Observations were made of the relative number of catkins produced by the varieties being studied (Table 9).

Varieties that seemed to have a consistently high number of catkins were Casina, Eclipse, Ennis, Hall's Giant/Merveille de Bollwiller (syn.), Segorbe and TBC.

Table 9. Relative number of catkins produced on average at each site for the varieties being evaluated (1 = few - 5 = many).

	OR	**MV**	**MY**	**TL**	**KET**
Variety	**5yrs**	**3yrs**	**3yrs**	**3yrs**	**2yrs**
Atlas	3.6	2.0	2.0	3.7	
Barcelona	3.1	2.7	2.0	1.7	1.5
Butler	2.2	2.0	1.7	2.5	3.0
Casina	2.6	3.7	3.7	1.7	3.5
Daviana			1.0		
Eclipse	3.5		2.5	3.3	2.5
Ennis	3.5	4.0	4.5	1.5	2.5
Hall's Giant	4.1	4.0	3.7	2.3	
Hammond 17			1.5		4.0
Merveille de Bollwiller			4.3		5.0
Montebello			2.2		3.5
Negret	2.3		2.7	1.7	
Royal			4.0		0.5
Segorbe	3.4	3.0	5.0	1.3	1.5
Square Shield	3.4		3.7	2.2	3.5
TBC	4.5	4.7	5.0	4.8	5.0
TGDL	2.6	3.0	1.5	3.2	1
Tonda di Giffoni	3.1	3.0	3.0	1.2	4
Tonda Romana	3.6		2.7	2.2	4.5
Tonollo			1.8		
Victoria	4.3	3.3	5.0	2.8	3
Wanliss Pride	1.4	3.0	1.2	1.7	0.5
Willamette	2.8		2.5		2.5

3.2 Leaf out

Observations were made across all sites of the dates when leaf out had commenced. Average dates for this occurrence are shown in Table 10.

The number of observations varied with varieties, from only two with Whiteheart to at least 10 for most varieties. Season and site differences of up to five days on either side of the average value were observed.

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

Table 10. Average leaf out dates for the varieties being evaluated in the field experiments, compared with estimated chilling hour requirements and dates on which leaf out was observed in Oregon, USA.

Variety	**Average date for commencement of leaf out**			**Estimated chill hour requirements** [1]
	Julian day	**Date**	**Oregon dates** [1]	
Tonda di Giffoni	234	20 Aug	26 Feb	600–680
TGDL	236	22 Aug	26 Feb	760–860
White American	236	23 Aug		
Atlas	236	23 Aug		
Royal	237	23 Aug		
Montebello	239	26 Aug	26 Feb	990–1040
Lewis	241	28 Aug		
Wanliss Pride	242	28 Aug		(Imp Trez[2] 990–1040)
Tonda Romana	244	30 Aug	5 Mar	1040–1170
Barcelona	246	1 Sept	26 Feb	990–1040
Willamette	246	1 Sept	5 Mar	860–990
Whiteheart	249	5 Sept		
Tonollo	252	8 Sept		
Negret	258	13 Sept	5 Mar	760–860
Segorbe	259	14 Sept	12 Mar	1170–1255
Victoria	260	15 Sept		
Butler	260	15 Sept	5 Mar	1040–1170
Daviana	261	16 Sept		
TBC	262	17 Sept		
Hammond 17	262	18 Sept		
Casina	263	18 Sept	12 Mar	1395–1550
Ennis	264	19 Sept	5 Mar	1040–1170
Merveille de Bollwiller	264	20 Sept		
Eclipse	265	21 Sept		
Square Shield	265	21 Sept		
Hall’s Giant	269	24 Sept	19 Mar	990–1040

(1) Mehlenbacher, 1991. (2) Wanliss Pride is considered to be a selection from Imperial de Trebizonde (Imp Trez).

3.3 Tree growth

Differences were observed and measured in tree growth between cultivars and sites. At Orange, the growth of Wanliss Pride, TGDL and Negret was extremely poor, with many plants dying and requiring replanting. Some of the replanted trees also died and had to be replaced. Wanliss Pride has been the worst cultivar in this regard, with none of the original trees remaining, all having been replanted at some stage. When the cultivar Willamette became available for planting in 2000, the inner two yield evaluation trees of Negret at Orange were replaced with Willamette. Similarly, when the cultivar Lewis became available in 2001, the inner two trees of TGDL in all replicates 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 being planted in 1999. Spaces had been left for this variety. The variety White American, which was originally planted, was replaced with Lewis in the winter of 2001. White American appeared to be identical to Wanliss Pride, hence it was removed to make room for Lewis.

Differences were noted in tree growth between cultivars and sites. At Orange and Toolangi, the cultivars Wanliss Pride, Negret and TGDL made the poorest growth. Wanliss Pride was generally the weakest growing cultivar at all sites (Figure 4). It grew best at Myrtleford, as did all other cultivars.

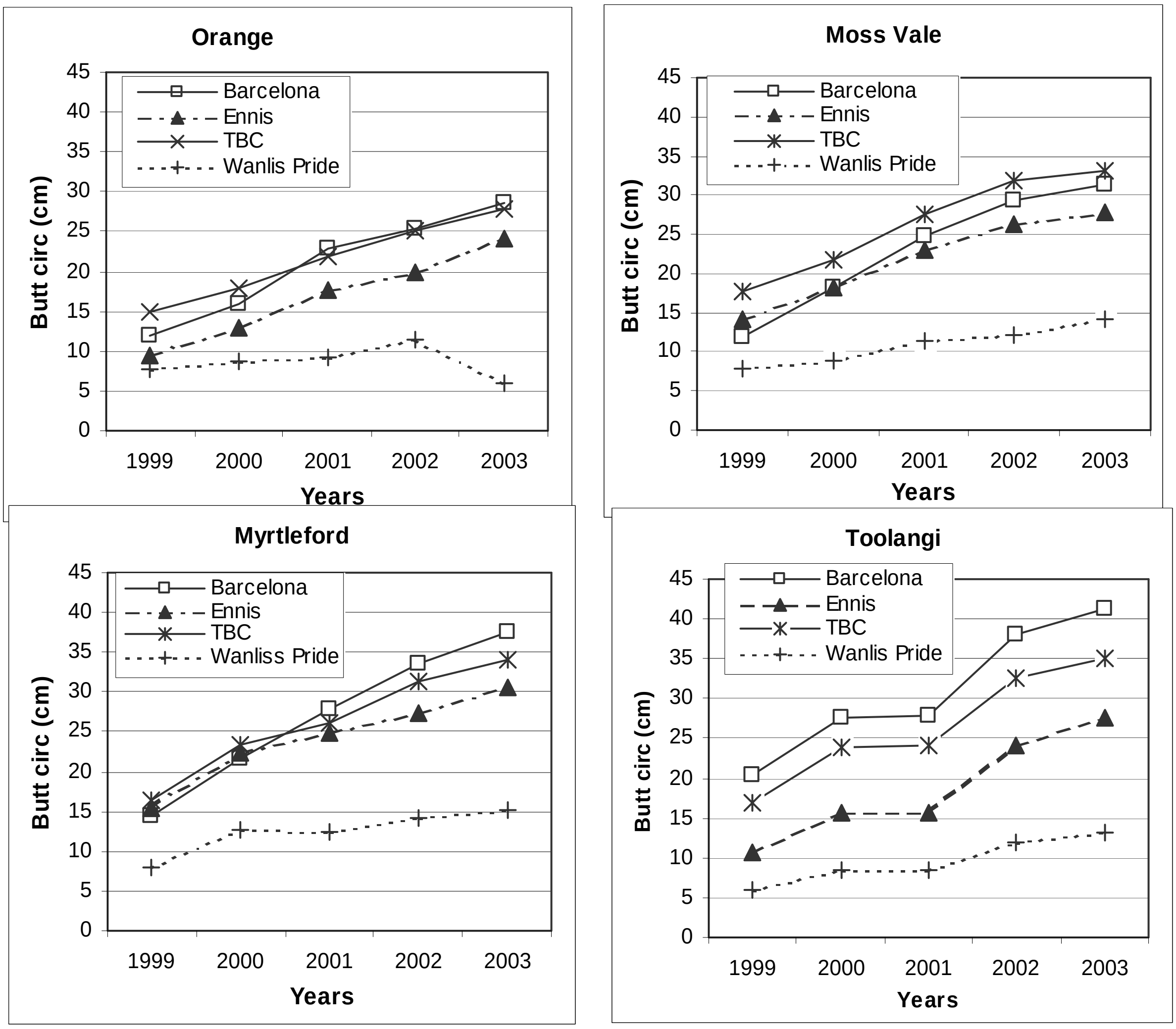
Varieties that grew vigorously at all sites, based on visual ratings of tree growth and measurements of butt circumference, included Atlas, Barcelona, Hall’s Giant, Tonda di Giffoni, Segorbe and TBC. The growth of Ennis was good at all sites but was generally a little less vigorous than the aforementioned varieties, as can be seen in Figure 4.

Tonollo and Butler demonstrated a high level of vigour at Myrtleford. Tree growth rates at Myrtleford and Toolangi were similar for Barcelona, which achieved an average butt circumference of 38cm at both sites by the end of the seventh year of leaf, which was in 2002 at Toolangi and 2003 at Myrtleford.

It appeared that soil and seasonal conditions both had an effect on tree growth. It is difficult to separate the effects of nutritional and physical factors of soil. Lagerstedt (1979) reported that hazelnut trees grown in Oregon grew best when planted in deep soils and rich, river-bottom loams. They are less productive when planted on shallow soils and do not tolerate poorly drained 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). It should be noted that the rainfall pattern in Oregon is one of a wet winter and relatively dry summer (Figure 14). As the trees are normally grown without irrigation, it is anticipated they must be able to draw on moisture from considerable depths to fill nuts and kernels in that environment.

It appeared that the prolonged period of wet weather in the winter and spring of 2000 at Toolangi (Table 11 and Figure 6) adversely affected tree growth in that year. Trees appeared stressed in November, following the extended wet period, and the increase in butt circumference as measured in April 2001 was small (Figure 4). However, it can be seen that the trees recovered from this temporary setback and grew well in the following year.

Figure 4. Relative tree growth as assessed by annual butt circumference measurements.



The 628mm of rainfall recorded at Moss Vale in August 1998 (Figure 6) did not appear to have any adverse effect on tree growth. It may be that wet conditions, when trees are dormant, are less harmful than when the trees are commencing active growth in September and October. It is likely that short periods of wet soil are less damaging than the extended wet conditions that were experienced at Toolangi in 2000.

Table 11. Winter–spring rainfall in two wet seasons at Moss Vale (1998) and Toolangi (2000).

		Months						
Field Site	**Year**	**May (mm)**	**Jun (mm)**	**Jul (mm)**	**Aug (mm)**	**Sep (mm)**	**Oct mm**	**6 month total (mm)**
Moss Vale	1998	28	118	59	628	57	36	1179
Toolangi	2000	224	135	162	125	177	229	1276

In the spring of 2000, some young trees died at Kettering. This was thought to have occurred as a result of wet soil conditions combined with the application of nitrogen fertiliser. A total of 299mm of rainfall was recorded at Kettering in September and October, 2000, causing the poorly drained soil to become saturated.

Plant tissue testing 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 over the period 1997–2003.

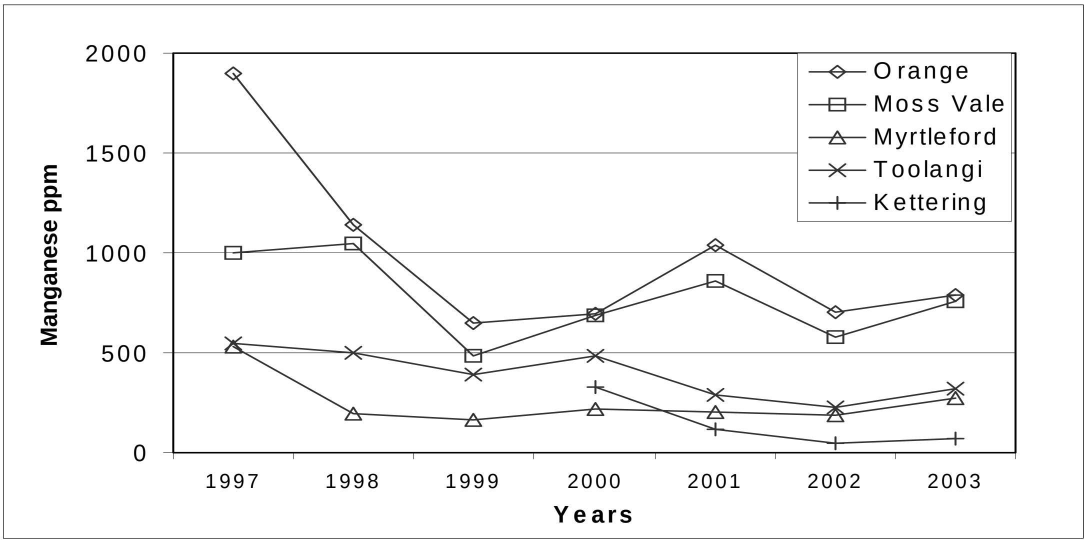
Elements	Sites					Desirable Range(1)
	Orange	**Moss Vale**	**Myrtleford**	**Toolangi**	**Kettering**	
	Site ranges, lowest –highest					
Nitrogen %	2.4–3.1	2.3–2.9	2.5–2.9	2.7–3.1	2.2–3.5	2.2–2.5
Phosphorus %	0.12–0.17	0.12–0.19	0.12–0.18	0.13–0.29	0.31–0.4	0.14–0.45
Calcium %	1.2–2.0	1.0–1.6	0.9–1.6	1.2–1.5	1.2–1.5	1.0–2.5
Magnesium %	0.13–0.20	0.16–0.30	0.14–0.30	0.12–0.23	0.21–0.3	0.25–0.5
Potassium %	0.7–1.3	0.4–1.2	0.6–1.3	0.6–1.5	0.7–1.3	0.8–2.0
Sodium %	<0.05	<0.05–0.17	< 0.01	<0.05–0.13	0.06–0.12	<0 0.1 (2)
Aluminium ppm	126–300	125–274	137–250	147–420	60–103	
Manganese ppm	649–1900	484–1050	162–530	230–550	46–327	26–650
Sulphur %	0.1–0.2	0.15–21	0.1–0.21	0.10–0.2	0.1–0.2	0.12–0.2
Boron ppm	35–67	25–68	25–57	46–60	20–53	30–75
Copper ppm	7–12	5–9	5–11	7–17	5–10	5–15
Zinc ppm	19–32	20–40	16–34	18–45	21–42	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, 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 5), where trees had made least growth, and were lowest at Myrtleford, where trees had generally grown best. It is possible that high levels of soil manganese may adversely affect the growth of hazelnut trees, although this is not documented in the literature on hazelnut nutrition. However, Grau et al. (2001) considered that poor growth of hazelnuts in Chile may have been due to high levels of manganese. It seems possible that some cultivars such as Barcelona, TBC and Tonda di Giffoni are more tolerant to high levels of soil manganese than are cultivars such as Wanliss Pride and Negret. Crops 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).

Figure 5. Levels of manganese in leaf samples collected annually from all sites.



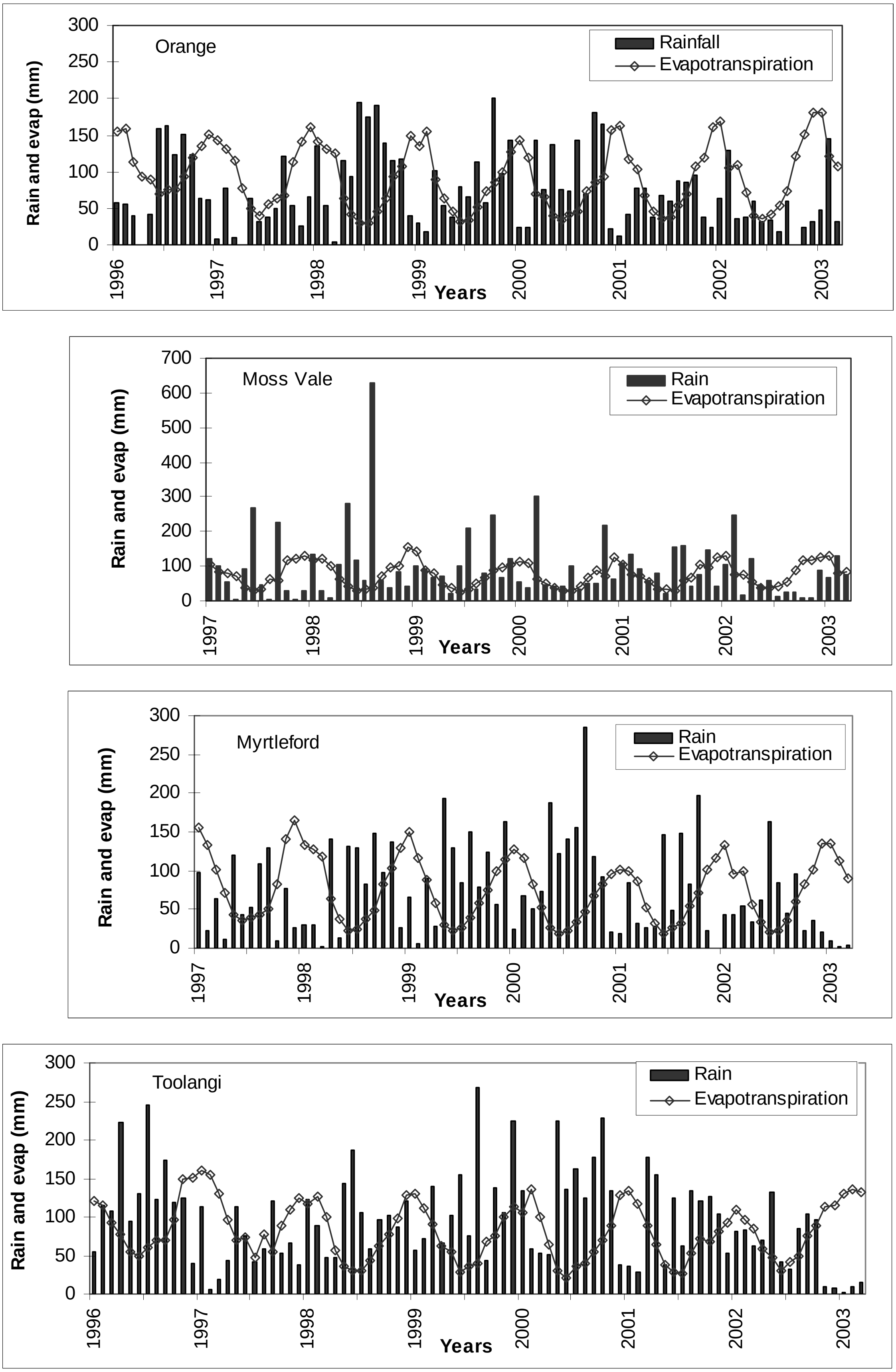
Manganese availability is influenced by soil type, with krasnozem soils derived from basalt frequently containing high levels of this compound. The availability of manganese is also affected by soil pH, with manganese becoming less available as soil pH is increased (Uren, 1999). The lime applied pre-planting at all sites raised soil pH by 0.5 to 1 unit (Table 13). The general decline in the levels of manganese (Figure 5) is probably due to the rise in soil pH.

Table 13. Soil analysis data for each of the hazelnut variety trial sites.

	Orange		**Moss Vale**		**Myrtleford**		**Toolangi**	
Attribute	**1995**	**2003**	**1996**	**2003**	**1996**	**2003**	**1995**	**2003**
pH_{Ca} (1:5 soil $CaCl_2$)	5.7	6.7	4.3	5.2	4.5	5.6	4.5	5.2
Phosphorus (P) Bray test (mg/kg)	21	61	9	18	7	10	3	4
Total carbon (%)	2	1.9	3.8	3.2	3.3	2.8	6.6	6.1
Potassium (K) meq/100g	0.6	0.98	0.3	0.35	0.6	0.57	0.5	1.8
Calcium (Ca) meq/100g	6.8	12	3.9	8.4	5.6	10	3.8	11
Magnesium (Mg) meq/100g	0.7	1	1.4	1	2.3	2.5	0.8	1.8
Aluminium meq/100g	<0.1	<0.05	0.6	0.12	0.2	<0.05	1.4	0.31
Total exchangeable cations (mg/kg)	8.1	14	6.4	9.9	8.8	13	6.6	15
Ca/Mg ratio	9.7	12	2.8	8.4	2.4	4	4.8	6.1

Irrigation water was applied at all sites, with quantities varying with both 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. It appeared the trees became moisture stressed in late spring and summer in that incredibly dry year (Figure 6) with growth (Figure 4), yield (Figure 7) and kernel quality (Figure 8) seeming to be adversely affected by the moisture stress. It should be noted that in Figure 6, the term ‘evapotranspiration’ refers to an estimate of potential water loss from the orchard.

Figure 6. Monthly rainfall and estimated potential evapotranspiration recorded at each of the mainland sites.



3.4 Nut yields

The most reliable yield data has been obtained from the Myrtleford and Moss Vale sites where nut losses from sulphur crested cockatoos have been minor, compared with the other two mainland sites. Yield losses from cockatoos were substantial at Toolangi in 2003 and high at Orange in 2002. In 2003, the nuts were picked green at Orange to minimise loss from birds. When picked green, the nut numbers obtained were multiplied by average nut weights from mature nuts collected later in that season.

Bearing in mind the limitations to some of the data, there is no single cultivar that has out-yielded all others at all sites in all seasons (Figure 7 and Tables 14–17). However, there are about four cultivars that have generally yielded well at all sites. Barcelona has given consistently high yields at all sites, being one of the four highest yielding cultivars. TBC also generally produced high yields and was consistently the highest producing cultivar at Moss Vale (Table 16) and in the top two at Toolangi. Both Tonda Romana and Tonda di Giffoni have yielded well: Tonda di Giffoni performed very well at Moss Vale. Tonda Romana was one of the highest yielding varieties at Myrtleford, but its cumulative yield at that site was not significantly different from Tonda di Giffoni (P=0.05).

Ennis appears to have been the highest yielding variety at Orange (Table 14 and Figure 7). Unfortunately, the figures at this site are not totally reliable as losses from cockatoo attack occurred in 2002. At other sites Ennis did less well.

All the cultivars discussed above yielded higher than Wanliss Pride, which had been the most widely grown cultivar in Australia until the early 1990's. At that time, this cultivar was viewed as the industry standard or benchmark cultivar in Australia.

Barcelona, Butler, Tonda Romana and Tonollo produced the highest cumulative yields at Myrtleford (Table 15). Unfortunately Tonollo was not included for yield comparisons at other sites. Tonollo was reported as the highest yielding genotype in the field evaluation planted at Glen Innes in 1937 (Trimmer, 1965). Snare (Department of Agriculture NSW, 1982) reported that Tonollo trees in the variety collection at Orange also yielded well.

Atlas gave moderate yields at most sites, but did not seem to perform as well as reported in previous studies. High yields were recorded for Atlas by Snare at Orange (Department of Agriculture NSW, 1982) and later by Sample (1993) at Myrtleford.

Segorbe grew well at all sites and produced some moderately good yields, producing cumulative yields at Myrtleford that were not significantly different from those of TBC (P=0.05).

It was noted at Orange that where sulphur crested cockatoos were present, these birds seemed to have a slight preference for small nuts such as Casina, but, given the opportunity, they also ate the large nuts of Ennis.

Table 14. Annual and cumulative nut yields recorded at Orange (2000–2003).

Varieties	Year				Cumulative nut yield (kg/tree)
	2000	2001	2002	2003	
Atlas	0.20	0.56	0.74	2.18	3.68
Barcelona	0.60	0.58	1.47	2.96	5.62
Ennis	0.23	1.21	2.12	3.38	6.93
Segorbe	0.24	0.17	0.80	1.19	2.40
TBC	0.56	1.62	0.70	1.70	4.58
Tonda di Giffoni	0.67	0.67	0.69	0.63	2.66
Tonda Romana	0.48	0.66	0.50	2.23	3.87
Wanliss Pride	0.07	0.14	0.00	0.00	0.21

Table 15. Annual nut yields for the key varieties grown at Myrtleford, excluding the late planted trees of Lewis and Willamette.

Variety	Year[1]			Cumulative nut yields (kg/tree) [1]
	2001	2002	2003	
Atlas	1.53	2.15	4.14	8.18
Barcelona	1.37	6.00a	5.06a	12.99a
Butler	1.11	5.39a	5.31a	12.16a
Casina		3.08	2.95	
Daviana	0.91	1.16	0.64	1.72
Eclipse	0.41	2.30	2.16	5.22
Ennis	0.89	3.34	3.51	8.09
Hall’s Giant	0.03	0.21	0.02	0.79
Hammond 17		2.91	3.60	
Merveille de Bollwiller	0.04	0.45	0.29	1.14
Montebello		2.66	2.74	
Negret	0.48	2.13	1.87	4.83
Royal	0.60	1.63	2.16	4.74
Segorbe	1.02	4.46	3.58	9.41
Square Shield		1.15	1.88	
TBC	2.07a	2.89	3.46	8.76
TGDL	1.00	2.39	2.37	6.11
Tonda di Giffoni	2.25a	2.71	4.71a	10.02
Tonda Romana	2.19a	5.20a	4.08	11.67a
Tonollo	0.99	5.12a	4.73a	12.03a
Victoria	0.89	2.38	2.62	6.25
Wanliss Pride	1.48	0.75	1.86	4.44
LSD[2] (P = 0.05)	0.45	0.99	0.65	1.54

Notes:
1. The annual and cumulative yields have been adjusted to take into account the variation in year of planting, using a co-variate analysis. Highest yields in each column are followed by the letter “a”, this indicates they are not statistically different at P=0.05 probability level.
2. LSD, abbreviation for Least Significant Difference, a statistic used to compare differences in mean yield and to overcome experimental variation.

Table 16. Annual and cumulative nut yields recorded at Moss Vale (2001–2003).

Variety	**Year**			**Cumulative nut yields (kg/tree)**
	2001	**2002**	**2003**	
Atlas	0.29	0.78	0.15	1.22
Barcelona	0.75	2.17	1.03	3.95
Casina	0.04	0.68	0.05	0.77
Ennis	0.49	1.74	1.47	3.70
Hall's Giant	0.03	0.07	0.06	0.16
Segorbe	0.47	2.01	0.64	3.12
TBC	1.64	2.83	2.19	6.66
Tonda di Giffoni	1.66	2.03	1.28	4.97
Tonda Romana	0.34	1.73	0.88	2.95
Victoria	0.93	1.41	1.35	3.69
Wanliss Pride	0.37	0.38	0.25	1.00
LSD (P = 0.05)	0.33	0.51	0.32	

Table 17. Estimates of annual nut yields for key varieties grown at Toolangi (2000–2003).

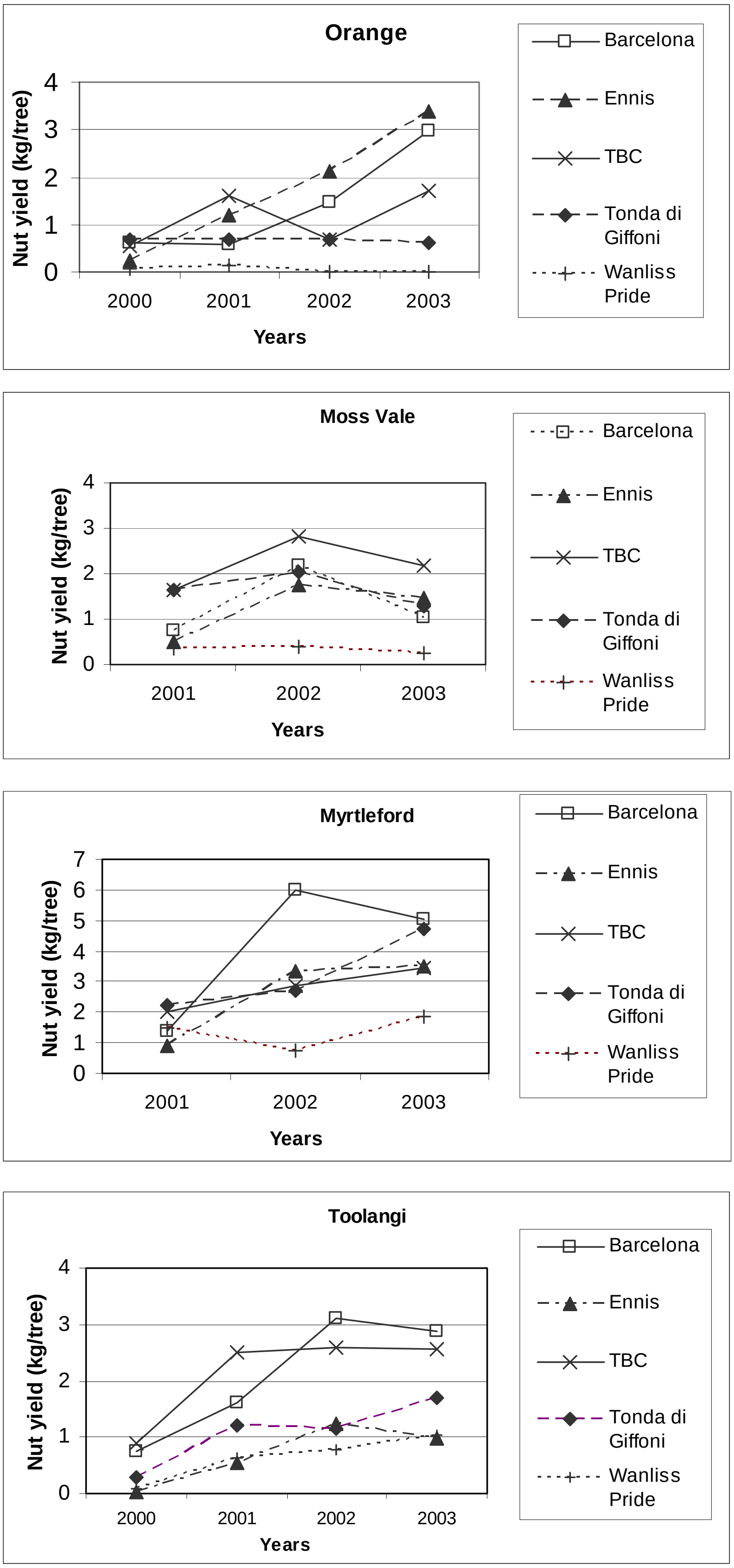
Variety	Year				Cumulative nut yields (kg/tree)
	2000	2001	2002	2003	
Barcelona	0.76	1.62	3.11	2.86	8.35
Ennis	0.02	0.55	1.24	0.97	2.78
Segorbe	0.34	1.22	1.68	1.55	4.79
TBC	0.89	2.51	2.59	2.55	8.54
Tonda di Giffoni	0.29	1.22	1.14	1.69	4.34
Tonda Romana	0.10	0.66	1.44	1.55	3.75
Wanliss Pride	0.09	0.64	0.78	1.04	2.55

It is considered that the yield decline for Barcelona and TBC, recorded at Myrtleford in 2003 (Figure 7), may be the beginning of a biennial bearing pattern for these two cultivars. The general decline in yield in 2003 for Moss Vale is considered to be more likely due to moisture stress at that site owing to the very dry seasonal conditions and lack of water for irrigation.

The apparent yield plateau at Toolangi almost certainly reflects a high loss in yield due to predation from sulphur crested cockatoos.

In general, nut yields reflect tree growth. The best growth and nut yields have been obtained at Myrtleford.

Figure 7. Development of yield with time for five key varieties.



3.5 Nut size and kernel quality

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

Ennis consistently produced the largest nuts (Table 18). Although the nuts of Royal were nearly as large as Ennis, the nut yield from Royal was low. The large size of the Ennis nuts makes them attractive for the in-shell market. In the USA and Europe, Ennis receives a premium price for the in-shell market. Ennis kernels are relatively large and, in some situations, did not seem to fill well (Figures 8 and 9). They do not blanch (Table 18). The kernels are larger than the general size preference for kernels in the confectionery trade, but may be readily marketed as kernels in snack foods. Hall's Giant, which is synonymous with Merveille de Bollwiller, also produced large nuts, but the yields were low.

Table 18. Mean nut and kernel weights with relative blanching characteristics of the varieties being evaluated.

Variety	**Mean nut weight (g)**	**Mean kernel wt. (g)**	**Blanching (Score 1 = 100% - 7 = nil)**		
			Range	**Mean**	**No. of samples**
Atlas	3.04	1.22	2.5 - 5.5	4.1	7
Barcelona	3.25	1.40	3 - 4.5	3.8	11
Butler	3.23	1.54	5 - 6.5	5.9	6
Casina	1.61	0.83	4.5 - 6.5	5.9	8
Daviana	2.76	1.35	4 - 6.5	5.3	2
Eclipse	2.59	1.15	1.5 - 4.5	3.1	5
Ennis	3.98	1.66	6 - 7	6.6	10
Hall's Giant	3.38	1.44	3.5 - 5	4.5	6
Hammond 17	3.22	1.47	4.5 - 6.5	5.0	2
Merveille de Bollwiller	3.34	1.45	3.5 - 5	4.3	2
Montebello	2.94	1.15	1.5 - 3.5	2.8	2
Negret	1.86	0.89	1 - 2	1.5	5
Royal	3.51	1.42	3.5 - 4.5	4.0	2
Segorbe	2.29	0.96	2.5 - 5.5	4.3	11
Sq. Shield	2.86	1.30	3 - 5.5	4.6	4
TGDL	2.39	1.15	2 - 4.5	3.0	11
TBC	3.03	1.38	2.5 - 4.5	3.5	11
Tonda di Giffoni	2.63	1.20	2 - 3.5	2.8	3
Tonda Romana	2.89	1.12	1.5 - 4	3.0	11
Tonollo	3.21	1.32	1.5 - 4.5	3.6	4
Victoria	3.04	1.29	4 - 6	5.0	6
Wanliss Pride	3.00	1.42	1 - 3.5	2.2	8
Willamette	2.64	1.15	1.5 - 3. 5	2.5	2

The higher yielding varieties, Barcelona, Tonollo, TBC, Tonda Romana, Tonda di Giffoni and Segorbe, all produce medium to small nuts and kernels (Table 18). Apart from Segorbe, these varieties blanch moderately well, that is, removal of the pellicle after blanching is in the order of 75–90%. TBC and Tonda Romana blanched slightly better than the other varieties.

Segorbe blanches less well, but has a thin pellicle and may be best suited to the sector of the kernel market seeking unblanched kernels. Tonollo has a very thick pellicle, which makes it unattractive unless blanched. It is likely there may be buyer resistance to kernels that have a thick pellicle.

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 would be thin so a high crack out is achieved, that is the weight of kernels per kilogram of nuts cracked is high. Data obtained from cracking 100 nut samples showed that in general few kernels were downgraded or rejected due to mould, brown stain or black tips. The main defects were shrivelled and poorly filled kernels. Assessing plump or well-filled kernels brings in some subjective assessment, but criteria were developed and agreed on by those carrying out these assessments.

The proportion of inferior quality kernels (i.e. poorly filled and shrivelled) is shown in Figures 8 and 9 for Moss Vale and Myrtleford, respectively, for some of the key varieties. At Moss Vale, the proportion of inferior quality kernels seemed to be higher for the varieties Barcelona, Ennis and Tonda di Giffoni in the 2003 harvest year. At that site, Tonda Romana generally produced the best filled kernels, with an average of about 5% being poorly filled. In contrast, Ennis produced many poorly filled kernels in 2003, although kernel fill was good in the other two years. It is considered that the shortage of water during kernel fill may have reduced photosynthesis at this critical time. A decrease in photosynthesis, nut and kernel size was reported by Tombesi and Rosati (1997) in studies they undertook on the effects of water availability during nut growth and kernel fill in Italy.

Figure 8. The proportion of inferior quality kernels (i.e. poorly filled and shrivelled) obtained from cracked nuts for seven key varieties harvested at Moss Vale in the years 2001–2003.

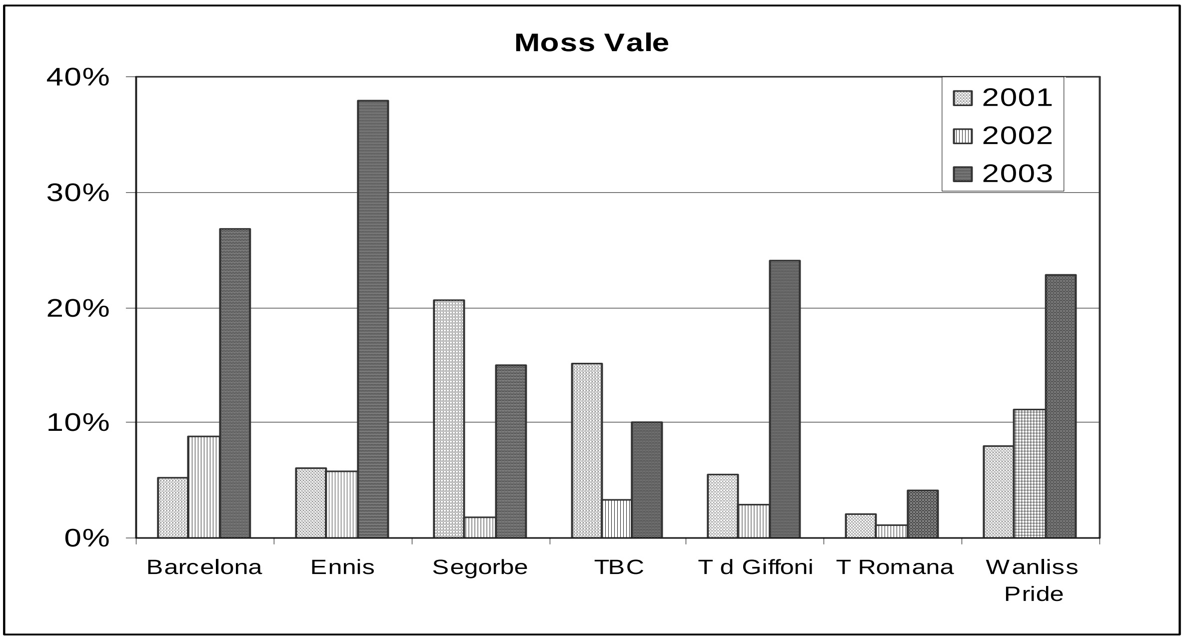
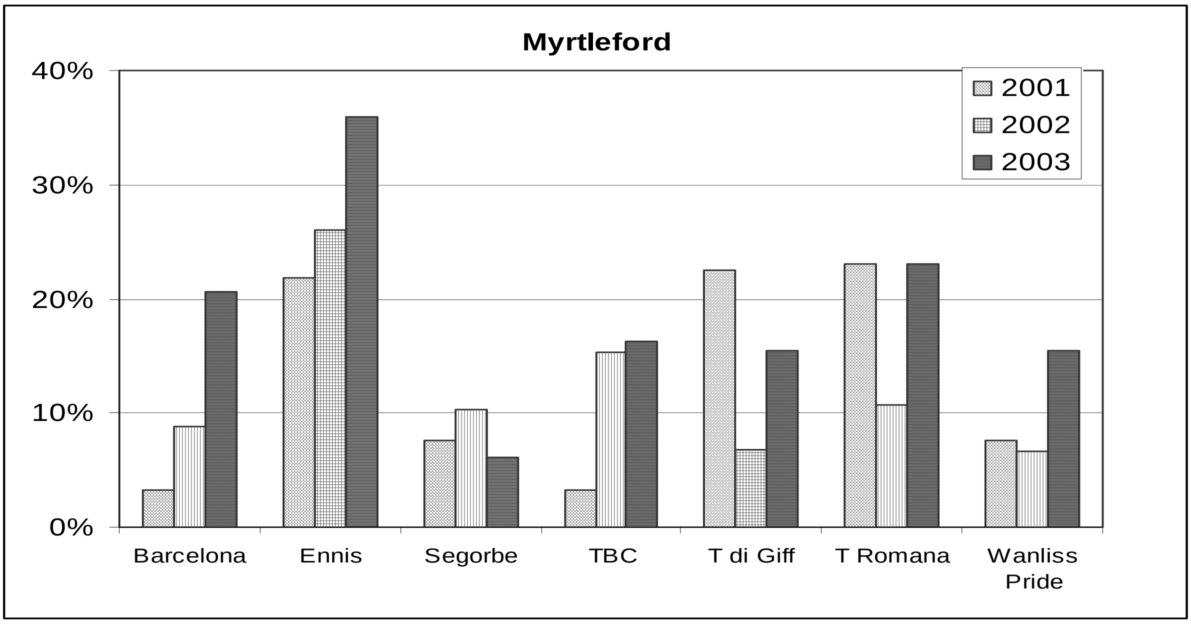


Figure 9. The proportion of inferior quality kernels (i.e. poorly filled and shrivelled) obtained from cracked nuts for seven key varieties harvested at Myrtleford in the years 2001–2003.



At Myrtleford, the seasonal pattern was less clear, and the varietal pattern was a little different from Moss Vale. At this site, results for Tonda Romana and Ennis were generally poorer than at Moss Vale. At this stage it would be unwise to read too much into these figures which were not statistically analysed. However, they do suggest that under certain conditions a relatively high proportion of kernels may not be well filled and some varieties may be more prone to this problem. It is an important aspect of kernel quality that needs to be studied more thoroughly in future years.

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, Tonda Romana and Segorbe all had oil contents of at least 60% and sugar contents of 4–6%. Wanliss Pride was found to have the highest sugar content at 6.9%, with TBC the next highest at 5.6%.

4. Discussion

4.1 Genetic compatibility

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, 1997a).

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 19. For example, in Barcelona ($S_{\underline{1}}S_2$), only the dominant allele $S_{\underline{1}}$ is expressed, whereas in Hall's Giant ($S_{\underline{5}}S_{\underline{15}}$) the S-alleles are co-dominant, therefore both are expressed.

Table 19. Example of some cultivars that are compatible with Barcelona and can be used as pollinisers, compared with an incompatible variety, Montebello.

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

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

S-alleles for some introduced cultivars included in the field studies are shown in Table 20. Unfortunately, the S-alleles for the Australian selections Tokolyi/Brownfield Cosford (TBC), Tonollo and Wanliss Pride are unknown. However, Mehlenbacher has taken scion wood of Tonollo and TBC to Oregon, where young trees are now producing some pollen. Wanliss Pride is already in the United States Department of Agriculture (USDA) germplasm collection at Corvallis.

From his most recent studies on the S-alleles of these three Australian selections, Mehlenbacher (personal communications, 21/6/03) reports:

> **Tokoyi Cosford (TBC)**
> Pollen is compatible on all known S-alleles, but results on S_5 need to be retested. Excellent pollen shed.
>
> **Tonollo**
> Pollen expresses S_1 as it is incompatible on S_1 females. Pollen is compatible on females expressing all other alleles (S_{21} and S_{23} not yet tested).
>
> **Wanliss Pride**
> Pollen expresses S_{10}. Because it is so similar (and perhaps identical) to Imperiale de Trebizonde, I expected to find S_2 also present. But only S_{10} pollen gives an incompatible response on Wanliss Pride females. I used Wanliss Pride as a parent – and testing of the progeny will reveal if Wanliss Pride is homozygous ($S_{10}\,S_{10}$) or has a new S-allele. The seedlings are very young, so results are a few years away.

The S-alleles that are known for cultivars included in the field sites, including the buffer rows, are shown in Table 20.

Table 20. The incompatibility S-alleles and the chill hour requirements of some hazelnut cultivars introduced into Australia.

Cultivars	**S-alleles** (1) (2)	**Chill Hours Required** (3)		
		Catkins	**Female flowers**	**Leaf buds**
Barcelona	1 2	240 - 290	600 - 680	990 - 1040
Butler	2 3	100 - 170	860 - 990	1040 - 1170
Casina	10 21	240 - 290	1170 - 1255	1395 - 1550
Daviana	3 11			
Kentish Cob	8 14			
Ennis	1 11	290 - 365	1170 - 1255	1040 - 1170
Hall's Giant/ Merveille de Bollwiller (syn)	5 15	290 - 365	600 - 680	990 - 1040
Jemtegaard #5 (J#5)	2 3			
Lewis	3 8			
Montebello	1 2	170 -240	680 - 760	990 - 1040
Negret	10 22	240 -290	480 - 600	760 - 860
Royal	1 3			
Segorbe	9 23	240 - 290	600 - 680	1170 - 1255
TGDL	2 7			
Tonda di Giffoni	2 23	170 - 240	600 - 680	600 - 680
Tonda Romana	10 20	100 - 170	760 - 780	1040 - 1170
Wanliss Pride (3)	10 ?			
Willamette	1 3	290 - 365	680 - 760	860 - 990

Source (1) Thompson, 1979 (2) Mehlenbacher, 1991. (3) Mehlenbacher, 1997.

4.2 Potential varieties

The first key objective of this research was to determine the most suitable hazelnut varieties that could be used for the establishment of a hazelnut industry in south-eastern Australia.

As the kernel market is the largest in Australia, the suitability of varieties to meet this market will be a major consideration. A hazelnut breeding program is being undertaken at Oregon State University, to produce cultivars for the kernel market that have resistance to eastern filbert blight, a major disease problem in Oregon, and also resistance to big bud mite (Mehlenbacher, 1995). In addition to the resistance to these diseases and pests, OSU is selecting for the following characteristics:

- Early bearing
- High yield
- Early maturity
- Free falling nuts
- Round nut shape
- High percentage kernel weight
- Kernel blanching ability
- Few kernel defects

These attributes are also desirable in the Australian situation and should be considered when evaluating the material grown in these field studies. An additional attribute might be adaptation to a wide range of soil and climatic conditions.

Although the trees at the trial sites are only in early bearing, some varieties have shown considerable promise over all sites. As the kernel market is the largest, the suitability of varieties to meet this market will be discussed first. These are the varieties that produce small–medium sized kernels as this size is generally preferred by buyers in this market.

It is obviously important to determine if the varieties being studied are true to type. As many of the European cultivars appear to be of the “heritage” type, some variation within them appears likely. The material planted in these field experiments was kindly provided by hazelnut propagators from their collections (Table 4). The material under evaluation is available on the market for investors to purchase. If varieties are not true to name they may not have the published S-allele genetic constitution and therefore incorrect pollinisers may be inadvertently recommended and planted.

The most promising varieties for kernel use are Barcelona, TBC, Tonda di Giffoni, Tonda Romana and Segorbe. Tonollo has given good results at Myrtleford but this was the only site where it has been evaluated. The Oregon cultivars, Lewis and Willamette, have also shown promise, but as these were planted at a later stage than most other varieties, it is not possible to comment on these, as yet. Nuts of Lewis appear to fall free from their husks, whereas nuts of Willamette tend to fall with the husks adhering.

Barcelona

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

Barcelona is a versatile variety that appears to adapt to a wide range of conditions. It has generally produced well-filled kernels, of good flavour, which blanch quite well. It is a variety with medium chill requirements and therefore blooms in mid-season. Suggested pollinisers for this variety are shown in Table 21.

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 characteristic nutty flavour. Nuts have a characteristic indent or groove. One processor reported that the indented nuts sometimes split on the line of the indent which results in the kernels being retained in the two halves of the shell. Potential pollinisers are shown in Table 21.

Table 21. Potential pollinisers for key varieties in the field studies.

	Potential pollinisers		
Variety	**Early**	**Mid-season**	**Late**
Barcelona $S_{\underline{1}\ 2}$	Segorbe Butler	Tonda Romana Casina Willamette Lewis Daviana	Hall's Giant Kentish Cob
Segorbe $S_{\underline{9}\ 23}$	Tonda Romana Casina Willamette Lewis Daviana	Hall's Giant	Jemtegaard #5 Kentish Cob
Tonda di Giffoni $S_{\underline{2}\ 23}$	Barcelona Segorbe	Casina Willamette Lewis	Hall's Giant
Ennis $S_{\underline{1}\ 11}$	Butler Casina Willamette Daviana Lewis	Hall's Giant	Jemtegaard #5 Kentish Cob

Segorbe

One of the better yielding cultivars, Segorbe has grown well at all sites and has a small nut and kernel. It has produced a high percentage of good nuts with well-filled kernels. It does not blanch well, but has a thin pellicle.

Tonda Romana

There is some debate as to whether the variety Tonda Romana, which is included in these studies, may be misnamed, as varietal characteristics seem to differ from those observed in Oregon. The period of pollen shed is earlier than trees of this cultivar grown in Oregon and the kernels blanch better than the Tonda Romana grown there. The nuts grown in the trials have been examined by Mehlenbacher, who considered they were more like those of Montebello (Mehlenbacher, personal communication, July 2003). The cultivar in our field experiments is also slightly different from that growing in the small collection of Italian cultivars imported by Ferrero Australia, that is located at the Orange site. The Ferrero Tonda Romana is slightly later in pollen shed. This cultivar is a traditional or "heritage" cultivar from Central Italy where it has been grown for many centuries. It appears that, in that region, there is variation within the cultivar. Studies have been made on this variation and selection for a superior cultivar from this diversity of types is being pursued (Monastra, Raparelli and Fanigliulo, 1997).

At this stage, therefore, it is recommended that those who are interested in planting this particular cultivar recognise these risks. Further studies need to be conducted to verify the ambiguity in the nomenclature of this promising variety and to validate potential pollinisers.

TBC (Tokolyi / Brownfield Cosford)

It is considered that this is an Australian seedling, which was initially selected by Imre Tokolyi and was planted extensively at Acheron, in Victoria. Subsequent selection was made in that orchard. The S-allele complement is unknown, except for the observations by Mehlanbacher that the pollen is effective on all known S-alleles, although the S_5 allele needs retesting. As the variety appears to produce good quantities of pollen mid-season it is a potential polliniser for many varieties. TBC produced good nut yields at all sites with kernels generally being well-filled and with good blanching attributes. Its main drawback is that it tends to fall in husk which may require dehusking in the field. However, it is not uncommon for commercial vacuum harvesters to have in-built dehuskers. The nut is round despite the term ‘Cosford’ in its name, which suggests a long nut.

Grower observations suggest that TBC is pollinated by the Australian seedling selections, Turkish Cosford, North-east Barcelona and Woodnut. Studies were initiated in July 2003 at the University of Sydney, Orange to try to ascertain pollinisers for this variety using a fluorescent microscope technique, as described by Mehlanbacher (1997b). Preliminary results are shown in Table 20. The polliniser varieties tested were those that generally shed pollen at a similar time to female bloom in the variety TBC.

The results shown in Table 22 must be treated with caution, as this was the first time the researchers had tried this technique. The technique involved dipping individual female flowers of TBC into collected pollen from each of the potential polliniser varieties and leaving these flowers for 16–20 hours before examining the development of pollen tubes. Pollen is considered to be compatible when long, parallel pollen tubes can be seen under a fluorescent microscope after staining with aniline blue. If pollen is incompatible, the pollen tubes are short and stumpy. Long pollen tubes were clearly seen with some of the pollinations, but there were others where the result was unclear. The variation in results for the varieties with the $S_{\underline{3}}$ dominant allele is of concern as it would be expected that these would all give the same reaction. Several factors could give negative results, non-viable pollen being an example. The positive results for the Australian selections Turkish Cosford and Woodnut, that growers consider are effective pollinisers, are encouraging. It is planned to repeat these tests in future years.

Table 22. Results of preliminary pollen compatibility tests for the variety TBC using trees from the field sites, including the buffer rows.

Pollen donor[1]	**S-alleles**	**Test results**	
		First test	**Second test**
Butler	2 $\underline{3}$	Negative	Negative
Casina	$\underline{10}$ $\underline{21}$	Positive	Negative
Daviana	$\underline{3}$ 11	Positive	Positive
Ennis	$\underline{1}$ 11	Not tested	Negative
Kentish Cob	$\underline{10}$ $\underline{14}$	Positive	Positive
Jemtegaard #5	2 $\underline{3}$	Negative	Negative
Merveille de Bollwiller	$\underline{5}$ $\underline{15}$	Negative	Positive
Turkish Cosford	Unknown	Positive	Positive
Woodnut	Unknown	Positive	Positive
Willamette	1 $\underline{3}$	Negative	Negative

1. The pollen donor varieties were grown at Orange and include trees grown for the yield evaluation as well as pollinisers in the buffer rows.

Ennis

This variety produces a large nut which is well suited to the in-shell market. At Orange, it is the highest yielding cultivar (Table 12). At Myrtleford, Ennis appears to be a little slower coming into production than some other varieties (Table 13), but has shown considerable promise. It is late in female bloom, which is a concern when there may be limited pollen in the orchard late in the season. The planting of the pollinisers Hall’s Giant /Merveille de Bollwiller and Jemtegaard #5, which are both late in pollen shed and are genetically compatible with Ennis, is recommended. Very high yields of Ennis are produced in Oregon and it will be interesting to monitor yield development at the Australian sites.

Comments on other varieties

Atlas was generally a vigorous growing variety at all sites and showed yield potential. The kernels have a very coarse pellicle which is likely to be a disadvantage.

Butler has grown very well and shown considerable yield potential at Myrtleford. Its kernels do not blanch.

Casina nuts are very small and tended to fall in the husk. It 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.

Daviana has been an important polliniser for Barcelona in Oregon, but has been superseded by Butler.

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

Hall's Giant and **Merveille de Bollwiller** are valuable late pollinisers and are compatible with many cultivars. They have grown well at all sites and produce many catkins. Their nut yields are low. It is considered that these are probably the same cultivar, as the trees had very similar characteristics.

Hammond 17 appears to be a variant of Butler. It appears to be of limited value.

Montebello is an early variety. It was planted later than most other varieties at Myrtleford. More data is required on this cultivar.

Negret produces a small nut. It grew very poorly at Orange and appears to have limited value under Australian conditions.

Royal is a low yielding variety; the kernels do not appear to fill well. It does not appear to have any useful attributes under Australian conditions.

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.

TGDL made poor growth at Orange. There is some doubt as to whether it is true to type, but at Orange it showed very similar characteristics to the TGDL in the Ferrero Australia collection.

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

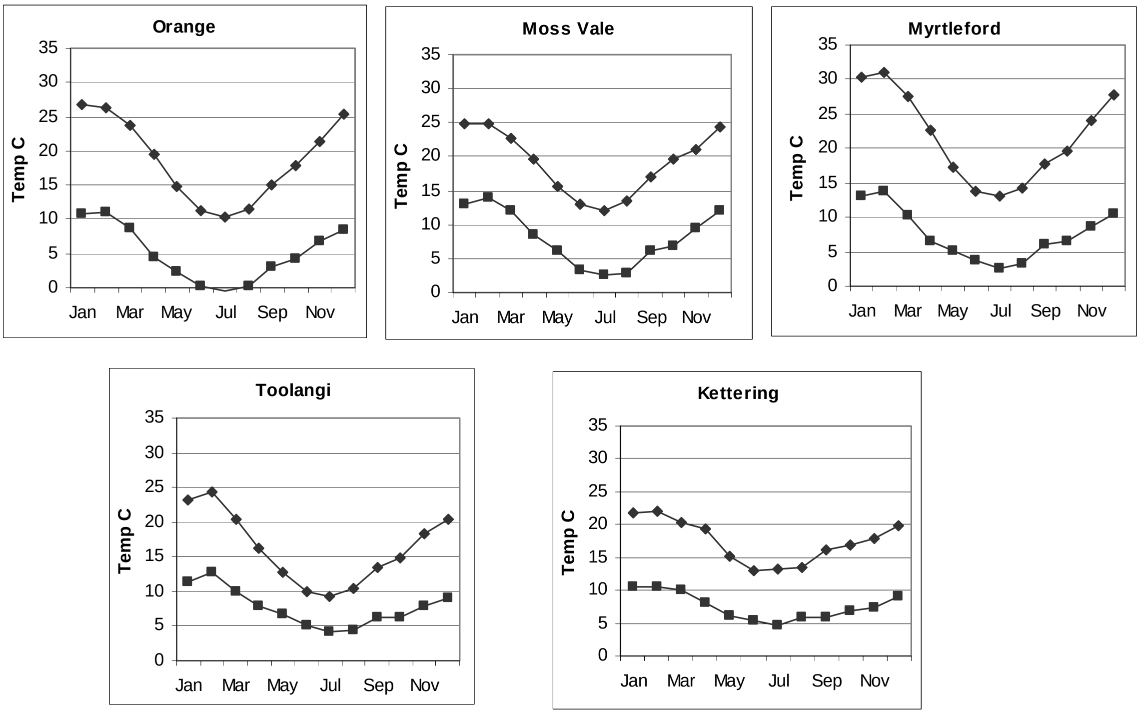
Wanliss Pride has been widely planted in the past. It was the main variety grown in the Ovens Valley in the 1920's. There are examples of some very productive trees of this variety in parts of Victoria. It produces a very attractive nut and a nice flavoured kernel. Some growers of this variety have reported that it does not keep well. In these studies, the growth and yield of Wanliss Pride was very variable and was lower than many varieties.

Whiteheart was one of the latest additions to the trials and is only included in yield testing at Kettering. Trees in the buffer rows at Orange have made very poor growth. It appears to be very late in female bloom. More data is required on this variety that is reputed to yield well and produce high quality kernels in New Zealand.

4.3 Climate and soil effects

The second key objective has been to assess the effects of geographical region and climate on hazelnut production and varietal performance. At the outset of these studies, it was considered that climate might play a key role in production. In the Northern Hemisphere, centres of hazelnut production are limited to quite specific locations that have a Mediterranean or maritime climate. The study sites were chosen to represent a range of agro-climatic conditions. Contrasting temperature patterns were recorded (Figure 10), from continental patterns of Orange and Myrtleford to the maritime climate of Kettering. The highest average summer temperatures were recorded at Myrtleford with the mildest temperatures at Kettering.

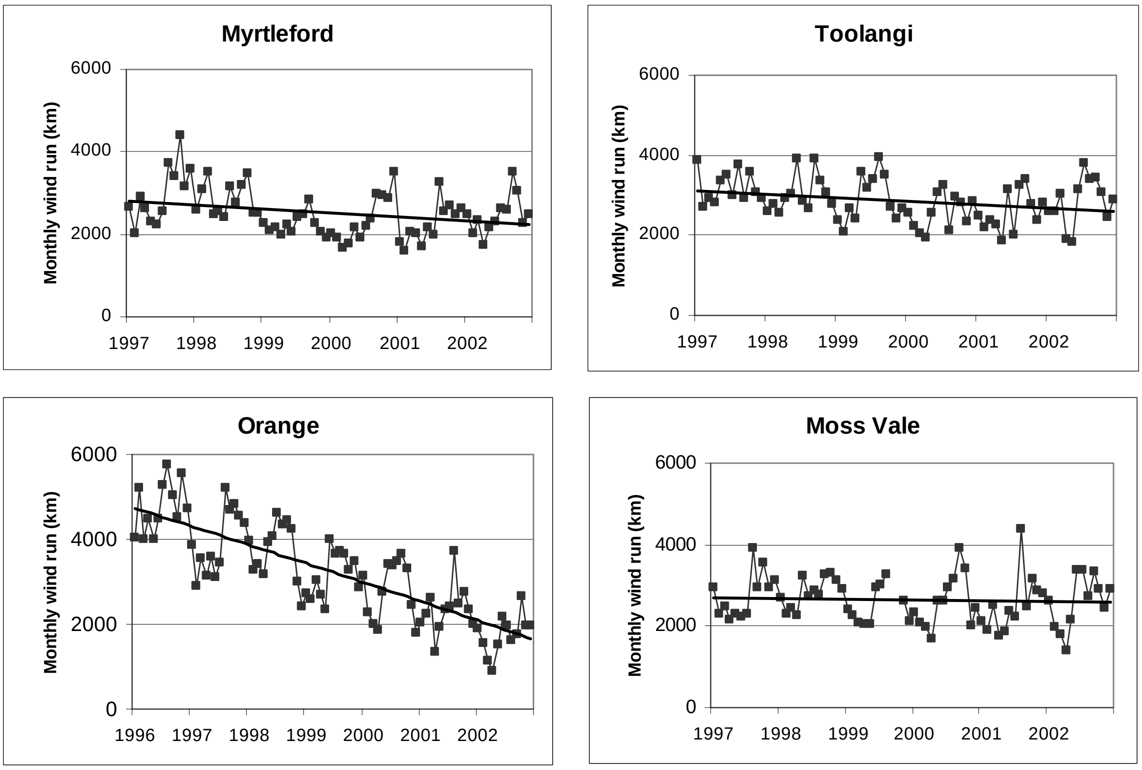
Figure 10. Average maximum and minimum temperatures at the five field sites.



So far, the studies suggest that, so long as the climate provides sufficient winter chill, is not too hot in summer and irrigation is available to supplement rainfall deficits in the growing season, climate is not as important as originally considered. However, hazelnut trees do appear to be 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 than those further down the slope, where there appeared to be greater wind protection.

One of the reasons for poor growth at Orange may be partly attributed to wind, as that site was initially very open to wind. It appears that the casuarinas planted at Orange to reduce wind speed have been effective (Figure 11). It is likely that, as the hazelnut trees grow, they become mutually protective. 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 appear to cause leaf scorch in summer. At this stage of the research, areas with hot summer conditions are not recommended for hazelnut production. Late spring frosts do not appear to have any detrimental effects on the trees in the Australian context.

Figure 11. Pattern of total monthly wind run (km) for the four mainland sites.



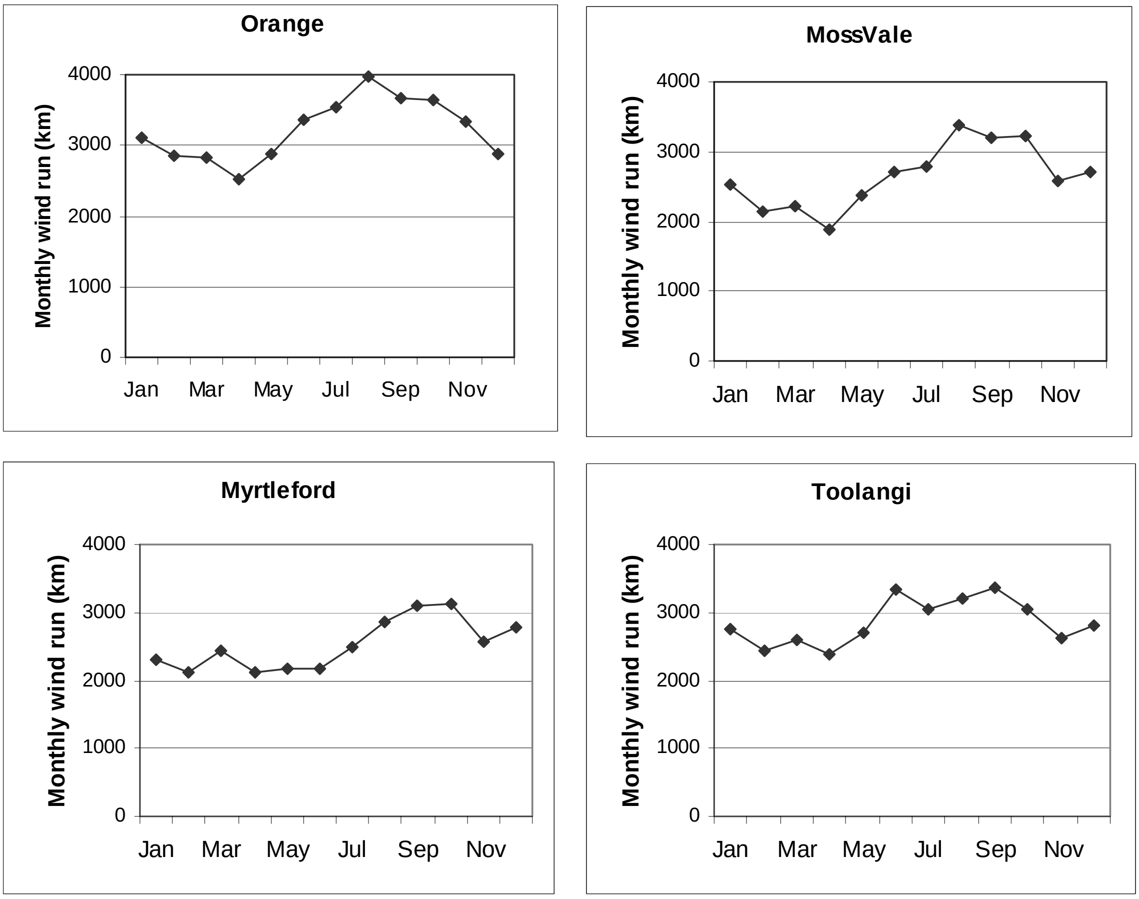
At most sites, the windiest period of the year was in the spring (Figure 12), when new leaves and soft shoots are developing. These tender new tissues are particularly vulnerable to wind damage. On exposed sites, planting shelter trees in advance of orchard establishment is highly recommended.

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 have been recorded. At Glen Innes, on the Northern Tablelands of NSW, a minimum of -11°C has been recorded by the Commonwealth Bureau of Meteorology (2002). At the end of June 2001, damage to female flowers of Negret was observed at Orange, following an overnight temperature of -5.6°C and heavy frost. However, the varieties Atlas and Tonda di Giffoni, that were also in bloom at this time, appeared unaffected.

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

Soil type appears to be a key issue in hazelnut production in Australia. Deep alluvial loams appear to be the ideal. It is noteworthy that in Oregon, hazelnut orchards are generally situated on soils of alluvial origin and care appears to be taken in site selection to ensure good tree growth and nut yields.

Figure 12. The average pattern of monthly wind run for the four mainland sites.



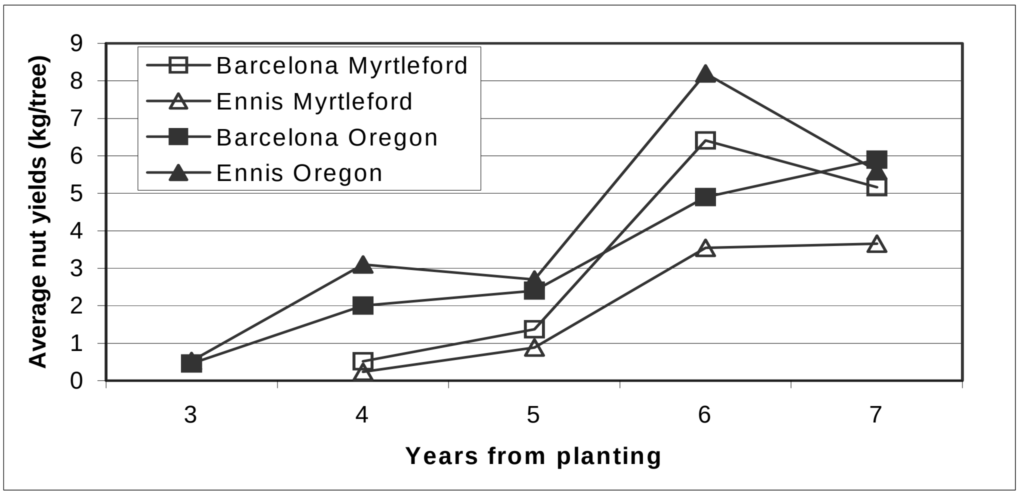
These field studies and overseas literature both suggest that poorly drained podsolic soils should be avoided. It is recommended that growers undertake a profile analysis of potential orchard sites before planting. Although basaltic krasnozem soils are generally well drained, the high levels of manganese that commonly occur in these soils may be a problem. Further studies will need to be undertaken to verify this hypothesis.

4.4 Potential hazelnut production

The third and final objective was to assess the productive potential of hazelnuts (*Corylus avellana* L.) in Australia.

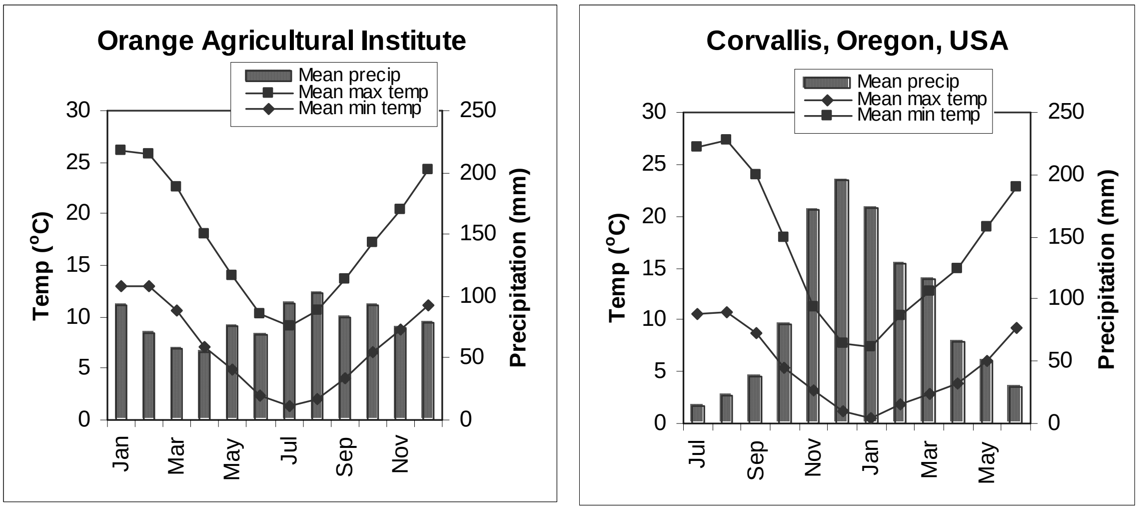
The site at Myrtleford indicates the potential of the crop. A comparison of nut yields from Myrtleford for the cultivars Barcelona and Ennis was made with data from a cultivar evaluation experiment conducted by the Oregon State University research team (McCluskey et al., 2001) (Figure 13). Considering the OSU team used one-year-old trees compared with the rooted suckers that were planted in these experiments, the yield from the Barcelona trees grown at Myrtleford compares very favourably with those in Oregon. Although the Ennis yields from Myrtleford were good, they were not as good as those obtained at the OSU site. This data generally suggests great promise for hazelnuts grown in favourable situations in Australia. It should be recognised that, in 2003, the trees at all sites are just entering their productive phase. There is the potential to gather some extremely valuable yield data from the experimental sites in the next three years.

Figure 13. Comparisons of the development in nut yield for the cultivars Barcelona and Ennis 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 14). This suggests that the climate at Orange should be just as suitable for hazelnut growing as Oregon and also supports the notion that probably soil acidity and manganese toxicity effects at Orange are the main factors limiting yields at Orange. If this is the case, it should be possible to resolve the problem by liming well in advance of planting and using varieties that are suited to krasnozem soils. If these strategies are successful, there is considerable potential for hazelnut production on the Central Tablelands of NSW.

Figure 14. A comparison of mean monthly temperature and rainfall patterns between Corvallis in the USA and Orange, Australia.



Although there is limited data from the Tasmanian site, to date the trees have grown very well, indicating the potential for hazelnut production in that state. As there have been previous attempts at establishing orchards in Tasmania, it appears likely that big bud mite infestations could have been a problem with these plantings. If big bud mite can be controlled or managed, the indications are that there could be great scope for growing hazelnuts in parts of Tasmania, such as in the old orcharding 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).

5. Implications

This report marks the end of the second phase of a major study on the potential for hazelnut production in Australia. The first phase involved the establishment of the field study sites. This second phase examined young trees coming into production. The third and final phase will examine the overall yield potential of the crop, the acceptability of varieties to Australian processors and the economics of production.

The implications of the work to date show:

Production and product quality aspects

1. Hazelnuts have potential as a crop in the cooler climate areas of Australia
2. Some varieties appear to adapt well to a range of agro-climatic and soil conditions in south-eastern Australia
3. Care needs to be taken in site selection and development, as hazelnut trees require deep well-drained soils of low acidity and also require shelter from damaging winds
4. Manganese toxicity appears to be a concern, but soil testing and liming well in advance of planting should overcome this problem
5. Supplementary irrigation is likely to be needed in all situations, to ensure adequate growth in spring and to avoid moisture stress in summer, during the period of nut development and kernel fill
6. Kernel quality appears to be affected by climate and management practices. Further information is needed on this
7. In a separate study, Australian buyers and processors of hazelnut kernels considered the samples of kernels provided from these studies were acceptable and indicated a desire to purchase Australian grown kernels. However, further collaborative work needs to be undertaken to assess the market acceptance of Australian-grown hazelnuts and any particular varietal preferences.
8. There is limited data on the effects of high summer temperatures on hazelnut production; there could be risks of damage from excessive summer heat in such areas. More information is required on the performance of the crop under such conditions.
9. There appears to be enormous scope for hazelnut production in cooler parts of Australia, such as on the alluvial soils of the river valleys in north-eastern Victoria, in parts of Tasmania and on the Central Tablelands of NSW. Plantings in these areas could lead to a substantial industry that could meet all of Australia’s current hazelnut requirements.

Pest management issues

1. The serious pest, big bud mite, is present in Tasmania. Some strategies need to be set in place to prevent its spread to the mainland, where it does not appear to exist at present.
2. There do not appear to be any serious insect pests or diseases of hazelnuts in Australia, apart from big bud mite in Tasmania, giving potential to grow the crop organically and to capitalise on this market opportunity.
3. Sulphur crested cockatoos can be a major pest at the later stages of nut development and during nut fall. Growers need to be prepared for the management of this pest, which appears to be relatively easily scared and is mainly a problem in small orchards when landholders are absent.

6. Recommendations

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

Product quality, market acceptance and economic viability

- To gain further yield data over the next three years and to use this data to develop an economic model on the profitability of hazelnut production
- To further assess aspects relating to nut and kernel quality for the higher yielding cultivars, including assessment of any environmental or management factors that may influence kernel quality
- To liaise with potential buyers of hazelnut kernels to gain their views on the acceptability of kernels from the higher yielding cultivars

Action:
It is planned to act on these matters in collaboration with industry partners in the final phase of the project.

Productivity

- To determine which varieties will pollinate TBC
- To evaluate the factors limiting growth and production of hazelnuts on krasnozem soils, with an emphasis on studying the effects of manganese on tree growth and production and how any adverse effects can be managed

Action:
It is planned to act on these matters using resources within the University of Sydney, Orange.

Industry development and extension

- To conduct field days in collaboration with the Hazelnut Growers of Australia Ltd (HGA), agricultural advisors, consultants and buyers of hazelnuts, to disseminate the outcomes of the research and share experiences of growers.
- To develop a final report on the outcome of these studies, including aspects of production, kernel quality, market acceptability and economic feasibility for potential investors in hazelnut growing

Action:
It is planned to act on these matters in the final phase of the project in collaboration with industry partners.

Pest management

- Develop strategies to manage or prevent the spread of big bud mite in Australia, if this is not already being done.

Action:
There is a need to liaise with government departments to ascertain how this issue might be managed.

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