Department of Environmental Biology

School of Resources and Environment

Assessing growth performance of European olive (*Olea europaea* L.) on Mount Weld Pastoral station

Gary Norman Price

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of

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any other university.

Signature: ………………………………………………………..

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ABSTRACT

This thesis describes the growth of European olive (*Olea europaea* L.) at three different trial sites located near Laverton, in the north-eastern Goldfields region of Western Australia. The local region comprises part of the rangelands area of Australia and has a semi-arid climate.

The initial reason for planting olives was indirectly related to the rapid decrease in the local population and the economic downturn that resulted within that community during the late 1990's. This prompted an investigation into other possibilities for economic diversity for remote communities such as Laverton, which are located in the rangelands area of Australia.

In Australia, much of the southern and eastern areas of the country have similar climate to traditional olive growing areas in Europe. In the rangelands however, the environment is different to most other areas in the world where olive trees are grown and there is a notable absence of a commercial olive industry. Whilst locally, individual trees were also observed to be growing well and fruiting abundantly, it is not known whether it is possible to grow olive trees successfully on a commercial scale.

Two preliminary trials were established in an ad-hoc manner, to examine whether olive trees could be grown successfully in the rangelands environment. Eighty-eight trees of 5 different cultivars were planted on a shallow, clay soil profile at the first trial site. Ninety-eight trees of 11 different cultivar were planted on a deep sand soil profile at the second site. Higher mortality rate occurred at the first site, with most tree deaths being recorded in the first two years. Peak growth of branch tips occurred during the spring-summer seasons at both sites. Differences in trial design and timing of planting prevented statistical comparison of growth performance between sites however.

A third olive trial, consisting of 3 olive groves was established according to randomised design. In the north and middle groves, 54 trees of 3 different cultivar were planted on a deep alluvial soil profile. In the south grove, 53 trees of 3 different cultivar were planted on a shallow clay soil profile. High mortality rates were recorded at all 3 groves during the first year, as a result of high salinity levels in irrigation water during the establishment period. Overall, most tree mortality was recorded at the south grove. Significantly higher growth performance occurred within the deeper alluvial soil profile at the north and middle groves, compared to the shallow clay soil profile in the south grove.

Negligible olive fruit production occurred at the first site. At the second site, small quantities of olive fruit were produced during some seasons only. No olive fruit production occurred at any grove at the randomized site. Successful fruit formation appears directly related to tree health, as a function of water supply. Ripening of olive fruit occurred earlier than at other more temperate olive growing areas of

Australia. Similar major and trace element deficiencies occurred at all sites, interpreted to be a function of universal alkaline ground-water conditions.

This study failed to confirm conclusively, whether European olive could be grown successfully in the semi-arid climate, typical of much of the rangelands area of Australia. As a result of the study however, successful growth in this environment is confirmed to be highly dependent on three factors. Firstly, availability of reliable irrigation waters of sufficient quality. Secondly, choice of suitable soil types. Thirdly, selection of suitable cultivars. Quality of olive oil produced from fruit appears to be influenced by local climatic factors

The study also highlighted the issues of land tenure, current management attitudes and level of support within the local community as having a direct and significant impact on the trial.

TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABBREVIATIONS

mm:	millimetre.
cm:	centimetre.
m:	metre.
km:	kilometre
mg:	milligrams.
g:	grams.
kg:	kilograms
L:	litre.
ppm:	parts per million.
dS mm^{-1}:	deci-semens per centimetre.
dS m^{-1}:	deci-semens per metre.
meq:	milli-equants.
°C:	degrees celcius.
mo:	months.
yr:	years.
EXCH:	exchangeable.
DTPA:	standard analysis method for Australian soils.

DEFINITION OF TERMS

cultivar: variety of plant or tree that has been produced only under cultivation.

phloem: that part of a vascular bundle not included in the xylem, including sieve tubes and companion cells, parenchyma, secretory cells etc. that conducts photosynthesis from leaves.

halophyte: plant adapted to living in soil with a high concentration of salt.

edaphic: due to soil, substrate or topography.

abscission: the act of cutting off, or sudden termination.

FOREWORD

Why grow olives in Laverton?

The original inspiration for growing olive trees occurred during 1999 whilst travelling near Lecce, in south-east Italy. It was spring in the northern Mediterranean. The sun was bright, the sky was clear and blue, and the air was hot and dry. I felt the sting of the early spring sun on my skin. The countryside all around had commenced to fade before my eyes. The ground had begun to become parched by the early summer sun. For a short moment, it was reminiscent of the lands that I was more familiar with. It seemed so similar to the long, hot Australian summer. To the experiences spent in and around the Western Australia outback, spent working in the blistering heat.

I was travelling on the south-bound train, from Bari to Lecce as a tourist. I was still, I guess, searching for some form of inspiration when I happened to glance out of the window and sighted my first olive grove.

I am still unsure about what caught my attention on that day. Was it the colour, shape, or even the form of the trees I saw from that window of the speeding train?

It was more likely, the sense of order that the grove attained, when set amongst the countryside all around. Such a large numbers of well-groomed olive trees, all growing in rows. It was as if, the trees were actually standing to attention on my behalf, which probably caught my eye that day. I recollect how I thought that these trees seemed to have fought and perhaps actually conquered the natural and wild, unkept landscape that existed all around. Perhaps it was the same battle fought constantly by man over the harsh realities of the natural world.

Perhaps these trees could also survive the harsh and arid lands with which I was much more familiar, the hot and dry countryside that is the Australian outback.

It was at this point, I now recognise, that this apparent similarity was to end.

CHAPTER 1: INTRODUCTION

1.1) Background of the study

This thesis examines the growth of European olive (*Olea europaea* L.) at three different trial sites located near Laverton, in the north-eastern Goldfields region of Western Australia. Field studies commenced in an informal manner during 1999 when two groves were quickly established in an "ad-hoc" manner in nearby locations. During 2001 candidacy was granted for the Master of Science (School of Resources and Environment) at Curtin University of Technology. Formal studies commenced by means of external research. A third trial site was established at a nearby location to a more rigorous design.

Consequently, this thesis includes earlier, informal observations completed before formal research commenced, as well as observations and conclusions drawn from the later, formal, research project.

1.2) Location of field study sites

This study was conducted on olive groves established at three different sites (Figure 1.1), located on Mount Weld pastoral station, near the township of Laverton, in the central southern part of Western Australia (Figure 1.2). Laverton is small community in a remote location. It is located 380 km by road in a north-northeast direction from the much larger regional centre of Kalgoorlie, in the Goldfields region of Western Australia. The local region comprises part of the rangelands area of Australia (Figure 1.3) and has a semi-arid climate.

1.3) Statement of study aims

This study has two key aims;

1) To explore the growth of European olive as a possible option for enhancing economic diversity in the rangelands of Western Australia,
2) To conduct a scientific study of growth performance of olive trees in the rangeland environment.

1.4) The initial impetus: possible options for economic diversity in the rangelands

1.4.1) Why plant olive trees in Laverton?

The initial reason for planting olives was indirectly related to the rapid decrease in the local population and the economic downturn that resulted within that community during the late 1990's. One event in particular during this period had a dramatic impact and effect on the author. The event was the sudden closure of one large gold mine during 1998, where the author was originally employed. The cessation of gold mining operations at the Barnicoat minesite, near Laverton resulted in the immediate departure of about 70 former employees. This represented about 20% of the population suddenly leaving the Laverton community for good, all in a period of less than one week!

There was a sudden realisation by the author of how much the local community depended on mining. The impact on Laverton township was immediate, especially for those local businesses that relied most heavily on the community to survive. Surely, there must be other options apart from mining?

This prompted an investigation into other possibilities for economic activity for remote communities such as Laverton, which are located in the rangelands area of Australia.

1.5) What alternative industries could provide a solution?

The decision to trial olive trees as a possible option for economic diversification in the north-eastern Goldfields region was originally based on earlier observations by the author. During overseas travels in May 1999, groves of olive trees were observed to be growing well in the south-east of Italy, in a hot and dry climate that appeared to be not dissimilar to that of the Laverton area. This led to further investigation into growing olive trees locally, on a trial basis, which included consultation with olive tree growers and suppliers and a brief review of available literature. The concept that olive trees may represent a possible alternative industry that may result in broader economic diversity for the Laverton community was also discussed at the local level.

1.6) Scientific study of growth performance of olive trees

1.6.1) Could olive trees grow in the semi-arid environment of the Laverton area?

The history of olive trees growing in the Mediterranean has been well documented by numerous authors. Much of the southern and eastern areas of Australia have similar climates to traditional olive growing areas in Europe (Nix, 2004). Olives are a crop well suited to extensive areas of South Australia which have a Mediterranean climate (Hobman, 1995). Much of the south-western part of Western Australia also enjoys Mediterranean-like climates, which appear suitable for olive cultivation (Kailis, 1997). European olive grows vigorously in the southwest of Western Australia, in the coastal strip between latitudes 28ºS and 36ºS (Kailis, 1997). There is a notable absence of commercial olives however, in the central interior of Western Australia where climatic conditions are dry and arid (Kailis, 2002).

A single olive tree was observed to be growing at the site of the original homestead site on Mount Weld pastoral station (29ºS 122º30’E) close to the study area. Small plantings of olive trees were also observed to be growing well and fruiting abundantly within the region, at Kalgoorlie and Menzies (Price *et al.*, 2002). This suggests commercial olive trees can survive in the semi-arid climate that is typical of the north-eastern Goldfields region. There is little available information however, confirming whether it could be possible to grow olive trees successfully, on a commercial scale in the Laverton area.

I established trial groves on Mount Weld pastoral station to allow for the study of the growth of European olive in this area. The final aim of this research is to provide detailed scientific information about the growth performance of *O. europaea* in the semi-arid environment. This could then provide the basis, by which the suitability of olive trees could be assessed as a suitable tree-crop to be planted on a commercial basis in this, as well as other similar areas within the rangelands.

1.7) Important issues that affected the study

The following quotes from conversations with relevant individuals highlight the broader theme behind the project and draw attention to key issues affecting the study;

1) "Successful growth would depend heavily on the availability of good water", pers. comm. Mr Greg Brennan, Agriculture Department of Western Australia, 2001.
2) "Olive trees in this area (Alice Springs) do not produce fruit regularly, which is probably the result of the warmer temperatures and the lack of chill during winter", pers. comm. Mr Andrew Nesbitt, Department of Primary Industry and Fisheries, Northern Territory, 2002.
3) "The key issue is successful growth of trees, as opposed to growth of trees", pers. comm. Professor Henry Nix, Australian National University, 2005.
4) "They (…olives) are not right for here", pers. comm. Mr David McQuie, Bulga Downs pastoral station, 2005.
5) "An olive tree is only worth the value of the product it produces", pers. comm. Mr Peter Jacobs, Head of Agribusiness, ANZ Bank, 2005.

The first quote highlights the issue of availability of good quality ground waters and successful growth. The second highlights the issue of winter chilling and successful fruit formation. The third highlights the link between successful olive tree growth and climate. The fourth highlights the issue of public perception towards land use in the pastoral zone. The final quote highlights the over-riding issue of agro-economics surrounding the commercial growth of European olive in remote and other locations.

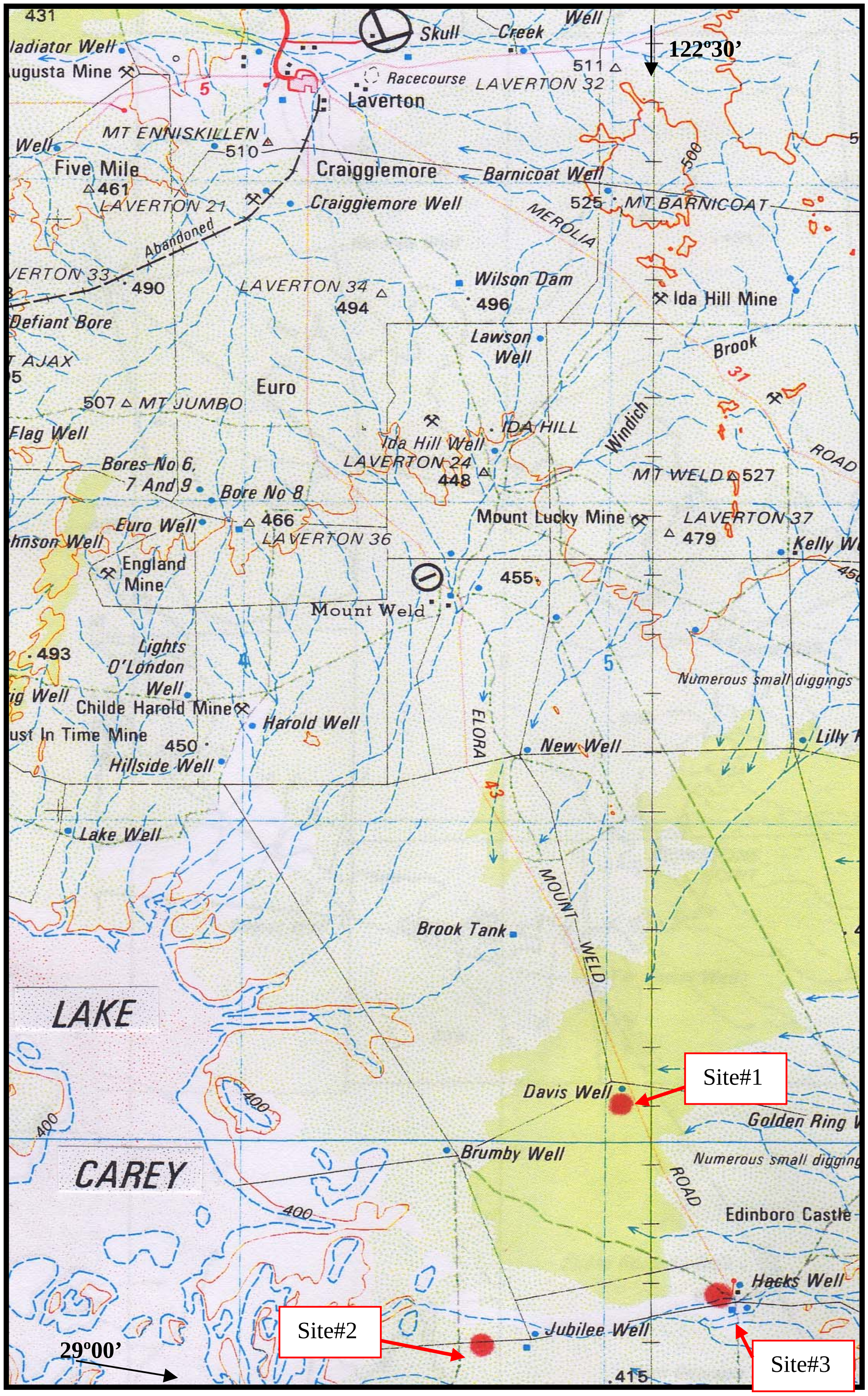


FIGURE 1.1: Topographic map of study area, showing grove locations and Laverton township (adopted from Sheet SH 51-2 Laverton 1:250 000, Ministry of Resources and Energy, 1987).

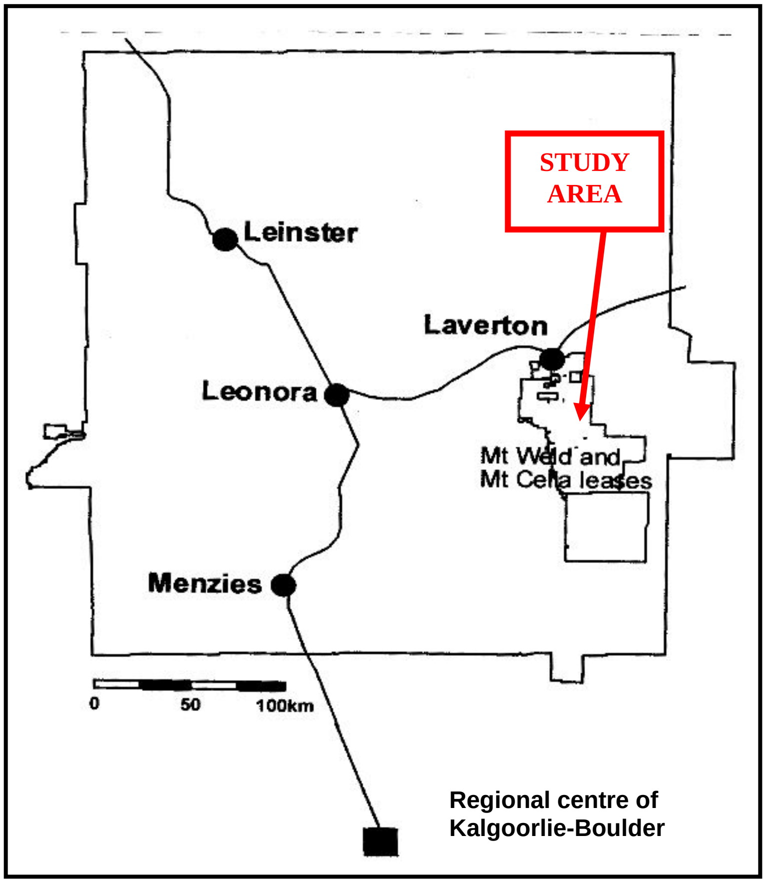


FIGURE 1.2: Map showing location of study area, on Mount Weld pastoral station, within the north-eastern Goldfields region of Western Australia (map adopted from James *et al.*, 2001).

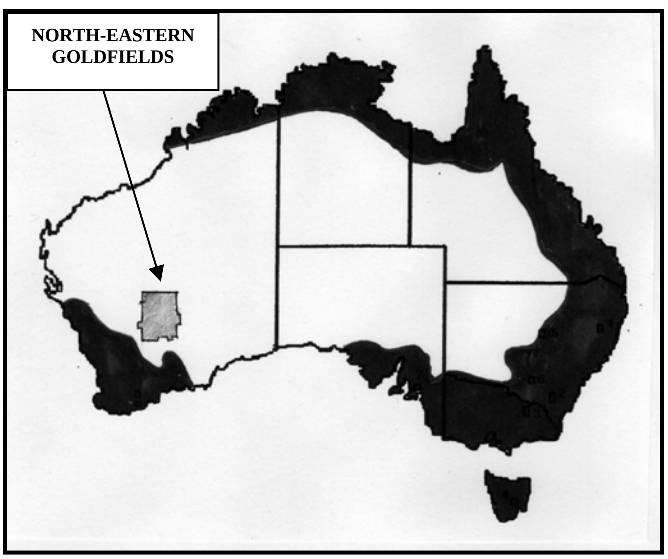


FIGURE 1.3: Rangelands area of Australia, represented by the unshaded portion of the map (map adopted from Wilson and Graetz, 1979).

CHAPTER 2: LOCAL ENVIRONMENT

2.1) Introduction

The local environment of the north-eastern Goldfields region differs from most other areas in the world where olive trees are grown. Hence, an understanding of the local environment is important to this study. A brief insight into characteristics of the study area is provided in this chapter. Impacts of the environment on the growth of olive trees are detailed in later chapters.

2.2) Description of the local landscape

The landscape of the north-eastern Goldfields consists of wide, shallow to flat-lying open plains, referred to historically as peneplains (Jutson, 1914). The open plains are divided by shallow ridgelines that trend roughly parallel, in a north-south direction. Ground elevation in the study area is approximately 400 to 450m above sea level. The landscape is ancient, the result of sustained weathering and erosion of a complex suite of rocks with a genesis dating as far back as the Archaean period (2,500 to 3,800 million years ago).

A thick cover of regolith, consisting of deep profiles of sand and clay type soils covers most areas of the plains. Soils are mostly ancient, nutrient poor and generally alkaline as a result of the mineral composition of the parent rocks (James *et al.,* 2001). Lateritic profiles have developed in the soil in many areas. Shallow, stony (skeletal-type) soils occur around exposed rocks associated with the higher elevated ridgeline areas (Hall and Milewski, 1994, in James *et al*., 2001). As a result of sustained erosion over a long period, large drainage systems (palaeo-channels) have developed in the lower-lying areas. These consist of irregular, anastomising networks of creeks and channels, which are usually dry except after occasional heavy rains. Creeks and channels are filled with interbedded layers of transported gravel and sands that have been eroded and are of a younger geological age than the surrounding regolith.

Most creeks are densely vegetated by either mulga or eucalypt species, as a result of residual moisture being trapped within the channels after rainfall. Soils are saline in the run-on areas where water accumulates and evaporates (James *et al.,* 2001), which is partially related to downstream increase in groundwater salinity to evapo-transpiration by the vegetation (Allen, 1994). Locally in the study area, the drainage systems generally run towards the west. Creeks commonly drain into Lake Carey, the large salt lake that runs along the western side of Mount Weld pastoral station at an elevation of about 10 m lower than the study area.

2.3) Geology, geomorphology and regolith

Geology of the eastern Goldfields area (Yilgarn Block) of Western Australia has been researched by many authors including Morgan (1965, 1993), Allen (1986), Ollier *et al*. (1988) and Fagan (1995).

Regional geology is documented as comprising mafic and ultramafic rock types of Archaean age from the greenstone suite, surrounded by granites that have a younger geological age. "Greenstone", is a broad term, indicating that the lithology of the metamorphic rocks is not readily apparent (Morgan, 1965). At outcrop, it is common for rocks of the greenstone suite to have a pervasive, dull green discolouration as a result of the presence of the alteration mineral chlorite. Chlorite (Mg-Fe-Al silicate), is an alteration mineral that commonly forms during metamorphism of the original rock-forming minerals in mafic and ultramafic rocks, which comprise a large part of the Archaean-aged suite of rocks in the eastern Goldfields.

Greenstone suite rocks are steeply inclined and heavily folded, commonly metamorphosed and deeply weathered. They comprise part of a complex series of north-northwest to south-southeast trending greenstone belts that occur in a roughly linear succession from east to west across the greater Yilgarn Block, in the southern central part of Western Australia.

The present day physical landscape is the result of weathering and erosion of the underlying geological formations over millions of years (James *et al.*, 2001). Current landforms largely reflect the underlying geology. Greenstone suite rocks generally occur in the lower-lying areas, namely the open plains. These areas are commonly surrounded by granite rock types, which generally outcrop in the higher elevated areas such as the shallow ranges, low hills and breakaway/strike ridges (Ollier *et al.*, 1988).

According to the underlying geology, sand soil types are interpreted by the author as being derived in areas where granitic rocks underlie. Clay soil types (red earth) are derived in areas where greenstone suite rocks underlie. Alluvial gravel-type soils are derived from erosional sources and are restricted to scree slopes and drainage channels. Trials of *O. europaea* have been conducted to test each of these contrasting soil profiles as part of this study.

2.4) Hydrogeology

Successful growth of *O. europaea* in the arid environment may be highly dependent on availability of suitable and reliable supplies of ground water (pers. comm., Brennan, 2001). Availability of ground waters of good quality is an issue considered important to this study.

In the study area wells and bores supply ground waters that contain low to moderate levels of salinity, ranging from 0 to 8.5 dS m^{-1}, equivalent to 5000 mg L^{-1} total dissolved solids (TDS). Ground waters in wells on Mount Weld station are commonly alkaline, with pH readings ranging between 7 and 9 (James *et al.*, 2001). This is a result of high concentrations of minerals in the water that have been dissolved from the aquifer parent rocks over a long period. Ground waters also contain high background levels of nitrate, often above 0.05 dS m^{-1} (>30 mg L^{-1} TDS)(James *et al.*, 2001). Jacobsen (1993) identified high

Further west and south of the study area quality of ground water decreases significantly. This is reflected in the decrease in number of wells and bores that have historically been commissioned in these parts of Mount Weld pastoral station. Ground waters become more highly saline, increasing to greater than 8.5 dS m^{-1} (5000 mg L^{-1} TDS) in the lower elevated drainage corridors and around the edge of Lake Carey. At the edge of the lake ground water permeates into the salt lake system, intermixing with brines associated with the deep palaeo-drainage system. The ground water in Lake Carey is commonly hyper-saline, with salinity concentrations of 510 dS m^{-1} (300,000 mg L^{-1} TDS) being recorded (Allen, 1994).

2.5) Local climate

Mean climatic data for the Laverton town site (Laverton aero monitoring station) is presented for the period 1899-2002 in Figure 2.1. Mean climatic data for the period of the duration of the trial (September 1990 to October 2004) from the same monitoring station is presented in Figure 2.2.

2.5.1) Climatic summary for the region

A general summary of the climate in the north-eastern Goldfields region during the summer and winter periods is detailed (after Gilligan, 1994):

During summer (November to April), temperatures are warm to hot and the climate is influenced by anti-cyclonic systems. Weather conditions usually consist of easterly winds and hot days with clear skies, with occasional thunderstorm activity. Stationary heat lows are common, with temperatures during the day being hot to very hot, with little or no cloud, and easterly winds. Evening brings only slight downward variation in temperature with an easing in wind velocity and directional change to southeasterly. Occasionally, remnant tropical cyclones, which have crossed the coast between Carnarvon and Port Hedland, pass over the area. They proceed in a southeasterly direction, weakening as they progress to become rain-bearing troughs or depressions.

Associated with these depressions can be strong wind gusts, which can cause severe wind erosion problems and dust storms. Summer maximum day temperatures (January-February) commonly exceed 40 °C. Evaporation levels are very high (>200 mm mo^{-1}) during the summer months. Humidity levels are low (daytime range 21-36%) and dews are rare except during and immediately following periods of rainy weather. In most years a dry spell can be expected, lasting from 4-6 months and commencing not later than October.

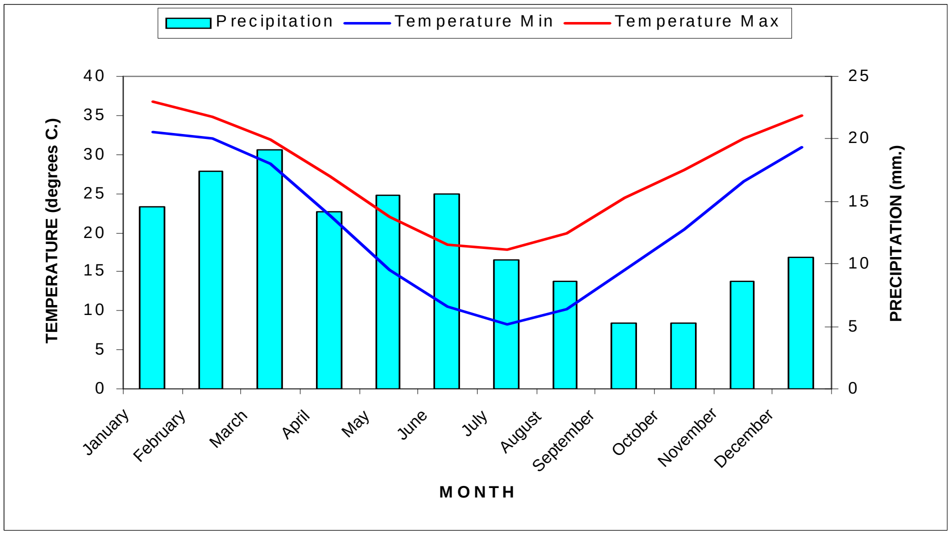


FIGURE 2.1: Monthly mean figures for rainfall, temperature maximum/minimum for period 1899-2002. Bureau of Meteorology climate figures for Laverton aero weather station (Hollingshead, 2002).

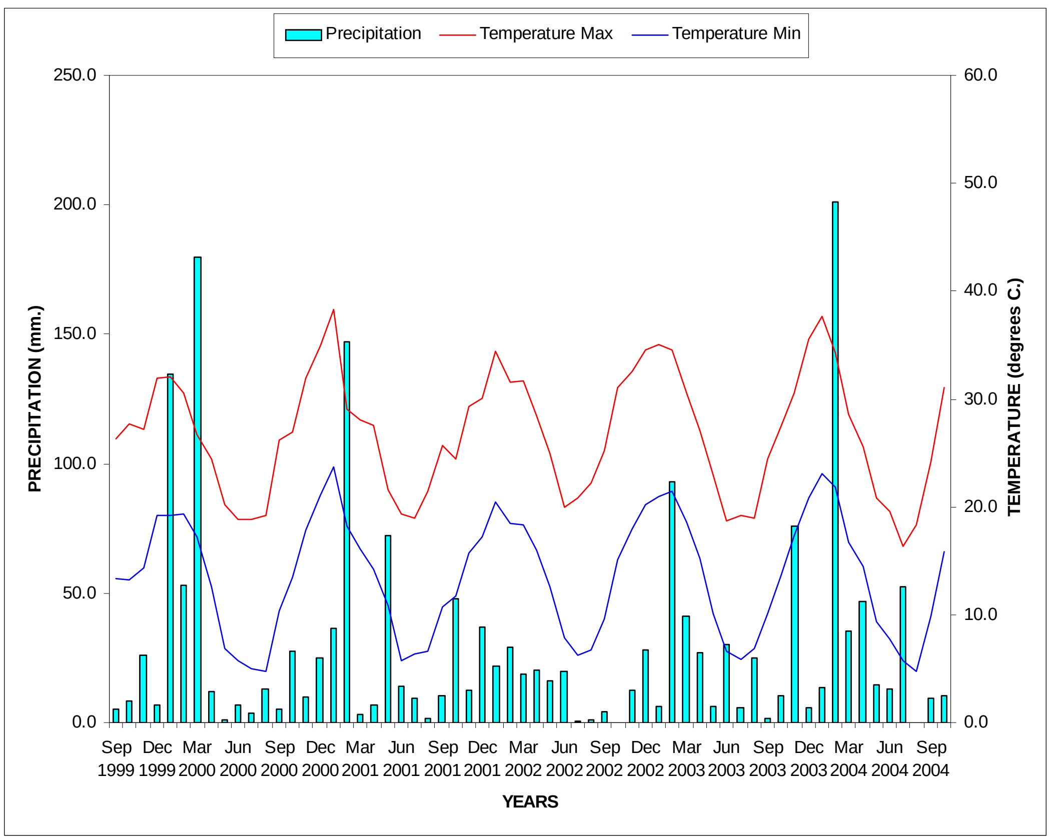


FIGURE 2.2: Local weather over duration of the trial period (September 1999-October 2004). Bureau of Meteorology climate figures from Laverton aero weather station, Monthly mean figures for rainfall, temperature maximum/minimum (Dal Pozzo, 2005).

During winter (May to October), the temperature is cooler and the climate is influenced by anti-cyclonic systems moving from west to east. This is associated with depressions bringing rain-bearing frontal systems through the area. Winds are usually moderate but occasionally westerly gales can extend into the area. Useful winter rains most often occur between late May and early August. Minimum temperatures may occasionally fall below freezing point for several successive days.

During winter mean minimum temperatures (during July) range from 3.9 to 6 °C. Evaporation levels are greatly reduced during the winter months (100-150 mm mo^{-1}) and generally, the total rainfall during the wettest months of July to August does not exceed the evaporation rate. Humidity levels increase during the winter months (daytime range 38-61%) as compared with summer, except during and immediately following wet weather.

2.6) Impact of climatic factors on the study area

Rainfall is highly variable, from flooding rains to searing drought which is a major determinant of the growth patterns of native species on Mount Weld pastoral station (James *et al*., 2001). Some key characteristics of the climate of the north-eastern Goldfields region clearly have the potential to impact greatly on this study.

2.6.1) Definition of an arid zone climate

Climate of the north-eastern Goldfields region is described as being arid (Morgan, 1965). This is one of the driest parts of Western Australia (Gilligan, 1994). Arnold (1963) defines an arid climate as "*any area which does not receive adequate rainfall to allow the regular production of crops without supplementary water sources*" (Gilligan, 1994). This does not imply that there is a lack of rainfall or vegetation, but that rainfall is inadequate to sustain plant growth (Beard, 1990).

Importantly, according to the definitions for an arid environment, a regular growing season using natural rainfall is not possible in the study area.

2.6.2) Rainfall variability

Frequency of rainfall (or rainfall "variability") is considered to have an important impact on the growth of vegetation in arid environments. The occurrence of rainfall, though described as being erratic, is considered to be more regular in autumn and early winter than in spring and summer (Beard, 1990). Heavy rains that cause floods occur occasionally during the summer season (Gilligan, 1994). Thus, rainfall is not reliable in the region and droughts are a regular feature of the climate. Mount Weld pastoral station falls within a moderate to severe drought risk zone (Reynolds *et al*., 1983). A total of six droughts have been documented in the Laverton area during the 81 years prior to 1994 (Gilligan, 1994).

2.6.3) Discussion

Rainfall in this region is highly variable. This is confirmed in the rainfall data presented for the duration of the trial period (Table 2.2). Although rainfall has been described by some as more regular during the winter period, the greatest amount of rain falls in the region during the summer months. This is directly the result of rain-bearing troughs or depressions that are caused by cyclone-related weather patterns (Gilligan, 1994). These occur during some years only, but are a normal part of the climatic cycle of the region. During such years mean annual rainfall for Mount Weld station can be as high as 250 mm per annum. For more than half of the years however, this weather cycle does not occur and the climate can be considerably drier. Mean annual rainfall during these years is commonly within the range of 80-150 mm per annum.

2.6.4) Temperature and rainfall effectiveness

Temperature is the dominant climatic factor affecting growth of native flora in the semi-arid (Arnold, 1963). During the summer months hot temperatures result in a significant increase in evaporation rates, which limits the effectiveness of rainfall. Evaporation ranges between 3000-3800 mm per year in the region, which represents more than ten times the annual rainfall. As a result of the evaporation effect tree growth is considered to be a function of the effectiveness of the rainfall, as opposed to the actual volume of rainfall received (Gilligan, 1994). Rainfall effectiveness is describes as "*a measure of the duration of conditions of sufficient soil moisture to induce significant plant growth*" Gilligan (1994).

In this region growth of native flora is greater during winter than in summer, resulting from a higher level of rainfall effectiveness during the winter season (Gilligan, 1994). Any growth observed in the summer season, results from only the heaviest rainfalls. It is only after the occurrence of flood-events that evaporation levels drop and soil moisture levels are sufficiently recharged to allow native flora to grow. This may have important implications for trial of *O. europaea*, a non-indigenous species that appears to have most growth during the summer season.

2.7) Introduction to the agro-climatic model

"The key issue is successful growth of fruit on trees, as opposed to growth of trees" (pers. comm., Nix 2005). In the context of this quote, the climatic zone of the study area has a major potential impact on the growth of *O. europaea*.

The influence of climate on the global distribution of both natural and cultivated vegetation has resulted in the development of a global agro-climatic classification scheme, known as the GROWEST model (Hutchinson *et al*., 1992). This model is based on the responses of plants to the three major climatic determinants; light, temperature and moisture. For the Australian continent an agro-climatic model has been interpreted based on GROWEST. A total of 18 different growth regimes have been identified

(Hutchinson *et al*., 1992). An illustration of these zones within the Australian continent is presented in Figure 2.3 and a brief description of climatic conditions associated in each of the 18 agro-climatic is presented in Table 2.1.

2.7.1) Location of the study area within the agro-climatic model

The approximate position of the study area is highlighted in Figure 2.1. According to the agro-climatic model the study area is interpreted to be located within the vicinity of two different agro-climatic zones (**E6** and **G**). Climate regimes for zone **E6** and **G** are described as follows (Hutchinson *et al,*. 1992);

E6: Semi-arid climate; too dry to support field crops. Soil moisture tends to be greatest in winter.
G: Desert climate; supporting very little plant growth due to water limitation.

Whilst the climate in the study area fits generally with the agro-climatic model, it should be recognised that the GROWEST model does not account for climatic variability between individual seasons and/or years (Hutchinson *et al*., 1992). The model should ideally be viewed as an analogue (pers. comm., Nix 2005). Hence, the area designated is wholly based on similarities in climate in the context of plant growth performance, as opposed to being based on actual productivity in terms of agricultural activity.

The climate in the study area is largely affected by the degree of rainfall variability. The impact of flood-events during some summer seasons is dramatic, as is the impact of prolonged drought conditions. The agro-climatic model does not take this intense variability of the climate into account. Hence, the model can only be used as a general guide for predicting the growth of natural or cultivated vegetation in the study area. This includes using the agro-climatic model to predict growth of *O. europaea* in this area.

2.8) Environmental transition in southern Australia

As well as the agro-climatic model proposed by Hutchinson *et al.* (1992), there is another classification for the environment of southern Australia that is also relevant to this study.

For more than 100 years there has been recognition of a fundamental latitudinal environmental transition across southern Australia. On the basis of differences in the distribution of fauna by Spencer in 1896, southern Australia was divided into two separate provinces; “Bassian” and “Eyrian” (Hill, 2004). Since this early classification a transition zone dividing these two environments has been identified. This environmental transition zone is characterised by documented changes in distribution of flora and fauna, regolith minerals, ground and surface waters, climate and the distribution and morphology of regolith carbonate accumulation (RCA’s) that all correspond with a roughly east-west trending zone, with a width of approximately 70-100 km (Hill 2004).

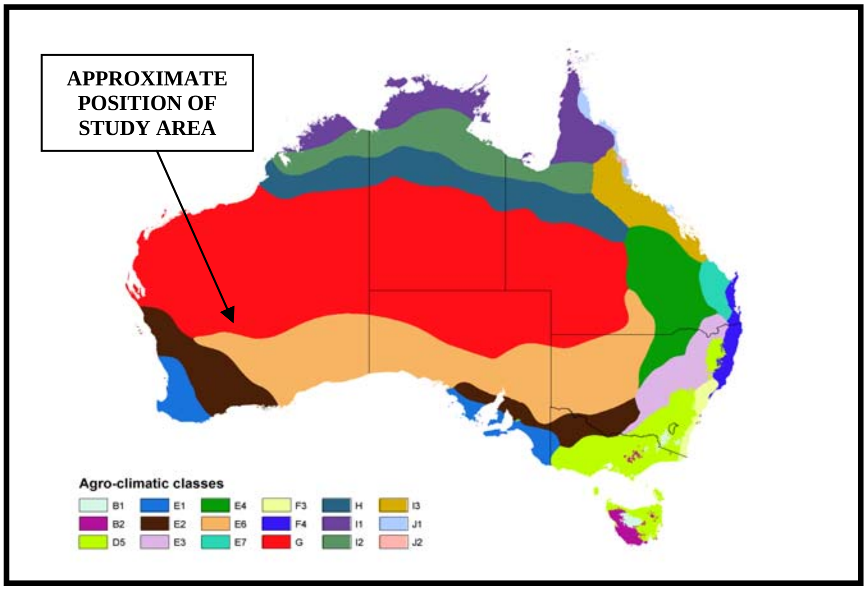


FIGURE 2.3: The 18 agro-climatic zones in Australia (after Hutchinson *et al*., 2005)

TABLE 2.1: Description of the climate for all 18 agro-climatic regimes in Australia (after Hutchinson *et al*., 2005).

CODE	SUMMARY OF THE CLIMATE
B1	Very cold winters and summers too short for crop growth.
B2	Less severe winters and longer moist summers suitable for some crops.
D5	Moisture availability high in winter-spring, moderate in summer, most plant growth in spring.
E1	Classic "Mediterranean" climate with peaks of growth in winter and spring and moderate growth in winter.
E2	"Mediterranean" climate, but with drier cooler winters and less growth than E1.
E3	Most plant growth in summer, although summers are moisture limiting. Temperature limits growth in winter.
E4	Growth is limited by moisture rather than temperature and the winters are mild. Growth is relatively even through the year.
E6	**Semi-arid climate that is too dry to support field crops. Soil moisture tends to be greatest in winter.**
E7	Moisture is the main limit on crop growth. Growth index lowest in spring.
F3	Cooler end of the warm, wet sub-tropical climates.
F4	Warmer and wetter than F3.
G	**Desert, supporting very little plant growth due to water limitation.**
H	Semi-arid, with some growth in the warm season, but too dry for cropping.
I1	Strongly developed wet and dry seasons with plant growth determined by moisture availability.
I2	Temperature and moisture are more seasonal than for I1 and the growing season is shorter.
I3	This has cooler winters than I1 and I2 with a growing season lasting at least 6 months.
J1	Moisture and temperature regime supports growth for 8-9 months of the year, with a 3-4 month dry season.
J2	As for J1 but with a shorter dry season.

In Western Australia compilation of environmental observations revealed a general latitudinal transition zone passing near to the town of Menzies. This zone clearly follows the 30ºS parallel, before passing further north at its most western margin, towards Shark Bay. The zone was originally referred to as the "Sofoulis Line", but has more recently been referred to as the "Menzies Line" (Butt. *et al*., 1977, Chen *et al*., 2002).

2.8.1) Impact of the "Menzies Line" on this study

The Menzies Line (ML) is an arbitrary boundary which defines the change between two different climatic regimes (winter-dominated rainfall in the south, verses summer-dominated rainfall in the north). This boundary runs roughly east-west, along the latitude of 29°30'S and crosses the north-eastern Goldfields region near to the township of Menzies (Morgan, 1969). This is not a sharp boundary, rather more a wider and more variable transitional zone that divides the two overlapping environments (pers. comm., Clarke and Worrell, 2005).

This transitional zone runs east-west through the north-eastern Goldfields region (Figures 2.4 and 2.5) passing close to the study area on Mount Weld pastoral station. Significant differences in climate, hydrogeology, geology, soil, flora and fauna have been documented as corresponding with this transition and all may have some relevance to this study and have been presented in Table 2.2.

2.8.2) Trial site location in respect to Menzies Line

The study area is interpreted to be located immediately north of the ML. This interpretation by the author was based on similarities observed between climate, groundwater, soil-types, flora and fauna that were/are familiar to the study area. These all corresponded with similar conditions documented by other authors from observations conducted in the area north of the ML.

There is variation however in the case of soil pH (alkaline instead of acid), ground water (high salinity documented in some water-points in study area) and fauna (termite distribution). This suggests that there is a partial/minor overlap of some conditions that were typical to areas south of the ML. Hence, whilst the comparisons generally confirmed the study site to be located north of the ML some evidence suggests the study site is located within the confines of the wide transitional zone that divides the two overlapping environments.

As a consequence of the location of the study sites in respect to the ML, I consider it is important to examine the impact of the local environment on the growth of olive trees. This will be discussed in later chapters.

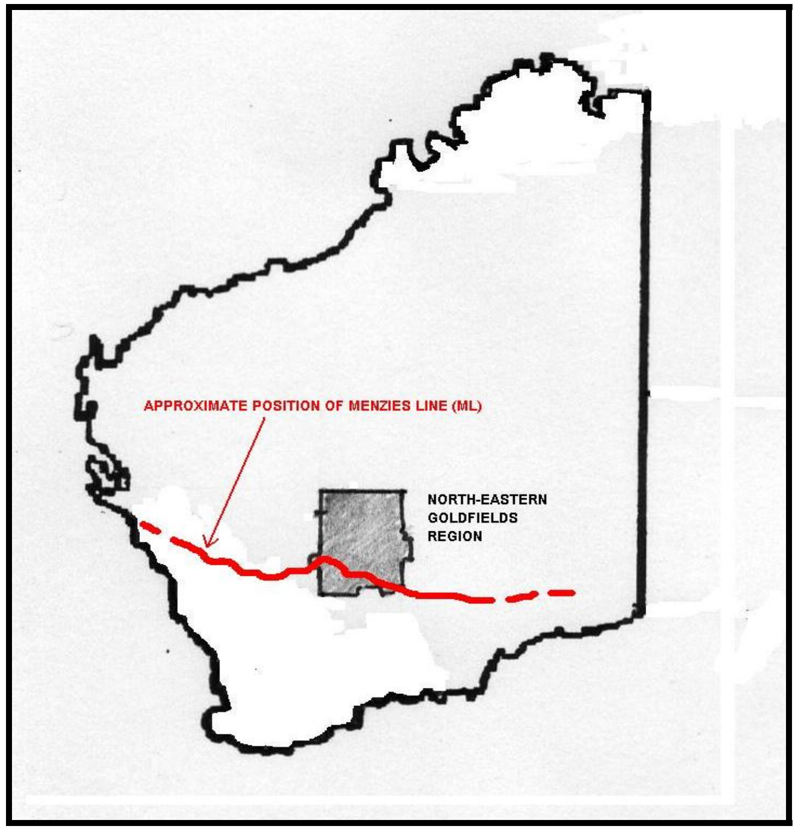


FIGURE 2.4: Approximate location of the Menzies Line (ML), in Western Australia (map adopted from Butt *et al*., 1977). Shaded portion represents north-eastern Goldfields region.

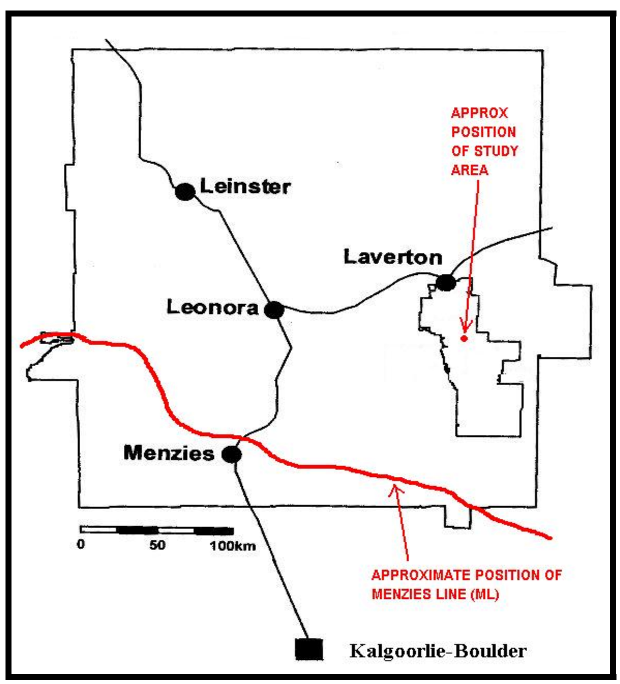


FIGURE 2.5: Interpreted location of the Menzies Line (ML), within the north-eastern Goldfields region (map adopted from James *et al*., 2001).

TABLE 2.2; Summary of differences between north and south of Menzies Line (ML).

VARIABLE	NORTH	SOUTH	REFERENCE
RAINFALL	Summer-dominated rainfall pattern (cyclone-related rainfall depressions), infrequent winter rains only.	Winter-dominated rainfall pattern, infrequent summer storms only.	(1&2)
DUST STORMS	Differences in frequency of dust storms between north and south of the ML.		(3)
GROUND WATER	pH: more alkaline, Salinity: low-moderate.	pH: less alkaline-neutral, Salinity: moderate to hypersaline.	(3) (3)
	Changes in groundwater geochemistry as a function of change in climate, with increase in salinity south of ML being the direct result.		(4)
GEOLOGY	Rapid increase in groundwater salinity has resulted in the dissolution of calcretes south of ML.		(5)
	ML marks the approximate southward limit of calcrete occurrence in the drainage system.		(6)
SOILS	Changes in soil profiles and vegetation types at ML transition.		(6)
	Soil pH is neutral to acid.	Soil pH is more alkaline.	(3&6)
	Soils are calcium deficient.	Soils are calcium dominated.	(6)
	There is a 2-fold increase in the rate of calcium deposition south of ML transition.		(3)
	Soil types consist of red coloured non-calcareous earths, sands and lithosols. Lateritic profiles are common.	Soil types consist of orange to brown coloured, non-calcareous earths and earthy sands, associated with abundant saline and calcareous loams with kankar development.	(6)
FLORA	Mulga vegetation dominates, owing to acid soils and summer-dominant rainfall	Mallee vegetation dominates, owing to calcareous soils and alkaline soil pH.	(3)
	Vegetation consists of shrub lands, dominated by mulga. Eucalypts, such as the river red gum (*E. camaldulensis*) common only along watercourses and in some calcretes.	Vegetation consists of open forests of salmon and giblet gums (*Eucalyptus salmonophloia* and *E. salubris*) and shrublands of mulga (*Acacia* spp), *Grevillea* spp, mallee eucalypts and *Casuarina* spp..	(6)
FAUNA		occurrence of biological soil crusts south of ML.	(3)
	Changes in the distribution of termite, tick, diving beetle and bird species identified to correspond with ML transition		(3)

References (1): Gentilli (1971); (2): Morgan (1993); (3): Hill (2004); (4):Gray (2001); (5); Morgan (1965); (6): Butt *et al.* (1977).

CHAPTER 3: INTRODUCTION TO THE EUROPEAN OLIVE
(species; *Olea europaea* L.)

This chapter presents an insight into the olive tree, based on information obtained from relevant references, including the University of California, Olive Production Manual (Ferguson *et al*., 1994). The suitability of the olive tree to the local environment of the study area is also discussed in this chapter.

3.1) Description of the European olive

European olive (*O. europaea*) is a long-lived evergreen tree species that has been cultivated for the fruit in the Mediterranean basin for thousands of years. In that region, some specimens are reported to have lived for 1000 years and hundreds of cultivated varieties have been selected for their adaptation to various microclimates and soil types. Within different countries certain cultivars predominate in different producing districts (Connell, 1994).

All the commercial olive-producing areas of the world are found between 30º and 45º north and south latitudes. Whilst most of the world's olive trees are currently grown in the Mediterranean region, there has also been successful commercial production in other areas. This has been on a relatively small scale including some parts of North and South America, South Africa and Australia (Connell, 1994). Typically in the Mediterranean, olive trees have been traditionally grown in areas that have poorer quality soils, or in locations, such as steep hillsides or near cliffs, in areas considered not suitable for other crops (pers. comm., Bazzani, 1999). Approximately 85% of the olives produced around the world today are grown in groves relying on rain-fed agricultural practices (Luccheti, 2002). The tree is said to take a long time to come into bearing. This is true in dry zones, or where the plantations are neglected, in which case it may even be necessary to wait 15 or 20 years to obtain a paying crop. On the other hand, under very good conditions, a tree can cover annual production costs beginning with the sixth year after planting (Pansiot and Rebour, 1961).

3.1.1) Botany of the olive tree

The olive tree has a typically dense assembly of branchlets with short internodes and compact foliage. The olive tree is shallow-rooted. Olive tree wood is dense and resists decay. If the top of the tree is killed by mechanical damage, or after exposure to environmental extremes new growth arises from the root system. Olive leaves are thick, leathery and oppositely arranged. Leaves persist for more than 2 years. They have stomata on their lower surfaces only. Stomata are nestled in peltate trichromes that restrict water loss and make the olive tree relatively resistant to drought (Martin, 1994).

Whether propagated by seed or cuttings, roots typically grow to about 0.8-1.2 m depth, even in deep soils (Martin, 1994). It is above all the nature of the soil that determines the manner of growth of the root system. If the soil is heavy and badly aerated, a network of fine roots typically grows near surface, but in sands, the root system becomes very large (Pansiot and Rebour, 1961).

For maximum production, olive trees prefer non-stratified, moderately fine textured soils (including sandy loam, silt loam, clay loam, and silty clay loam). Such soils are permeable, provide aeration for root growth, and have high water-retention capacity. This is opposed to sandy soils do not have good nutrient or water-retention ability and/or heavier clays that often do not have adequate aeration for root growth (Sibbett and Osgood, 1994). *O. europaea* is a non-halophyte, with a low to moderate tolerance of saline conditions (Maas, 1986). In the case of non-halophytes, salt-waterlogging is known to reduce the transfer of oxygen to the plant roots resulting in anaerobic conditions (Galloway and Davidson, 1991). *O. europaea* is very sensitive to water excess and the subsequent lack of oxygen that results with terminals of new roots becoming seriously inhibited or killed within 1-4 days in saturated soils (Connell and Catlin, 1994).

3.1.2) Inflorescence and flower formation

The initial bud is formed prior to the season when flowering occurs. Buds may remain dormant for more than a year however and then begin growth, forming variable inflorescence with flowers a season later than expected. When each leaf axil maintains a developing inflorescence there are hundreds of flowers per twig. Each inflorescence contains between 15 and 30 flowers, depending on developmental processes for that year and the cultivar (Martin, 1994).

Two types of flowers are present each season: perfect flowers, containing stamen and pistil, and staminate flowers, containing aborted pistils and functioning stamens. The proportion of perfect and staminate flowers varies with inflorescence, cultivar and year. Large commercial crops occur when 1 or 2 perfect flowers are present among the 15 to 30 flowers per inflorescence. As a rule, more staminate flowers then pistillate flowers are present. The reason for flower and young fruit abscission is not well known however, pistil abortion is often involved. Stress from lack of water and nutrients during floral development can lead to pistil abortion and large proportions of staminate flowers. Also, excessive populations of flowers or leaf loss up to a month before full bloom contribute to pistil abortion (Martin, 1994).

3.2) Climate

European olive is best suited to areas of Mediterranean climate. This climate is characterised as having a long, hot growing season and a relatively cool winter with minimum temperatures above a lethal limit. The best olive production and quality occur in areas having mild winters and long, warm, dry summers to mature the fruit. Winter temperatures that fluctuate between 1.5 ºC and 18 ºC are ideal, supplying the needed winter chilling for subsequent flower development. The trees do not usually survive below about

TABLE 3.1: Summary of recommended conditions for successful growth of *O. europaea*.

VARIABLE	RANGE	COMMENT / DISCUSSION	AUTHOR
TEMPERATURE	< -12 ºC	Most cultivars affected, death common at -15 ºC.	(1)
	1.5-18 ºC	Chilling temperature required during winter period for fruit set (duration of 6 weeks).	(2)
	15-30 ºC	Optimal temperature for photosynthesis.	(3)
	>30 ºC	Dormancy induced by stomata closure.	(3)
ANNUAL RAINFALL	600 to 1000 mm	Perceived optimum requirement for *O. europaea* per annum, in arid regions.	(4)
		Summer rainfall areas not recommended.	(2)
		Excess soil moisture causes problems with root growth	(5)
		Prolonged soil saturation can kill roots of *O. europaea*.	(6)
IRRIGATION		Adequate water must be available throughout the growing season to ensure maximum tree growth and olive production.	(5)
		O. europaea has a low to moderate tolerance to salinity.	(7)
	2.4 dS cm^{-1} 0.024 dSm^{-1} 14.12 ppm	Maximum threshold for groundwater salinity. Generally, European olive can produce crops when irrigated with groundwater with lower than this threshold of salinity.	(6)
	5.5 dS/m	Toxic threshold for soil salinity.	(8)
		O. europaea sensitive to water excess. Anaerobic conditions result in new root terminals being inhibited and/or killed within 1-4 days in saturated soil.	(5)
SOIL	pH 5-8.5	Recommended range for soil pH.	(2)
		Recommended soil types for *O. europaea* are non-stratified, moderately fine textured loam soils. Particularly permeable soils, that provide aeration for root growth and have high nutrient and water-holding capacity.	(2)
	0.8-1.2 m	Maximum depth of root growth for *O. europaea*.	(5)
		Alkaline/sodic soils are not recommended, owing to the tendency of these soils to become water-logged.	(2)
		With non-halophytes such as *O. europaea*, salt-waterlogging is known to reduce transfer of oxygen to the plant roots resulting in anaerobic conditions.	(9)
WIND		Winds can affect evaporation rates and affect soil-water. Strong wind can affect inflorescence/flower formation.	(6)
EVAPORATION		High evaporation rates during summer period can affect soil-water.	(6)

References (1): Connell (1994); (2): Sibbett and Osgood (1994); (3): Krueger (1994); (4): Nuberg and Yunusa (2003); (5): Connell and Catlin (1994); (6): Archer (1996); (7): Maas (1986); (8): Yunusa (2004); (9): Galloway and Davidson (1991).

-15 ºC and most cultivars are injured at about -12 ºC. In tropical regions nearer to the equator, olives grow vegetatively, but most cultivars do not set fruit, presumably due to insufficient winter chilling, which prevents flower formation (Connell, 1994).

3.2.1) Climate: comparison between the study area and other olive growing regions

The climate in the study area is considerably drier than most other growing areas worldwide. Rainfall received is less than half of the mean annual fall for the Mediterranean region including Spain, Italy and Greece (Price *et al.,* 2002). The Western Australian mean annual rainfall is probably lower than that of most arid olive growing regions of the world; Morocco, Tunisia, Libya, Egypt, South Africa and South America. There are also differences in rainfall frequency when compared to these other areas (Price *et al.,* 2002). Olive growing areas in the Mediterranean region typically receive most of their rainfall during the winter season and have characteristically dry summers. In Australia most olive growing occurs in the southern coastal strip, with rainfall predominantly in winter and spring (Yunusa, 2004).

In the study area, the amount and frequency of rainfall is highly variable however. Heaviest rainfall usually occurs during the summer season, as a result of cyclone-related troughs which occur only during some seasons (Gillian, 1994). Heavy rainfall as a result of cyclonic weather patterns usually results in the occurrence of flood-events, which result in the soils becoming waterlogged. The majority of seasons however, have considerably less rainfall associated and prolonged periods of drought have also been documented by Reynolds *et al.* (1983).

3.2.2) Comparisons with olive growing areas in Europe

Much of southern and eastern areas of Australia have been interpreted as possessing similar climates to the traditional olive growing areas of Europe (Nix, 2004). Areas in Australia with climate similar to traditional olive growing regions in Europe are illustrated (Figure 3.1). Importantly, this interpretation was closely based on the climatic divisions assigned within the agro-climatic model for the Australian continent (Hutchinson *et al.*, 1992).

The study area is interpreted to be located close to the northern boundary of this agro-climatic zone. This suggests that these trials of *O. europaea* are being conducted on the northern limit of the climatic zone that is considered traditionally to be most suitable for the growth of olive trees. According to the interpretation by Nix (2005) the location of the study area has important implications. The fact that the study area is at the most northern boundary of this agro-climatic zone may well govern the potential for successful growth of *O. europaea* in this area.

3.3) Soils

Soils typical of olive growing areas in Europe are products of widespread glacial action that has exposed

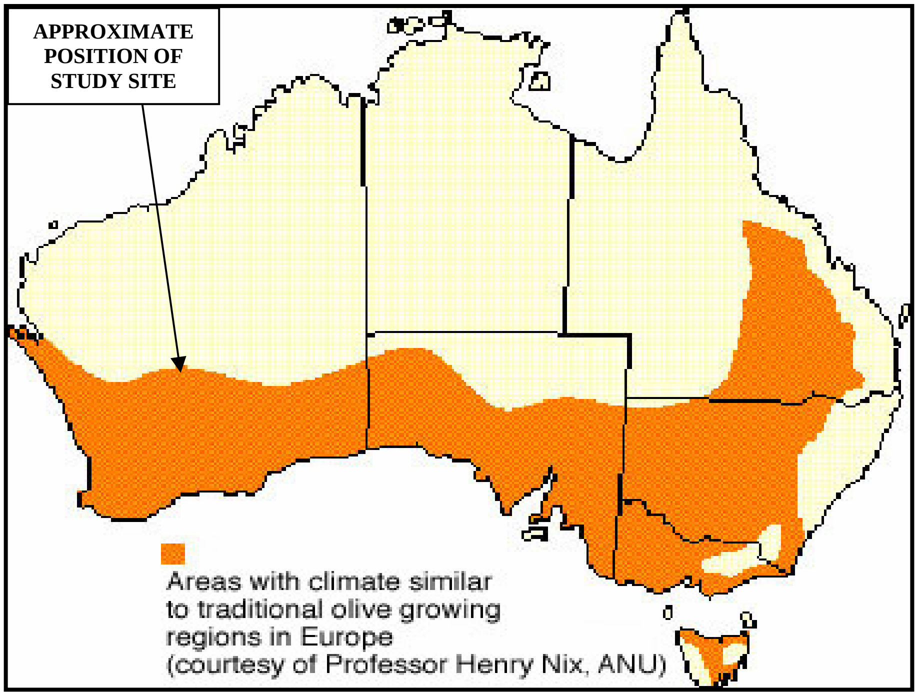


FIGURE 3.1: Areas with climate similar to traditional olive growing regions in Europe (Nix, 2005). (from the website: http://www.australianolives.com.au/, accessed 2005).

extensive areas of unweathered rock during the Pliocene (last 5 million years). Soil types are principally derived from weathering of these rocks over considerable time under conditions of a temperate climate (Gunn *et al.*, 1988). Common soil types include; calcium-rich, light-coloured soils derived from limestone or sedimentary lithologies; iron-rich, red-coloured soils derived from volcanic lithologies; and alluvial soils deposited in river valleys.

Compared with Europe, soil types in Australia are derived from a considerably more ancient landscape. Soil types are principally derived from a mantle of deeply weathered rocks that formed during the Tertiary (last 65 million years). Over this period prolonged weathering, chemical alteration, leaching and laterisation processes were dominant (Gunn *et al.*, 1988). Soil types are principally derived from weathering of these rocks over considerable time under conditions of an arid climate.

As a result of the different genesis of soils in Australia under arid conditions, they are generally considered to be mineral and nutrient-poor. Soils can also have other negative attributes as a result of their genesis, including excess salinity or sodicity. Hence, most soil types in Australia would be generally considered to be less fertile when compared to soils in the traditional olive growing area in the Mediterranean and may also not be as suitable for horticulture.

3.4) Rainfall and groundwater

In traditional olive growing areas, most olive trees (about 85%) are rain-fed (Luccheti, 2002). In the study area however, rainfall is considerably less and successful irrigation of *O. europaea* may be dependent on the availability of ground water. In many parts of the north-eastern Goldfields region (including the study area), ground water in many aquifers are highly alkaline (James *et al*., 2001), contain elevated levels of salinity and high concentrations of nitrates (Allen, 1994). Hence, the quality of groundwater supply may be poor and not necessarily suitable for irrigation of *O. europaea*.

3.5) Discussion

Successful growth of *O. europaea* is highly dependent on a number of factors, including suitable climatic conditions, suitable soil type and sufficient rainfall or supply of water of a certain quality. Comparisons were completed between the study area, and other areas worldwide where *O. europaea* has been traditionally grown. This comparison has identified inconsistencies with climate, soil type and groundwater quality in the study area when compared to traditional olive-growing regions in other parts of the world. It is recognized by the author, that these inconsistencies have the potential to impact on successful growth of *O. europaea* in this environment.

CHAPTER 4: METHODS

4.1) Introduction

Monitoring of growth performance of *O. europaea* commenced at the first two groves during 2000. After I started the MSc. study during mid 2001 growth measurements were repeated at each grove at approximately 2-3 month intervals through the duration of the trial. The final round of measurements was completed in October 2004, which marked the conclusion of the trial on Mount Weld pastoral station.

4.2) Tree measurements

The following tree growth dimensions were recorded for all trees at all groves, using the listed methods;

1) **Tree height**; measured by hand-held tape measure, to the nearest cm,
2) **Base of canopy**; measured by hand-held tape measure, from ground to bottom of lowest branch,
3) **Canopy diameter**; measured in both east-west and north-south directions, by hand-held tape measure,
4) **Trunk diameter**; measured in north-south direction by vernier calipers, at height of 30 cm above ground surface.

In addition to growth performance measurements, the following observations were also recorded during each session for all trees, in all 3 sites;

1) **Tree condition**; general health recorded, according to 5 categories; excellent, good, fair, poor, dead.
2) **Other details**; recording of comments about other visible indicators of tree health including; degree of curvature of leaves, chlorosis, dullness of leaf lustre, die-back and evidence of insect or animal attack. Irregularities in the symmetry of the tree canopy were also noted.

All field measurements and observations were recorded on-site by hand, onto specially designed logging sheets. These data were later entered into a computer spreadsheet (excel format), which comprised part of the growth performance database. Statistical analysis was subsequently completed on this data (using excel and SPSS software) to generate conclusions about the growth performance of *O. europaea*.

4.3) Other data collection

Other monitoring was conducted at various times to examine other aspects of growth performance;

1) **Tip-extension measurements**; conducted on selected limbs to determine peak growth period,
2) **Foliar samples**; composite samples collected during peak growth period to assess tree health,
3) **Flower (inflorescence) and olive fruit production**; estimates of flowering % and audit of olive fruit produced (no of olive fruit and wt.) to assess productivity of trees in the semi-arid environment,
4) **Olive fruit samples**; composite samples collected for chemical analysis of olive oil quality.

4.3.1) Description of method: (1) tip-extension measurements

For Davis Well grove, 2 trees of each cultivar were selected randomly (n=10 trees). For Jubilee Well grove, 2 trees of cv *New Norcia Mission* and 1 tree of each other cultivar (except for cvs *Olea Mission* and *Jumbo Kalamata*) were selected randomly (n=10 trees). No tip-extension measurements were conducted at Hacks Well (Site 3) groves.

For each selected tree, 5 branches were then individually selected and marked for the purpose of tip-extension monitoring. One branch was selected from the top and bottom part of the canopy, with the remaining three being selected at different points around the middle part of the tree canopy. Each of the 5 selected branches was subsequently marked with flagging tape of different colours; yellow, red, pink, white and green. This marker was tied by hand, approximately half way between the trunk and the branch tip.

During each field measurement, each selected tree was identified and the markers located. For each, the distance from marker to branch tip was measured using a hand-tape and recorded. Branches that had been damaged or broken, forked or died at the tip were also recorded. Once tags were lost, measurement of these individual branches was halted.

The measurement data were then entered into an excel spreadsheet, within the growth performance database. Mean values were calculated at both groves to determine the rate of tip growth change between each measurement period. Results were later plotted graphically and conclusions drawn.

4.3.2) Description of method: (2) vegetation samples

Leaf nutrient analysis is the best method for diagnosing tree nutrient status and represents an important tool for determining future fertilisation requirements (Benton-Jones, 1985). Recommended timing for foliar sampling for *O. europaea* is during January (after Reuter and Robinson, 1997), or alternatively, during the “peak-growth” months of February and March (pers. comm. G. Proudfoot, CSBP Laboratory, 2001). At Davis Well (Site 1) and Jubilee Well (Site 2), foliar samples were collected on four occasions. An initial round of preliminary samples was collected during September 2001, with three further samples being collected during the “peak-growth” period in March 2002, 2003 and 2005. At Hacks Well (Site 3), only two rounds of foliar samples were collected during February in 2003 and 2005. No foliar samples were collected at any site during 2004, owing to absence of the author during this period.

For each grove, fresh leaf materials from a sample of ten trees (n=10) were taken. Trees were originally selected to include most cultivars and cover most parts of the grove. The same 10 trees were sampled on each occasion. Foliar samples comprised of composite samples of fresh leaf matter (about 100 g). Sampling method consisted of the collection by hand of two composite samples, consisting 5 or 6 individual leaves (about 10 g) from each of the 10 trees. The first sample included suitable "new-growth" leaves collected from the tips of the limbs. The second sample included suitable "old-growth" leaves collected from the base of the limbs, at close proximity to the trunk of the tree.

Samples were placed into individually labeled paper bags and air-dried, before being dispatched to CSBP Laboratory (Kewdale, Perth) for chemical analysis. Each sample was tested to determine concentrations of a standard range of major elements (N, Ph, P, K) and trace elements (S, Ca, Mg, Fe, Mn, Cu, B, Zn, Na, Cl) present within the leaf matter.

4.3.3) Description of method: (3) flower and fruit formation

Occurrence of flower formation (inflorescence) on individual trees was recorded at all groves during the months of September-October each year. For each tree, this figure was estimated from the number of tree limbs that hosted flowers (approximated figure presented as "percentage of limbs with flowers").

Olive fruit formation on individual trees was recorded at all groves during each summer season. For each tree, the quantity of individual olive fruit was counted. Where possible, the degree of ripeness was estimated according to fruit colour and appearance (green; unripe, purple; semi-ripe, black; ripe, shriveled/fallen fruit; over-ripe). During the first season (2001-02), total weight of olive fruit collected from each tree was calculated from directly weighing of the total sample. During subsequent seasons, this method was changed. Total weight was calculated instead, by counting of the individual olive fruit multiplied by a weight factor of 5 g per olive fruit (mean estimate of the author, independent of cultivar).

Mean figures for % limbs with flowers and total number/weight of olive fruit produced for each tree were entered into an excel spreadsheet at the end of each respective season. Mean values were calculated for each cultivar for each year. Comparisons were made between different years and conclusions drawn.

4.3.4) Description of method: (4) testing of fruit samples

Small samples of olives fruit produced by trees were collected for the purpose of chemical testing during the two most successful seasons for olive fruit production at the Jubilee Well grove (summer 2001-02 and 2004-05). On both occasions, composite samples were collected from trees of cvs *New Norcia Mission* and *Verdale*. These samples were dispatched to the Chemistry Centre of Western Australia (East Perth), for chemical analysis to determine quality according to international and NATA protocols.

Samples were prepared and tested for oil and free fatty acid (FFA) percentages. Testing for oil percentage involved extraction of the oil fraction with hexane in a soxhlet apparatus. Testing for free fatty acid percentage was by the Canadian Grain Commission method (Rothnie, 2002 and 2005).

4.4) Site investigations

Site investigations conducted at trial sites included;

1) **Water testing**; conducted to examine quality of groundwater at each well,
2) **Soil testing**; conducted to examine soil properties at each grove site,
3) **Root-zone excavation;** conducted to examine the pattern of root system distribution.

4.4.1) Description of method: (1) water testing

Samples of groundwater were collected from Davis Well (Site 1), Jubilee Well (Site 2) and Hacks Well (Site 3) to determine quality. Individual samples, size of approximately 1 litre were collected (in sterile containers) from immediately below the top surface at each well site. Samples were tested with standardized hand-held instruments at the PGS laboratory (on-site) to determine pH level, electrical conductivity (dS m^{-1}) and concentration of salinity (ppm).

4.4.2) Description of method: (2) soil testing

At Davis Well (Site 1) and Jubilee Well (Site 2), soil samples were collected after grove establishment to examine soil properties. At Davis Well (Site 1), a small pit was dug to a depth of 40-50 cm (to the laterite contact) in one area immediately adjacent to the grove. A single composite sample, weight 1-2 kg was collected for the purpose of soil testing. At Jubilee Well (Site 2), a small pit was dug to 1.2 m depth in the area immediately adjacent to the grove. Two composite samples, weight 1-2 kg were collected (intervals; 0-0.8 m and 0.8-1.2 m) for the purpose of soil testing.

Samples were tested at the PGS laboratory (on-site) to determine; conductivity (dS m^{-1}) and concentration of salinity (ppm) of soil solution (according to procedures described by Williams, 2000), textural classification (according to procedures described by Williams, 2000), dispersion testing to determine water retention ability (according to procedures described by Addison *et al*., 2003), bulk density, porosity and void ratio (according to procedures described by Williams, 2000).

At Hacks Well (Site 3), soil testing was completed during November 2001 before the groves were established. A total of 28 soil pits were excavated by backhoe, each at a distance of approximately 25-30 m apart along a series of roughly north-south sections. Immediately after being excavated, the soil profile of each soil pit was mapped and photographed. Cross-sections were generated by hand from the mapping data. Composite soil samples were collected from selected pits and later dispatched to CSBP laboratory (Kewdale, Perth) for chemical analysis (N, Ph, P, K, S, C, Cu, Zn, Mn, Ca, Mg, Na, B, Cl, conductivity and pH). After mapping and sampling were completed, each pit was re-filled by backhoe and the ground surface leveled by machine bucket.

4.4.3) Description of method: (3) root-zone excavation

For Davis Well (Site 1) and Jubilee Well (Site 2), two trees were selected randomly from the population of living trees. At each site, one quarter of the root zone was carefully excavated. The exposed root system was subsequently measured by hand-tape, mapped and photographed. Each excavation was re-filled at the conclusion of the examination.

No root-zone excavations were conducted at Hacks Well (Site 3).

4.5) Maintenance methods

Part of the on-going monitoring also involved conducting regular maintenance of trees. The following maintenance methods were conducted over the duration of the trial at all three trial sites;

1) **Tree pruning and control of suckers**,
2) **Treatment of termites,**
3) **Monitoring of invasive spread.**

4.5.1) Description of method: (1) Tree pruning and control of suckers

Minimal tree pruning of selected trees was conducted where required, as part of the regular management procedure. As the primary aim of the experiment was to assess growth performance of trees, a minimal approach to pruning was conducted at all 3 sites during the course of the trial. This procedure involved the removal of any limbs within the canopy that were broken, or that had been affected by die-back as a result of poor tree health. Any shoots that developed in the lower trunk area of trees were also removed. Suckers, or new shoot growth from the root bulb area were commonly observed to have developed on some trees during the spring-summer seasons. This shoot growth was regularly pruned at the same time and cuttings consequently removed from the grove area.

4.5.2) Description of method: (2) Treatment of termites

When termite infestation was observed the affected tree was treated immediately. Limbs that had been subject to severe attack were removed where possible to reduce the risk of further infestation. For the main trunk treatment involved the area being initially scoured and cleaned with a blunt tool. This aimed at the removal of any termites or nest material immediately around the infestation. A diluted solution of the commercial product "Azanol" (extract of Neem oil) was then applied to the immediate area, down the trunk and around the base of the tree to control further infestations. Specimens of soldier termites were collected for the specific purpose of identification (pers. comm., Barrett-Lennard 2002) and preserved in alcohol. These were later dispatched for the purpose of identification by a qualified entomologist.

4.5.3) Description of method: (3) Monitoring of invasive spread

Invasive spread, or "feral-growth" of *O. europaea* is a major ecological issue in the southern parts of Australia (Crossman *et al.*, 2002). This is considered to be an important issue that also has the potential to occur in semi-arid environments. A management procedure was adopted to reduce the risk of invasive spread of *O. europaea* in the immediate area around all groves. This involved regular monitoring of the immediate area around the groves, which was conducted on foot. This was a requirement stipulated by the Pastoral Board of Western Australia, as part of the original conditions in the licence that allowed for the trial to be conducted on Mount Weld pastoral station.

CHAPTER 5: PREPARATION AND MATERIALS

5.1) Introduction

Study of the growth performance of *O. europaea* was conducted at three different sites on Mount Weld pastoral station. Each of these trial sites is examined in detail and similarities and differences between each site are discussed.

5.2) Trial site#1; Davis Well grove

The first olive grove (site 1) was established near the historic water-point of Davis Well (Plate 5.1). This grove has grid co-ordinates 450400mE, 6801700mN (GDA94), in the central area of the northern half of the station (Chapter 2, Figure 2.1). The northeastern corner of the grove compound is located at a distance of less than 100m away from the well head. Site preparation works were completed in readiness for planting during August-September 1999. Details of site preparation are included in Appendix 1.

The immediate countryside around Davis Well has historically been subject to heavy and sustained grazing pressure and is heavily eroded as a consequence. Remaining vegetation is sparse, consisting of old growth mulga (*Acacia aneura*) and scattered grassy undergrowth. Thick stands of mulga are present around the edges of the grove area.

5.2.1) Pastoral classification

The trial site at Davis Well is located within the Monk landsystem. This landscape is described as being hardpan plains with occasional sandy banks, supporting mulga (*Acacia aneura*) shrublands and wanderrie (Genus *Eragrostis*) grasses (Pringle, 1994).

5.2.2) Grove design

All trees planted at Davis Well grove were supplied by Olea Nurseries (Waroona, Western Australia). All stock was propagated from rooted cuttings and was approximately 2 years of age. Trees were planted immediately after they had arrived on-site, during September 1999.

Planting order was defined by the way the trees were originally placed on the vehicle tray when they were transported to the grove site. In all, 88 trees were planted. This comprised 8 trees each being planted along a total of 11 north-south rows, according to a rectangular grid. The plant spacing was 8 x 10 m, with the distance between each row being 10 m for the first 9 rows from the eastern side. In the last 2 rows on the western side however, spacing was changed to 8 x 8 m owing to a lack of space within the fenced compound. The arrangement of trees at Davis Well grove is illustrated in Figure 5.1.

The 88 trees planted at Davis Well grove comprised the following cultivars;

PLATE 5.1: View from north-eastern corner across Davis Well olive grove (Site 1). Photograph taken December 2001

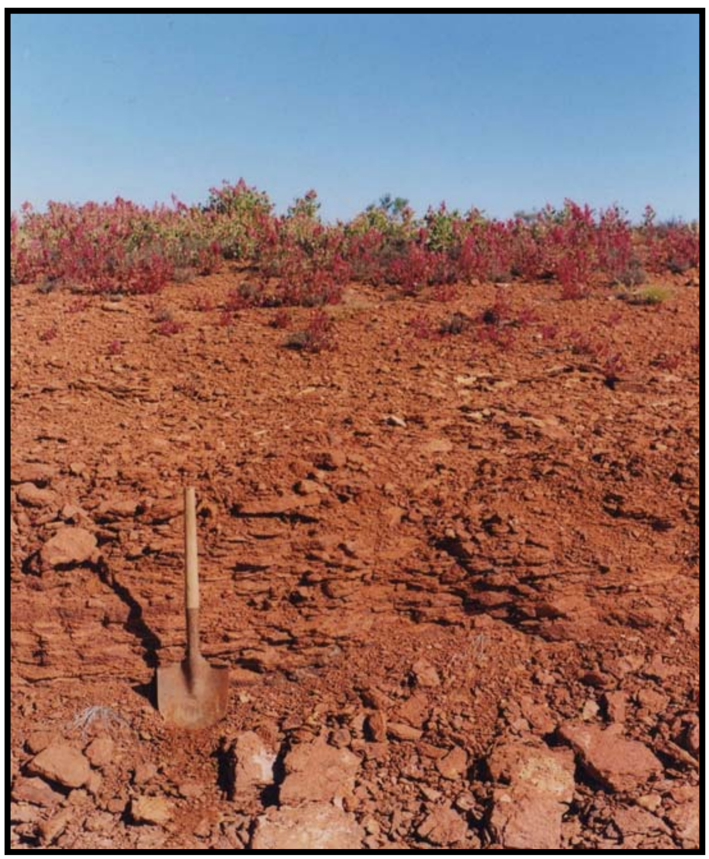


PLATE 5.2: Exposure of lateritic soil profile within road gravel pit at nearby location to Davis Well (Site 1). Length of shovel is 70cm.

1) *Verdale* (23 trees),
2) *Manzanillo* (22 trees),
3) *New Norcia Mission** (17 trees),
4) *UC136A* (15 trees),
5) *Ascolana* (11 trees).

*NB *New Norcia Mission* is an alternative name for cv *Frantoio*

5.2.3) Reticulation

Water was supplied to the grove by a reticulated system, which consisted of a single main supply line (40 mm poly-pipe) laid from east to west at the north end of the grove. This supply line was connected to a single 25,000 L tank. This tank was placed next to the wellhead at Davis Well and was supplied by a windmill.

Along each of the 11 rows, single supply lines (19 mm poly-pipe) were installed from north to south. At each planting hole, two adjustable drip-feeders were fitted to supply water to each tree. The reticulation was installed in series, with no parallel connection being fitted at the south end of the supply lines. As a result of the low feed pressure and series connection, a differential water supply resulted during the first part of the trial.

5.2.4) Water supply

Davis Well is considered by station staff to be a reliable source of reasonably good water quality. Depth to water table was observed to be approximately 4 m below ground surface. The water level was observed to drop as a result of continuous pumping at a rate of approximately 500 L per hour and to become dry after between 4 to 5 hours of continuous pumping. Testing of water samples during summer 1999-2000 revealed;

1) pH reading=9.0,
2) electrical conductivity reading=0.42 dS m^{-1}.

From the initial establishment of the grove at Davis Well during September 1999 water supply to all trees was provided by rainfall and supplemented by irrigation. Irrigation water was usually supplied to the grove via the reticulation once every week on average. No irrigation was supplied to the grove immediately after periods of heavy rainfall. Irrigation supplied to each tree ranged between 150-250 L per tree/week. This practice was discontinued after summer 2003, with the grove being run according to rain-fed agricultural practice until the end of the trial in October 2004.

WEST

V	**V**	**A**	**Mz**	**A**	**U**	**Mz**	**Mz**	11
Mz	**Mz**	**V**	**NN**	**V**	**A**	**U**	**V**	10
NN	**V**	**NN**	**Mz**	**NN**	**Mz**	**V**	**NN**	9
Mz	**A**	**Mz**	**Mz**	**A**	**A**	**A**	**Mz**	8
Mz	**V**	**V**	**V**	**V**	**NN**	**Mz**	**NN**	7
Mz	**V**	**V**	**Mz**	**V**	**NN**	**Mz**	**U**	6
NN	**U**	**A**	**U**	**V**	**V**	**U**	**V**	5
NN	**Mz**	**NN**	**V**	**A**	**NN**	**V**	**A**	4
NN	**Mz**	**V**	**NN**	**A**	**NN**	**U**	**Mz**	3
Mz	**NN**	**U**	**Mz**	**Mz**	**NN**	**U**	**V**	2
U	**V**	**U**	**V**	**U**	**U**	**U**	**U**	1
8	7	6	5	4	3	2	1	

EAST

FIGURE 5.1: Site layout of the Davis Well grove (Site 1). Diagram not to scale.
NB: V=cultivar *Verdale*; Mz=cultivar *Manzanillo*; NN=cultivar *New Norcia Mission*; U=cultivar *UC136A*; A=cultivar *Ascolana*.

5.2.5) Soil profile at Davis Well

The soil profile was shallow and comprised a single A-horizon consisting entirely of clay over laterite (Plate 5.2). Soils in this area were interpreted by the author to be residual and derived from the weathering of in situ rocks of mafic and ultramafic lithology (greenstones). At the surface the soil was hard and heavily compacted as a result of previous grazing activity. In low-lying areas across the grove area drainage hollows had formed. Cracked and peel-like textures were observed in the clay soil surface in these areas where water had pooled after heavy rainfall and later evaporated.

Soil consisted of fine to very fine, red-brown coloured clay, which was massive and uniform down to the laterite horizon. Clays were weakly to moderately indurated, with a slightly consolidated texture. Little to no organic matter was observed in any samples or exposures. Once saturation point was reached, caused by rainfall or over-irrigation, clays exhibited a strong swelling characteristic and formed cracked textures once the clay soil had dried.

At a depth of 0.4-0.5 m below the surface a laterite horizon was intersected. This horizon was very hard and brittle and had a sub-horizontal, layered structure/form. The laterite had a dull cream to grey-brown colouration and was weakly stained by red-brown coloured iron oxides. Individual fragments of the laterite had a texture that was similar to hardened putty or plastic and fractured in a brittle manner in the form of sharp shards when struck with a pick or pinch-bar. The bright spark emitted, and pungent smell that emanated, when fragments were struck was similar to that observed by the author with quartz veins being broken during the process of open pit mining. This confirmed the laterite was probably comprised of a high percentage of silica.

The only place that root matter was observed in the profile was along the top surface of the laterite horizon. Some finer roots were also being noted to have penetrated into small gaps provided by fine fractures along the top surface of the laterite. This suggested that the horizon was largely impermeable and warranted further investigation.

A simple field test was conducted, which involved pouring a large volume of water into a freshly excavated soil pit that was dug down to the laterite contact. After a period of several hours had passed, the hole was examined and the water level was checked. More than 50% of the water still remained in the hole, which confirmed the laterite horizon to be largely impermeable. Most of the water loss over this period was expected to be the result of either evaporation or absorption of water into the clay A-horizon exposed in the walls of the pit. Walls of the pit were confirmed to be highly saturated where they had been in contact with the water.

5.2.6) Soil testing

Further testing of this horizon was completed on a composite soil sample from Davis Well grove. This sample was collected from depth 0-0.3 m and tested by a variety of methods to further evaluate the soil and classify the soil type (Appendix 1). Mechanical analysis failed to confirm the correct textural classification, owing to the fact that a large percentage of the sample was consolidated. The high percentage of soil clods in the sample skewed the mechanical analysis. Subsequent testing of particle distribution by dry sieving resulted in an incorrect ratio, which classified the soil type incorrectly as a sandy soil.

Conductivity testing indicated that this soil type was within the category of a sodic soil (Qureshi and Barrett-Lennard, 1998). This is further confirmed by the frequent occurrence of cracking and peel-type textures within soils at the site. There was no further testing conducted, however, to determine the sodium absorption ratio (SAR) of the soil type.

5.3) Trial site#2; Jubilee Well grove.

The second olive grove (site 2) was established about 20 km south of the first site at Davis Well at a distance of 2 km further west of the historic water-point of Jubilee Well (Plate 5.3). This grove is at grid co-ordinates 447000mE, 6793700mN (GDA94), in the central part of the northern half of the station (Chapter 2, Figure 2.1). Site preparation works were completed in readiness for planting during March 2000. Details of the site preparation are included in Appendix 1.

The immediate countryside around the site has historically been subject to intermittent periods of grazing activity. Whilst there was a minor impact by grazing the area was not as heavily denuded of original vegetation or as severely eroded when compared with Davis Well grove site. Vegetation consisted of sparse and densely vegetated stands of old growth Mulga (*Acacia aneura*) and other Acacia species. Apart from scattered trees, most ground cover consisted of thick but patchy undergrowth consisting of perennial and non-perennial vegetation.

5.3.1) Pastoral classification

The Jubilee Well trial site is located within the Carnegie landsystem. This is described as comprising salt lakes with fringing chenopod plains and dunes of kopi or sand (Pringle, 1994).

5.3.2) Site layout

All trees planted at Jubilee Well grove were supplied by Olea Nurseries (Waroona, Western Australia). All stock was propagated using rooted cuttings and was approximately 3 years of age. All trees were in good condition when they arrived on-site during September 1999. Owing to delays in grove establishment however, trees were not planted until March 2000. The condition of some of the stock had

PLATE 5.3: View towards east across Jubilee Well olive grove (Site 2). Photograph taken April 2003.

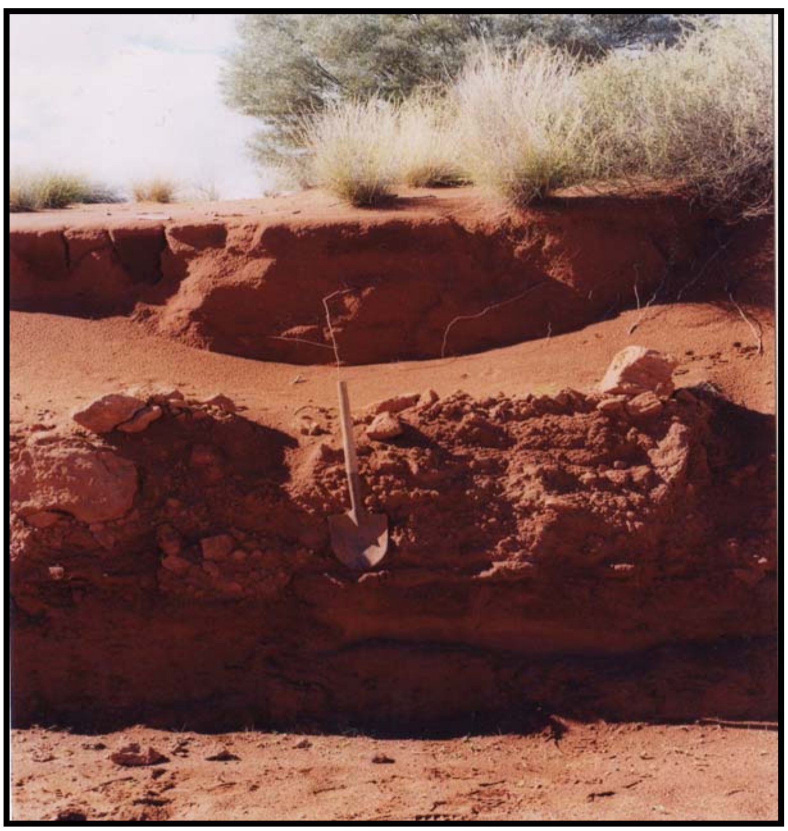


PLATE 5.4: Exposure of soil profile within road cutting at nearby location to Jubilee Well (Site 2). Length of shovel is 70cm.

deteriorated during this period, with several tree mortalities being observed.

Trees were planted according to cultivar. Trees of each cultivar were grouped along separate rows in the grove. In all, a total of 98 trees were planted. This comprised 14 trees planted along a total of 7 north-south rows, according to a rectangular grid. The planting spacing was 6 x 10 m, with the distance between rows being 10 m. The arrangement of trees in the Jubilee Well grove is illustrated in Figure 5.2.

The 98 trees planted at Jubilee Well grove comprised the following cultivars;

1) *New Norcia Mission** (25 trees),
2) *Ascolana* (25 trees),
3) *Kalamata* (10 trees),
4) *Verdale* (9 trees),
5) *Leccino* (9 trees)
6) *Nabtari* (6 trees),
7) *Barouni* (6 trees),
8) *Olea Mission* (3 trees),
9) *Manzanillo* (2 trees),
10) *Pendolino* (2 trees),
11) *Jumbo Kalamata* (1 tree).

*NB: *New Norcia Mission* is an alternative name for cv *Frantoio*

5.3.3) Reticulation

Water was supplied to the grove by a reticulated system which comprised of a single main supply line (40 mm poly-pipe) laid from east to west at the south end of the grove. This supply line was connected to a 25,000 L tank. This tank was placed on a shallow tank stand adjacent to the south end of the grove and was supplied by a windmill at Jubilee Well.

Along each of the 7 rows, single supply lines (19 mm poly-pipe) were installed from south to north. At each tree site, a single short length of hose (5 mm flexible) was installed with a drip-feeder placed on the end. The reticulation was installed in series, with no parallel connection at the north end of the supply lines. As a result of the low feed pressure and series connection, a differential water supply resulted during the first part of the trial.

5.3.4) Water supply

Jubilee Well is considered by station staff to be a reliable source with reasonably good quality. Depth to water table was observed to be about 3 m below ground surface. The water level was observed not to drop as a result of continuous pumping at a rate of about 500 L/hour. Testing of water samples

NORTH

V	**NN**	**B**	**A**	**P**	**L**	**L**	14
NN	**NN**	**B**	**A**	**P**	**Mz**	**L**	13
NN	**Ol**	**B**	**A**	**A**	**Mz**	**L**	12
NN	**NN**	**B**	**A**	**A**	**B**	**L**	11
Ol	**NN**	**V**	**A**	**A**	**K**	**L**	10
NN	**NN**	**V**	**A**	**A**	**K**	**L**	9
NN	**NN**	**V**	**A**	**A**	**K**	**B**	8
NN	**NN**	**V**	**A**	**A**	**K**	**L**	7
JK	**NN**	**V**	**A**	**A**	**K**	**N**	6
NN	**NN**	**V**	**A**	**A**	**K**	**N**	5
NN	**NN**	**V**	**A**	**A**	**K**	**N**	4
NN	**NN**	**V**	**A**	**A**	**K**	**N**	3
NN	**NN**	**Ol**	**K**	**A**	**K**	**N**	2
NN	**NN**	**NN**	**A**	**A**	**L**	**N**	1
7	6	5	4	3	2	1	

SOUTH

FIGURE 5.2: Layout of the Jubilee Well grove (Site 2). Diagram not to scale.

NB: V=cultivar *Verdale*; Mz=cultivar *Manzanillo*; NN=cultivar *New Norcia Mission*; Ol=cultivar *Olea Mission*; A=cultivar *Ascolana*; N=cultivar *Nabtari*; L=cultivar *Leccino*; B=cultivar *Barouni*; K=cultivar *Kalamata*; JK=cultivar *Jumbo Kalamata*; P=cultivar *Pendolino*.

conducted by the author during summer 1999/2000 revealed the following results;

1) pH reading=8.4,
2) electrical conductivity reading=0.25 dS m^{-1}.

From the initial establishment of the grove at Jubilee Well during March 2000 water supply to all trees was provided by rainfall and supplemented by irrigation. Irrigation water was usually supplied to the grove via the reticulation once per week on average. No irrigation was supplied to the grove immediately after periods of heavy rainfall. Irrigation supplied to each tree ranged between 150-250 L per tree/week. This practice was discontinued after summer 2003, with the grove being run according to rain-fed agricultural practice until the end of the trial in October 2004.

5.3.5) Soil profile at Jubilee Well

This soil profile was deep (>1 m depth), and from surface was comprised of a single A-horizon consisting entirely of a sandy soil (Plate 5.4). This contained intermittent layers of fine to coarse sands, with a dull yellow-grey colouration. The sand was unconsolidated from surface to 70 cm depth. Below this depth, minor sub-horizontal, weakly indurated layers were observed in the profile. These were interpreted to be the result of laterisation processes in the deeper parts of the profile. Close examination of the soil matrix confirmed the presence of a small percentage of clay.

The soil profile was excavated to a depth of 1.2 m, with no B-horizon being intersected. This soil type was interpreted by the author to be derived from the weathering of the granite bedrock (felsic lithology).

5.3.6) Soil testing

Further testing of this horizon was completed on two composite samples of soil. These samples were collected from depth 0-80 cm and 80 cm-1.2 m and tested via a variety of methods to further evaluate the soil and classify the soil type (Appendix 1). Testing confirmed the soil to consist of fine to coarse sand. The soil contains a minor percentage of clay but has very low water retention ability.

5.4) Trial site#3: Hacks Well

The third trial site (site 3) consisted of three identical groves which were established near the historic station yard and shearing shed at Hacks Well (Plates 5.5 and 5.6). The groves are at grid co-ordinates 453550mE, 6795600mN (GDA94), in the central area of the northern part of the station (Chapter 2, Figure 2.1). Site preparation works were completed in readiness for planting during May-September 2002. Details of the site preparation are included in Appendix 1.

The immediate countryside at Hacks Well has historically been subjected to sustained grazing pressure and is heavily eroded as a consequence. This area lies at the most eastern point within "Long Paddock", originally one of the main mustering points on Mount Weld pastoral station. This paddock has been classified as a degraded area by the Department of Agriculture and has since been allocated to the land-use category of future rehabilitation (James *et al*., 2001). After this allocation, the area had been ripped by bulldozer tyne to promote growth of native flora.

The countryside consists of an open flat plain, which has largely been denuded of native vegetation. The creek areas along the north and south flank of the site were thickly vegetated by mulga (*Acacia aneura*). The grove area was largely devoid of vegetation, except for a patchy cover of grasses. There were still a few remaining old growth trees; mulga (*Acacia aneura*) and corkwood (*Hakea suberea*). The groves were established within the corridor of relatively flat country that lies between the two creeks. The impact of soil erosion is subtle across the site with effects becoming more pronounced within the vicinity of the creek systems. Many sharp gullys and rills could be observed in these areas, the result of erosion during episodes of creek flooding.

5.4.1) Pastoral classification

The Hacks Well site is located within the Monitor landsystem. This is described as comprising of distributary alluvial fans and wash plains supporting mulga with saltbush and/or bluebush shrublands (Pringle, 1994).

5.4.2) Site layout

All trees planted at Hacks Well were supplied by Olea Nurseries (Waroona, Western Australia). All stock was propagated by rooted cuttings and was approximately one year of age. All trees were in good condition when they arrived on-site during October 2001. Owing to delays in grove establishment however, trees were not planted until September 2002. The condition of some of the stock had deteriorated as a result of this delay.

In all three groves, trees were planted according to an identical design. This was based on a multiple latin-square design (Mead *et al*., 1983), with trees of three different cultivars arranged according to this random distribution. In all, a total of 161 trees were planted, consisting of 54 trees at the north and middle groves and 53 trees at the south grove. Each grove consisted of six identical squares, or "cells". Each contained a total of 9 trees, 3 trees of each cultivar arranged according to the same design (Figure 5.3). The six cells were amalgamated to form a single grove (Figure 5.4). Hence, each grove consisted of 6 trees, east to west direction by 9 trees, north to south direction, arranged according to a rectangular grid. Planting spacing was 8 x 8 m. The Hacks Well site layout is illustrated in Figure 5.5.

PLATE 5.5: View towards east across “middle” grove, Hacks Well (Site 3), with Hacks Well shearing shed and stock yards in background. Photograph taken April 2003.

PLATE 5.6: Newly planted olive tree within shallow laterite soil at “south grove”, Hacks Well (Site 3). Photograph taken September 2002.

The 181 trees planted at the three groves at Hacks Well comprised the following cultivars;

1) *New Norcia Mission**(76 trees),
2) *Verdale* (75 trees),
3) *Barnea* (76 trees).

*NB: *New Norcia Mission* is an alternative name for cv *Frantoio*

Cvs *New Norcia Mission* and *Verdale* were chosen based on measured growth performance and fruit productivity in previous trials at Davis and Jubilee Well. Cv *Barnea* was a rootstock that was originally propagated in Israel. This cultivar had not been trialed previously at Sites 1 and 2, but was chosen owing to the expected suitability to the arid zone climate (pers. comm., Kailis, 2001).

5.4.3) Reticulation

Water was supplied to all three groves by a reticulated system, which was identical in design and consisted of a single main supply line (40 mm poly-pipe) that ran from the main supply tank to each grove. The main supply was positioned centrally, between all 3 groves and consisted of two large tanks (combined capacity of 45,000 L). The tanks were positioned on an earth-filled tank stand, at a height of 0.5 m above ground level. These tanks were connected to the supply at Yard Bore (on the eastern side of the Hacks Well yards) by a single line (40 mm poly-pipe) and fed by an electric pump.

The three supply lines running from the tanks to each grove were of equal length. At each grove this line was connected to smaller diameter supply lines (25 mm poly-pipe) that were laid around the perimeter of each grove. Individual supply lines (19 mm poly-pipe) were then installed from east to west along each of the 9 rows and connected at both ends to form a parallel water supply grid. At each tree site, two short lengths of hose (5 mm flexible line) were installed with a drip-feeder placed on the end. As a result of the low feed pressure a differential water supply resulted during the first part of the trial.

5.4.4) Water supply

Water was available locally from two water-points. The closest supply was at Yard Bore, located at the eastern end of the yards at a distance of about 150 m from the grove sites. The second supply was available from Hacks Well, one of the historical wells on the station that was located about 400-500 m further south of the groves.

Hacks Well is considered by staff to be a reliable source, with reasonably good water quality. Depth to water table was observed to be less than 1 m below ground surface. Testing of water samples conducted by the author during summer 1999/00 revealed the following results;

B	NN	V
NN	V	B
V	B	NN

FIGURE 5.3: The configuration of the multiple Latin square design used for the Hacks Well trial (after Mead *et al*., 1983).

NB: NN=cv *New Norcia Mission*; V=cv *Verdale*; B=cv *Barnea*.

NORTH

B	**NN**	**V**	**B**	**NN**	**V**	9
NN	**V**	**B**	**NN**	**V**	**B**	8
V	**B**	**NN**	**V**	**B**	**NN**	7
B	**NN**	**V**	**B**	**NN**	**V**	6
NN	**V**	**B**	**NN**	**V**	**B**	5
V	**B**	**NN**	**V**	**B**	**NN**	4
B	**NN**	**V**	**B**	**NN**	**V**	3
NN	**V**	**B**	**NN**	**V**	**B**	2
V	**B**	**NN**	**V**	**B**	**NN**	1
6	5	4	3	2	1	

SOUTH

FIGURE 5.4: Standard layout for each grove at the Hacks Well experiment, which was based on a rectangular design comprising of six amalgamated blocks, each of the same Latin square design (Mead *et al*., 1983). Diagram not to scale.

NB: “NN”=cultivar *New Norcia Mission*; “V”=cultivar *Verdale*; “B”=cultivar *Barnea*.

1) pH reading=7.62,
2) Electrical conductivity reading=1.31 dS m^{-1},
3) Salinity=823 ppm.

Like Hacks Well, the water-point at Yard Bore was also considered by station staff to be a reliable source, with reasonably good water quality. Owing to the close proximity of Yard Bore, it was chosen as the primary water supply from the start of the experiment. The pump at Yard bore was operated approximately once per week to fill the main supply tanks that had been placed within the middle of the three groves. The pump supplied the tanks in a continuous manner for most of the 2002-03 summer period.

From the initial establishment of the three groves at Hacks Well during September 2002 water supply to all trees was provided by rainfall and supplemented by irrigation. Irrigation water was usually supplied to all groves equally via reticulation once every week on average. No irrigation was supplied to the grove immediately after periods of heavy rainfall. Irrigation supplied to each tree ranged between 150-250 L per tree/week. This practice was discontinued after summer 2003, with the grove being run according to rain-fed agricultural practice until the end of the trial in October 2004.

5.4.5) Soil profile at Hacks Well

A comprehensive examination of the soil profile was conducted at the Hacks Well site during November 2001. A total of 28 small soil pits were excavated by backhoe, the soil profile was mapped and cross-sections were generated by hand. A summary of test pit positions, mapping data and analytical results from the soil tests completed are included in Appendix 1.

Immediately from surface, red-brown coloured clay soil was intersected in all holes excavated. This A-horizon was shallow but appeared to be continuous across the entire Hacks Well site. Immediately below this surface A-horizon however, the soil profile varied significantly in different parts of the site.

Within the north part of the site, a deep B-horizon comprising of alluvium was intersected in the soil pits that continued below 1 m depth (Plate 5.7). Further south however, a laterite horizon was intersected in the soil pits at a depth of 40-50 cm (Plate 5.8). This horizon was impenetrable and could not be breached with the backhoe. In the soil pits dug further south, the laterite horizon was intersected at a depth of 80 cm or deeper. Mapping suggested that this soil profile was continuous in the southern direction for a distance of several hundred meters down to the main creek.

An unconformity was interpreted from the soil mapping in the middle area of the Hacks Well site which defined the contact between the two different soil profiles; alluvium soils in the north, and laterite in the south. At surface, the unconformity corresponded approximately with the east-west trending fence line that runs across the middle of the Hacks Well site. Soil pit mapping identified that the unconformity contact between the two soil types had a strike of north-west to south-east, and dipped steeply towards the north-east.

5.4.6) Soil profile: north of the unconformity

From surface, the soil profile consisted of a shallow A-horizon of clay soil, above a B-horizon consisting of alluvial soil. The A-horizon had a variable depth, ranging between 20 and 70 cm, but the average depth was 30 cm in most soil pits examined. At the base of the A-horizon fine pisolithic gravel was observed within some of the soil pits.

The B-horizon consisted of interbedded alluvium soil comprising poorly to well-sorted gravels, within a matrix of unconsolidated and non-indurated sand, silt and clay. This alluvial soil unit is interpreted to comprise part of a large palaeochannel. Gravel fraction ranges between fine to coarse-sized clasts, which were sub to well-rounded. Lithology consisted of a mixture of weathered mafic (greenstone) and haematitic gravel. Graded bedding was observed in some of the exposures. A "marker" horizon, consisting of light grey to off-white coloured gravels and sands was identified within many exposures and interpreted to be continuous within the central and southern part of the alluvial profile. This marker horizon was distinctive; the matrix was unconsolidated, had a gritty texture and contained high percentages of calcium and organic matter (fine roots). Samples from some of the soil pits within this area were also observed to be moist. The occurrence of a single corkwood (*Hakea suberea*) was also observed in this part of the Hacks Well site, which is considered locally, to suggest the possible presence of ground waters of good quality at shallow depth (based on discussion with members of the local Wongatha community).

5.4.7) Soil profile: south of the unconformity

Thickness of the A-horizon increased towards the southern direction. Near the unconformity the profile depth was about 40 cm, but the depth increased to about 1 m further south, adjacent to the main creek. Soils consisted of fine clays with red-brown colouration. A laterite horizon was intersected at the base of the clay soils in all exposures, which was interpreted to be continuous across the entire southern half of the site. This horizon was very hard and brittle and could not be breached by the backhoe bucket. The laterite had a dull cream to grey colouration that was weakly stained by red-brown coloured iron oxides.

5.4.8) Discussion

From mapping conducted at the Hacks Well site, two different soil profiles were identified. In the north, a deep alluvial soil profile was interpreted to comprise part of a much larger palaeochannel. In the middle of the site, an unconformity contact was identified. This marked the contact with a shallow clay

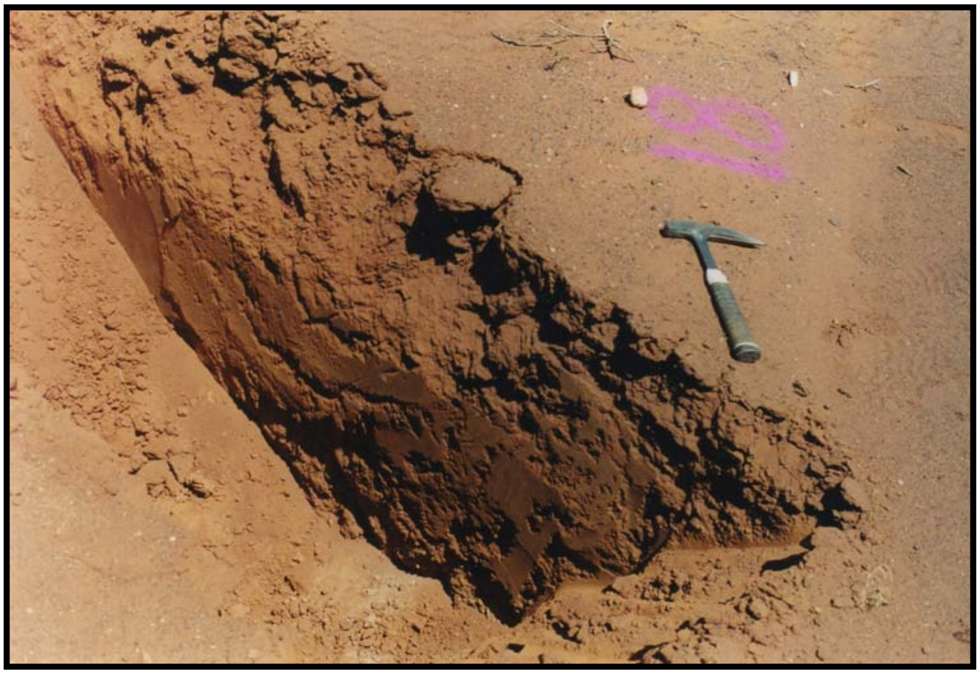


PLATE 5.7: Soil profile (test pit#18) in northern part of Hacks Well (Site 3). Photograph taken December 2001. Lighter calcitic horizon visible at base of hole (depth; 0.7-1.0 m).

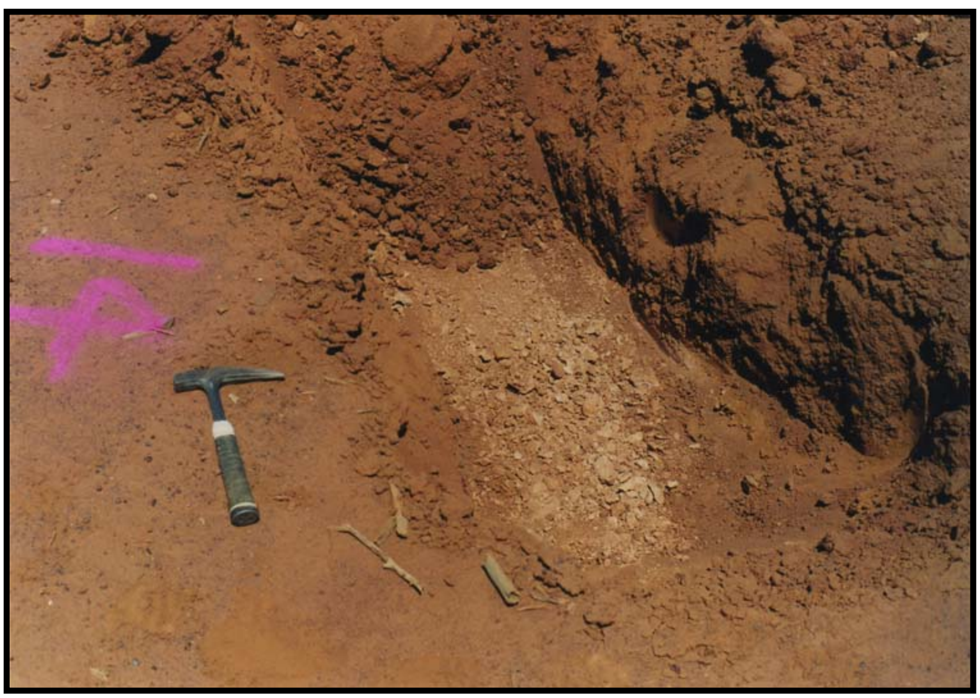


PLATE 5.8: Soil profile (test pit#14) in southern part of Hacks Well (Site 3). Photograph taken December 2001. Laterite horizon visible at base of hole (depth; 0.4 m).

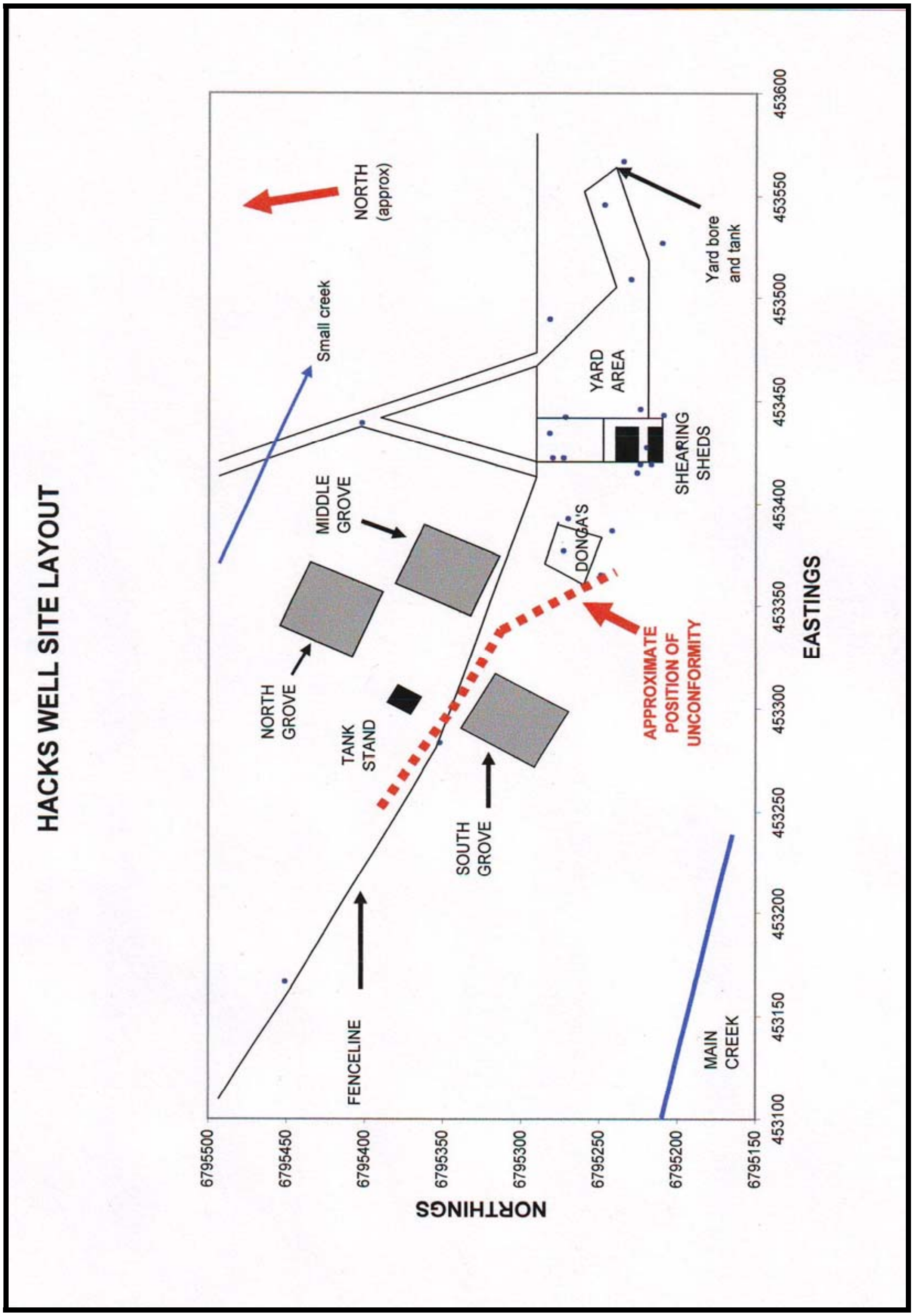


FIGURE 5.5: Plan showing approximate position of the three trial groves at Hacks Well (Site 3).

NB: Dotted line (▬ ▬ ▬) indicates approximate position of unconformity between different soil regimes in the north and south of the Hacks Well site.

and laterite soil profile that was continuous across the south part of the site. The shallow clay and laterite profile in the south was interpreted by the author as being similar to that observed at the previous trial site at Davis Well (Site 1). This soil type appears to be representative of a high percentage of soil types in this region.

Towards the north, mapping identified differences within the alluvial soil profile which suggested differences in the deposition of the original palaeochannel. Most importantly, the distinctive "marker" horizon was continuous in only some areas, plus, was interpreted to have lensoidal symmetry that striked roughly east, north-east to west, south-west. This was discordant to the general trend of the palaeochannel, which had an east-west strike. The central part of the marker horizon had the greatest thickness, of between 0.3 to >0.5 m (corresponding with pits 18, 20 to 23). The horizon was interpreted to pinch towards the north-west and south-east, with thickness of <0.3 m (corresponding with pits 17, 19 and 24 to 26). In the south-west, the marker unit pinched out sharply against the unconformity contact (corresponding with pit 24).

The marker horizon contained a large amount of calcium and was considered by the author to be of positive benefit to the growth of *O. europaea*. Hence, the presence or absence of this calcium-rich marker unit had the potential to affect tree growth. Analytical testing confirmed differences in concentrations of many major/trace elements within the samples submitted, which confirms differences in the soil profile that had the potential to affect growth of *O. europaea*. As a consequence, the design of the trial incorporated two separate groves within the alluvial soil profile in the north of the Hacks Well site. The first grove, known as "middle grove" was designed to test growth of *O. europaea* within the calcium-rich marker horizon. This grove was placed in the south-east part of the site, where the calcium-rich horizon was at its thickest and deepest (Figure 5.5).

The second grove, known as "north grove" was placed directly towards the north-west of "middle grove". In this area, the calcium-rich marker unit was interpreted to be thinner and was intersected at shallow depth in the soil test pits (Figure 5.5).

A third grove, known as "south grove" was placed directly south of the unconformity. Here *O. europaea* was planted in the shallow clay and laterite soil profile (Figure 5.5). Hence, the three grove sites were established on contrasting soil profiles. This allowed for comparisons to be completed between 3 different cultivars of *O. europaea*, within three contrasting soil types.

5.5) Comparison between groves

Growth performance of *O. europaea* was conducted at three trial sites under conditions that were similar in the case of some factors and different in the case of others (Table 5.1).

TABLE 5.1: Comparison of climate, soil, groundwater and design factors between the 3 groves.

FACTOR	Davis Well (Site 1)	Jubilee Well (Site 2)	Hacks Well (Site 3)	Discussion/Conclusion
RAINFALL	√	√	√	•Amount of rainfall constant at all 3 grove locations (negligible variation only).
TEMPERATURE	√	√	√	•Maximum/minimum temperature constant at all 3 grove locations (negligible variation only).
SOIL	X	X	X	•Different/contrasting soil profiles at all three sites. •Similarity soil profiles at Davis Well and Hacks Well south grove however.
IRRIGATION REGIME	√	√	√	•Irrigation regime was reasonably constant for Davis Well and Jubilee Well groves (150-250L tree/week). Differential effect for first part of trial only. •Irrigation regime was interrupted at start of trial, but stabilised after first 2-3 months of trial (150-250L tree/week). Differential effect for first part of trial only. •Irrigation halted to all trials from Summer 2003.
GROUND WATER QUALITY	√	√	√	•Water quality reasonably similar from Davis Well and Jubilee Well water-points (minor salinity only).
GROVE DESIGN	X	X	X	•Planting density varied across Davis Well grove. •Trees planted at Davis Well and Jubilee Well site were not placed in a randomised order (NB: statistical comparison <u>is not possible</u> between these groves). •Trees planted at all 3 groves at Hacks Well according to identical "Latin square" design (NB: statistical comparison <u>is possible</u> between different groves and cultivar).
CULTIVARS	X	X	X	•Four common cultivars planted at Davis Well and Jubilee Well groves. •Choice of 2 out of 3 cultivar for Hacks Well trial based on earlier fruiting performance of these cultivar at Jubilee Well grove.

(√): conditions similar/equal between groves; (X): conditions different between groves.

Climatic factors including rainfall and temperature are considered to be constant at each of the sites. Groundwater quality was similar between the 3 sites. Although the Hacks Well trial was established later than the Davis and Jubilee Well trials, the irrigation regime was similar. The halting of irrigation to all 3 groves during the latter part of the trial occurred at the same time. For each of the above factors, the impact on growth of *O. europaea* over the duration of the trial was similar at each grove, and a negligible difference is interpreted. There is a contrast between the soil profiles at all 3 sites. The design of each trial, timing and method of establishment and cultivars planted differed between the 3 sites. These factors may impact significantly on growth of *O. europaea* over the duration of the trial.

CHAPTER 6: RESULTS AND DISCUSSION

Site#1; Davis Well grove

6.1) Tree mortality

Of 88 *O. europaea* planted, 14 trees died at Davis Well grove between planting in September 1999 and October 2004. This represents total mortality of 16%. Mortality rates varied over the duration of the trial. Four trees succumbed in the first year but most deaths occurred during the second year after the grove was established. Only one tree died during the following three years (Table 6.1).

A mortality rate of 5% was quoted as being “about normal”, during conversations with other growers in the southern coastal part of Australia for the first year of grove establishment assuming trees had been planted a suitable soil type and irrigated with sufficient water. The mortality rate was 4.5% for the first year after the grove was established, which was similar to the 5% mortality rate quoted by growers.

During the second year the mortality rate more than doubled however. This suggested that other site-specific factors, apart from the usual establishment issues that impacted on tree health and resulted in the increased tree mortality observed during the second year. A review of data collected on the visible indicators of tree health was conducted (excessive curvature, dullness of leaf lustre, dye-back etc.) to determine whether any trends could be determined.

In general, tree health was variable during the early part of the trial and the subsequent review of observations failed to find any obvious correlation between tree health and increased mortality rate. The investigation was broadened to examine other site-related factors, to determine whether these had the potential to cause increased tree mortality. This included an examination of the effects of soil profile depth, soil texture and properties, presence of salinity and the impact of competition from flora and fauna.

6.1.1) Soil depth

The soil profile at the Davis Well site had a shallow depth (40 to 50 cm). The shallowness of this profile may have impacted on the root system development of *O. europaea* and resulted in an increase in tree mortalities at this site. Hence, an investigation was conducted to examine the impact of the soil profile on root growth of *O. europaea* with the specific aim to determine any possible link between depth of profile and tree mortality. Excavation of two tree sites was conducted during November 2001 (Plate 6.1 and 2). Root distribution was examined in detail to determine any link between the shallow depth of the soil profile and the increase in tree mortalities observed during the second year after grove establishment.

From the surface, root growth was observed as dominantly sub-vertical as opposed to sub-horizontal.

TABLE 6.1: Summary of mortality of *O. europaea* at Davis Well grove (Site 1), between September 1999 and October 2004.

Cultivar	No. Planted	Tree mortalities by year from planting					All deaths (50 mo) + (percent)
		Sept. 1999- Sept. 2000	Sept. 2000- Sept. 2001	Sept. 2001 Sept. 2002	Sept 2002 Sept. 2003	Sept 2003 Sept. 2004	
Ascolana	11		1				1 (9%)
Manzanillo	22	2	2				4 (18%)
New Norcia Mission	17	1	1				2 (5.9%)
UC136A	15		2		1		3 (20%)
Verdale	23	1	3				4 (17%)
Total:	n=88	4	9	0	1	0	14
Mortality Rate (%)		4.5%	10.2%		1.1%		15.9%

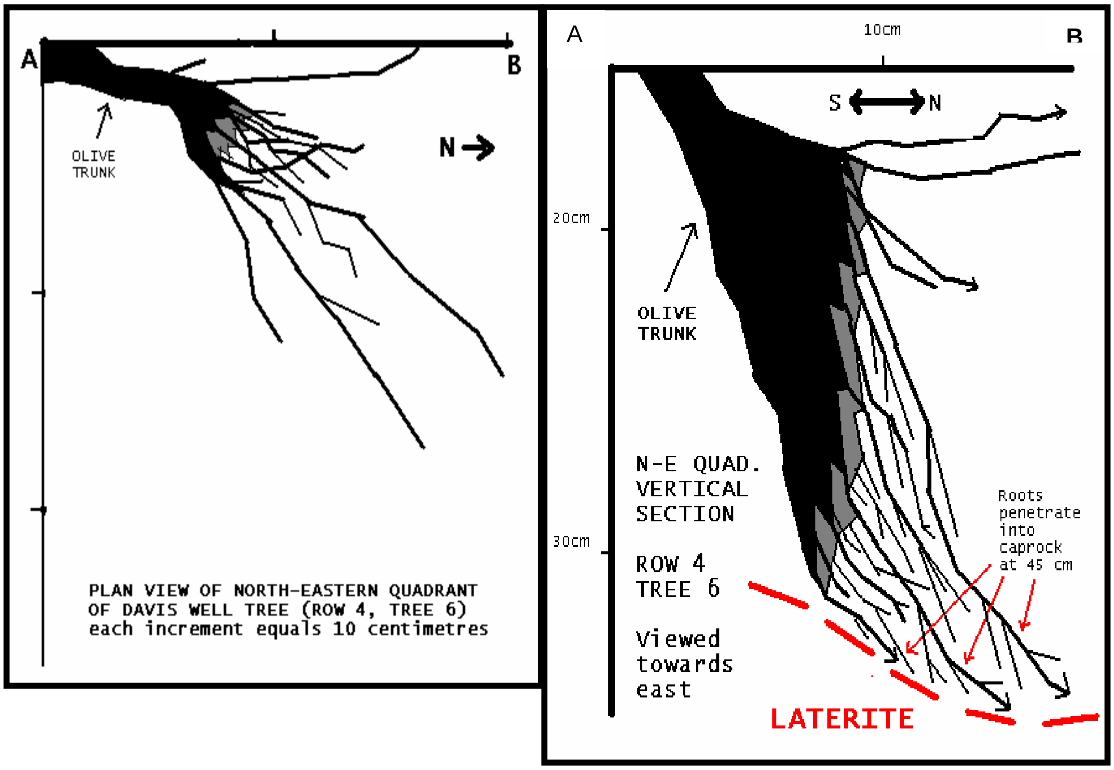
There was little evidence of lateral root growth at shallow depths (in the top 20 cm). Most root growth was observed to be sub-vertical, from this depth, down to 40 to 50 cm depth within the A-horizon (to the laterite). Importantly, the root system failed to penetrate the lateritic horizon. Instead, prolific growth of lateral roots was observed along the top of this impenetrable contact, with only some of the finer roots being noted to have exploited the occasional crack or fracture along the top surface of the laterite.

The clay soil was considered to be heavy and badly aerated, but the absence of roots growing near to surface was in contrast to the typical root system development. The excavations confirmed that root system development differed from that expected of *O. europaea* according to the observations of Pansiot and Rebour (1961). At depth, root growth was constrained by the impermeable laterite horizon. Clearly, this had the potential to impact on growth performance of *O. europaea* planted at this site. The investigation failed to yield any clear relationship between the shallow rooting profile observed in on-site excavations and the increase in tree mortality rates evidenced during the second year of the trial. Consequently, site investigations were broadened to other locations in the study area which aimed at examining tree growth and mortality in relationship to soil depth.

6.1.2) Examinations of nearby sites

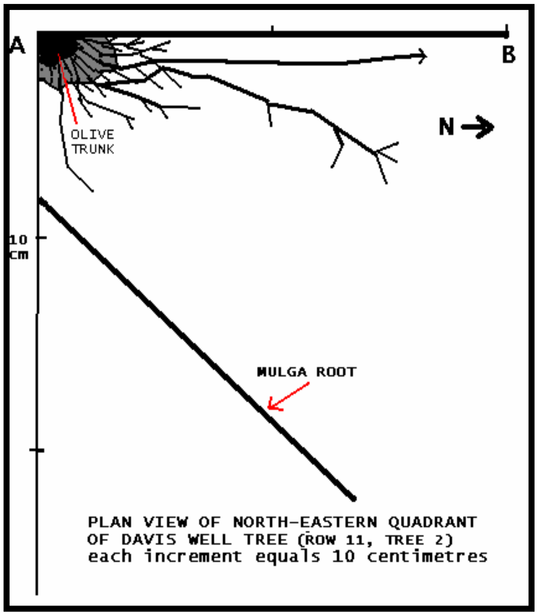
In the immediate area around the grove site, differences were noted in tree growth patterns of native species that also appeared to be related to the shallow depth of the soil profile. Here, old-growth mulga (*Acacia aneura*) was observed as attaining a shorter height compared to the same species in many other parts of Mount Weld pastoral station. This was thought to reflect a shallow soil profile in this area (pers. comm. Barrett-Lennard, 2001). In another location on the nearby Laverton Downs pastoral station, exposed root systems of mulga appeared to also exhibit a similar pattern of root development to that observed with *O. europaea* at the Davis Well site (Plate 6.3). Here, in a shallow soil profile within a heavily eroded exposure, the root system of a single mulga had grown to a shallow depth (less than 50 cm) across the top surface of a hard laterite horizon. Within this exposure, the root system had a dominantly lateral distribution which radiated outward across the top of the exposed laterite. Roots had not infiltrated the laterite owing to its hard and impenetrable nature.

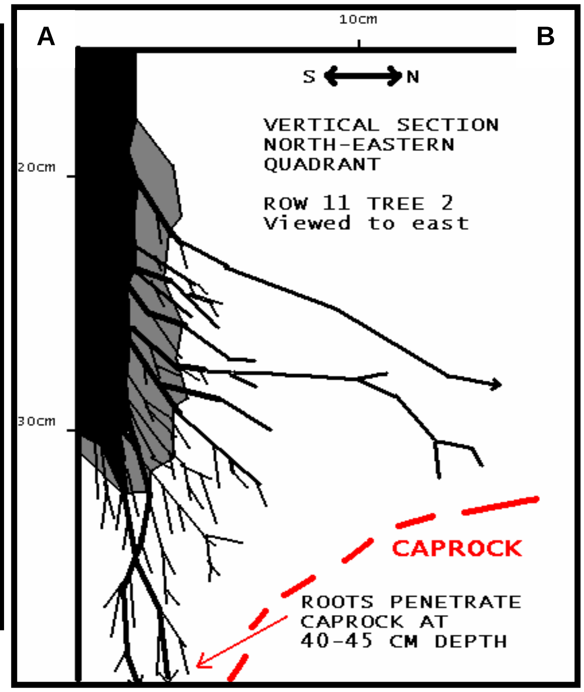
In excavations completed simultaneously at the Jubilee Well grove (Site 2), a site with contrasting soil profile, a different pattern of root growth of *O. europaea* was observed. The soil profile at this site was much deeper, with the soil type being sand, as opposed to the shallow, clay soils at Davis Well. The root systems observed in the Jubilee Well exposures differed considerably, when compared to Davis Well. They typically comprised a single, sub-vertical tap-root, surrounded by a large number of lateral roots that radiated outward at shallow depth (Chapter 7, Plate 7.1 and 2). Unlike the Davis Well exposures, pattern of root growth at Jubilee Well appeared to be similar to observations for root system development in *O. europaea* as described by Connell and Catlin (1994) and Pansiot and Rebour (1961).



FIGURES 6.1-2: Plan and sectional view of root system of tree 6, row 4 at Davis Well grove (Site 1) completed on 17th November 2001. Ticks on axes represent a distance of 10cm.

PLATE 6.1: Photograph of root exposure for tree 6, row 4 at Davis Well grove (Site 1).





FIGURES 6.3-4: Plan and sectional view of root system of tree 2, row 11 at Davis Well grove (Site 1) 17th November 2001. Ticks on axes represent a distance of 10cm.

PLATE 6.2: Photograph of root exposure for tree 2, row 11 at Davis Well grove (Site 1). Tape measure highlights a distance of 30cm.

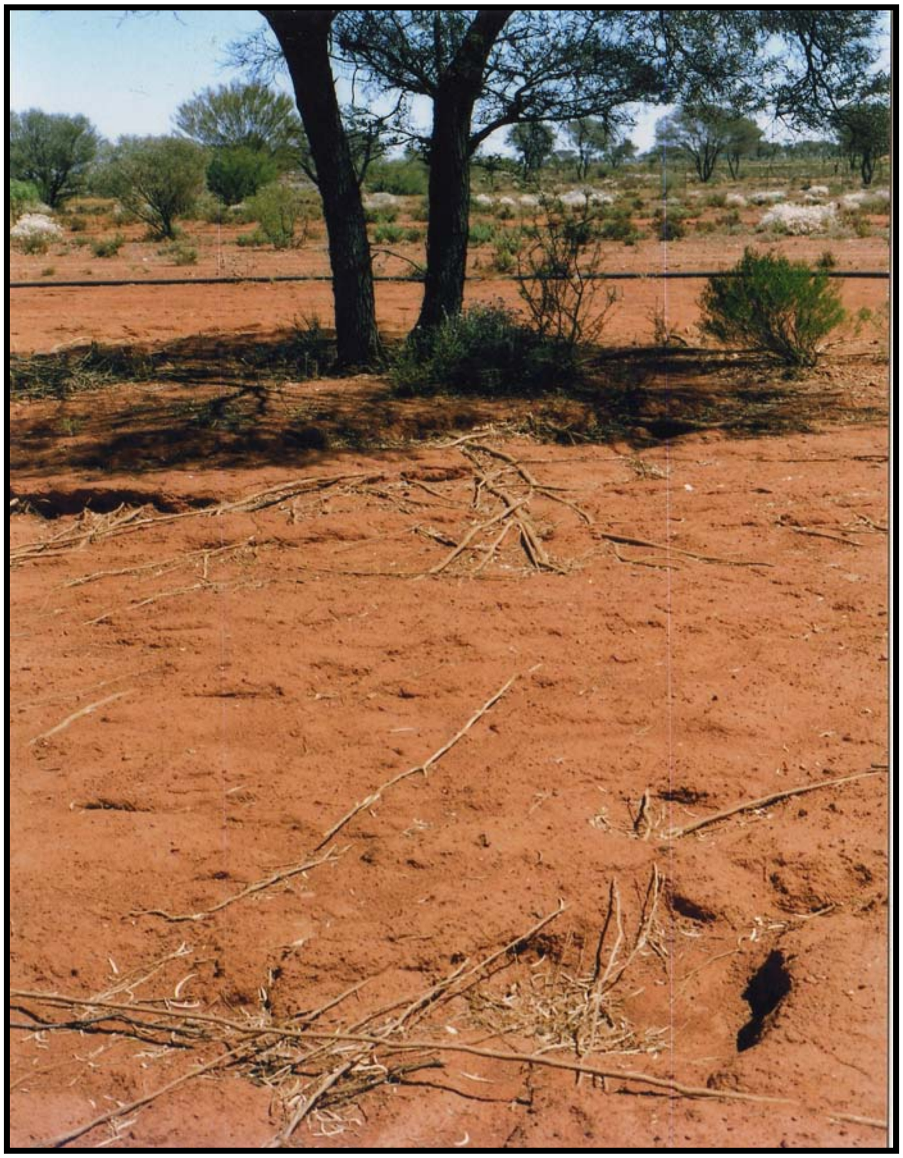


PLATE 6.3: Exposure of roots of mulga (*Acacia aneura*) within creek bed, as a result of heavy erosion. Roots have grown across the top of the impermeable contact with the exposed laterite. Photograph taken in October 2004, on Laverton Downs pastoral station.

The investigations completed at other sites in the study area also failed to identify any relationship between mortality of *O. europaea* and shallowness of soil depth. Consequently, the investigation was broadened to examine other possible causes of tree mortality at the Davis Well site.

6.1.3) Soil texture type and irrigation water quality

Examinations of soil texture and irrigation water quality aimed to identify any relationship with the increase in tree mortality that occurred at Davis Well grove during the second year of the trial. European olive has a low-moderate tolerance to salinity (Maas, 1986). Laboratory testing of a soil sample from the A-horizon confirmed a salinity level of 1.86 dS m^{-1} (Appendix 1) and irrigation water had a salinity level of 0.042 dS m^{-1}. Testing identified relatively low to moderate concentrations of salinity in both soil and water samples. Routine analysis of foliar matter confirmed elevated salinity levels during the first two years of the trial (Appendix 3). Concentrations for sodium and chloride in foliar samples identified concentrations that were all below the toxic threshold during this period (0.2% Sodium and 0.5% Chloride, after Reuter and Robinson, 1997).

Testing of soil, water and foliar matter all confirmed that salinity concentrations were below the toxic threshold for *O. europaea* during the initial two years of the trial. Hence, increases in tree mortality during the second year of the trial are interpreted not to be resultant from toxicity as a function of high salinity.

6.1.4) Salt-waterlogging

At Davis Well, surface soil saturation was frequently observed as a result of heavy rainfall or prolonged irrigation around the trees. Once the soils in the A-horizon became saturated, salt-waterlogging may have occurred and the anaerobic conditions that resulted may have contributed to an increase in tree mortality (interpretation based on conclusions of; Galloway and Davidson, 1991, Connell and Catlin, 1994). Also, once clays dry out, they became dehydrated and set hard, inhibiting root growth. Lack of available soil moisture and the hard setting nature of the clay soil would have hindered root growth during the frequent times when the soil profile was not saturated.

Properties of the clay soil in relation to extremes of moisture availability would have impacted on growth of *O. europaea*. Soil saturation, salt-waterlogging and hard setting all have the potential to affect root growth. There was a lack of lateral root growth at shallow depths in both of the excavations conducted at the Davis Well site which confirms this. Effects of soil saturation, salt-waterlogging and hard setting would have been greatest during the earlier part of the trial. During this period root system development of trees was limited, mostly to shallower depths within the soil profile. The high mortality rates recorded during the initial two years of the trial appear to reflect this. Presumably those trees that died early would have been those most unsuited to growth in this demanding soil type.

Once trees had become more established however root systems had probably expanded to greater depth. Whilst growth of roots was constrained by the impermeable laterite horizon, the distribution was predominantly along the top of the laterite at the base of the clay soil profile. Hence, once trees had become more established, the roots system would be deeper and less prone to being affected by soil properties issues such as soil saturation and salt-waterlogging which is reflected in the lower mortality rates evidenced during the latter part of the trial period.

6.1.5) Competition from native flora

Evidence of competition from native flora was identified during root system excavations that were completed at Davis Well grove during November 2001. In one excavation, a large root of a native species was observed to have grown at shallow depth in close proximity to the main trunk of the olive tree despite the fact that the nearest native tree was located at a distance greater than 10m from the excavation (Figure 6.3). This highlights the possibility that growth of some *O. europaea* may have been affected by native flora growing in the vicinity.

The grove area was cleared and ripped before trees were planted in September 1999, but some of the existing old growth trees within the grove area were left untouched as a conservation measure. Both at the edge and within the grove existing trees are expected to have responded to the stimulii of both irrigation and physical damage caused to lateral roots as a result of the ripping by new root growth. Irrigation was introduced almost simultaneously at each tree site to supply the newly planted olive trees. It was expected that new root growth from the existing natives would have been drawn towards the irrigated tree sites within the grove area.

A review of the tree growth database was conducted for the first two years of the trial, which failed to determine any direct link between competitive effects and tree mortality. Over the duration of the trial, vigorous re-growth of native flora (both grasses and young mulga) was observed to occur within the grove area. Although clearing of native growth was conducted on several occasions over the duration of the trial period (Appendix Plate A1.2), there was the potential that vigorous re-growth may have impacted on the growth of *O. europaea* at the Davis Well grove. The effect of competition from native growth in the grove was not monitored by the author over the duration of the trial however.

6.1.6) Competition from native fauna: termites

The first evidence of termite attack at Davis Well grove was observed in March 2002. From this date monitoring of termite presence within trees was conducted during every site visit until conclusion of the trial. The following statements summarise the conclusions reached from the observations:

Firstly, the pattern of termite attack on trees appeared to be localised to only certain areas of the grove.

PLATE 6.4: Damage to main trunk of an olive tree as a result of rabbit attack at Davis Well grove (Site 1). Photograph taken September 2002.

This was interpreted (by the author), to be proximal to the main nesting site of the termites.

Secondly, termite attack was more frequently on trees that were in poor health. There was an obvious relationship between termite attack and such indicators of declining tree health as; widespread leaf curvature, dull leaf lustre and die-back.

Over the duration of the trial only one tree death was confirmed as resulting from termite attack. This was tree 6, row 2 (cv *UC136A*), which was recorded as a mortality during February 2003. This tree was one of two trees that were initially attacked by termites at Davis Well grove (that attack was recorded in March 2002). Death was a function of poor tree health combined with prolonged termite attack.

Samples of termites were collected from timber within the grove area in spring 2004 for later identification. Subsequent examination by an entomologist during March 2005 revealed these soldier termites to be Heterotermes spp., possibly H. occiduus (after Hill, pers. comm. Heterick, 2005).

6.1.7) Competition from fauna: rabbits

Trees at Davis Well grove (Site 1) were attacked extensively by rabbits during spring 2002 (Plate 6.4). In most of the trees examined small areas of the outer bark in the area above the root bulb had been stripped and eaten by rabbits. In several instances the outer layer of bark had been completely removed, which gave the attacked trees the appearance of being ring-barked. The attacks had not penetrated the underlying layers of bark however, which was probably because this was fresher and more difficult to digest.

The growth database for Davis Well confirmed that 28% of trees showed some evidence of rabbit attack during spring 2002. There were no tree mortalities recorded at Davis Well grove however as a consequence of bark being stripped by rabbits.

6.2) Growth performance

Summaries of mean tree dimensions of survivors by cultivar at the Davis Well grove (Site 1) are presented for the 50 month period between September 2000 and October 2004 in Table 6.2-4.

According to the mean dimensions of surviving trees at Davis Well grove (n=74), a 5.8-fold increase in trunk diameter occurred between September 2000 and October 2004 (50 mo). Highest growth in trunk diameter occurred with cv *New Norcia Mission* (38.2 mm), followed by cv *Verdale* (38.1 mm), *Manzanillo* (37.2 mm), *Ascolana* (31.7 mm) and *UC136A* (28.9 mm) (Table 6.2). Statistical analysis using one-way anova identified no significant difference in growth of trunk diameter between different cvs ($P>0.05$).

TABLE 6.2: Mean trunk diameter (in millimeters) at Davis Well (Site 1), between September 2000 and October 2004 (Standard deviations shown). Measurements taken 30 cm above ground surface.

Cultivar	Number of survivors	Irrigation + rainfed		Rainfed only	Total increase in mean trunk diam. (Sept 00-Oct04)
		Mean trunk diameter (September 2000)	Mean trunk diameter (March 2003)	Mean trunk diameter (October 2004)	
Ascolana	10	6.5 ± 1.1	31.0 ± 10.5	38.2 ± 15.4	31.7
Manzanillo	18	7.0 ± 0.8	30.9 ± 5.2	44.2 ± 9.7	37.2
NN Mission	15	8.8 ± 1.5	33.8 ± 7.8	47.0 ± 13.4	38.2
UC136A	12	7.4 ± 1.7	28.5 ± 10.7	36.3 ± 15.5	28.9
Verdale	19	6.7 ± 1.2	32.2 ± 7.7	44.8 ± 12.4	38.1
Mean:	74	7.3 ± 1.5	31.4 ± 8.1	42.8 ± 13.2	35.5

TABLE 6.3: Mean tree height (in metres) at Davis Well (Site 1), between September 2000 and October 2004 (Standard deviations shown).

Cultivar	Number of survivors	Irrigation + rainfed		Rainfed only	Total increase in mean tree height (Sept 00-Oct04)
		Mean tree height (September 2000)	Mean tree height (March 2003)	Mean tree height (October 2004)	
Ascolana	10	1.09 ± 0.15	1.36 ± 0.30	1.54 ± 0.44	0.45
Manzanillo	18	1.23 ± 0.16	1.59 ± 0.17	1.92 ± 0.24	0.69
NN Mission	15	1.35 ± 0.13	1.71 ± 0.20	1.96 ± 0.29	0.61
UC136A	12	1.05 ± 0.33	1.39 ± 0.36	1.45 ± 0.48	0.40
Verdale	19	1.07 ± 0.20	1.44 ± 0.30	1.79 ± 0.43	0.72
Mean:	74	1.17 ± 0.19	1.51 ± 0.29	1.77 ± 0.31	0.60

TABLE 6.4: Mean canopy diametre (in metres) at Davis Well (Site 1), between September 2000 and October 2004. (Values averaged between N-S and E-W measurements, standard deviations shown).

Cultivar	Number of survivors	Irrigation + rainfed		Rainfed only	Total increase in mean canopy Diameter (Sept 00-Oct04)
		Mean canopy diameter (September 2000)	Mean canopy diameter (March 2003)	Mean canopy diameter (October 2004)	
Ascolana	10	0.33 ± 0.10	1.31 ± 0.37	1.55 ± 0.52	1.22
Manzanillo	18	0.35 ± 0.10	1.33 ± 0.27	1.56 ± 0.24	1.21
NN Mission	15	0.33 ± 0.08	1.36 ± 0.28	1.69 ± 0.30	1.36
UC136A	12	0.34 ± 0.09	1.00 ± 0.36	1.09 ± 0.51	0.75
Verdale	19	0.32 ± 0.12	1.23 ± 0.26	1.43 ± 0.37	1.11
Mean:	74	0.33 ± 0.10	1.25 ± 0.32	1.48 ± 0.37	1.15

A 1.5-fold increase occurred for tree height between September 2000 and October 2004 (50 mo). Highest mean growth in tree height occurred with cv *Verdale* (0.72 m), followed by cv *Manzanillo* (0.69 m), *New Norcia Mission* (0.61 m), *Ascolana* (0.45 m) and *UC136A* (0.40 m) (Table 6.3). Statistical analysis using one-way anova identified an almost significant difference in height between cvs *Verdale* and *Ascolana* (P=0.079).

A 4.4-fold increase occurred in canopy diameter between September 2000 and October 2004 (50 mo). Highest mean growth in canopy diameter occurred with cv *New Norcia Mission* (1.36 m), followed by cv *Ascolana* (1.22 m), *Manzanillo* (1.21 m), *Verdale* (1.11 m) and *UC136A* (0.75 m) (Table 6.4). Statistical analysis with one-way anova (after cosine transformation) identified significant difference in growth of canopy diameter between cv *New Norcia Mission* and *UC136A* (P<0.05).

Statistical comparisons (for trunk diameter, tree height and canopy diameter) among the 5 cultivars trialed at Davis Well grove were not as clear, as they may have been with more trees planted and if planting had followed a randomised design. Also, the spacing between tree rows was different in the last two rows on the western side of Davis Well grove.

6.2.1) Changes in performance under rain-fed conditions

The irrigated water supply was halted during February 2003. From this point, until the end of the trial in October 2004, surviving trees were dependent on rain only for their moisture supply. A comparison was completed for the growth performance of all living trees (n=74), between the first 30 mo of the trial when trees at Davis Well grove regularly received irrigated water, versus the last 20 mo with only rainwater. Monthly means were calculated for each tree dimension to allow for unequal periods (30 mo versus 20 mo).

A 4.2-fold increase in trunk diameter occurred over the first 30 mo when the trees were supplemented by irrigation. This compares with a 1.4-fold increase over the last 20 mo when the trial was rain-fed. That equates to an increase of 0.14-fold/month for the first 30 mo, as opposed to 0.07-fold/month for the last 20 mo of the trial.

For tree height a 1.3-fold increase occurred over the first 30 mo with irrigation, compared with a 1.2-fold increase over the last 20 mo when the trial was rain-fed. That equates to an increase of 0.04-fold/month for the first 30 mo, as opposed to 0.06-fold/month for the last 20 mo of the trial.

In the case of canopy diameter, a 3.7-fold increase occurred over the first 30 mo when supplemented by irrigation. This was compared to a 1.2-fold increase over the last 20 mo with no irrigation. That equates to an increase of 0.13-fold/month for the first 30 mo, as opposed to 0.06-fold/month for the last 20 mo of the trial.

Differences in growth rates are identified between the first 30 mo (irrigated period), verses the last 20 mo (rainfed period). Results assume a linear rate of tree growth however, which is not representative of natural growth patterns for *O. europaea*. Hence, it is not possible to conclude whether the highest rate of growth occurred in the first 30 mo when trees were supplemented by irrigation, verses the last 20 mo when trees were rainfed. Nevertheless, results confirm that mean growth rate of trunk diameter and canopy width both decreased during the rainfed period, compared to when trees where irrigated. The mean growth rate for tree height increased during the rainfed period however.

6.2.2) Tip-extension measurement

Measurements of branch tip extensions were recorded at tree monitoring sessions from September 2000 to April 2004 (44 mo). Most branch markers had been lost or destroyed by this point in the experiment, with the sample population being deemed insufficient to provide a useful set of means. Mean growth data for tip extensions (individual trees) are presented in Appendix 2 (Table A2.1). Mean growth (all cultivars combined) for each of the measurement dates from September 2000 to April 2004 (44 mo) are presented in Figure 6.5.

Comparison of means (all cultivars combined) confirmed differences in growth rates of the selected branch tips between the different measurement periods. Over the 44 mo highest growth rate, or "peak-growth" period for branch tips of *O. europaea* corresponded with spring-summer seasons. Mean growth rates varied between each of the 3 spring-summer seasons however. Mean growth of branch tips during the winter period were considerably lower to negligible in comparison. This suggested that canopy growth of *O. europaea* is much less during winter with the possibility that the trees may have been somewhat dormant for, at least part of the winter season.

6.2.3) Other issues: tree canopy

During the first half of the trial, tree crowns of many trees were observed to be lop-sided with greater foliar growth observed towards the north and north-west direction. This growth pattern was initially interpreted (by the author) as resulting from environmental factors such as prevailing wind direction or orientation of the grove to the progress of the sun's track.

Tip extension measurements have identified the "peak-growth" period for *O. europaea* during spring-summer. During these seasons the prevailing wind direction is east to south-east (Gilligan, 1994). The dominant orientation of canopy growth at Davis Well grove was north and north-west however, which is oblique to the prevailing wind direction documented by Gilligan (1994). Hence it is likely that other

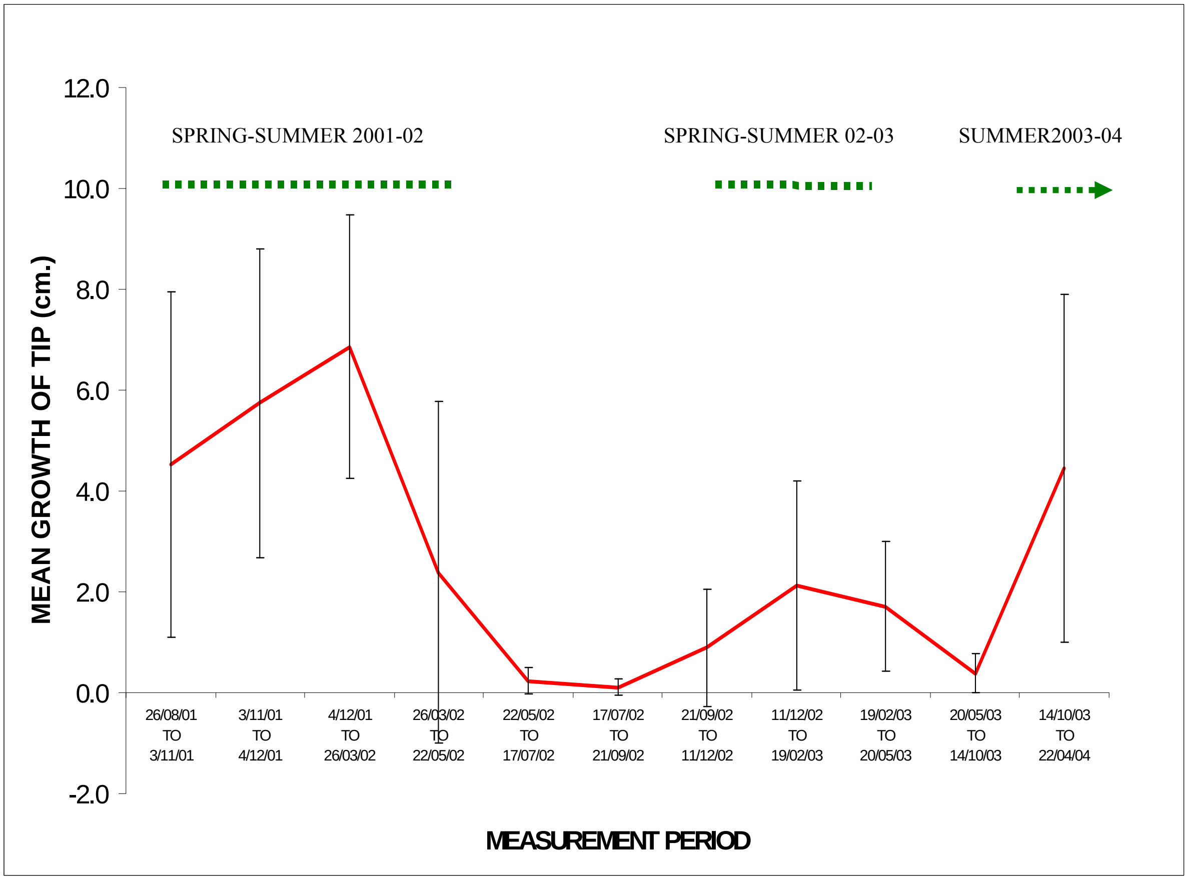


FIGURE 6.5: Mean growth of branch tips for all cultivars combined at the Davis Well grove (Site 1), between September 2000 and April 2004 (44 mo). (Error bars represent Standard Deviations).

factors, apart from prevailing wind direction caused the lop-sided growth of tree canopies at Davis Well.

Before trees were planted at Davis Well the entire area was ripped in a north-south direction. This may have created a propensity for easier root growth along a north-south strike, at least during the early stages of the trial. The growth of the canopy may have also corresponded with the growth of roots in this direction. Although the canopy growth was observed to be oriented predominantly towards the north and north-west during the first half of the trial, canopy growth became more evenly spread during the latter half of the trial. This suggests that once trees had become more established and the root systems better developed, the impact of weather and local site issues had less of an effect on canopy growth trends for trees at Davis Well grove.

6.3) Foliar analysis

Samples of foliar (leaf) matter were collected from selected trees at Davis Well grove to allow the nutrient status of *O. europaea* to be assessed at various times over the duration of the trial. Tables containing analytical results and graphs for all major and trace elements are presented in Appendix 3 (Tables A3.1 to 4, Figures A3.2 to 15). Interpretations of analytical results are presented for each macro and micro-nutrient tested;

Nitrogen:

A macro-nutrient that is mobile, or has a high degree of phloem mobility (Grundon *et al.*, 1997). Concentrations of nitrogen (total) and nitrate (extractable nitrogen) were higher in new growth compared with old growth leaves in all tests. For nitrogen (total) the CSIRO baseline for adequate concentration is 1.5% (no figures are available for nitrate). Concentrations were above the adequate threshold except in March 2005, when % N was marginally deficient in old growth leaves and just above the threshold for adequate in new growth leaves. Analysis highlights a potential deficiency of nitrogen which may have affected tree growth during the latter part of the trial.

Phosphorus:

A macro-nutrient that is mobile, or has a high degree of phloem mobility (Grundon *et al.*, 1997). Apart from the preliminary testing (September 2001), concentrations were higher in new growth compared with old growth leaves in the 3 peak-time tests. For phosphorus the CSIRO baseline for adequate concentration is 0.1%. New growth leaves contained adequate concentrations (all tests). Old growth leaves contained adequate concentrations until March 2002, but were deficient in later tests. A phosphorus deficiency was confirmed by analysis which may have affected tree growth during the latter part of the trial.

Potassium:

A macro-nutrient that is mobile, or has a high degree of phloem mobility (Grundon *et al.*, 1997). *O. europaea* has a high potassium demand especially during fruit production (Fernández-Escobar *et al.*, 1999). Concentrations were higher in new growth compared with old growth leaves in all 4 tests. For potassium the CSIRO baseline for adequate concentration is >0.8%. Both old and new growth leaves had adequate concentrations in all tests, although the concentration of potassium in the old growth sample during March 2003 had decreased to a marginally adequate level. Analysis confirmed that potassium concentrations in leaf matter samples were adequate in all tests.

Sulphur:

A macro-nutrient that is variably mobile, or has a variable degree of phloem mobility within the plant. Sulphur concentrations in old growth leaves do not respond as rapidly to declining nutrient supply compared to younger leaves which are generally the first to show symptoms of nutrient deficiency (Grundon *et al.*, 1997). No CSIRO baseline figures are available and testing was conducted only during the latter 2 tests (March 2003/2005). In March 2003 the concentration was higher in new growth compared with old growth leaves, but in March 2005, this trend was reversed. This appears to indicate the potential deficiency of sulphur in leaf matter that may have impacted on tree growth during the latter part of the trial.

Calcium:

A macro-nutrient that is immobile, or is phloem immobile within the plant. The visual symptoms induced by lack of calcium include; leaf-tip burn on established leaves, tip and marginal burns and distorted leaves with rolled margins on expanding leaves (Grundon *et al.*, 1997). Concentrations were higher in old growth compared with new growth leaves in all tests. For calcium the CSIRO baseline for adequate concentration is >1.0%. For old growth samples the concentration was marginally deficient in September 2001, but adequate in the following 3 tests. New growth samples were deficient in all tests however. A calcium deficiency was confirmed by analysis which may have affected tree growth over the duration of the trial. The occurrence of tip burns on old/new growth leaves, distorted leaves and rolled leaf margins was identified on leaves of many trees during observations conducted by the author. This provides further evidence that a calcium deficiency affected the growth of *O. europaea* at Davis Well grove.

Magnesium:

A macro-nutrient that is mobile, or has a high degree of phloem mobility within the plant (Grundon *et al.*, 1997). Concentrations were higher in old growth compared with new growth leaves in all 4 tests. For magnesium the CSIRO baseline for adequate concentration is 0.10%. Both old and new growth leaves contained adequate concentrations in all tests.

Iron:

A micro-nutrient that is immobile, or is phloem immobile within the plant (Grunton *et al.*, 1997). The symptoms induced by lack of iron are commonly referred to as "iron chlorosis" and are often seen on plants growing on calcareous soils or on soils with high soil pH (Ishizuka *et al.*, 1971). Concentrations were higher in old growth compared with new growth leaves in all tests. No CSIRO baseline figures are available for iron. Visual examination of trees is the best method for diagnosing Fe deficiency, a nutritional problem that negatively affects olives growing in alkaline, calcareous soils (Fernández-Escobar, 1993). Intra-veinal chlorosis was identified on leaves of many trees during observations conducted by the author. This condition is described; veining of individual leaf developed a dull, yellow colouration that affected some to many leaves of most trees during the spring-summer seasons.

The occurrence of iron chlorosis on trees at Davis Well is well documented and suggests that a deficiency in iron may have occurred. Higher concentrations of iron in old growth as opposed to new growth leaves also suggests the potential deficiency of iron owing to its "phloem immobile" status. Hot, dry summers intensify the severity of iron deficiency (Grundon *et al.*, 1997). This was confirmed at Davis Well grove with the occurrence of intra-veinal chlorosis being documented on trees during the spring-summer seasons. Irrigation water from the Davis Well source was confirmed to be highly alkaline (pH=9) which is also expected to have affected the availability of iron to trees and resulted in an iron deficiency.

Manganese:

A micro-nutrient that is immobile, or is phloem immobile within the plant (Grundon *et al.*, 1997). Concentrations were higher in old growth compared with new growth samples for all tests. For manganese the CSIRO baseline for adequate concentration is >20 mg/kg. For both old and new growth samples concentrations were above the adequate threshold in all tests.

Copper:

A micro-nutrient that is variably mobile, or has a variable degree of phloem mobility within the plant (Grundon *et al.*, 1997). Apart from the preliminary testing (September 2001), concentrations were higher in new growth compared with old growth leaves in latter tests. For copper the CSIRO baseline for adequate concentration is >4.0 mg/kg. New growth concentrations were above the adequate threshold in all tests. Old growth concentrations were above the adequate threshold until March 2002, but concentrations became deficient after this test. Thus, copper deficiency may have affected tree growth during the latter part of the trial.

Boron:

A micro-nutrient that is immobile, or is phloem immobile within the plant. It has low to minimal mobility and does not appear to be retranslocated from old leaves to new growth, hence deficiency symptoms usually occur in young growing areas of the plant (Grundon *et al*., 1997). Concentrations fluctuated between both old and new growth leaves in the 4 tests. During the preliminary test in September 2001, concentrations were marginally higher in new growth leaves. In March 2002 concentrations were higher in old growth. In the later tests concentrations were higher in new growth leaves. For boron the CSIRO baseline for adequate concentration is 19-150 mg/kg. Both old and new growth samples contained concentrations that were above the adequate threshold in all tests.

Zinc:

A micro-nutrient that is variably mobile, or has a variable degree of phloem mobility within the plant (Grundon *et al.*, 1997). Concentrations were higher in old growth compared with new growth samples until to March 2002. Concentrations then became higher in new growth samples. For zinc the CSIRO baseline for adequate concentration is 10-30 mg/kg. Concentrations were above the adequate threshold for old and new growth samples in all tests.

Sodium:

Concentrations were higher in old growth, compared to new growth samples except for the March 2003 test. The concentration was only marginally lower for the old growth sample in this test however. For sodium the CSIRO threshold for toxicity is 0.2%. Concentrations were below the toxic threshold for both old and new samples in all tests. Nevertheless, the concentration of sodium was elevated in the old growth leaves during the initial 2 tests suggesting there is potential for salinity issues to occur at Davis Well.

Chloride:

Concentrations were higher in new growth, compared to old growth samples in all tests. For chloride the CSIRO threshold for toxicity is 0.5%. Concentrations were below the toxic threshold for both old and new samples in all tests. Nevertheless, the concentration of chloride was elevated in the new growth leaves in all tests. As with sodium, this suggests there is potential for salinity issues to occur at Davis Well.

6.3.1) Summary: Key macronutrients; nitrogen, phosphorus and potassium

All of these macro-nutrients are mobile, or have a high degree of phloem mobility from leaves and occur in high concentrations in the phloem sap and cycle rapidly through the plant. As the supply becomes limited young leaves retain the nutrients at the expense of older leaves (Smith and Loneragan, 1997). Macro-nutrients are readily retranslocated from old leaves to new growth. Hence, deficiency symptoms usually occur initially in the older leaves (Grundon *et al*., 1997). Concentrations of nitrogen, phosphorus and potassium are commonly higher in new growth compared with old growth leaves in *O. europaea* and alternative bearing will also influence macro-nutrient accumulation in leaf matter (Fernández-Escobar *et al.*, 1999).

6.3.2) Other macro-nutrients; sulphur, calcium and magnesium

These three have different degrees of phloem mobility within the plant (Grundon *et al.*, 1997). Calcium has low to minimal mobility and does not appear to be retranslocated from old leaves to new growth hence, deficiency symptoms generally occur first in young growing areas of the plant (Grundon *et al.*, 1997). For *O. europaea* concentrations of calcium and magnesium are usually higher in old growth leaves, as opposed to new growth leaves (Fernández-Escobar *et al.*, 1999).

6.3.3) Micro-nutrients; iron, manganese, copper, boron and zinc

These are required only in minute quantities for *O. europaea* (Krueger, 1994). The influence of a micro-nutrient deficiency on crop load is barely perceptible, because of the lower requirements of these elements for plant growth (Fernández-Escobar *et al.*, 1999).

6.3.4) Other nutrients; sodium and chloride

High levels of sodium or chloride in the soil or irrigation water can cause toxic reactions as a result of specific ion toxicity in leaves and may also affect water-relations as a result of osmotic effects within the root zone of trees (Connell and Catlin, 1994).

6.3.5) Discussion

Deficiencies of particular macro-nutrients identified by chemical analysis at Davis Well (Site 1) have important implications for growth. To avoid deficiency of macro-nutrients plants must have a continuous supply in the external medium, or be able to tap reserves stored in organs other than leaves. Roots, young leaves, buds, seeds and/or fruits may fail to develop normally when this external supply becomes inadequate (Smith and Loneragan, 1997). As trees at Davis Well grove were not supplied with any fertiliser, either before grove establishment or during the trial, these deficiencies provide an important indication of the naturally occurring soil and water conditions at this site.

The soil pH may impact on the availability of plant nutrient elements (Troug, 1953). The soil and groundwater were highly alkaline hence, a decline in the availability of macro and micro-nutrients was expected particularly during the irrigated period. This is not confirmed by the leaf matter testing however, as concentrations of macro and micro-nutrients generally declined over the duration of the trial.

In the case of macro-nutrients; nitrogen and phosphorus concentrations in old growth samples decreased below the adequate threshold by the final test in March 2005. This suggested that the amount of available nitrogen and phosphorus within the soil profile decreased over time. This was probably related to the natural decrease of soil nutrients as a result of natural processes such as soil leaching, as well as consumption by *O. europaea* and other plant species that become established over the duration of the trial. The deficiency of nitrogen and phosphorus identified in leaf matter reflected a significant decrease in the availability of these important macro-nutrients within the soil. This had the potential to impact significantly on tree health and growth performance of *O. europaea* at least over the latter part of the trial.

A deficiency of calcium occurred in new growth leaves throughout the trial and suggests that the clay soil at Davis Well was calcium-deficient. Although soil was not tested to determine the sodium absorption ratio (SAR), results of leaf matter analysis provides evidence that the clay soil is dominated by sodium, and is deficient in calcium. This was reflected by the swelling and cracking behaviour of this soil type once it became saturated. It was later re-confirmed by the elevated concentrations of sodium identified in leaf matter samples. High sodicity can cause a physical deterioration of the soil which can decrease soil porosity, create water-logging, surface crusting and compaction, which creates problems for root penetration and cultivation (Qureshi and Barrett-Lennard, 1998). For cultivation of *O. europaea*, basic (alkaline) or sodic soils should be avoided (Sibbett and Osgood, 1994). Chemical analysis of leaf matter highlights the calcium-deficient nature of soil at the Davis Well site which may play a role in poor growth of *O. europaea*.

6.4) Flowering and fruiting

No flower formation was observed on tree stock examined prior to planting in September 1999. Flower formation was observed on some trees at Davis Well grove during September 2000. This was before the formal commencement of my MSc. study and flower formation data were not recorded. All flowers were subsequently removed to boost the growth of trees in the early stages after grove establishment.

From this point, successful formation of flowers and fruit was recorded for all trees. Summaries of flower formation rates and olive fruit production at Davis Well grove are presented in Table 6.4 and 6.5. Yearly summaries of flower and fruit data are presented in Appendix 4 (Tables A4.1 to 4).

Season 1: September 2001 to March 2002

Flower formation occurred on only 15% of all trees at Davis Well grove. For these 11 trees a mean of 34.5% of limbs hosted flowers. Flowers were recorded on some trees of 4 of the 5 different cultivars. Most flower formation was recorded on trees of cv *Ascolana* (50% trees flowered). For these 5 trees a mean of 48% of limbs hosted flowers. This was followed by cv *Manzanillo* (17% trees flowered). For these 3 trees a mean of 25% of limbs hosted flowers. Flowers were recorded on only 2 trees of cv *Verdale* (9.5% trees) and one single tree of cv *New Norcia Mission*. No flower formation was observed on trees of cv *UC136A*.

A total of 25 olive fruit (125 g olive fruit) were produced by trees at Davis Well grove during the 2001-02 summer season. Occurrence of olive fruit was recorded on 4 trees (5% trees produced olive fruit). Olive fruit was recorded on two trees of cv *Ascolana*, and one single tree of cvs *Manzanillo* and *Verdale*.

Season 2; September 2002 to April 2003

Flower formation occurred on only 4% of all trees at Davis Well grove. For these 4 trees a mean of 15% of limbs hosted flowers. Flowers were recorded on some trees of 1 out of 5 cultivar (cv *Ascolana*). For this cultivar, a total of 30% trees (3 trees) flowered.

A total of 5 olive fruit (25 g olive fruit) were produced by one tree of cv *Ascolana* at Davis Well grove during the 2002-03 summer season.

Season 3: September 2003 to April 2004

Flower formation occurred on only 10.5% of all trees at Davis Well grove. For these 7 trees, a mean of 58% of limbs hosted flowers. Flowers were recorded on some trees of 2 of the 5 different cultivars. Most flower formation was recorded on trees of cv *Manzanillo* (33.3% trees flowered). For these 6 trees a mean of 57.5% of limbs hosted flowers. This was followed by cv *Ascolana* (10% trees flowered). For this tree 60% of limbs hosted flowers. No flower formation was observed on trees of cv *New Norcia Mission*, *Verdale* or *UC136A*.

No olive fruit was subsequently produced during the 2003-04 summer season.

Season 4: September 2004 to March 2005

Flower formation occurred on only 9.3% of all trees at Davis Well grove. For these 8 trees a mean of 61% of limbs hosted flowers. Flowers were recorded on some trees of all 5 cultivar. Most flower formation was recorded on trees of cv *Verdale* (16% trees flowered). For these 3 trees a mean of 67% of limbs hosted flowers. This was followed by cv *Manzanillo* (11% trees flowered). For these 2 trees a mean of 52.5% of limbs hosted flowers. Flowers were recorded on only 1 tree of cvs *Ascolana* (10% trees), *UC136A* (8.3% trees) and *New Norcia Mission* (6.6% trees).

No olive fruit was subsequently produced during the 2004-05 summer season.

6.4.1) Summary

The most consistent flower formation occurred with cv *Ascolana*. Overall, 25% of trees produced flowers over the 4 consecutive summers examined. This was followed by cv *Manzanillo*, with 20.4%

TABLE 6.5: Mean % flower formation on flowering trees at Davis Well grove (Site 1), between September 2001 and October 2004.

Cultivar	Total Surviving trees	Mean % tree limbs with flowers (+ No. trees)				Mean No. trees with flowers (+ years)
		October 2001	September 2002	October 2003	October 2004	
Ascolana	10	48% (5 trees)	15% (3 trees)	60% (1 tree)	80% (1 tree)	25 (4 years)
New Norcia Mission	15	5% (1 tree)	0	0	25% (1 tree)	6.7 (2 years)
Verdale	19	30% (2 trees)	0	0	67% (3 trees)	13 (2 years)
Manzanillo	18	25% (3 trees)	0	57.5% (6 trees)	52.5% (2 trees)	20.4 (3 years)
UC136A	12	0	0	0	80% (1 tree)	8.3 (1 year)
Mean % limbs with flowers: (+ No. trees)		34.5% (11 trees)	15% (3 trees)	58% (7 trees)	61% (8 trees)	
Trees with flowers (%):	n=74	15%	4%	10.5%	9.3%	

Table 6.6: Total olive fruit production at Davis Well grove (Site 1), between March 2002 and March 2005.

Cultivar	Total Surviving trees	Total number of olive fruit produced (+ No. trees)				Total No. olive fruit (+weight)
		March 2002	March 2003	March 2004	March 2005	
Ascolana	10	20 (2 trees)	5 (1 tree)	0	0	125 (125gms)
New Norcia Mission	15	0	0	0	0	0
Verdale	19	10 (1 tree)	0	0	0	10 (50gms)
Manzanillo	18	20 (1 tree)	0	0	0	20 (100gms)
UC136A	12	0	0	0	0	0
Total No. olive fruit produced: (+ No. trees)	n=74	50 (4 trees)	5 (1 tree)	0	0	55 (275gms)

trees producing flowers during 3 out of the 4 seasons. Flowers were only produced during 2 out of 4 seasons by cv *Verdale* (13% trees produced flowers during both seasons) and cv *New Norcia Mission* (6.7% trees produced flowers during both seasons). The least consistent flower formation occurred with cv *UC136A*, with 8.3% trees producing flowers during the final season only.

Olive fruit production occurred during the first 2 summer seasons only. Most olive fruit was produced by only a few of trees of cv *Ascolana*. Two trees produced 20 olive fruit (100 g olive fruit) during summer 2001-02. One tree produced 5 olive fruit (25 g olive fruit) during the following year. From other cultivar, one single tree of cv *Manzanillo* produced 20 olive fruit (100 g olive fruit) and one single tree of cv *Verdale* produced 10 olive fruit (50 g olive fruit) during the summer 2001-02 season. As a consequence of the small amount of fruit produced no testing could be conducted to confirm the quality of oil produced by olive fruit from trees at Davis Well grove.

6.4.2) Discussion

No examination was conducted to determine the proportion of perfect to staminate flowers produced by trees during each summer season. The total amount of olive fruit produced by trees at Davis Well grove during the first 2 seasons was negligible and no olive fruit was produced during subsequent seasons. This suggests that production of perfect flowers from which olive fruit can successfully develop, was minimal. Stress from lack of water and nutrients during floral development can lead to pistil abortion and large proportions of staminate flowers being produced (Martin, 1994). These conditions were prevalent throughout the duration of the trial hence, most of the flowers produced by trees at Davis Well grove were probably of the staminate variety.

CHAPTER 7: RESULTS AND DISCUSSION

Site#2; Jubilee Well grove

7.1) Tree mortality

At Jubilee Well 98 *O. europaea* were planted. Only 4 trees died between planting in March 2000 and September 2005. This represents a total mortality of 4%, a much better survival rate than attained at Davis Well (Chapter 6) and that suggested by experienced olive growers. One tree was lost in each of the first two years. No deaths were recorded during the third year. Two more trees were lost during the final 18 months of the trial (Table 7.1).

Lower mortality may be a function of the age difference of the tree stock planted. Trees planted at Jubilee Well (Site 2) were 3 yr old, compared to those at Davis Well (Site 1) that were 2 yr old. Jubilee stock was probably hardier, despite a delay of about 6 months before trees were planted. This resulted in some becoming pot-bound. Roots of these had to be broken up by hand on planting. Whilst this was expected to result in some transplant shock, clearly if this did eventuate it was not serious. Perhaps the loosening of roots, with some breakages, may have been beneficial.

The trunk of the first mortality (cv *Leccino*), had been broken previously, at approximately 20 cm above ground level, but the tree failed to re-shoot. Detailed notes were not collected at this point of the study and cause of death of this tree was not clear.

The second mortality was recorded during March 2002 (cv *New Norcia Mission*). This tree death was attributed to a sustained decline in tree health. Partial die-back was observed during spring 2001. Actual death occurred over summer 2002. Remains of this tree were later excavated for the purpose of detailed examination to determine cause of decline in tree health.

The third succumbed during spring 2003 (cv *Kalamata*). This tree was attacked severely by termites, the main trunk was weakened and it subsequently broke-off. The tree failed to re-shoot and by October 2003 was recorded as dead. A number of trees of cv *Kalamata* in this row were also subjected to simultaneous termite attack. Each of these trees were able to withstand the attack by vigorous re-growth however, and all continued to grow.

The final tree succumbed during April 2004 (cv *Kalamata*). This tree was also attacked by termites during spring 2003, but vigorous re-growth occurred (tree condition was documented as being “good” during measurements in February 2003). A considerable amount of die-back of the tree canopy was observed during winter-spring 2003, with tree death recorded during April 2004. This death was attributed to sustained decline in tree health, probably triggered by the initial termite attack.

TABLE 7.1: Summary of mortality of *O. europaea* at Jubilee Well grove (Site 2), between March 2000 and October 2004.

Cultivar	No. planted	Tree mortalities by year from planting					All deaths (56 mo) + (percent)
		March 2000- Feb 2001	March 2001- Feb 2002	March 2002- Feb 2003	March 2003 Feb 2004	March 2004 Oct.2004	
Ascolana	25						0
Kalamata	10				1	1	2 (20%)
J.Kalamata	1						0
Pendolino	2						0
Olea Mission	3						0
N.N.Mission	25		1				1 (4%)
Verdale	9						0
Nabtari	6						0
Leccino	9	1					1 (11%)
Barouni	6						0
Manzanillo	2						0
Total:	n=98	1	1	0	1	1	4
Mortality (%):		1%	1%		1%	1%	4.1%

For the second tree death, the exact cause was not clear. Remains of this tree were later excavated (winter 2002) for detailed examination to determine whether site-related issues had contributed to decline in tree health (Plate 7.1).

The roots of the tree were removed and closely examined. Removed roots presented no evidence of attack by insects or nematode. The root system however, had a rounded geometry, and the diameter of the roots had a spread of only 30-40 cm. This diameter was considerably smaller than expected and appeared to correspond with the diameter of the original hole that this tree was planted in 2 years earlier. The pattern of root growth observed with this tree did not correspond with that observed at the two healthy tree sites excavated at a later date at this (Jubilee Well) grove. Poor development of roots may have resulted from inadequate release from the "pot-bound" condition when originally planted. It was concluded by the author that poor development of the root system after planting resulted in a prolonged decline in tree health which resulted in die-back and eventual tree death during the second year of the trial.

7.1.1) Soil depth

Soil depth at Jubilee Well (Site 2) exceeded 1.2 m, considerably deeper than at Davis Well (Site 1). It is probable that both the greater depth of this soil profile and the coarse, sandy texture of the soil were more suitable for successful growth of *O. europaea* and probably a major factor contributing to the low mortality at Jubilee Well grove. To test this assumption, the root zone of two trees at the Jubilee Well site where excavated during November 2001 (Plate 7.2).

At both tree sites the root system consisted of a large sub-vertical tap-root which had grown below the depth of the excavation. This was surrounded by a large number of lateral roots which radiated outward from the root bulb at a shallow depth below ground surface. Measurements conducted with hand tape confirmed that individual roots had grown to a length of greater than 2 m in both exposures. Although the length of roots was considerably greater than the canopy diameter at both sites, they still appeared to fall within the range of 1.5 tree heights. This is said to be typical of 65% of tree species worldwide (Qureshi and Barrett-Lennard, 1998).

No roots were observed immediately below ground surface. Instead, lateral roots commonly grew at a depth of 10-20 cm. This is thought to be a function of extremely high soil temperatures expected within the top part of the soil profile during the summer months, which are likely to inhibit root growth. There is also a lack of effective rainfall for much of the year which suggests a deficit of available soil-moisture near to ground surface, especially during summer. Both factors would not be conducive for growth of roots immediately below the ground surface within the soil profile.

PLATE 7.1: Photograph of root section of second mortality (tree 14, row 6) from Jubilee Well grove (Site 2). Scale rule represents distance of 30 cm.

PLATE 7.2: Exposure of root section of tree at Jubilee Well grove (Site 2). Shovel represents distance of 150 cm.

Excavation of roots at both tree sites confirmed a root growth pattern similar to the general descriptions of Pansiot and Rebour (1961) for *O. europaea* grown in sandy soils. Thus, greater soil depth and coarse sandy texture at Jubilee Well contributed to successful growth and better survival of *O. europaea* than at Davis Well.

Sandier soils however, do not have good nutrient or water holding capacity and this soil type is difficult to manage for maximum production (Sibbett and Osgood, 1994). Although the low mortality rate appeared to reflect at least the relative suitability of the soil type at Jubilee Well for growth of *O. europaea*, there is evidence to suggest that this soil profile may not be completely suited for successful growth of trees in a commercial manner. It is reported that *O. europaea* prefer loam-type soils which provide aeration for root growth, high permeability and have high water holding capacity (Sibbett and Osgood, 1994).

7.1.2) Competition from native flora

Although the grove area was completely cleared of all native vegetation before trees were planted there was substantial re-growth of native grasses and small trees over the trial period. Although no losses were attributable to competition, growth of *O. europaea* may have been influenced through competition for soil-water and nutrients. The effect of competition from native growth in the grove was not monitored by the author over the duration of the trial however.

7.1.3) Competition from native fauna: termites

First evidence of termite attack at Jubilee Well grove was noted in February 2003, a year after the first attack was observed at Davis Well (Chapter 6). The pattern of termite attack was similar to that at Davis Well. Firstly, termite attack was localised to only certain areas of the grove. Secondly, termite attack was more frequently observed on trees in poor health. The third and fourth tree deaths both occurred during the final 18 months of the trial. Both were attributed to termite attack.

7.1.4) Competition from fauna: rabbits

Trees at Jubilee Well (Site 2) were attacked extensively by rabbits during spring 2002. This was simultaneous with rabbit attacks at Davis Well (Site 1) and the nature of the damage was very similar (outer layer of bark was stripped around the base of many trees). A review of the tree growth database during spring 2002 confirmed that 11.5% of the trees at Jubilee Well grove showed some evidence of rabbit attack. As with the Davis Well (Site 1), no tree mortality was identified at Jubilee Well grove as a result of rabbit attack.

7.2) Growth performance

Summaries of mean tree dimensions of survivors by cultivar at the Jubilee Well grove (Site 2) are presented for the 53 month period between June 2000 and October 2004 in Tables 7.3 to 7.5.

According to the mean dimensions for surviving trees at Jubilee Well grove (n=94), a 3.2-fold increase was attained for trunk diameter between June 2000 and October 2004 (53 mo). Highest mean rate of growth in trunk diameter occurred with cv *Jumbo Kalamata*, (57 mm), followed by cvs *Pendolino* (50 mm), *Leccino* (46.4 mm), *Manzanillo* (37 mm), *Barouni* (34.7 mm), *Verdale* (34.5 mm), *Ascolana* (34 mm), *Olea Mission* (33.7 mm), *New Norcia Mission* (33.1 mm), *Kalamata* (21.3 mm) and *Nabtari* (21 mm) (Table 7.2). Statistical analysis (one-way anova) identified significant differences in growth of trunk diameter among different cultivars ($P<0.05$).

For tree height, a 1.3-fold increase was attained between June 2000 and October 2004 (53 mo). Highest mean rate of growth in tree height occurred with cv *Leccino* (1.09 m), followed by cvs *Manzanillo* (0.87 m), *Pendolino* (0.80 m), *Barouni* (0.71 m), *Jumbo Kalamata*, (0.65 m), *Olea Mission* and *Verdale* (0.49 m), *New Norcia Mission* (0.48 m), *Ascolana* (0.38 m), *Kalamata* (0.10 m) and *Nabtari* (0.02 m) (Table 7.3). Statistical analysis (one-way anova) identified significant differences in growth of tree height among different cultivars ($P<0.05$).

According to the mean data for survivors at Jubilee Well grove (n=94), a 2.5-fold increase occurred in canopy diameter between June 2000 and October 2004 (53 mo). Highest mean growth in canopy diameter occurred with cvs *Jumbo Kalamata* and *Pendolino* (1.50 m), followed by cvs *Leccino* and *Manzanillo* (1.40 m), *Barouni* (1.19 m), *Ascolana* (1.09 m), *Olea Mission* (1.07 m), *Verdale* (1.03 m), *New Norcia Mission* (0.96 m), *Nabtari* (0.64 m) and *Kalamata* (0.61 m) (Table 7.4). Statistical analysis (one-way anova) identified significant differences in growth of canopy diameter among different cultivars ($P<0.05$).

7.2.1) Discussion

Statistical comparisons among the 11 cultivars planted in the Jubilee Well grove suffer from scale and are not presented in detail. There were unequal numbers, planting was not randomised and guard rows were not used. Conclusions regarding performance were generated from a straight comparison of mean growth figures as a consequence.

7.2.2) Changes in performance under rain-fed regimes

The irrigated water supply ceased during February 2003. From this point, until the end of the trial in October 2004, surviving trees were dependent on rain only for their moisture supply. This resulted in reduced available soil moisture during the latter part of the trial with an anticipated subsequent decrease

TABLE 7.2: Mean trunk diameter (millimeters) at Jubilee Well (Site 2), between June 2000 and October 2004 (Standard deviations shown). Measurements taken 30 cm above ground surface.

Cultivar	No. Planted	Irrigation + rainfed		Rainfed only	Total increase in mean trunk diam. (June 00-Oct 04)
		Mean trunk diameter (June 2000)	Mean trunk diameter (Feb 2003)	Mean trunk diameter (October 2004)	
Ascolana	25	16.1 ± 2.0	42.7 ± 5.0	50.1 ± 6.8	34.0
Barouni	6	17.8 ± 3.8	43.0 ± 8.2	52.5 ± 9.5	34.7
Kalamata	8	13.6 ± 1.9	34.0 ± 7.6	34.9 ± 16.6	21.3
Leccino	8	15.5 ± 3.4	46.5 ± 14.8	61.9 ± 21.2	46.4
Manzanillo	2	11.0 ± 1.4	39.0 ± 1.4	48.0 ± 1.4	37.0
Nabtari	6	14.3 ± 1.2	30.8 ± 2.6	35.3 ± 2.4	21.0
N.N. Mission	24	20.2 ± 2.6	44.7 ± 11.3	53.3 ± 15.2	33.1
O. Mission	3	20.0 ± 2.7	45.3 ± 8.0	53.7 ± 8.7	33.7
Pendolino	2	12.5 ± 0.7	49.0 ± 14.1	62.5 ± 19.1	50.0
Verdale	9	13.7 ± 1.8	41.1 ± 5.7	48.2 ± 5.5	34.5
J. Kalamata	1	21.0	59.0	78.0	57.0
Mean:	94	16.64 ± 3.51	42.20 ± 9.54	50.27 ± 14.07	33.63

TABLE 7.3: Mean tree height (metres) at Jubilee Well (Site 2), between June 2000 and October 2004 (Standard deviations shown).

Cultivar	No. Planted	Irrigation + rainfed		Rainfed only	Total increase in mean tree height (June 00-Oct 04)
		Mean tree height (June 2000)	Mean tree height (Feb 2003)	Mean tree height (October 2004)	
Ascolana	25	1.62 ± 0.17	1.97 ± 0.23	2.00 ± 0.22	0.38
Barouni	6	1.34 ± 0.55	1.98 ± 0.55	2.05 ± 0.58	0.71
Kalamata	8	1.53 ± 0.19	1.85 ± 0.30	1.63 ± 0.67	0.10
Leccino	8	1.35 ± 0.32	2.23 ± 0.44	2.44 ± 0.48	1.09
Manzanillo	2	1.28 ± 0.04	1.98 ± 0.11	2.15 ± 0.21	0.87
Nabtari	6	1.62 ± 0.22	1.63 ± 0.12	1.64 ± 0.16	0.02
N.N. Mission	24	1.70 ± 0.20	2.12 ± 0.40	2.18 ± 0.42	0.48
O. Mission	3	1.68 ± 0.23	2.10 ± 0.36	2.17 ± 0.32	0.49
Pendolino	2	1.10 ± 0	1.85 ± 0.28	1.90 ± 0.28	0.80
Verdale	9	1.52 ± 0.23	1.93 ± 0.15	2.01 ± 0.20	0.49
J. Kalamata	1	1.95	2.50	2.60	0.65
Mean:	94	1.568 ± 0.27	2.001 ± 0.35	2.045 ± 0.43	0.477

TABLE 7.4: Mean canopy diametre (metres) at Jubilee Well (Site 2), between June 2000 and October 2004. (Values averaged between N-S and E-W measurements, standard deviations shown).

Cultivar	No. Planted	Irrigation + rainfed		Rainfed only	Total increase in mean canopy diameter (June 00-Oct 04)
		Mean canopy diameter (June 2000)	Mean canopy diameter (Feb 2003)	Mean canopy diameter (October 2004)	
Ascolana	25	0.67 ± 0.12	1.43 ± 0.18	1.76 ± 0.22	1.09
Barouni	6	0.59 ± 0.10	1.43 ± 0.28	1.78 ± 0.34	1.19
Kalamata	8	0.59 ± 0.15	1.12 ± 0.19	1.20 ± 0.52	0.61
Leccino	8	0.66 ± 0.20	1.39 ± 0.37	2.06 ± 0.65	1.40
Manzanillo	2	0.48 ± 0.11	1.40 ± 0	1.88 ± 0.18	1.40
Nabtari	6	0.68 ± 0.09	1.17 ± 0.08	1.32 ± 0.09	0.64
N.N. Mission	24	0.80 ± 0.18	1.37 ± 0.33	1.76 ± 0.44	0.96
O. Mission	3	0.80 ± 0.10	1.42 ± 0.13	1.87 ± 0.32	1.07
Pendolino	2	0.55 ± 0.14	1.93 ± 0.32	2.05 ± 0.21	1.50
Verdale	9	0.61 ± 0.22	1.29 ± 0.18	1.64 ± 0.16	1.03
J. Kalamata	1	0.70	1.60	2.20	1.50
Mean:	94	0.683 ± 0.17	1.368 ± 0.27	1.716 ± 0.42	1.033

in the growth of *O. europaea*. To test this a comparison was completed for mean apparent change between the first 33 mo of the trial, when trees at Jubilee Well received irrigation, versus the last 20 mo, with only rainwater. Monthly means were calculated for each tree dimension to allow for unequal periods (33 mo verses 20 mo).

For trunk diameter; a 2.5-fold increase occurred over the first 33 mo, compared to a 1.2-fold increase over the last 20 mo when the trial was rain-fed. That equates to an increase of 0.07-fold/month for the first 33 mo, as opposed to 0.06-fold/month for the last 20 mo of the trial.

For tree height; a 1.3-fold increase occurred over the first 33 mo, compared to a 1.0-fold increase over the last 20 mo. That equates to an increase of 0.04-fold/month for the first 33 mo, as opposed to 0.05-fold/month for the last 20 mo of the trial.

For canopy diameter; a 2.0-fold increase occurred over the first 33 mo, with irrigation, compared to a 1.3-fold increase over the last 20 mo, with no irrigation. That equates to an increase of 0.06-fold/month for the first 33 mo, as opposed to 0.07-fold/month for the last 20 mo of the trial.

Differences in growth rates are identified between the first 33 mo (irrigated period), verses the last 20 mo (rainfed period). Results assume a linear rate of tree growth however, which is not representative of natural growth patterns for *O. europaea*. Hence, it is not possible to conclude whether the highest rate of growth occurred in the first 33 mo when trees were supplemented by irrigation, verses the last 20 mo when trees were rainfed. Nevertheless, results confirm that mean growth rate of tree height and canopy width both increased during the rainfed period, compared to when trees where irrigated. The mean growth rate for tree height decreased during the rainfed period however.

7.2.3) Tip-extension measurements

An analysis of the growth pattern of branch tips of was completed from September 2000 to April 2004 (44 months) on a population of 10 selected trees at Jubilee Well grove (Site 2). Mean growth of tip extensions (individual trees) are presented in Appendix 2 (TableA2.2). Mean growth (all cultivars combined) for each of the measurement dates between September 2000 to April 2004 are presented in Figure 7.1.

Comparison of means (all cultivars combined) confirmed differences in growth rates of the selected branch tips between measurement periods. Over the 44 mo, highest growth rates, or “peak-growth” period for branch tips of *O. europaea* corresponded with the spring-summer seasons. Mean growth rates varied between each of the 3 spring-summer seasons however. Mean growth of branch tips during the winter period were very low to negligible in comparison. This suggests that canopy growth of *O.*

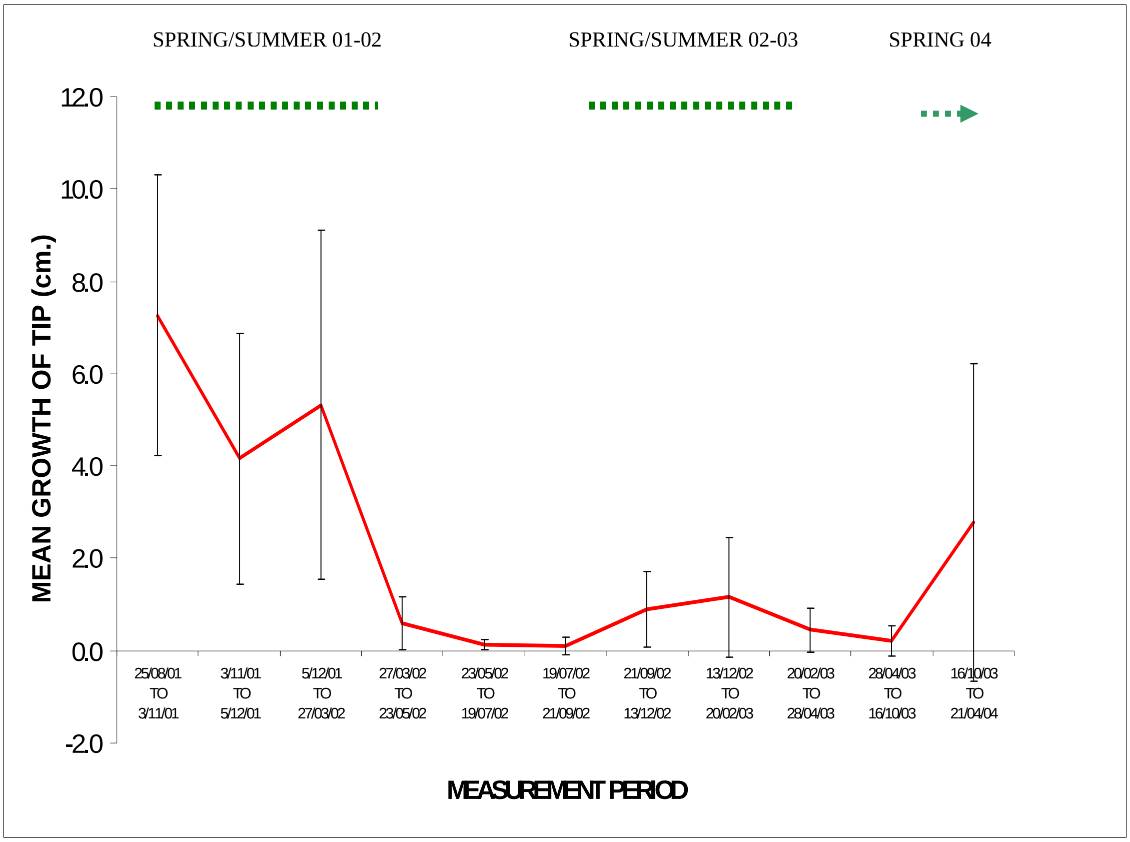


FIGURE 7.1: Mean growth of branch tips for all cultivars combined at Jubilee Well grove (Site 2), between September 2000 and April 2004 (44 months). (Error bars represent standard deviations).

europaea is much less during winter, with the possibility that the trees may have been somewhat dormant for at least part of the winter season. This pattern of growth of leaf tips is similar to that identified in *O. europaea* at Davis Well grove (Chapter 6).

7.3) Foliar analysis

Samples of foliar matter were collected from selected trees to allow the nutrient status of *O. europaea* growing at Jubilee Well grove to be assessed over the duration of the trial period. Tables containing analytical results and graphs for all major and trace elements are presented in Appendix 3 (Tables A3.5 to 8, Figures A3.16 to 29). Interpretations of analytical results are presented for each macro and micro-nutrient tested;

Nitrogen:

Apart from the preliminary testing (September 2001), concentrations of nitrogen (total) and nitrate (extractable nitrogen) were higher in new growth than in old growth leaves. Concentrations were below the deficient threshold in all tests, except for old growth in September 2001 and new growth leaves in March 2003. Nitrogen deficiency may well have affected tree growth during much of the trial.

Phosphorus:

Concentrations of phosphorus were higher in new growth than in old growth leaves in all 4 tests. Concentrations were below the deficient threshold in all samples, except for new growth in March 2003. This deficiency in phosphorus may have adversely affected tree growth during much of the trial.

Potassium:

Apart from the peak-time test in March 2002, concentrations were higher in new growth compared to old growth leaves. Concentrations were above the adequate threshold for old and new growth samples in all tests. Soils of the site have allowed olive trees to secure adequate concentration of potassium in leaf tissues over the duration of the trial.

Sulphur:

Testing was conducted only during the latter 2 tests (March 2003/2005). In March 2003 concentrations were similar in old and new growth leaves, but in March 2005 the concentration was higher in the old growth than in the new growth sample. This suggests potential deficiency of sulphur in leaf matter that may have impacted on tree growth during the latter part of the trial.

Calcium:

Concentrations were higher in old growth compared with new growth samples in all tests. In old growth samples the concentration was marginally deficient in September 2001, but above the adequate threshold in later tests. New growth samples were deficient in all tests however. Calcium deficiency may have affected tree growth over the duration of the trial. The occurrence of visual indicators of calcium deficiency, such as tip burns, distorted and rolled leaves were also noted by the author, providing further evidence of calcium deficiency at this site during the trial.

Magnesium:

Apart from March 2003 concentrations were higher in old growth compared with new growth samples. Concentrations were above the adequate threshold for old and new growth samples in all tests, except for new growth in March 2001, which was borderline adequate. Thus, an adequate concentration of magnesium was present in leaf tissue over the duration of the trial.

Iron:

Apart from March 2003 concentrations were higher in old growth compared with new growth samples. No CSIRO baseline figures are available for iron and visual examination is the best method for diagnosing Fe deficiency. Intra-veinal chlorosis was identified on leaves of many trees during observations conducted by the author (Plate 7.3-4). This occurred during every spring-summer season over the trial period suggesting the possibility of seasonal iron deficiency.

Manganese:

Concentrations were higher in old growth compared with new growth samples in all tests. All samples returned concentrations above the adequate threshold in both old and new growth samples.

Copper:

Concentrations were higher in new growth compared with old growth samples in all tests. Concentrations in new growth samples were above the adequate threshold in all tests. Concentrations in old growth leaves were above the adequate threshold until March 2003, but then became deficient in the final test (March 2005). Thus, a copper deficiency may have affected tree growth during the later part of the trial.

Boron:

Concentrations were higher in new growth, compared with old growth samples in all tests. For old growth samples the concentration was marginally deficient in the preliminary test (Sept. 2001), but above the adequate threshold in the next 3 tests. New growth concentrations were adequate in all tests. Apart from the preliminary test, analysis suggests that boron concentration in leaf matter was adequate for most of the trial period.

PLATE 7.3: Yellowing of leaves of *O. europaea* as a result of iron deficiency during spring season. Photograph taken during September 2001 at Jubilee Well grove (Site 2).

PLATE 7.4: Visible chlorosis on leaves of *O. europaea* as a result of iron deficiency during spring season. Photograph taken during September 2001 at Jubilee Well grove (Site 2).

Zinc:

Apart from March 2002 concentrations were higher in new growth compared with old growth samples. For both old and new growth samples concentrations were adequate in all tests. However, concentrations in both old/new growth were borderline adequate in March 2005. Analysis suggests that adequate concentrations of zinc were present in leaf matter over the trial period, but concentration declined to become close to deficient towards the end of the trial period.

Sodium:

Concentrations were higher in old growth compared with new growth samples in all tests. Concentrations were below the toxic threshold for both old and new growth samples in all tests. Nevertheless, the concentration of sodium was elevated in old growth samples, especially in March 2002. This suggest there is potential for salinity issues to occur at Jubilee Well.

Chloride:

Concentrations were higher in new growth compared with old growth samples in all tests. Concentrations were below the toxic threshold for both old and new growth samples in all tests. Nevertheless, the concentration of chloride was elevated in old growth samples, especially at the September 2001 test and, as with sodium, this suggests the potential for salinity issues to occur.

7.3.1) Discussion

Foliar nutrient analysis confirmed higher concentrations of nitrogen, phosphorus and potassium in new growth, compared to old growth samples in all tests. Analysis of other macro-nutrients: calcium and magnesium confirmed higher concentrations in old growth in comparison. These results are in general agreement with other findings (e.g. Smith and Loneragan, 1997; Grundon *et al*., 1997; Fernández-Escobar *et al*., 1999), regarding the degree of phleom mobility of each of these major nutrient elements.

7.4) Flowering and fruiting

Flower formation was first evident on some of the rootstock that arrived on-site during September 1999. Some of this stock produced small quantities of olive fruit during the subsequent summer period, whilst trees were still in the pots. During September 2000 occurrence of flower formation was observed on some of the trees. All flowers were removed at this time to prevent formation of olive fruits and to further promote tree growth. No record was kept of rates of flower or olive fruit formed during the first two spring-summer seasons as these events occurred before the formal commencement of the MSc. study.

From this point (September 2001), successful formation of flowers and olive fruit were found for all trees of the Jubilee Well grove. A summary of flower formation and olive fruit formation is given in

Table 7.5 and 7.6. Yearly summaries are presented in Appendix 4 (Tables A4.5 to 7).

Season 1: September 2001 to March 2002

Flower formation occurred on 64% of trees. For these 60 trees, a mean figure of one-third of all limbs hosted flowers. Flowers were recorded on some trees of 9 of the 11 different cultivars. No flower formation was observed on any trees of cvs *Barouni* or *Manzanillo*.

A total of 2343 olive fruit (about 7.5kg of olive fruit) were harvested during March 2002. Olive fruit formation occurred on 48 out of the 60 trees that originally flowered. Olive fruit production was recorded on some trees of each cultivar that produced flowers during September 2001 (Plate 7.6).

Season 2: September 2002 to March 2003

No inflorescence was observed on any tree during September 2002 and consequently, no olive fruit formation occurred.

Season 3: September 2003 to March 2004

Flower formation occurred on 12.8% of trees. For these 12 trees a mean of 35% of limbs hosted flowers. Flowers were recorded on some trees of 6 of the 11 different cultivars represented. No flower formation was observed on any trees of cv *Kalamata, Pendolino, Olea Mission, Nabtari* or *Barouni*.

A total of 14 olive fruit (less than 100g of olive fruit) were harvested during March 2004. Olive fruit production occurred on 2 of the 12 trees that originally flowered. This included one tree each of the cvs *New Norcia Mission* and *Verdale*.

Season 4: September 2004 to March 2005

Flower formation occurred on 80% of tree. For these 75 trees a mean of 74% of limbs hosted flowers (Plate 7.5). Flowers were recorded on some trees of all 11 different cultivars.

A total of 1775 olive fruit (approximately 8kg of olive fruit) was harvested during March 2002. Olive fruit formation occurred on 47 of the 75 trees that originally flowered. Olive fruit production was recorded on some trees of 10 of 11 cultivars that had produced flowers during September 2001. No fruit production was recorded on trees of cv *Pendolino*.

7.4.1) Summary

Flower production was recorded on some trees of 5 different cultivars during 3 out of 4 years (no flowers in spring-summer 2002-03). The most consistent cultivars were cv *Jumbo Kalamata* (one tree produced flowers during 3 years), cv *New Norcia Mission* (66.7% trees produced flowers during 3 years), cv

TABLE 7.5: Mean % tree limbs with flower formation on flowering trees at Jubilee Well grove (Site 2), between September 2001 and October 2004.

Cultivar	Total surviving trees	Mean % tree limbs with flowers (+trees)				Mean No. trees with flowers (+years)
		October 2001	September 2002	September 2003	October 2004	
Ascolana	25	37.5% (10 trees)		30% (1 tree)	86.3% (12 trees)	30.7 (3 years)
Kalamata	8	33.3% (9 trees)			56% (5 trees)	76.3 (2 years)
Jumbo Kalamata	1	5% (1 tree)		65% (1 tree)	95% (1 tree)	100 (3 years)
Pendolino	2	32.5% (1 tree)			25% (2 trees)	75 (2 years)
Olea Mission	3	8.3% (2 trees)			73.3% (3 trees)	50.3 (2 years)
New Norcia Mission	24	25.5% (20 trees)		30.7% (7 trees)	75.2% (21 trees)	66.7 (3 years)
Verdale	9	45.6% (8 trees)		20% (1 tree)	82.8% (9 trees)	66.4 (3 years)
Nabtari	6	50.8% (6 trees)			95% (6 trees)	100 (2 years)
Leccino	8	45% (2 trees)		5% (1 tree)	58.8% (8 trees)	45.8 (3 years)
Barouni	6				47.5% (6 trees)	100 (1 year)
Manzanillo	2			90% (1 tree)	95% (2 trees)	75 (2 years)
Mean limbs with flowers (%): (+ No. trees)		33.3% (60 trees)		35.4% (12 trees)	73.6% (75 trees)	
Trees with flowers (%):	n=94	63.8%		12.8%	79.8%	

Table 7.6: Summary of olive fruit production at Jubilee Well grove (Site 2), between March 2002 and March 2005.

Cultivar	Total surviving trees	Total number of olive fruit produced (+ trees)				Total No. olive fruit produced (+ weight)
		March 2002	March 2003	March 2004	March 2005	
Ascolana	25	70 (6 trees)			25 (1 tree)	95 (475g)
Kalamata	8	31 (5 trees)			10 (3 trees)	41 (205g)
Jumbo Kalamata	1	23 (1 tree)			43 (1 tree)	66 (330g)
Pendolino	2	13 (1 tree)				13 (65g)
Olea Mission	3	163 (2 trees)			79 (2 trees)	242 (1210g)
New Norcia Mission	24	1198 (18 trees)		4 (1 tree)	455 (15 trees)	1657 (8285g)
Verdale	9	567 (7 trees)		10 (1 tree)	274 (9 trees)	851 (4255g)
Nabtari	6	265 (6 trees)			62 (5 trees)	327 (1635g)
Leccino	8	13 (2 trees)			723 (7 trees)	736 (3680g)
Barouni	6				60 (2 trees)	60 (300g)
Manzanillo	2				44 (2 trees)	44 (220 g)
Total No. olive fruit produced: (+ No. trees)	94	2343 (48 trees)		14 (2 trees)	1775 (47 trees)	4132 (20.66kg)

Verdale (66.4% trees produced flowers during 3 years), cv *Leccino* (45.8% trees produced flowers during 3 years) and cv *Ascolana* (30.7% trees produced flowers during 3 years).

Five other cultivars showed flower formation in 2 out of 4 years. These were cvs: *Nabtari* (100% trees produced flowers during 2 years), *Kalamata* (76.3% trees produced flowers during 2 years), *Pendolino and Manzanillo* (75% trees produced flowers during 2 years) and *Olea Mission* (50.3% trees produced flowers during 2 years). The least consistent flowering was in cv *Barouni* (100% trees with flowers during final year).

Olive fruit production occurred during 3 out of 4 years in two cultivars only (no olive fruit occurred during spring-summer 2002-03). The most consistent cultivars in terms of fruiting over the duration of the trial were cv *New Norcia Mission* (47.2% trees produced 1657 olive fruit during 3 years) and cv *Verdale* (63% trees produced 851 olive fruit during 3 years). These cultivars also produced the largest percentage of olive fruit over the duration of the trial.

The next most consistent cultivars (producing olive fruit during 2 seasons) included; cv *Leccino* (52.9% trees produced 736 olive fruit during 2 years), followed by cvs *Nabtari* (91.7% trees produced 327 olive fruit during 2 years), *Olea Mission* (66.7% trees produced 242 olive fruit during 2 years), *Ascolana* (14% trees produced 95 olive fruit during 2 years), *Jumbo Kalamata* (one tree produced 66 olive fruit during 2 years) and *Kalamata* (44.4% trees produced 41 olive fruit during 2 years). The least consistent producers of olive fruit were cv *Barouni* (2 trees produced 60 olive fruit during the final year), cv *Manzanillo* (both trees produced 44 olive fruit during the final year) and cv *Pendolino* (one tree produced 13 olive fruit during the first year only).

Comparisons between different cultivar for flower and olive fruit production were complicated by the small number of trees of some cultivars at Jubilee Well (6 cultivars had a sample population of 6 or fewer trees). Nevertheless, the most consistent production of olive fruit occurred from trees of cvs *New Norcia Mission* and *Verdale*. The greatest quantity of olive fruit was successfully produced by some trees of these cultivars during 3 of 4 spring-summer seasons. Although trees of the other 9 cultivars also produced olive fruit, they were less consistent and total volume produced was less. For several of these cultivars the amount of olive fruit produced over the duration of the trial was negligible.

7.4.2) Discussion

At Jubilee Well the timing of floral induction occurred during early September (start of spring), with the olive harvest occurring during the middle of March. Observations at Jubilee Well grove indicated a time period of between 150-170 days from flower to fruit. Olive fruits are ready to be harvested about 180-200 days after full bloom, but the interval is shorter for table cultivars which are harvested at green

PLATE 7.5: Flower formation visible on olive tree at Jubilee Well grove (Site 2). Photograph taken September 2004.

PLATE 7.6: Olive fruit on tree at Jubilee Well grove (Site 2). Photograph taken February 2002.

maturation (Gucci and Cantini, 2002). The timing of floral induction (inflorescence) and olive fruit harvest also occurred approximately 1-2 months earlier, compared with other olive producing areas with more temperate climates. This is based on observations conducted by the author of olive trees in many locations in coastal southern Australia, confirming that floral induction (inflorescence) occurred during October-November, with harvest of ripe olive fruit during April-May by comparison.

In studies of olive groves conducted in Italy summer drought greatly reduces fruit growth, yield and oil accumulation but it enhances pre-harvest fruit drop and shortens fruit harvest time (Inglese *et al.,* 1997). Other studies have shown that low crop load advances and shortens fruit ripening. Hence, the shorter fruit maturation period and earlier occurrence of inflorescence and fruit ripening observed at Jubilee Well were probably related to both climatic and site-related factors.

At Jubilee Well grove the timing of the two most successful years for flower production (2001-02 and 2004-05) appears to correlate closely with the occurrence of heavy rainfall (Figure 7.2). Both years were preceded by heavy rainfall (flood-events) which occurred late during the previous summer season. These heavy rains are a consequence of cyclone-related weather patterns typical for this region during the summer period (Gilligan, 1994). Minimal to negligible flower formation was observed in the other two years (2002-04 and 2003-04), which were preceded by drier conditions (no flood-events).

Typically during the summer period, rainfall effectiveness is low in semi-arid environments. Trees are subjected to a moderate to severe moisture deficit, with minor growth only being observed as a result of the heaviest rainfall (Gilligan, 1994). Apart from growth rates, the rainfall effectiveness may also influence other issues, including tree health and the amount of flower formation that occurs from year to year in this environment. For *O. europaea*, the bud is usually formed on the current season's growth and begins visible growth the following season. Buds may remain dormant for more than a year however, forming viable inflorescence with flowers a season later than expected (Martin, 1994). Whilst this appears to have occurred at Jubilee Well grove, the reasons for bud dormancy are not completely clear.

High temperatures (>32ºC) during flowering and the immediately following period reduce and even eliminate fruit set in the olive (Porlingis and Voyiatzis, 1997). Whilst there is a possibility that high temperatures during the spring period may have reduced flower formation, this would also have been influenced to a certain extent by the degree of irrigation deficit to which the trees were subjected. During inflorescence, water-stress and/or nutrient deficit can lead to pistil abortion, triggering formation of staminate flowers which results in abscission of flower and young fruit abscission (Martin, 1994). A similar correlation between bud dormancy and soil-water deficit is also postulated by the author.

Similar links between rainfall and flower formation have been identified with certain native species

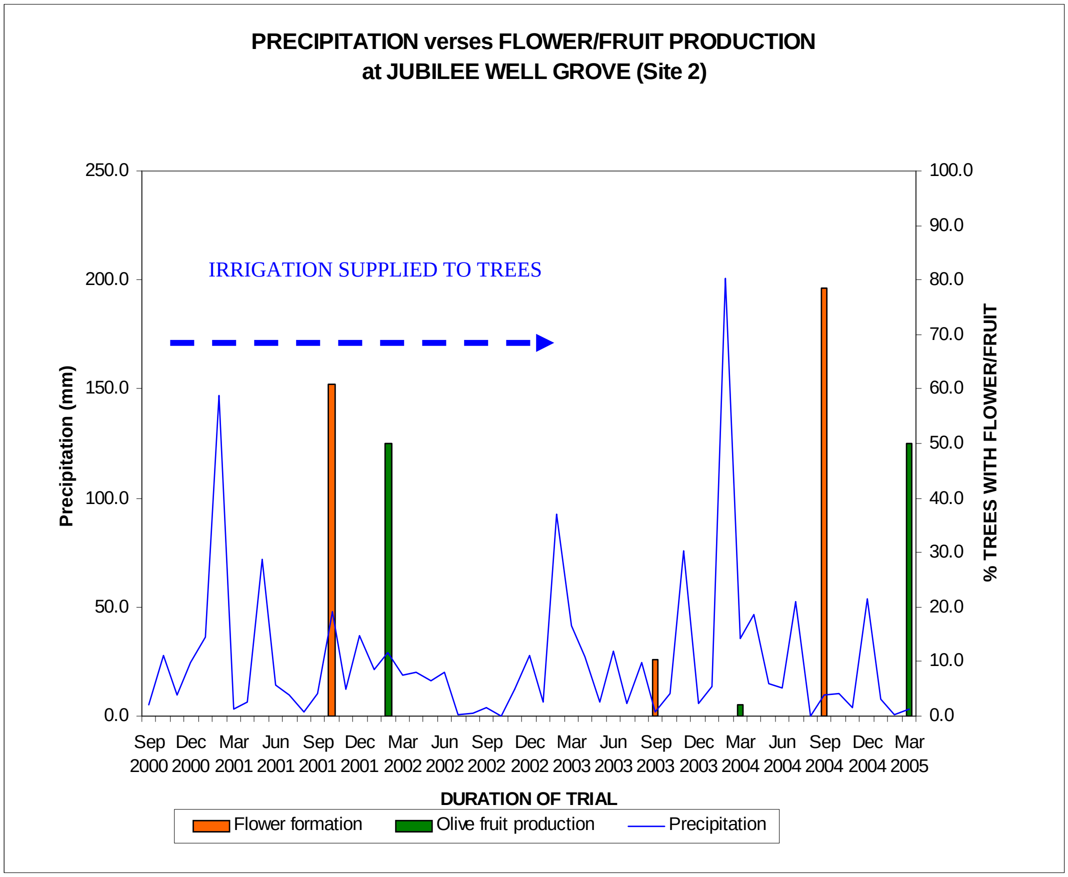


FIGURE 7.2: Precipitation received, and percentage of flowers and olive fruit produced at Jubilee Well grove (Site 2) between September 2000 and March 2005.

NB: highest peaks for precipitation correspond with "flood-events", associated with cyclonic weather patterns. Irrigation was halted to grove during February 2003, with tree subjected to a rain-fed regime until end of trial growing in the semi-arid and arid environments. With sandalwood (*Santalum spicatum*) large amounts of flower formation have been observed to occur after heavy summer rainfall (pers. comm. Woodall, 2006) and with Bush tomato (*Solanum orbiculatum*) in the Alice Springs area (Northern Territory), the biggest harvests of fruit result after summer seasons when highest rainfall occurred (pers. comm. Ryder, 2006). Hence, it is interpreted that the minimal rates of flower formation observed in olive trees at Jubilee Well grove during years 2002-03 and 2003-04 are primarily a function of the lower amounts of rainfall received during this period.

There was great inconsistency in the amount of olive fruit produced by trees at Jubilee Well in different years. Trees did not appear to conform to an alternate bearing cycle during the trial period. Alternate bearing refers to the natural tendency of *O. europaea* (as with a number of other tree species) to yield a heavy crop one year and little to no fruit the next (Gucci and Cantini, 2002). The irregular pattern of olive fruit production of trees at Jubilee Well grove did not conform to this biennial cycle which suggests that environmental factors, such as extremes in irrigation deficit may override the natural occurrence of a biennial bearing cycle.

The small amount of fruit produced at Jubilee Well grove over the 4 years highlights important concerns regarding the commercial potential of *O. europaea* grown in semi-arid environments. There is a correlation between the volume of irrigation received and the fruit and oil yield produced by *O. europaea*, but only up to a point. Also, there is currently no consensus on irrigation requirements for olive trees in arid regions and reports of optimum irrigation requirements range from 600 to 1000 mm (Nuberg and Yunusa, 2003). Whereas some correlation between flower/fruit production and rainfall at Jubilee Well grove was noted, there appears to be no correlation with irrigation supplied to trees. Similar volumes of olive fruit were produced both when trees were supplemented with irrigation (in 2001-02), and after the irrigation was halted (in 2004-05). Irrigation supplied to trees during the first 33 mo of the trial ranged between 150-250 L per tree/week. This suggests that the volume of irrigation supplied to trees had a negligible impact on the amount of olive fruit produced at Jubilee Well grove over the first 33 mo of the trial.

Hence, it is concluded that semi-arid environments impact significantly on growth of *O. europaea*, and as a consequence, far greater volumes of irrigation water would be required for successful production of olive fruit. No figures are currently available regarding the water requirements for successful growth of *O. europaea* in the study area. Hence, the amount of water required is considered a paramount issue (by the author), in consideration of potential commercial developments of *O. europaea* in this region in the future and further detailed study is required.

7.5) Laboratory testing of olive fruit samples

Samples of ripe olive fruit harvested from trees of cvs *New Norcia Mission* and *Verdale* during March 2002 and 2005 were tested by chemical analysis to determine the quality of olive oil produced.

In March 2002, a delay of approximately 4 days occurred between harvest of olive fruit and dispatch of the samples for testing. Samples were stored at room temperature (non-refrigerated). No samples were submitted during March 2003 and 2004, owing to insufficient quantities of olive fruit being produced by trees during both spring-summer seasons. In March 2005, the harvested samples of olive fruit were placed immediately into an esky (ice-filled) whilst on-site at the grove and later transferred to a refrigerated storage (approximately –3 degrees C.) for a period of several months before being dispatched for analysis. During both years the individual sample weights were less than the recommended sample size of 150g as recommended by the Chemistry Centre (pers. comm. Murray, 2002). Results from chemical analysis during March 2002 and 2005 are presented in Table 7.7.

7.5.1) Flesh:stone ratio

Flesh:stone ratios varied for both cultivar between the two different years tested. The ratio for cv *Verdale* olive fruit was 5.7:1 in 2002, compared to 3.5:1 in 2005. The ratio for cv *New Norcia Mission* olive fruit was 3.4:1 in 2002, compared to 4.4:1 in 2005. Although olive fruit samples during both years were collected at approximately the same time with olive fruit being of similar degree of ripeness, the flesh:stone ratio determined by testing was not consistent for either cultivar, between the two different years.

Flesh to pit ratio is an indicator of suitability of olives for table fruit with a ratio greater than 5:1 being regarded as desirable (Burr, 1998). According to the recommendation by Burr (1998), the flesh to pit ratio calculated for olive fruit from cv *New Norcia Mission* is below the ratio considered suitable as "table fruit". Olive fruit from cv *Verdale* was above this threshold in 2002, but the inconsistency in the ratio observed with the 2005 sample highlights potential concerns regarding consistency of fruit quality between seasons.

7.5.2) Moisture

Moisture % was higher for both cultivars in the 2005 samples. For cv *Verdale*, moisture content in olive fruit was 35.5% in 2002 and 54.1% in 2005 (increased by 52%). For cv *New Norcia Mission*, moisture content of olive fruit was 51.1% in 2002 and 59.2% in 2005 (increased by 16%). Moisture content was not consistent between years in the case of either cultivar. Highest moisture % readings in olive fruit occurred in the 2005 samples.

Both olive fruit samples in 2005 contained moisture contents close to 60%. High water content in olive

TABLE 7.7: test results from analysis of olive samples from Jubilee Well grove during March 2002 and March 2005 (Rothnie, 2002 and 2005).

Analysis	cv *Verdale*		cv *New Norcia Mission*	
	March 2002	March 2005	March 2002	March 2005
Sample weight (g):	70.88	82.20	98.78	99.10
Flesh weight (g):	60.31	61.88	76.30	76.21
Stone weight (g):	10.57	17.69	22.48	17.36
Flesh:stone ratio:	5.7:1	3.5:1	3.4:1	4.4:1
Moisture (%):	35.5%	54.1%	51.1%	59.2%
Freefatty acid (%): (as oleic acid):	0.5%	2.0%	0.8%	1.7%
Oil content (%):	33.8%	20.1%	24.4%	15.0%

fruit can make commercial extraction of oil difficult due to oil/water emulsions being formed during malaxation (Di Giovacchino, 1996). Moisture contents of 60% and higher can cause problems with the efficiency of oil separation during processing (pers. comm., Sweeney, 2005).

7.5.3) Free fatty acids

Percentage of free fatty acid (FFA) were more than double for both cultivars in 2005 samples, compared to 2002 samples. For cv *Verdale* fruit, FFA was 0.5% in 2002 and 2.0% in 2005 (increased by 4-fold). For cv *New Norcia Mission* fruit, FFA was 0.8% in 2002 and 1.7% in 2005 (increased by 2.1-fold). Highest FFA % occurred in both cultivars in the 2005 test.

The limit set by the International Olive Oil Council (IOOC) for permissible amounts of free fatty acid contained in virgin olive oil is 0.8% (pers. comm. Mailer, 2005). A high level of saturated fatty acids is not desirable for the human diet (Sweeney, 2005). In the 2005 samples, FFA% figures were considerably higher than the IOOC limit of 0.8% for both cultivar.

7.5.4) Oil content

Oil content (%) was lower in the 2005 samples, compared to 2002 samples for both cultivars. For olive fruit from cv *Verdale*, oil content was 33.8% in 2002 and 20.1% in 2005. For olive fruit from cv *New Norcia Mission*, oil content was 24.4% in 2002 and 15.0% in 2005.

In 2005 samples, oil content was lower by more than 50% for both cultivar compared to 2002 samples. Lower oil content in olive fruit in 2005 tests may be attributed to an increase in the size and density of tree canopies at Jubilee Well grove over the period 2002 to 2005. In *O. europaea*, a decrease in fruit size, oil content and an increase in moisture content can occur in olive fruit grown in the lower or more heavily shaded parts of the tree (Tombesi *et al.*, 1997). No pruning of trees was conducted at during the period March 2002 to 2005. During this period, substantial thickening of many of the individual tree canopies was documented for trees at Jubilee Well grove. The thickening of canopies that occurred over this period may have contributed to the lower oil content % in olive fruit tested in 2005, when compared to the olive fruit tested in 2002.

7.5.5) Discussion

Chemical testing of samples was only completed during the two most productive years, in 2002 and 2005. This was primarily a function of the inconsistency in olive fruit availability on trees at Jubilee Well over the duration of the trial (several seasons with nil to negligible quantities of olive fruit produced). For this reason, it is not possible to draw conclusions about olive oil quality based on extrapolation between these two sets of data. Nevertheless, the results from chemical analysis of olive fruit samples yield important information that provides some insight about oil quality from trees at

Jubilee Well grove. Test results identify the potential for olive fruit grown in this site to contain small flesh:stone ratios, high moisture content and high FFA%. These are all issues that have the potential to impact on the quality and consistency of olive fruit produced by *O. europaea* in this environment.

CHAPTER 8: RESULTS AND DISCUSSION

Site#3: Hacks Well grove

8.1) Tree mortality

Of 161 *O. europaea* planted, 76 trees died at the Hacks Well site between planting out in September 2002 and October 2004. This represents total mortality of 47%. During the first year of the trial tree losses were high. A total of 71 trees died during this period, which represented more than 90% of all deaths that occurred over the duration of the trial (Table 8.1).

Over the entire trial period most tree deaths occurred in south grove. Here, 32 trees died between planting out in September 2002 and October 2004. Tree deaths at south grove represent 42% of the total mortality. Fewer deaths occurred at the north and middle groves in comparison. At each of these two groves 22 trees died between planting in September 2002 and October 2004, representing 29% of the total mortality.

Of the 3 cultivars trialed at Hacks Well (Site 3), the highest mortality rate occurred with cv *Verdale* in all 3 groves. From 53 trees of cv *Verdale* planted, 37 trees succumbed between planting in September 2002 and October 2004. All trees of this cultivar planted in the south grove subsequently died over the duration of the trial. Fewer deaths occurred with cvs *Barnea* and *New Norcia Mission*. From 54 trees of both cultivar planted, 20 trees of cv *New Norcia Mission* and 19 trees of cv *Barnea* succumbed between planting out in September 2002 and October 2004 (Table 8.2).

Of 54 *O. europaea* planted at the north grove, 22 trees were lost between planting out September 2002 and October 2004. This represents a mortality of 40.7%. All occurred during the first year after establishment. For cvs *Verdale* and *New Norcia Mission*, 8 deaths occurred from 18 planted. For cv *Barnea*, 6 deaths occurred from 18 planted.

Of 54 *O. europaea* planted at middle grove, 22 trees died between planting out September 2002 and October 2004. This is a mortality rate of 40.7% of trees. Twenty tree deaths occurred during the first year and only 2 more in the second year. In cv *Verdale*, 12 deaths occurred from 18 planted. For cv *Barnea*, 8 deaths occurred from 18 planted. For cv *New Norcia Mission*, 2 deaths occurred from 18 planted.

Of 53 *O. europaea* planted at the south grove, 32 trees succumbed between planting out in September 2002 and October 2004. This represents a mortality rate of 60.4% of trees at south grove. Twenty-nine tree deaths occurred during the first year and only 3 tree deaths occurred during the second year. For cv *Verdale*, all 17 trees died. For cv *New Norcia Mission*, 10 deaths occurred from 18 planted. For cv

TABLE 8.1: Summary of tree mortality at north, middle and south groves, Hacks Well (Site 3), between September 2002 and October 2004.

Grove	No. planted	Tree mortalities by year from planting		All deaths
		September 2002-October 2003	October 2003-October 2004	Sept 2002-Oct 2004
North grove	54	22	0	22
Middle grove	54	20	2	22
South grove	53	29	3	32
Total:	161	71	5	76
Mortality (%):		44.1%	3.1%	47.2%

TABLE 8.2: Summary of tree mortality for each cultivar (all groves combined), Hacks Well (Site 3), between September 2002 and October 2004.

Cultivar	No. planted	Tree mortalities by year from planting		All deaths
		September 2002-October 2003	October 2003-October 2004	Sept 2002-Oct 2004
Barnea	54	18	1	19
New Norcia Mission	54	19	1	20
Verdale	53	34	3	37
Total:	161	71	5	76
Mortality (%):		44.1%	3.1%	47.2%

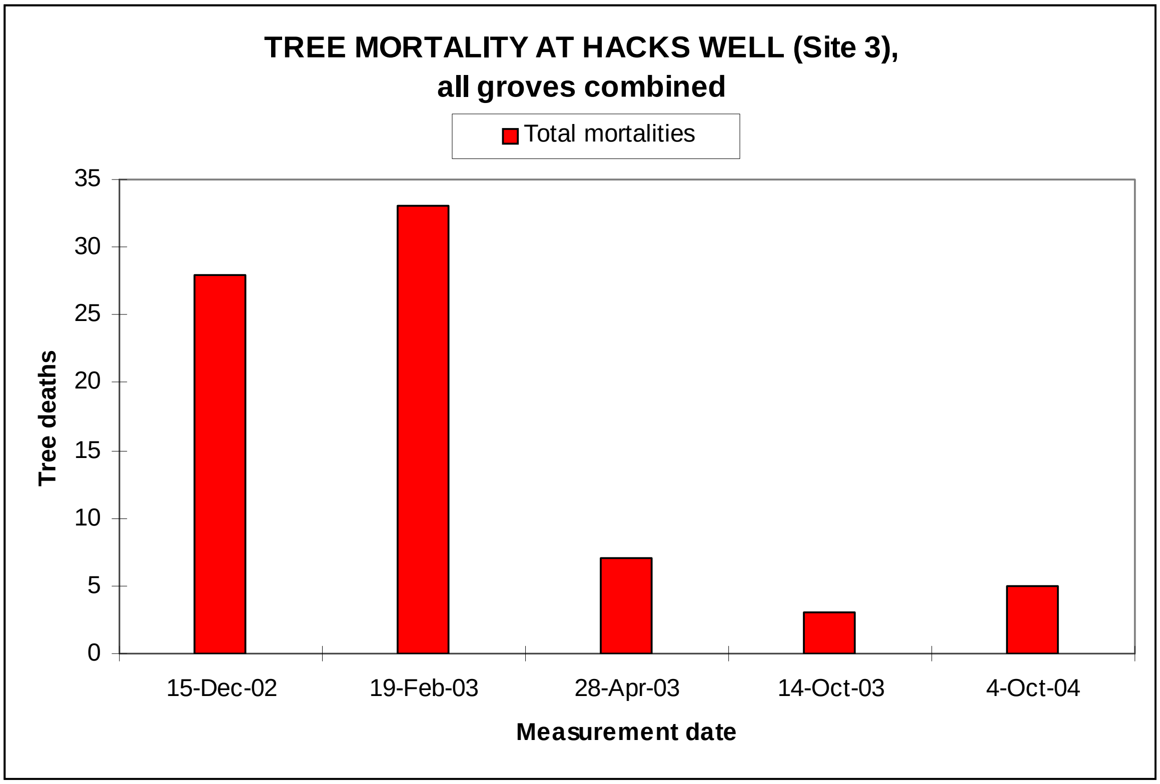


FIGURE 8.1: Timing of tree deaths for all groves combined over duration of trial period, at Hacks Well (Site 3).

Barnea, 5 deaths occurred from 18 planted.

The overall mortality rate was 44% for the first year of the trial (3 groves combined), considerably higher than the 5% figure quoted by olive growers (based on the industry estimate). Timing of tree mortality over the duration of the trial is illustrated in Figure 8.1. Of the 71 tree deaths that occurred during the first year of the trial, 61 occurred in the initial 5 months of the trial (from September 2002 to February 2003). The other 10 trees succumbed in the final 7 months of the first year (from February to October 2003).

Tree deaths at Hacks Well (Site 3) were particularly high during the first 5 months after establishment especially compared to mortality observed at previous trials at Davis Well (Site 1, Chapter 6) and Jubilee Well (Site 2, Chapter 7). The Hacks Well experiment was located in proximity to both of these previous sites and hence, is influenced by similar climate. Soil profile and texture at south grove Hacks Well, were similar to that at Davis Well grove (Site 1). Groundwater used to irrigate trees was accessed from a local water-point which was assumed to be similar in quality to that at previous sites. Despite these similarities, mortality rates experienced at all 3 groves at Hacks Well (Site 3) were four times greater than those observed at the previous trial sites. This suggests that other, specific site-related factors apart from local environment may have influenced the amount of tree mortality at Hacks Well site. A review was conducted to examine other possible factors that had the potential to explain the excessive tree mortality during the first 5 months of the trial.

8.1.1) Soil audit

Soil sampling and chemical analysis was conducted at the Hacks Well site in November 2001, before trees were planted. Testing of soils samples confirms that the soil profile had moderate levels of electrical conductivity (Table 8.3). Sodium and chloride concentrations although elevated, were below the toxic threshold of 0.2% for sodium and 0.5% for chloride (Reuter and Robinson, 1997). European olive has low-moderate tolerance to salinity (Maas, 1986). These salinity concentrations below the toxic threshold for *O. europaea* suggest background salinity probably had a negligible effect on mortality after planting.

8.1.2) Irrigation regime

Trees were irrigated at between 100-250 L tree/week on average, for the first year of the trial. Some irregularity in the supply volume occurred during the initial 3-5 months of the trial (based on personal observations of the author). Irrigation was provided to all 3 groves via low-pressure feed from the main tank. This resulted in a differential water supply in some areas of the site during the first 4-5 months until a petrol-powered pump was fitted during February 2003. A minimal amount of rainfall (50.8 mm) was recorded between September 2002 and January 2003, but heavier rainfall (92.8 mm) followed

TABLE 8.3: Analytical results from soil sampling program conducted at Hacks Well (Site 3) during November 2001 (CSBP, 2001).

Hole	Depth (m)	Conductivity mS/cm	Sodium Meq./100g	Chloride mg/kg	Depth (m)	Conductivity mS/cm	Sodium Meq./100g	Chloride mg/kg
20	0-0.3m.	2820	0.22	61	0.3-0.8m.	1110	0.21	11
21	0-0.3m.	3690	0.50	82	0.3-0.8m.	1170	0.38	19
22	0-0.3m.	620	0.20	4	0.3-0.9m.	1190	0.92	38
23	0-0.2m.	510	0.08	3	0.2-1.1m.	680	0.19	9
24	0-0.3m.	2560	0.30	96	0.3-0.8m.	3400	0.36	265
25	0-0.3m.	1590	0.52	58	0.3-0.8m.	5090	1.65	656

NB; Holes 20-25 all located in the north part of the Hacks Well site (Figure 5.6)

TABLE 8.4: Monthly rainfall (mm) for Laverton aero, September 2002 to March 2003 (Dal Pozzo, 2005).

Month	September 2002	October 2002	November 2002	December 2002	January 2003	February 2003
Rainfall (mm):	4.0	0.0	12.6	28.0	6.2	92.8

PLATE 8.1: Salt scalding observed at tree site at Hacks Well groves (Site 3), during October 2002.

during February 2003 (Table 8.4). Irregularity with irrigation supply and minimal rainfall may have subjected trees to moisture deficit, which may have contributed to increased mortality of *O. europaea* during the initial 5 months of the trial.

8.1.3) Water supply

According to station staff Yard Bore provides a reliable water supply of good quality. Owing to the close proximity of Yard Bore to the grove sites this supply was chosen over the historic water point at Hacks Well. No testing of water quality was completed before the supply was commissioned. Evidence of high concentrations of salinity within this water supply became visible during October 2002 when salt scalding was observed at many tree sites (Plate 8.1). This was a result of discharge of water from the drip-feeders that contained high concentrations of salinity.

This was confirmed by chemical analysis of foliar samples collected for routine testing conducted during February 2003 (Appendix 3, Table A3.9). In this analysis, sodium concentration in foliar samples collected from trees in south grove exceeded the toxic threshold of 0.2% (Reuter and Robinson, 1997). In foliar samples from north and middle groves, sodium concentrations were elevated but below the toxic threshold of 0.2%. For the same set of foliar samples, chloride concentrations were elevated but below the toxic threshold of 0.5% (Reuter and Robinson, 1997) for all 3 groves.

Hence, the high salinity of the ground water supplied to trees at all 3 groves during the initial part of the trial is expected to have impacted on tree health during this period. This is interpreted (by the author), to have resulted in the high mortality rates evidenced during this period.

8.1.4) Competition from native fauna: termites

Evidence of termite attack was observed on a small number of trees at Hacks Well (Site 3) at various times over the duration of the trial. No tree deaths were recorded during the trial however. Samples of termites were collected from within the grove area during spring 2004. Subsequent examination by an entomologist during March 2005 revealed these termites to be Schedorhinotermes reticulatus (after Froggatt, pers. comm., Heterick, 2005).

8.2) Growth performance

Summaries of mean tree dimensions for survivors by cultivar at north, middle and south groves at Hacks Well (Site 3) are presented for the period December 2002 to October 2004 (23 mo) in Table 8.5 to 8.7.

8.2.1) Trunk diameter

Comparison of means of survivors (n=85) suggests a 3.9-fold increase was attained for trunk diameter in north grove, 4.2-fold in middle and 2.9-fold in south grove in the 23 mo period between Dec. 2002 and

Oct. 2004 (Table 8.5). The population set of trunk diameter data did not conform to a normal distribution, even after a square-root transformation was performed. With non-parametric testing (Tukey Test) a significant difference was detected in mean trunk diameter growth between the middle and south groves ($p<0.05$). No significant differences were detected among the cultivars using either Kruskal-Wallis or Mann-Whitney test.

South grove data did not have a normal distribution (no cv *Verdale* survivors) and was removed from the population. No significant difference was detected in mean trunk diameter growth between the north and middle groves by one-way anova. For cultivars a significant difference was detected in mean growth between the cvs *New Norcia Mission* and *Verdale* ($p<0.05$) at the north and middle groves.

Mean growth in trunk diameter was significantly greater in both the north and middle grove, compared to the south grove using non-parametric methods ($p<0.05$).

8.2.2) Tree height

A 1.7-fold increase was attained for tree height in the north grove compared with 1.6-fold in the middle grove and 1.2-fold increase in the south grove over the 23mo period (Table 8.6). Height data conformed close to a normal distribution ($p=0.04$) after square-root transformation. Comparisons were completed using the Tukey HSD test. For groves, significant difference was detected in mean growth between north and middle groves, versus south grove by one-way anova ($p<0.05$). For cultivars, a significant difference was detected in mean growth between cv *Verdale* and cv *Barnea* ($p<0.05$).

A significant difference was detected among mean height growth for all three groves ($p<0.05$) by anova. No significant difference was detected in mean growth between different cultivars however. Testing confirmed no interaction effect between groves and cultivar (significant difference between groves not a function of cultivar).

South grove data were removed from the population and the north and middle grove data were tested by one-way anova. No significant difference was detected in mean growth between groves, or between cultivars by t-test. Cv *Verdale* data were removed from the population and the remaining sets compared by non-parametric methods (Kruskal-Wallis and Mann-Whitney test). A significant difference was detected in mean growth between both north and middle groves, versus south grove ($p<0.05$). No significant difference was detected in mean growth between different cultivars.

Mean growth of tree height was significantly higher in both north and middle grove, versus south grove ($p<0.05$). Mean growth of tree height was significantly higher for cv *Barnea*, versus cv *Verdale* ($p<0.05$). Testing by two-way anova confirmed no interaction effect between groves and cultivars.

TABLE 8.5: Mean trunk diameter (mm) at Hacks Well (Site 3), between December 2002 and October 2004 (standard deviations shown). Measurements taken 30 cm above ground surface.

Grove		Cultivar			All
		Barnea	*N.N. Mission*	*Verdale*	
North	Survivors at Oct. 2004	12	10	10	32
Mean trunk diameter (mm) Dec. 2002		6.1±0.9	6.3±0.8	3.6±1.3	5.38±0.60
Mean trunk diameter (mm) Oct. 2004		22.0±6.1	24.1±10.8	16.6±7.4	20.97±1.60
Increase (mm) Dec. 2002 to Oct. 2004		15.9	17.8	13.0	15.59
Middle	Survivors at Oct. 2004	10	16	6	32
Mean trunk diameter (mm) Dec. 2002		6.7±1.3	6.5±0.9	4.2±0.8	6.13±1.24
Mean trunk diameter (mm) Oct. 2004		28.9±10.1	27.3±9.6	14.5±4.8	25.41±5.49
Increase (mm) Dec. 2002 to Oct. 2004		22.2	20.8	10.3	19.28
South	Survivors at Oct. 2004	13	8	0	21
Mean trunk diameter (mm) Dec. 2002		6.7±0.8	6.7±1.3	0	6.71±2.09
Mean trunk diameter (mm) Oct. 2004		19.7±5.8	18.5±2.8	0	19.24±6.12
Increase (mm) Dec. 2002 to Oct. 2004		13.0	11.8	0	12.52
All Hacks Well groves: survivors		35	34	16	85

TABLE 8.6: Mean tree height (m) at Hacks Well (Site 3), between December 2002 and October 2004 (standard deviations shown).

Grove		Cultivar			All
		Barnea	*N.N. Mission*	*Verdale*	
North	Survivors at Oct. 2004	12	10	10	32
Mean tree height (m) Dec. 2002		1.042±0.232	0.960±0.147	0.385±0.116	0.811±0.138
Mean tree height (m) Oct. 2004		1.567±0.369	1.415±0.362	0.975±0.218	1.335±0.141
Increase (m) Dec. 2002 to Oct. 2004		0.525	0.455	0.590	0.523
Middle	Survivors at Oct. 2004	10	16	6	32
Mean tree height (m) Dec. 2002		1.11±0.105	0.966±0.265	0.367±0.137	0.899±0.211
Mean tree height (m) Oct. 2004		1.685±0.367	1.484±0.21	1.108±0.246	1.476±0.269
Increase (m) Dec. 2002 to Oct. 2004		0.575	0.519	0.742	0.578
South	Survivors at Oct. 2004	13	8	0	21
Mean tree height (m) Dec. 2002		1.119±0.105	0.975±0.096	0	1.064±0.347
Mean tree height (m) Oct. 2004		1.308±0.233	1.206±0.170	0	1.269±0.406
Increase (m) Dec. 2002 to Oct. 2004		0.188	0.231	0	0.204
All Hacks Well groves: survivors		35	34	16	85

TABLE 8.7: Mean canopy diameter (mm) at Hacks Well (Site 3), between December 2002 and October 2004 (standard deviations shown).

Grove		Cultivar			All
		Barnea	*N.N. Mission*	*Verdale*	
North	Survivors at Oct. 2004	12	10	10	32
Mean canopy diameter (m) Dec. 2002		0.310±0.093	0.355±0.098	0.220±0.055	0.296±0.026
Mean canopy diameter (m) Oct. 2004		1.106±0.306	1.250±0.447	0.760±0.224	1.043±0.096
Increase (m) Dec. 2002 to Oct. 2004		0.796	0.895	0.540	0.747
Middle	Survivors at Oct. 2004	10	16	6	32
Mean canopy diameter (m) Dec. 2002		0.320±0.090	0.280±0.059	0.163±0.034	0.271±0.055
Mean canopy diameter (m) Oct. 2004		1.220±0.320	1.272±0.310	0.675±0.172	1.144±0.255
Increase (m) Dec. 2002 to Oct. 2004		0.900	0.992	0.513	0.873
South	Survivors at Oct. 2004	13	8	0	21
Mean canopy diameter (m) Dec. 2002		0.271±0.074	0.284±0.102	0	0.276±0.085
Mean canopy diameter (m) Oct. 2004		0.890±0.181	0.944±0.262	0	0.911±0.280
Increase (m) Dec. 2002 to Oct. 2004		0.619	0.659	0	0.634
All Hacks Well groves: survivors		35	34	16	85

8.2.3) Canopy diameter

A 3.5-fold increase in mean canopy diameter occurred in north grove, a 4.2-fold increase in middle grove and a 3.3-fold increase in south grove over the same 23 mo period (Table 8.7). Data conformed to a normal distribution ($p>0.05$). Analysis of variance was completed by Tukey HSD test. A significant difference was detected with mean growth in south grove, versus middle grove by one-way anova ($p<0.05$). Significant difference was detected in mean growth of cv *Barnea* and cv *New Norcia Mission*, versus cv *Verdale* by one-way anova ($p<0.05$).

Analysis of variance was completed by two-way anova. No significant difference was detected in growth between different groves or different cultivars. Significant difference was detected in growth for all groves, versus all cultivar ($p<0.05$), but the interaction effect is independent. South grove data were removed from the population and the remaining data tested by one-way anova. No significant difference was detected in growth between north and middle grove by t-test. Significant difference was detected in mean growth of cv *Barnea* and cv *New Norcia Mission*, versus cv *Verdale* by t-test ($p<0.05$).

All data for cv *Verdale* was removed from the population and the remaining data was tested by one-way anova. Significant difference was detected in mean growth for south, versus the middle grove by t-test ($p<0.05$). No significant difference was detected in mean growth between different cultivars by t-test.

Mean growth of canopy diameter was significantly higher in the middle grove, versus south grove ($p<0.05$). Mean growth of canopy diameter was significantly higher for cv *Barnea* and *New Norcia Mission*, versus *Verdale* ($p<0.05$). Testing by two-way anova confirmed significant difference between groves and cultivar, but no interaction effect. Comparisons were completed between different groves and cultivars without the south grove data. Mean growth in canopy diameter was significantly higher in cvs *Barnea* and *New Norcia Mission*, versus cv *Verdale* at the north and middle groves ($p<0.05$). Comparisons were completed between different groves without data for cv *Verdale*. Mean growth of canopy diameter was significantly higher in the middle grove, versus south grove ($p<0.05$).

8.3) Foliar analysis

The initial round of “new-growth” foliar samples was collected during February 2003 from all 3 groves at Hacks Well (Site 3). Another round of foliar samples (both “new-growth” and “old-growth” samples) where collected during February 2005. Results of chemical analysis are presented in Appendix 3 (Tables A3.9 to 12). Interpretation of analytical results is presented here for each of the macro and micro-nutrient elements;

Nitrogen:

Levels of nitrogen (total) and nitrate (extractable nitrogen) were higher in new growth compared with old growth leaves for all 3 groves in the 2005 test. In 2003, concentrations were above the adequate threshold for all 3 groves, but decreased to borderline adequate in the 2005 test. Thus, a potential deficiency of nitrogen may have affected tree growth during the latter part of the trial.

Phosphorus:

Concentrations were higher in new growth compared with old growth leaves for all 3 groves in the 2005 test. In 2003, test concentrations were above the adequate threshold for all 3 groves. In 2005, test concentrations were above the adequate threshold for old/new growth in south grove and new growth in north and middle grove. Old growth samples were deficient in north and middle groves in the 2005 test however, which may have affected tree growth during the latter part of the trial.

Potassium:

Concentrations were higher in new growth compared with old growth in the 2005 test for all 3 groves. Concentrations were above the adequate threshold in both tests for all 3 groves and these sites are able to supply an adequate level of potassium for olive trees.

Sulphur:

Concentrations were higher in old growth compared with new growth in the 2005 test in all 3 groves. Concentrations differed between groves between 2003 and 2005. In the north and south grove concentrations were higher in 2003, compared to 2005. In the middle grove however, concentration in the old growth sample was higher in the 2005 test. Little can be read into these results.

Calcium:

Concentrations were higher in old growth compared with new growth foliage in the 2005 test for all 3 groves. In 2003, test concentrations had been above the adequate threshold for north and middle groves, but deficient in south grove. In 2005, test concentrations were above the adequate threshold in old growth, but deficient in new growth foliage in all 3 groves. Results suggest a deficiency in calcium in south grove throughout the trial period and a deficiency in calcium in north and middle groves during the latter part of the trial.

Magnesium:

In contrast to calcium an adequate concentration of magnesium was present in leaf matter over the duration of the trial. Concentrations were higher in old growth compared with new growth leaves in the 2003 test for all 3 groves. Concentrations were above the adequate threshold in both tests for all 3 groves.

Iron:

Concentration was higher in old growth compared with new growth foliage in 2005 in all 3 groves. Concentrations were higher in 2003 compared with 2005 for all 3 groves. No CSIRO baseline figures are available for iron and visual examination is the best method for diagnosing Fe deficiency. I was able to diagnose intra-veinal chlorosis on leaves of trees during both of the spring-summer seasons, which suggests that an iron deficiency occurred in leaf matter during this period.

Manganese:

Concentrations were higher in old growth compared with new growth leaves in 2005 for all 3 groves. Concentrations were above the adequate threshold in both tests for all 3 groves. Thus, it is presumed that an adequate concentration of manganese was present in leaf matter over the duration of the trial.

Copper:

Concentrations were higher in new growth compared with old growth leaves in 2005 for all 3 groves. Concentrations differed between groves between both tests. In 2003, concentrations were above the adequate threshold in the north and south groves, but deficient in the middle grove. In 2005, concentrations were above the adequate threshold in all 3 groves. A possible deficiency of copper in leaf matter at the middle grove may have had an impact on tree growth during the initial part of the trial.

Boron:

Concentrations were higher in new growth compared with old growth leaves in the 2005 test in all 3 groves. Concentrations were higher in 2003 compared to 2005. In 2003, concentrations were about double in south grove, compared to north and middle grove. Concentrations were above the adequate threshold in both tests for the 3 groves.

Zinc:

As with boron concentrations were above the adequate threshold in both tests for all 3 groves, suggesting that an adequate concentration of zinc was present in leaf matter throughout the trial period. Concentrations were higher in new growth compared with old growth leaves in the 2005 test for all 3 groves.

Sodium:

Concentrations were higher in old growth compared with new growth leaves in the north and south groves, but similar for old and new growth in the middle grove in 2005. Concentrations were considerably higher in 2003 compared with 2005 for all 3 groves. In 2003, the concentration in leaf matter from south grove was above the toxic threshold. Concentrations in leaf matter from north and middle groves was elevated, but below the toxic threshold. In 2005, concentrations in new and old growth leaf matter was elevated, but below the toxic threshold at all 3 groves. Analysis has confirmed elevated to toxic concentrations of sodium within leaf matter during the first part of the trial which may have resulted in tree mortality. This highlights the potential for salinity issues to occur at the Hacks Well site.

Chloride:

Concentrations were higher in new growth compared with old growth leaves in all 3 groves in 2005. Concentrations were higher in 2003, compared with 2005 for north and middle groves. For south grove concentration was higher in new growth leaves in 2005. Analysis has confirmed elevated concentrations of chloride within leaf matter which may have affected tree growth and resulted in tree mortality over the duration of the trial. As with sodium, chloride results highlight the potential for salinity issues to develop at the Hacks Well site.

8.3.1) Discussion

For the first round of testing in February 2003, the small size of many trees allowed for samples of “new-growth” leaves only. As a consequence, no comparisons were possible at this point in the trial regarding distribution of major or trace elements, in regard to their respective phloem mobilities. In the February 2005 test, analysis of macro-nutrients; nitrogen, phosphorus and potassium confirmed higher concentrations in new growth compared with old growth samples in all 3 groves. In contrast, macro-nutrients; sulfur, calcium and magnesium had higher concentrations in old growth compared to new growth. These results are in general agreement with various authors (e.g. Smith and Loneragan, 1997; Grundon *et al*., 1997; Fernández-Escobar *et al*., 1999) regarding the phloem mobility of each of these elements.

Results from both tests identified potential deficiencies of macro-nutrients; nitrogen, phosphorus calcium, and micro-nutrients; iron and copper, in samples of foliar matter. This had the potential to affect tree health, and impact on growth rates, flower and fruit formation of *O. europaea* for each of the 3 groves at Hacks Well during the trial period.

8.4) Flowering and fruiting

Flower and olive fruit formation were observed on a small number of cv Verdale trees during spring-summer 2001-02, after the stock had arrived on-site. This occurred before trees were planted and no record of the rate of flower formation or olive fruit production was kept. Observations of flowering rates were recorded from September 2002 when trees were planted at Hacks Well. A summary for flower formation at each grove from September 2002 to October 2004 is presented in Table 8.8. Yearly summaries for flower formation are presented in Appendix 4 (Tables A4.8 and 9).

TABLE 8.8: Mean % flower formation on flowering trees at Hacks Well (Site 3), between September 2003 and October 2004.

Grove		Cultivar			Mean % limbs w. flowers
		Barnea	*N.N. Mission*	*Verdale*	
North	Survivors at Oct. 2004	12	10	10	
Mean % limbs with flowers Sept. 2003		10 (2 trees)	0	15 (2 trees)	12.5 (4 trees)
Mean % limbs with flowers Oct. 2004		75 (10 trees)	20 (4 trees)	18.8 (4 trees)	50.3 (18 trees)
Mean % trees over trial period		50 (2 years)	40 (1 year)	30 (2 years)	
Middle	Survivors at Oct. 2004	10	16	6	32
Mean % limbs with flowers Sept. 2003		0	0	30 (1 tree)	30 (1 tree)
Mean % limbs with flowers Oct. 2004		33.8 (8 tree)	27.5 (2 trees)	0	32.5 (10 trees)
Mean % trees over trial period		80 (1 year)	12.5 (1 year)	16.7 (1 year)	
South	Survivors at Oct. 2004	13	8	0	21
Mean % limbs with flowers Sept. 2003		0	0	deceased	0
Mean % limbs with flowers Oct. 2004		18.8 (4 tree)	0	deceased	18.8 (4 trees)
Mean % trees over trial period		30.8 (1 year)	0		
All Hacks Well groves: survivors		35	34	16	85

Season 1: September 2002 to March 2003

No flower formation was observed on any tree at any grove at Hacks Well.

Season 2: September 2003 to March 2004

Flower formation was observed on some trees in north and middle groves only. No flower formation was observed on trees in south grove.

At north grove flower formation occurred on 4 trees (12.5% trees). A mean of 12.5% of limbs hosted flowers. Flower formation occurred on trees of cvs; *Verdale* and *Barnea* (cv *New Norcia Mission* had no flowers). Most flower formation occurred on trees of cv *Verdale* (20% of trees flowered). For these 2 trees a mean of 15% of limbs hosted flowers. Less flower formation occurred on trees of cv *Barnea* (16.6% trees flowered). In the case of these 2 trees a mean of 10% of limbs hosted flowers.

At the middle grove flower formation occurred on one singleton only (3.1% trees) of cv *Verdale*, which hosted flowers on 30% of limbs. No flower formation occurred on any tree of cvs *Barnea* or *New Norcia Mission*.

All flowers were removed before olive fruit formation with the aim of boosting tree growth during the initial spring-summer season. There was no formation of olive fruit as a consequence.

Season 3: September 2004 to March 2005

Flower formation was observed on some trees at all 3 groves during September 2004.

At north grove flower formation occurred on 56% of trees. For these 18 trees a mean of half the limbs hosted flowers. Flowers were recorded on some trees of all 3 cultivars. Most flower formation was recorded on trees of cv *Barnea* (83.3% of trees flowered). For these 10 trees a mean of 75% of limbs hosted flowers. Lesser amounts of flower formation occurred on trees of cvs *New Norcia Mission* and *Verdale* (40% trees flowered). For the 4 trees of cv *New Norcia Mission* a mean of 20% of limbs hosted flowers and of the 4 trees of cv *Verdale,* a mean of 20% of limbs bore flowers.

At middle grove flower formation occurred on 10 trees (31.3% of trees). For these 10 trees a mean of 32.5% of limbs had flowers. Flowers were recorded on some trees of cvs *Barnea* and *New Norcia Mission*. Most flower formation occurred on trees of cv *Barnea* (80% of trees flowered). For these 8 trees a mean of 33.8% of limbs hosted flowers. Flower formation was less on trees of cv *New Norcia Mission* (12.5% trees flowered). For these 2 trees a mean of 27.5% of limbs bore flowers. No flower formation occurred on any tree of cv *Verdale*.

At south grove flower formation was restricted to cv *Barnea* and occurred on only 4 trees (19% of tree population) with a mean of 31% trees producing flowers. And for these 4 trees a mean of 18.8% of limbs hosted flowers.

No olive fruit formation subsequently occurred however during spring-summer 2004.

8.4.1) Summary

The most consistent flower formation occurred at north grove, with highest mean population of trees that produced flowers from all 3 cultivars over two consecutive spring-summer seasons. At this grove most consistent flower formation occurred with cv *Barnea* (mean of 50% of trees produced flowers during consistent was cv *New Norcia Mission* (mean of 40% trees produced flowers during the final year).

In comparison, middle grove had a lower population of trees that produced flowers from all 3 cultivars only during one spring-summer season. At this grove most consistent flower formation occurred with cv *Barnea* (mean of 80% of trees produced flowers during the final year), followed by cv *New Norcia Mission* (mean of 40% of trees produced flowers during the final year). The least consistent was cv *Verdale* (one tree produced flowers during the previous year).

Least prolific flower formation occurred at south grove. At this grove flower formation was restricted to cv *Barnea* (mean of 30.8% of trees produced flowers during the final year). No flower formation was observed on trees of cvs *New Norcia Mission* or *Verdale*.

No olive fruits were produced by any tree at any grove at Hacks Well (Site 3) over the duration of the trial.

8.4.2) Discussion

Flower formation rates were inconsistent, both between each grove and between different years. Apart from before trees were planted, no olive fruit formation was recorded at Hack Well (Site 3) over the duration of the trial period. The inconsistency of flower formation and lack of olive fruit formation may have been a function of stress imposed, as a result of a deficiency in water and/or nutrients. Stress from lack of water and nutrients has been identified to impact on flower formation during floral development, resulting in pistil abortion and large proportions of staminate (as opposed to perfect) flowers being produced (Martin, 1994).

CHAPTER 9: GENERAL DISCUSSION

9.1) Duration of observations

At Davis Well (Site 1) observations ran for 50 mo. At this site the soil profile was comparatively shallow and this constrained root system growth. The presence of clay, that alternatively swelled and cracked depending on moisture availability also did not favour growth of olive trees. At Jubilee Well (Site 2) observations ran for 53 mo. Deeper, sandier soils enabled better survival and growth than at Davis Well. At Hacks Well (Site 3) observations ran for 26 mo. Fewer cultivars were used here but the planting was made in three distinct groves. Soils were alluvial and relatively deep in the north and middle groves, compared to a shallow clay-laterite soil at south grove.

9.2) Tree mortality

Industry contacts suggest that growers in Australia routinely lose some 5% of planted olives during the first year after grove establishment, assuming trees had been planted in suitable soil type and irrigated with sufficient water. Thus, we expect to incur some losses at planting. In addition, transportation of planting stock to remote locations may involve stress factors. Similarly, if plants are stored for any length of time other individuals may die. The amount of tree mortality, the timing and cause of tree deaths all varied considerably between the three sites. At two sites (Davis and Hacks Well), most deaths occurred immediately after planting. After establishment far fewer deaths occurred. The first year mortality rate of 5% at Davis Well was in line with expectations, but a further 5% of trees died in the second year.

Most deaths occurred at Hacks Well (Site 3). Here, close to half the planted trees died within the first 5 months of the trial. The main factor involved was excessive salinity within the irrigation water supplied to the trees during this period. Most tree deaths occurred in the south grove. Of the 3 cultivars planted, most mortality occurred with cv *Verdale*. Salt scalding was observed around the root zone of many trees. Highly elevated and toxic concentrations of sodium and elevated concentrations of chloride were later confirmed by chemical testing of foliar samples. Heavy rainfall in February 2003 and commissioning of an alternative water supply at Hacks Well shortly after resulted in a decrease in salinity concentrations and led to reduced tree mortality onward from February 2003, until the trial concluded in October 2004.

The mortality rate was also high at Davis Well (Site 1). Here, the loss of 10% within the first 2 years of the trial resulted from the impact of salt-waterlogging within the soil profile. At Jubilee Well (Site 2) in comparison, the mortality rate was less during the initial part of the trial. This appeared to reflect the suitability of this soil type for successful growth of *O. europaea* during early establishment. At Davis Well impact of shallow, clay soil as factors influencing tree growth and mortality is expected to have become negligible after the second year of the trial as a direct result of surviving trees being more established and root growth penetrating to greater depth. Competition effects from native flora and fauna also impacted on growth of *O. europaea*. Termite attack resulted in one tree death at Davis Well and two deaths at Jubilee Well. All deaths occurred during the later half of the trial, attributed directly to termite attack and a subsequent decline in tree health that resulted.

9.3) Growth performance

At Davis Well (Site 1), comparison of attained mean dimensions of trunk diameter and tree height indicated best growth (50 mo) in cvs *Verdale, New Norcia Mission* and *Manzanillo.* Least mean growth occurred with cvs *Ascolana* and *UC136A*. Comparison of mean values for growth of canopy diameter however, confirmed cvs *New Norcia Mission, Ascolana* and *Manzanillo* to have the best performance with poorest identified in cvs *Verdale* and *UC136A*.

Straight comparison of increases in mean dimensions failed to identify any cultivar(s) that exhibited best overall growth. In the case of cv *UC136A* however, mean growth for trunk diameter, trunk height and canopy diameter were all least of the five cultivars trialed at the Davis Well grove and measured over the 50 mo period. Cv *New Norcia Mission* had the greatest mean growth of trunk diameter and canopy diameter but was only third in mean tree height.

At Jubilee Well (Site 2) differences in attained dimensions were found among mean values for each of trunk diameter, tree height and canopy diameter. In trunk and canopy diameters cvs *Jumbo Kalamata* and *Pendolino* grew most over the 53mo. In contrast, cultivars *Nabtari* and *Kalamata* had least growth in all three dimensions. Nevertheless, the small sample populations of many of the cultivars planted makes identification of best or poorest performing cultivar imprecise. Perhaps any follow up trials should target the best two or three across the site.

At Hacks Well (Site 3) significant differences in mean dimensions for surviving trees were detected between both different groves and different cultivars. Mean trunk diameter, tree height and canopy diameters of trees were significantly higher at north and middle groves, versus south grove. Mean trunk diameter, tree height and canopy diameter were all significantly greater for cvs *Barnea* and *New Norcia Mission*, versus cv *Verdale* at the north and middle groves. No trees of cv *Verdale* survived the trial period at the south grove. Superior growth and lower mortality of trees occurred in the north and middle groves between December 2002 and October 2004, on the alluvial soil profile (palaeochannel). Lower growth and higher tree mortality occurred at the south grove, on the clay regolith soil profile (laterite).

9.3.1) Changes in performance under rain-fed conditions

At both Davis Well (Site 1) and Jubilee Well (Site 2) there was a larger net growth in all dimensions during the first part of the trial when trees were irrigated, as opposed to the last part of the trial when trees were rainfed. At Davis Well mean monthly changes suggest growth in mean trunk and canopy diameters was greater when the trees were irrigated. In contrast tree height increased more during the rain-fed period. At Jubilee Well mean monthly changes suggest growth in mean trunk was greater when the trees were irrigated. Tree height and canopy diameter both increased more during the rain-fed period however.

Cessation of irrigation to trees at both Davis and Jubilee Well groves was expected to result in reduced available soil moisture. Whilst a linear relationship was expected between availability of soil moisture and growth rates, it was not confirmed by the above growth comparisons. There is no clear explanation regarding this growth pattern except perhaps, that grove management practices may have influenced growth.

At Davis Well (Site 1) the shallow soil profile may have influenced growth, resulting in greater height growth during the latter part of the trial when trees had became more established. There is a possibility however that grove management adversely affected growth in tree height for both sites. Firstly, heavy pruning during the initial part of the trial may have skewed measurements. Secondly, many of the trees were not adequately staked. This was rectified later and may have resulted in increased growth of trunk height of some trees during the latter part of the trial, independent of irrigation being halted.

9.3.2) Comparison between sites

Differences were identified in growth of different cultivars at Davis Well (Site 1) and Jubilee Well (Site 2) but statistical comparisons could not be completed between these sites owing to differences in design, choice of cultivar, age of stock, method and date of establishment at each trial. Comparisons between when trees were supplemented by irrigation, versus when trees were rain-fed suggested a similar growth pattern at both sites. It was not possible however, to conclude in which regime any superior tree growth may have occurred. Comparison of growth of branch tips confirmed a similar pattern at both sites, with highest mean growth occurred during the spring-summer season and low to negligible growth occurring during the winter season.

At Hacks Well (Site 3) significant differences were identified between growth of trees in different soil types, but no significance difference was detected between cultivars at the different groves. Greater growth of trees occurred in deeper alluvial soil at north and middle groves, compared to lesser growth in the shallow clay-laterite soil at south grove. Owing to the similarity in soil profile at south grove Hacks Well (Site 3) and Davis Well (Site 1), it may be possible to extrapolate growth performance of *O. europaea* between these two sites.

9.4) Foliar analysis

At all sites concentrations of macro-nutrients in new and old growth foliar samples were in general agreement with the literature regarding the degree of phloem mobility of these macro-nutrients. For all sites deficiencies were confirmed with macro-nutrients; nitrogen, phosphorus, calcium and possibly sulphur and with the micro-nutrients; iron and copper. There appears to be a correlation with analytical results between sites. This was interpreted to be the result of the nutrient balance in leaf matter being overprinted, as a result of the impact of relatively alkaline groundwater and soil conditions that occur naturally in this region. Deficiencies may have contributed to poor tree health and probably to decreases in the rate of growth of *O. europaea* planted at each grove.

At Davis Well (Site 1) deficiencies were identified with both nitrogen and phosphorus concentrations in the latter part of the trial as well as a potential deficiency with sulphur. Deficiency of calcium occurred in new growth throughout the entire trial. High levels of sodium and chloride, common in both old and new growth especially during the first half correlates with application of irrigation water, with a low to moderate level of salinity. For micro-nutrients testing confirmed a deficiency of copper in the last part of the trial and a possibility of a seasonal deficiency of iron in leaf tissue. These findings were repeated at the other two sites.

Jubilee Well deficiencies were similar to those at Davis Well. For example, the micro-nutrients copper and iron were identified. However each of nitrogen, phosphorus and calcium appeared deficient through most of the trial period. Sulphur was similar at both sites. Concentrations of sodium and chloride were similar to Davis Well data and to also correlate with irrigation water.

Deficiencies at Hacks Well (Site 3) were identified in concentrations of phosphorus and calcium with potential deficiencies in nitrogen and sulphur. Concentrations elevated to toxic levels were identified with sodium and chloride in leaf matter at February 2003. This is associated with high mortality rates in all 3 groves when trees were supplemented with irrigation water from the Yard Bore source. Elevated, but not lethal concentrations of sodium and chloride were also identified in the February 2005 test confirming the constant nature of salinity at Hacks Well. For micro-nutrients, a potential deficiency was identified with the concentration of copper during the initial part of the trial. Observations during tree growth measurements also highlighted the possibility of a deficiency in iron manifest in leaf symptoms during the spring-summer season.

Deficiencies in macro and micro-nutrients identified by chemical analysis have important implications for tree health and growth performance of *O. europaea* in the region. Despite differences in soil type between different groves at the Hacks Well site, there was a similar pattern observed with deficiencies (both macro and micro-nutrients) at the 3 groves. This was despite the fact that fertiliser, was applied to most tree sites in north and middle grove immediately before the trees were planted and no fertiliser was applied to tree sites in the south grove.

9.5) Flower formation and olive fruit production

Rates of flower formation at Davis Well differed for all cultivars over the duration of the trial. Overall rates of flower formation varied considerably between seasons (all cultivars combined). Comparisons between each of the different cultivars over the duration of the trial identified trees of cv *Ascolana* to be the most consistent flower producers at Davis Well. However the mean number of trees of this cultivar that successfully formed flowers during all 4 seasons was only 25%, which is considered to be minimal. No other cultivar produced flowers during all of the seasons. Trees of cv *UC136A* were the least consistent and had the longest maturity time. Flowers were recorded on one tree only of this cultivar during the final summer season of the trial.

At Jubilee Well highest rates of flower formation occurred during the first and fourth seasons (spring-summer 2002 and 2005). No flower formation was observed on any tree during the second season (spring-summer 2002-03) and only minimal flower formation occurred during the third season.

The pattern of olive fruit formation was similar to that observed with flower formation. The amount of olive fruit produced was variable, both among cultivars and year. The highest rates of olive fruit formation occurred during the first and fourth seasons (spring-summer 2002 and 2005). No fruit was observed on any tree during the second season (spring-summer 2002-03) and negligible fruit was produced during the third season. Overall, the amount of flower formation and olive fruit produced by trees at Jubilee Well grove was minimal over the duration of the trial.

At Hacks Well rates of flower formation varied between groves, between cultivars and season. Flower formation rates (all cultivars combined) also varied between years. Highest rates of flower formation occurred during the final year (spring 2004). Trees at north grove were most consistent, where trees from 2 of 3 cultivars successfully produced flowers during both years. The most consistent and productive cultivar was *Barnea*. This was the only cultivar successful in producing flowers at all 3 groves over the trial period.

Lack of flower formation in the first year, probably reflected spring planting (the same time as the start of the inflorescence cycle). Minimal flower formation occurred during the second year (spring 2003). Highest rates of flower formation were observed for all three groves during the third year (spring 2004). Whilst this increase in flower formation appears to show some correlation with the previous trial at Jubilee Well many site-related factors also influenced flower formation at Hacks Well. These include;

differences in the age of the tree stock, differences in soil profile and variation in soil moisture availability.

Higher rates of flower formation observed at north and middle groves, compared to south grove appears to correlate with growth performance of *O. europaea* at each grove. Lower rates of flower formation at south grove correlate with lower mean growth and higher mortality at this grove. Hence, it is concluded that differences in rates of flower formation at each grove may also be interpreted to be a function of differences in edaphic characteristics.

Lack of olive fruit production over the duration of the trial is probably mainly due to the poor moisture supply status experienced at Hacks Well. It is likely that premature flower abscission was a consequence of soil moisture deficits during the final two spring-summer seasons.

In comparing groves flower formation was different among cultivars, and between years. Rates varied considerably between different groves. At Hacks Well (Site 3) no flower formation occurred during the first year (spring-summer 2002-03), minimal flower production occurred at north and middle groves only during the second year and highest rates of flower formation occurred at all 3 groves during the final season (spring-summer 2004-05). For all groves the most successful years for flower formation were spring-summer 2001-02 and 2004-05, which were preceded by heavy rains during the previous summer (flood-event). A correlation is postulated between the occurrence of summer flood-events and an increase in the rate of flower formation during the following spring.

The highest rates of olive fruit production occurred at Jubilee Well grove (Site 2). In total, about 20 kg of olive fruit was produced here over the 4 year period. Minimal to negligible rates of olive fruit production were recorded at the other two sites in comparison. During the two most productive years the timing from inflorescence to ripening of olive fruit ranged between 150-170 days. Inflorescence occurred in early September, and olive fruit was subsequently ripe in early March. Both observations suggest the fruiting cycle is earlier and the maturation cycle shorter for *O. europaea* when grown in the semi-arid, compared to more temperate environments.

Overall, the irregularity with flower formation and small to negligible amounts of olive fruit appears primarily, to be a function of moisture deficit. Water requirements are estimated to be equivalent to 600-1000mm of rainfall for *O. europaea* to be productive in an arid environment. During the trial period trees at all sites received considerably less than this amount, with negligible olive fruit produced. It is not clear whether the natural alternative bearing cycle of *O. europaea* may also have influenced the production of flowers and/or olive fruit production. Deficiencies in macro-nutrients may have impacted indirectly on tree health and affected the natural processes of flower and olive fruit formation.

9.6) Laboratory testing of olive fruit samples

Composite testing of samples from cvs *New Norcia Mission* and *Verdale* revealed important information about the quality of olive fruit produced by trees at Jubilee Well (Site 2). The flesh:pit ratios were small for both cultivars and ratios varied inconsistently between different years which could rule out suitability for "table olives". The moisture content was close to 60% for both cultivars in March 2005 which raises concerns about efficient oil extraction from olive fruit.

The free fatty acid content was considerably higher than the IOOC standard of 0.8% for both cultivars in March 2005 which raises concerns about the quality of fruit for production of olive oil. The oil content was considerably lower in both cultivars in March 2005 which could complicate economics of oil extraction owing to inconsistency in oil content between different years.

Differences in results between the two years may have resulted from a combination of different climatic and site-related factors. Olive fruit quality and consistency would have been affected by the degree of irrigation deficit, as a function of amount of rainfall received, temperature and evaporation rates over each summer period. On-site factors including deficiency in major/trace elements and differences in canopy density may also have impacted on olive fruit quality.

High moisture content in the March 2005 samples may be linked to the occurrence of heavy rainfall during the summer season before fruit was harvested. The natural occurrence of flood-events in this region during the summer period coincides with the fruit maturation and harvest phase and may impact on the quality of olive fruit. Those cultivars producing fruit with naturally low fruit moisture may be more suited for oil production in areas that commonly experience rainfall around harvest time.

The high free fatty acid content in olive fruit samples at March 2005 raises concerns about oil quality. A relationship has been identified between climate (temperature and to a lesser extent, elevation) and the composition of FFA within olive fruit. Temperature has a significant effect on concentrations of palmitic and oleic acid in olive fruit. Higher temperatures result in an increase in palmitic levels and a decrease in oleic levels in olive fruit, but have a lesser effect on the other components. Hence, further detailed examination of the components of free fatty acids within olive oil is necessary.

Testing of olive samples from Jubilee Well (Site 2) identified inconsistency in quality of olive fruit from cvs *Verdale* and *New Norcia Mission* trees in the two different years examined. This included differences in the flesh:pit ratio, moisture content, free fatty acid and oil content of olive fruit samples. Results highlight important issues regarding quality of olive fruit which has important implications in terms of the potential for future production of olives on a commercial basis in this semi-arid environment.

9.7) Concluding comments

Trials of *O. europaea* conducted on Mount Weld pastoral station were conducted under a range of climate, soil type and water supply. The trees received less water compared to traditional olive growing areas in other parts of the world. Whilst trees survived under semi-arid conditions the mortality rate, growth performance and flowering and olive fruit production rates were all highly variable. Overall, the amount of olive fruit produced was considerably lower compared to what would be expected in more temperate areas, such as along the coastal region of southern Australia.

This appears to correlate with the interpretation by Nix which designates an area in southern Australia, with climate similar to traditional olive-growing regions in Europe (Chapter 3, Figure 3.1). The study area is located on the perimeter of this area and given this interpretation, the results would appear to suggest that climate alone is key to the success or failure of *O. europaea* within the semi-arid environment.

Based on the studies to date, it is recognised that climate is clearly not the only issue in determining the success or failure of *O. europaea* grown in the study area. These other issues have not been addressed in the agro-climatic model by Hutchinson *et al.*, but have been recognised and better defined by the Menzies Line (ML) research in this work. This model has identified important changes in climate, soil types, ground water and salinity that have directly and indirectly influenced the growth of *O. europaea* within this part of the semi-arid environment.

Hence, the recognition of the ML transition is of paramount importance to future successful growth of *O. europaea*. The issues of the summer-dominated rainfall pattern, alkaline soil and groundwater conditions, and salinity have all impacted on growth of *O. europaea* at all 3 sites over the duration of the trial.

From the experience to date, it is now recognised by the author that the climatic, soil and groundwater conditions south of the ML may be better suited to growth of *O. europaea*. Here, the winter-dominated rainfall pattern, lower moisture deficit, calcium-dominated, as opposed to sodium-dominated soils and less alkaline ground waters may be better suited to commercial growth of *O. europaea*. Experiences at the Hacks Well trial site however highlight serious concerns about the salinity issue, which is widespread in a high percentage of groundwater supplies south of the ML.

Clearly, based on current management practices for all 3 sites to date, it is concluded that there is little potential for commercial development for *O. europaea* in the study area. The study confirmed that an insufficient supply of water (from irrigation and/or rainfall) hampers *O. europaea* to grow to its full potential this semi-arid environment. Hence, the issue of water supply is concluded to be paramount, regarding the lack of success with the trials to date. Any potential for future success would depend directly on a full and proper evaluation of water requirements for growth of *O. europaea* in the semi-arid environment. Also, the duration of the trial may have not been sufficient to allow a full assessment of growth potential given the length of time that *O. europaea* may take to reach their full potential in dry zones.

Nevertheless, the key issues of soil type, alkaline soil and groundwater conditions, salinity and moisture deficit have all been identified to impact on successful growth of *O. europaea* in this study. The preliminary testing conducted has also highlighted concerns about the quality and consistency of olive fruit produced by *O. europaea* in this semi-arid environment.

9.8) Recommendations for future trials

The following recommendations are suggested for future horticultural trials of *O. europaea* in the semi-arid environment;

1) **Investigation of trial site factors,**
2) **Design of trial,**
3) **Selection of suitable cultivar(s),**
4) **Pre-preparation of planting site,**
5) **Suitable timing and planting method,**
6) **On-going site monitoring and maintenance.**

9.8.1) Description of recommendation: (1) Investigation of trial site factors

Site selection criteria should incorporate a thorough investigation of soil, groundwater and other environmental factors. Before trees are planted, an audit of each factor and the potential impact on tree growth is recommended. All site audit investigations and observations to be documented.

Soil factors include; extent and consistency of soil type, nature of soil type and behaviour patterns associated, profile depth, presence of laterite and/or silicification, presence/evidence of salinity within soil and other soil quality factors (soil pH, mineral content etc.). Groundwater factors include; proximity to aquifer, groundwater depth and supply rates, groundwater quality (pH, salinity and other mineral concentrations). Other environmental factors include; natural drainage patterns, impact of current/previous land use activity (degree of soil erosion, grazing pressure and impact of previous grazing activity) and occurrence of pests and disease within the area (presence of termites, rabbits).

9.8.2) Description of recommendation: (2) Design of trial

For scientific trial of *O. europaea* a randomised design is mandatory. If several groves are incorporated, consistent design, tree placement and timing of plantings between groves are mandatory. Border rows are recommended to minimise potential for "edge effect".

9.8.3) Description of recommendation: (3) Selection of suitable cultivar(s)

Cultivar selection criteria should incorporate potential impact of the semi-arid environment. Cultivars more suited to hotter and drier environments are recommended. Older, more established rootstock is recommended (minimum 1-2 years, rootstock between 2-3 years of age is recommended).

9.8.4) Description of recommendation: (4) Pre-preparation of planting site

Site preparation is recommended before trees are planted, including clearing site of vegetation (living and dead) by machine with minimum disturbance of soil surface and fencing of perimeter to reduce impact of grazing by stock and/or wildlife. Ripping of planting lines and/or excavation of individual tree sites and pre-installation of reticulation are both requirements before planting of trees is commenced.

9.8.5) Description of recommendation: (5) Suitable timing and planting method

Cooler month recommended for planting of *O. europaea*. Reticulation commenced at each site (for up to 24 hours) before trees are planted to reduce transplant shock. Trees soaked (for up to 24 hours) before planting to reduce transplant shock. Continued irrigation of tree sites after planting via reticulation strongly recommended. Fertilisation recommended during planting according to macro/micro-nutrient requirements.

9.8.6) Description of recommendation: (6) On-going site monitoring and maintenance

For scientific trial of *O. europaea* regular monitoring of growth performance, tree health indicators, flower formation and olive fruit production are recommended. Foliar samples collected during peak-growth period (summer months) and collection of olive fruit samples during harvest (March) for chemical testing. Recording of all results and observations to facilitate scientific interpretation. Recording of rainfall received and irrigation applied over duration of experiment.

Recommended grove maintenance methods include; regular checking/calibration of reticulation system to ensure consistency of irrigation supply, removal of weeds from immediate root zone, removal of suckers and broken/damaged limbs from trees, staking of individual trees as required, detection and treatment of insect and/or animal attack, plus application of fertilization and on-going pruning of trees to promote flowering/fruiting in trees as required.

CHAPTER 10: MANAGEMENT AND COMMUNITY ISSUES

10.1) Permission for the trial

The trial sites are all located on Mount Weld pastoral station, which is a pastoral lease. Land use on this lease is governed by the Crown and administered by the Land Administration Act of Western Australia, 1997 (based on the original Land Act for the State of Western Australia, 1933). According to this lease land use is deemed for grazing purposes only, with special permission being required for the purpose of other activities. Schedule 120 of the Land Administration Act (No 30, 1997) for the State of Western Australia, states the following requirements:

<u>Permits for agricultural uses of land under a lease</u>

120.

(1) The Board may, on an application in writing from a pastoral lessee, issue a permit for the lessee to use specified land under the lease for crop, fodder, horticultural or other specified kind of agricultural production if it is satisfied that the proposed use is reasonably related to the pastoral use of the land.

(2) An application must specify the non-pastoral activity proposed and the areas of land proposed to be used for the activity.

(3) A permit under this section-

  (a) may include a permit for the sale of any produce arising from the activity permitted; and

  (b) may be issued for any period and subject to any conditions the Board thinks fit.

Before the commencement of the trial, an application was lodged with the Pastoral board of Western Australia for permission to clear approximately 2 hectares (total) of land on Mount Weld pastoral station for the purpose of scientific trials of *O. europaea*.

10.1.1) Department of Environmental Protection

In addition to this application one meeting was also organised with a representative from the Department of Environmental Protection of Western Australia (Dr Peter Curry). A number of environmental aspects of the trials, including impacts were discussed during this meeting.

10.2) Restrictions to alternative land use strategies

In regards to this trial, the conditions associated with amending land tenure were both complicated and time consuming. After the application was lodged a considerable period of time had passed (greater than 6 months), before the approval was granted to allow the trial to proceed.

The issue of restrictions to land use, as a result of pastoral leases has been subject to a detailed study by the Commonwealth Productivity Commission (2002). The tenure of Pastoral lease creates a restricted environment that hinders the introduction of new land use opportunities. Unlike freehold land, pastoral lands are considerably more governed with land use being primarily restricted to grazing purposes only. Regardless of the results of the experiment, land tenure is still a major impediment to any further developments of this type in the future. This results in the following issues;

1) A lack of permanence or ownership
2) The inability of attracting investment as a direct result of the above (Point 1)

10.3) Profitability of pastoralism

The relative profitability of pastoral sheep has been contrasted between different areas of Western Australia (Holm *et al*., 1995). This report challenges the profitability of pastoralism in many parts of Western Australia, including pastoral stations in the north-eastern Goldfields region. It is widely accepted that diminishing returns to wool production has resulted in the need for rangeland enterprise diversification (e.g. see: Pastoral Wool Industry Task Force report, 1993).

10.4) Examples of successful diversification of a Pastoral Lease

At Ti Tree 180 km north of Alice Springs in Northern Territory, special licence conditions have been specified by the Government allowing freehold leases to be granted on land formerly of pastoral lease tenure. This has allowed for development by private enterprise for the purpose of horticultural activities (pers. comm. A. Nesbitt, 2005). The successful development of a commercial grape and mango industry has been achieved on one-mile square freehold blocks that were excised from the Ti Tree station pastoral lease during the 1970's. This has resulted in land being used for a more profitable activity when compared to the grazing of cattle, which was a lower value enterprise per unit area.

10.5) Local management

Over the duration of the trial Mount Weld pastoral station was managed by the mining company; Placer Granny Smith. The project was administered by the Sustainability Department at the Placer Granny Smith mine site. Level of support varied considerably over the trial which resulted in key compromises with the running of the trials. Key issues that impacted on the operation and success of the trial where as follows;

Formal contract

At commencement of the experiment, a verbal agreement was obtained between the principal (Placer Granny Smith), the author, and the tertiary institution (Curtin University of Technology). Consequently,

PLATE 10.1: Commercial horticultural development at Ti Tree, freehold lease on land that was formally a pastoral lease. Photograph taken March 2002.

no formal agreement was constructed and the original verbal agreements were not documented.

Owing to the lack of formality of this agreement several issues had to be negated well after the commencement of the trial, including insurance coverage and site access permission. Many on-going site-management issues currently remain unresolved, including on-going management and/or closure.

Water Supply

The provision of a reliable water supply over the duration was paramount to the success of the trial. This supply was not maintained by the principal however, which resulted in the trial as conceived being compromised. At Hacks Well (Site 3), the lack of a reliable water supply led to design of the trial being changed, with the duration of the experiment also changed. As a result of these compromises assessment of water relations of *O europaea*, which was originally one of the aims of this experiment could not be completed. At Davis Well (Site 1) and Jubilee Well (Site 2) the lack of water supply resulting from windmill failures resulted in the early conclusion of the trial at both sites.

10.6) Local community

The perception of the olive trials within the local Laverton community is discussed:

Presentation to Shire Councillors

A formal presentation about the experiment was made to councillors from the Shire of Laverton, during May 2003. In hindsight, a formal presentation probably should have been planned earlier, as the olive trials had commenced several years beforehand. Informal discussions had been conducted previously however.

It appeared from this meeting that as far as some councillors were concerned, that there was little to no future potential for a commercial development of olives in the Laverton area. The opinions expressed by one senior councillor in particular, appeared to be based on limited knowledge of the olive industry (either locally and/or globally).

Local community perceptions

In general, it is the interpretation of the author that the local Laverton community has a “reactive”, as opposed to “pro-active” approach to new concepts and business opportunities. Locally, it appears that the community has expressed a tendency to look externally for inspiration, as opposed to the encouragement or fostering of the development of new ideas at a local level.

In many informal discussions conducted with members of the local community, most appeared apprehensive about the potential of a commercial olive industry in the local area. In a number of cases the concept was dismissed as being purely of “novelty value” only. In other cases there was some potential expressed, regarding the possibility that such a concept might be of interest for the “tourists”.

Involvement of the Wongatha community

The inability of the author to gain any level of involvement in the project from members of the local Wongatha community was considered to be one of the biggest failures of the enterprise.

10.7) The method of “madness”: creating change in the bush

Regardless of the scientific basis of this study the core theme behind the project deals directly with the issue of “change” within a conservative outback community. More specifically, the issue of a change to the conventional pattern of land use in a remote, semi-arid environment.

Theoretical approaches to the issue of change

The issue of creating change in the conservative workplace environment is a subject that has been examined in detail by many authors. The basic principles are still very relevant however to this study and especially, to the degree of success that has been achieved currently with the implementation of the concept of planting *O. europaea* in the semi-arid environment.

The following is a summary of theoretical steps, to help in making new ideas or concepts to problems become successfully accepted within the workplace environment (Thorp, 2005 after McKennah, 1999):

Get Buy-in

The new idea must be allowed to be considered by others, and it must stand up to rigorous debate before it should be considered further. If it’s simply a bad idea that one individual just happens to like, it’s probably doomed to fail as people will undermine any progress if they don’t feel involved.

Find an owner

Someone must be willing to stand up and drive the change process, meaning they must believe in the advantages it will bring and commit time to ensure the implementation process is continually moving forward. Without this drive, small distractions can derail a project indefinitely.

Top down buy-in

The owner must have support from senior management. If it is not supported by management, other people will soon pick up on the negative sentiment and consciously or subconsciously block the progress of the project.

Measure and sell

Once successfully implemented, the results must be monitored and improvements communicated widely. When people see ideas of others implemented and successfully improving their working environment, it will encourage them to offer their thoughts and suggestions. It also has the effect of showing people they have genuine power to change their own work situation if they are prepared to think critically about what they do. This will ensure that “buy-in” for the whole process spreads faster.

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APPENDIX 1: FURTHER TRIAL SITE DETAILS

Trial site#1; Davis Well grove

Grove establishment

During September 1999 a bulldozer was used to clear the grove area of all grass cover and dead timber. Living trees (old-growth mulga) were left intact within the site as a conservation measure. The grove area was ripped with a bulldozer tyne along the north-south direction (ripping was halted immediately around the remaining trees). Owing to the hardness of the laterite, the tyne only penetrated to shallow depth. This resulted in only minor breakage of the laterite, with the soil above being thoroughly ripped. Fencing was then erected around the perimeter of the grove, which consisted of a combination of ring-lock and barbed wire to a height of approximately 1 m. This aimed at reducing the risk of casual grazing of trees by native and introduced animals.

All stock was in good health when it arrived on-site. Before being planted, all trees were pre-soaked on-site for a period of 24 hours in a shallow tub to reduce transplant shock. Holes were dug by hand at each tree site and after trees were planted, the earth was mounded by hand around the base of the trunk.

The reticulated water supply system was then installed. This consisted of a single main supply line (40 mm poly-pipe) which was laid across the ground in an east-west direction at the north end of the grove. An on/off value was then joined and this was connected via the main supply pipe (40 mm poly-pipe) to a single 25,000 L water tank located approximately 100 m away and fed by the windmill at Davis Well. Individual water lines (19 mm poly-pipe), where installed in a north-south direction along each of the eleven rows. At each of the eight tree locations along the line, two adjustable drip-feeders where fitted to the supply line to supply water to each tree. The reticulated system was initially installed in series (no parallel supply connection at the south end) which resulted in a differential water supply during the initial stages after the grove was established.

Soil testing

Testing of this horizon was completed on a composite sample of clay soil (from depth 0-30cm) to further evaluate the soil and classify the soil type. Analysis of this sample revealed the following results:

1) Conductivity; Ec_e = 186.2 dS cm^{-1} (1.86 dS m^{-1})
2) Salinity; = 96.5ppm

The conductivity level present within the A-horizon falls within the category of a “sodic” soil-type (soil conductivity reading of Ec_e < 4 dS m^{-1}), according to soil classifications by Qureshi and Barrett-Lennard (1998).

Mechanical analysis was also completed on the composite sample of the A-horizon, according to the technique described by Williams (2000) to assess the textural class of this soil. This work failed to confirm the correct textural classification however, owing to the fact that a large percentage of the sample was consolidated. The high percentage of aggregates/peds in the sample skewed the mechanical analysis (particle distribution by dry sieving was identified as being equivalent to that of a sand soil). Dispersion testing of the composite sample confirmed the soil dispersion rating to be between 0-1 (according to classification by Addison *et al.*, 2003).

Other tests completed using the composite sample included bulk density, porosity and void ratio according to procedures described by Williams (2000). These tests revealed the following results;

3) Bulk density; 1.26 g cm^{-3}
4) Porosity; 52.5%
5) Void ratio; 1.11

The bulk density value of 1.26 g cm^{-3} is within the bulk density range for a compacted horizon in clay soil, which is between 1.2-2.0 g cm^{-3} according to the classification by White (1987), after Williams (2000).

The porosity was calculated to be 52.5%, using an assumed figure for solid phase density of 2.65 g cm^{-3} (according to procedure outlined by Williams, 2000). This porosity value fell within the classification range for silt and clay soil types denoted by Bouwer (1987), after Williams (2000).

The void ratio was calculated to be 1.11 (according to procedure outlined by Williams, 2000). This void ratio was close to the value of 1.3, which is the classification range for unconsolidated clay soil types denoted by Bouwer (1987), after Williams (2000).

Water supply

A storm during summer 2000-01 caused extensive damage to the windmill at Davis Well. The windmill was subsequently decommissioned and from this point onwards, an electric bore pump was used permanently to pump water from the well directly to the supply tank. This regime was discontinued after summer 2003, with the grove being run according to rain-fed agricultural practice until the end of the trial in September 2004.

Differential water supply

Differences were observed in the pattern of tree growth across the grove several months after the trees were planted. This appeared to suggest, that a differential water supply may have been affecting tree

PLATE A1.1: Elevated water tank, next to well-head at Davis Well (Site 1). Remains of windmill are visible in foreground. Photograph taken during December 2001.

PLATE A1.2: Clearing of re-growth within grove area by backhoe at Davis Well (Site 1). Clearing work avoided the area immediately near olive tree rows. Photograph taken during December 2001.

growth at the grove. This was interpreted to result from a combination of both the low supply pressure from the tank, along with a shallow downward gradient observed from the northern end towards the south-western corner of the grove (pers. comm., Barrett-Lennard, 2001). Changes to the water supply were subsequently completed during September 2000.

A parallel single supply line (19 mm poly-pipe) was installed at the southern end of the grove to assist with equalisation of the supply pressure. At each tree site, the two drip feeders were upgraded with a single drip feeder fitted on the end of a flexible line (5 mm). This was then positioned to allow a more centralised flow of irrigation water at each tree site.

Earthworks were completed by the Sustainability Department to increase the water supply pressure to the grove. The poly supply-tank was drained, removed and the well area cleared by backhoe. The wellhead was then re-stabilised to avoid further collapse with bricks and cement. The original concrete tanks that still remained next to the well was used to form an elevated tank stand. Firstly, the concrete tank was reinforced with tensioned wire cable, before being filled with earth by backhoe. The poly supply-tank was then placed on top of the structure at a new height of approximately 3 m above the surrounding ground level (Plate A1.1). A substantial increase in water supply pressure to the Davis Well grove was the net result.

Trial site#2; Jubilee Well trial grove.

Grove establishment

Site selection for the second grove was a joint decision between myself, and the acting station oversea (pers. comm., Farmer 2000). Main considerations at the time of site selection included a reliable water supply and the existence of contrasting soil type and profile compared to the first grove site. The site was located approximately 2 km from the water-point and a pipeline ran past the site that was currently supplying water from Jubilee Well to several troughs in the immediate area. The site was completely cleared by backhoe during March 2000. All trees and bushes were knocked over and the ground surface cleared of all grassy undergrowth. The grove was then fenced with a combination of ring-lock and barbed wire (height of 1.2 m) to reduce the risk of casual grazing of trees by native and introduced fauna.

Tree stock had arrived on site during September 1999 and remained in the Sustainability department compound until being planted in March 2005. Holes were dug immediately before planting at each tree site with the backhoe immediately before trees were planting (depth of approximately 1 m). Many of the trees had become pot-bound and some were in poor condition. All trees were pre-soaked for a period of 24 hours before being planted to help to reduce transplant shock (Plate A1.3). The root zone of pot-

PLATE A1.3: Pre-soaking of trees before planting at Jubilee Well (Site 2). Photograph taken March 2000.

PLATE A1.4: Planting of an olive tree at Jubilee Well (Site 2) during March 2000.

bound trees was broken open before they were planted, based on the advice from the nursery (pers. comm., Bazzani, 2000). Earth was mounded by hand approximately 0.5 m away from the tree trunk at each site immediately after planting (Plate A1.4).

A reticulated water supply system was then installed, which consisted of a single main supply line (40 mm poly-pipe) which was laid across the ground in an east-west direction at the south end of the grove. An on/off value was then joined and this was connected via the main supply pipe to a 25,000 L water tank, which was placed on a 0.5 m high tank stand (constructed on-site during March 2000). Individual water lines (19 mm poly-pipe), where installed in a north-south direction along each of the 7 rows. At each of the 14 tree locations along the line, a single flexible supply line (5 mm flexible hose) was then installed and a single drip-feeder placed at the end. The reticulated system initially consisted of supply lines connected in series from the southern end of the grove (no parallel supply connection at the north end). This is expected to have resulted in a differential water supply to trees across the grove, until the parallel connection was later installed.

Soil testing

Soil textures and characteristics observed within the A-horizon clays were considered to be very important in terms of the growth performance of *O. europaea* at the Jubilee Well grove site. Further testing of this horizon was completed on two composite samples of soil (samples collected from depth 0-80cm and 80cm-1.2metres depth) to further evaluate the soil and classify the soil type. Analysis of this sample revealed the following results:

1) Conductivity; 4.45 dS m^{-1} (0-0.8 m), 8.74 dS m^{-1} (0.8-1.2 m)
2) Salinity; 209ppm (0-0.8 m), 467ppm (0.8-1.2 m)

Mechanical analysis of both samples was completed according to the technique described by Williams (2000) to assess the textural class of this soil. This confirmed that this soil type ranged between the category of fine to coarse sand. Dispersion testing of the composite sample confirmed the soil dispersion rating of “0”, which indicates low water retention ability (according to classification by Addison *et al.*, 2003).

Other tests completed on only the upper composite sample (0-0.8 m), included bulk density, porosity and void ratio according to procedures described by Williams (2000). These tests revealed the following results:

1) Bulk density: 1.34 g cm^{-3}
2) Porosity: 49.4%
3) Void ratio: 0.98

The bulk density value of 1.34 g cm^{-3} is within the bulk density range for a well-aggregated loam, which is between 1.0-1.4 g cm^{-3} according to the classification by White (1987), after Williams (2000). The porosity was calculated to be 49.4%, using an assumed figure for solid phase density of 2.65 g cm^{-3} (according to procedure outlined by Williams, 2000). This porosity value fell within the classification range for fine sand soil types denoted by Bouwer (1987), after Williams (2000).

The void ratio was calculated to be 0.98 (according to procedure outlined by Williams, 2000). This void ratio was at about the middle of the classification of 0.7 for fine sand and 1.3 for unconsolidated clay as denoted by Bouwer (1987), after Williams (2000).

Water supply

Late in the summer season of 2002, the well head at Jubilee Well partially collapsed which resulted in the windmill being decommissioned. From this point onwards, an electric bore pump was used permanently to pump water from the well directly to the supply tank. This regime was discontinued after summer 2003, with the grove being run according to rain-fed agricultural practice until the end of the trial in September 2004.

Differential water supply

During September 2000 a parallel supply line (19 mm poly-pipe) was added at the northern end of the grove to equalise the water supply pressure in all parts of the grove.

Trial site#3; Hacks Well trial groves

Grove establishment

Initial site reconnaissance commenced during June 2001. A number of sites being examined, which were all proximal to existing water-points. An on-site examination was then conducted at each of these sites, including excavation and mapping of the soil profile, collection and testing of samples from each soil horizon intersected and testing of water samples from each water-point. During July 2001, the Hacks Well site was selected after consultation with supervisors. This site is located approximately 15 km due south of the first trial site at Davis Well and approximately 10 km east, north-east of the second trial site at Jubilee Well. Agreement was reached between all MSc. supervisors during a round-table meeting conducted at Curtin University during April 2002.

Site description

The Hacks Well site was established at the eastern end of Long Paddock, which was previously used as a mustering paddock on Mount Weld pastoral station. The area has been subjected to sustained grazing pressures and was assessed and classified Department of Agriculture as degraded pasture. Long paddock was classified under the land management category of "future rehabilitation" (James *et. al.,* 2001). Rehabilitation work had been recently conducted by the Sustainability Department, with much of the trial site area being ripped by bulldozer tyne to further promote re-growth. The trial site area was mostly devoid of vegetation, apart from a patchy cover of grass species and occasional bush. Few old-growth trees remained in the area and during the site preparation works, less than 10 living trees were removed.

Assessment of soil profile

A comprehensive audit of the soil profile was conducted across the site on 12th November 2001. A total of 28 small pits were excavated by backhoe at various points across the site. For each pit, the backhoe was used to dig a small test hole down to +1 m depth (to the maximum reach of the bucket unless ground was too hard). Holes were dug about 25 m apart to provide a series of sections right across the site. As each soil pit was excavated, the soil profile was then mapped (Table A1.1) and GPS co-ordinates were recorded for each location. Photographs were also taken of some of the test pits. Composite soil samples where collected from each different horizon exposed in most of the pits. Some of these samples were later selected and dispatched to CSBP laboratories (Bibra Lake, WA) for analysis of major and trace elements. After completion of the site work, all 28 holes were back-filled with the backhoe and the surface area around each hole was rehabilitated.

The GPS co-ordinates for all excavated soil pits were downloaded and a plan was generated for the Hacks Well site (Figure A1.1). Logging data for all 28 soil pits was downloaded onto excel spreadsheet. Mapping data for each soil profile was then plotted by hand to allow for a number of north-south oriented (Figure A1.3) and east to west oriented (Figure A1.4) cross-sections of the soil profile to be generated. A contour map for the calcium-rich "marker-unit" was then generated (Figure A1.5) based on the soil profiles, combined with the mapping data from individual soil test pits. This information was later incorporated into the final design for the experiment.

Analytical testing

Soil samples collected and submitted for analytical testing to determine the nature of differences in soil type between each of the test pits. Two composite samples from six different test pits (holes 20-25) were dispatched to CSBP laboratory (Bibra Lake, WA) for analytical testing. The first samples were selected from the A-horizon (0-0.3metres depth), with the second being selected from the calcium-rich gravel marker unit immediately below (Tables A1.2 and 3).

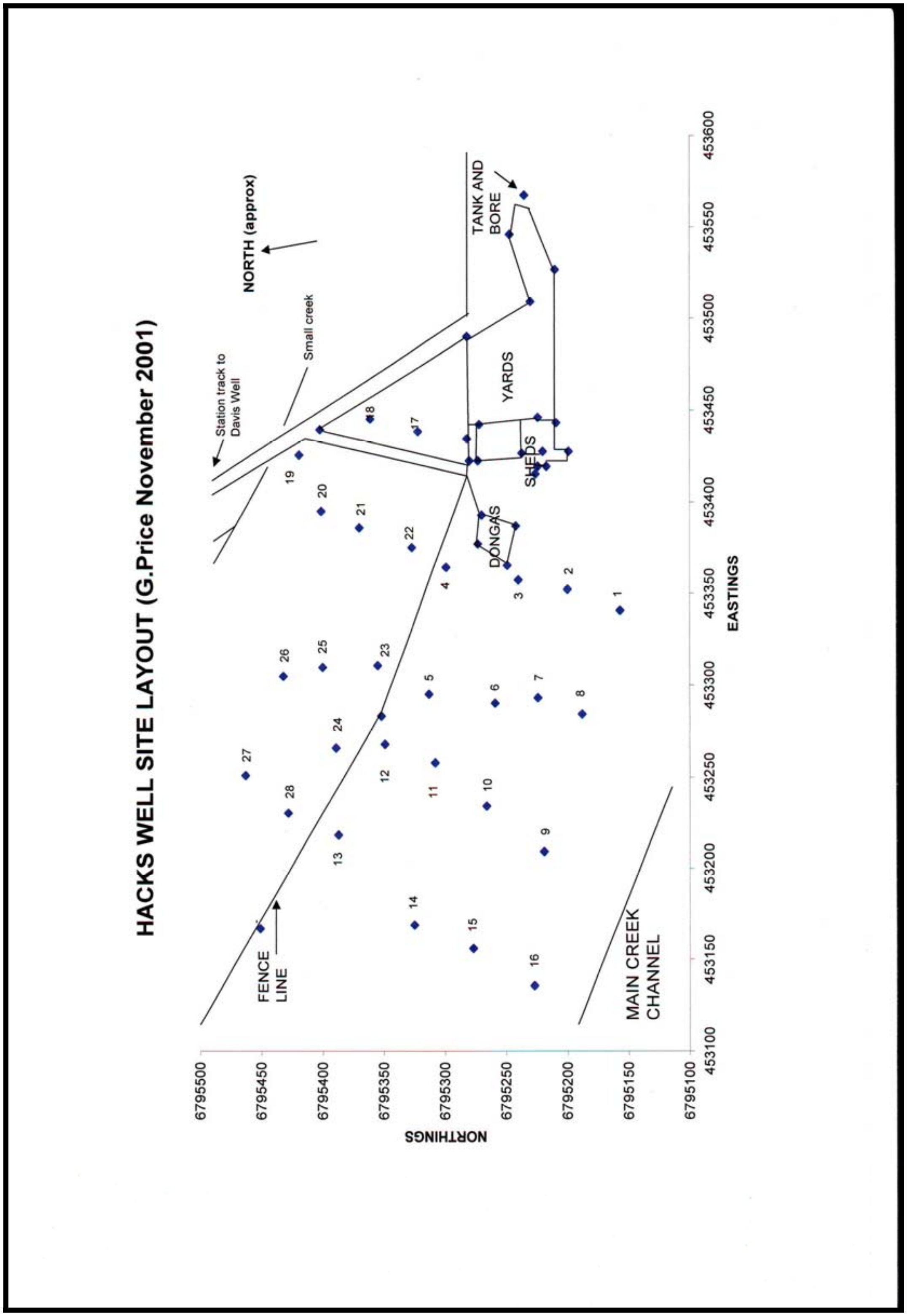


FIGURE A1.1: Layout of soil test pits excavated by backhoe at the Hacks Well (Site 3).
NB: Points plotted from pickup by hand-held GPS (GDA94 co-ordinates).

HOLE	FROM (m)	TO (m)	COLOUR	DESCRIPTION
1	0	0.45	rdbn	clay
1	0.45	1.3	rdbn	clay, with coarse/angular gravels (basalt/qtz with haematitic coatings, trace pisolithic gravels
2	0	0.15	rdbn	clay
2	0.15	0.2	rdbn	clay, graded gravel, coarse/rounded and haematite coated
2	0.2	1.1	rdbn	clay, coarse/rounded and haematite coated gravels. Angular chunks at base (unconformity?
3	0	0.2	rdbn	clay and pisolithic gravel (minor)
3	0.2	0.9	rdbn	clay and lateritic gravels
3	0.9	1	off white	calcitic clays and gravel
4	0	0.2	rdbn	clay
4	0.2	0.9	rdbn	clay and lateritic gravels
4	0.9	1.1	off white	calcitic clays and gravel
5	0	0.3	rdbn	clay and pisolithic gravel (minor)
5	0.3	0.7	rdbn	clays, mixed fine to coarse angular haematitic gravels
5	0.7	0.9	off white	cemented calcitic clays and gravel
6	0	0.35	rdbn	clay and pisolithic gravel (minor)
6	0.35	0.45	off white	cemented calcitic clays and gravel
7	0	0.6	rdbn	clay and pisolithic gravel rounded at surface to angular at depth
7	0.6	0.7	off white	cemented calcitic clays and gravel
8	0	0.35	rdbn	clay and rounded gravel (minor)
8	0.35	0.75	rdbn	clay and haematitic gravel (laterite)
8	0.75	0.95	off white	cemented calcitic clays and gravel
9	0	0.45	rdbn	clay, fine-medium rounded and haematitic gravels
9	0.45	0.7	off white	calcitic laterite
10	0	0.35	rdbn	clay, fine-medium rounded and haematitic gravels
10	0.35	0.4	off white	calcitic laterite
11	0	0.4	rdbn	clay, fine-medium rounded and haematitic gravels
11	0.4	0.65	off white	calcitic laterite
12	0	0.3	rdbn	clay, fine-medium rounded and haematitic gravels
12	0.3	1	rdbn/white	intermitten clay/calcitic laterite, with medium-coarse angular basalt and quartz
13	0	0.25	rdbn	clay and pisolithic gravel (minor)
13	0.25	0.5	rdbn	clay, coarse, angular/rounded gravels (basalt/qtz)
13	0.5	0.9	brown	clay, coarse, angular/rounded gravels (basalt/qtz)
14	0	0.4	rdbn	clay, fine-coarse rounded and haematitic gravels
14	0.4	0.55	off white	calcitic laterite
15	0	0.5	rdbn	clay, fine-coarse rounded and haematitic gravels
15	0.5	0.65	off white	calcitic laterite
16	0	0.5	rdbn	clay, fine-coarse rounded and haematitic gravels
16	0.5	0.65	white/bn	intermitten calcitic clays and angular gravels (ferrugenised chert? fragments)
17	0	0.4	rdbn	clay and fine-medium rounded haematitic gravel (minor)
17	0.4	0.95	brown	clay, medium-coarse rounded to angular haematitic gravel (basalt)
17	0.95	1.1	off white	calcitic clay, fine to coarse, well rounded gravels (creek wash)
18	0	0.7	rdbn	clay, with fine-medium rounded haematitic gravel (trace quartz)
18	0.7	1	white/bn	calcitic clay, fine to coarse mixed gravels (creek wash)
19	0	0.4	rdbn	clay, with fine-medium haematitic gravel
19	0.4	0.45	greybn	coarse-rounded, haematite coated basalt fragments
19	0.45	1.1	brown	clay, trace of haematitic gravel
20	0	0.7	brown	clay, minor fine,rounded haematitic gravels
20	0.7	1.2	white/bn	calcitic clays, with fine-coarse haematitic gravels
21	0	0.55	brown	clay, minor fine,rounded haematitic gravels
21	0.55	0.7	brown	clay, fine to coarse, rounded haematitic gravels (basalt)
21	0.7	1.2	white/bn	calcitic clays, with fine-coarse rounded to angular basalt gravels
22	0	0.5	brown	clay and graded gravels at depth, fine to medium and rounded
22	0.5	0.8	brown	clay, medium-coarse, very smooth to angular basalt/quartz gravels
22	0.8	1.1	white/bn	clay, mixed rounded and angular gravel with haematitic coatings
23	0	0.3	brown	clay, minor fine to medium/rounded gravels
23	0.3	1.1	br/orange	clay, fine to medium gravels grading to coarse, smooth-angular basalt, root matter
23	1.1	1.6+	white/bn	clay and gravel
24	0	0.45	brown	clay, fine to medium gravel
24	0.45	0.75	brown	clay, medium to coarse angular basalt gravel and root matter
24	0.75	1	brown	clay, with trace gravel
25	0	0.7	brown	clay, trace gravel
25	0.7	0.9	white/bn	calcitic clay and gravel, with root matter
25	0.9	1.3	brown	clay and coarse angular basalt fragments (unconformity?)
26	0	0.6	brown	clay, trace gravel
26	0.6	0.85	white/bn	cemented calcitic clay and gravel, with root matter
26	0.85	1.1	brown	clay and minor angular gravels
27	0	0.5	brown	clay, trace gravel
27	0.5	1	brown	clay, coarse rounded and broken chunks gravel, coated with haematite
28	0	0.3	brown	clay, trace of coarse, rounded gravels
28	0.3	0.75	brown	clay, fine-medium well rounded gravel, haematitic
28	0.75	1	brown	clay, minor coarse angular gravels
28	1	1.1	white/bn	calcitic clay

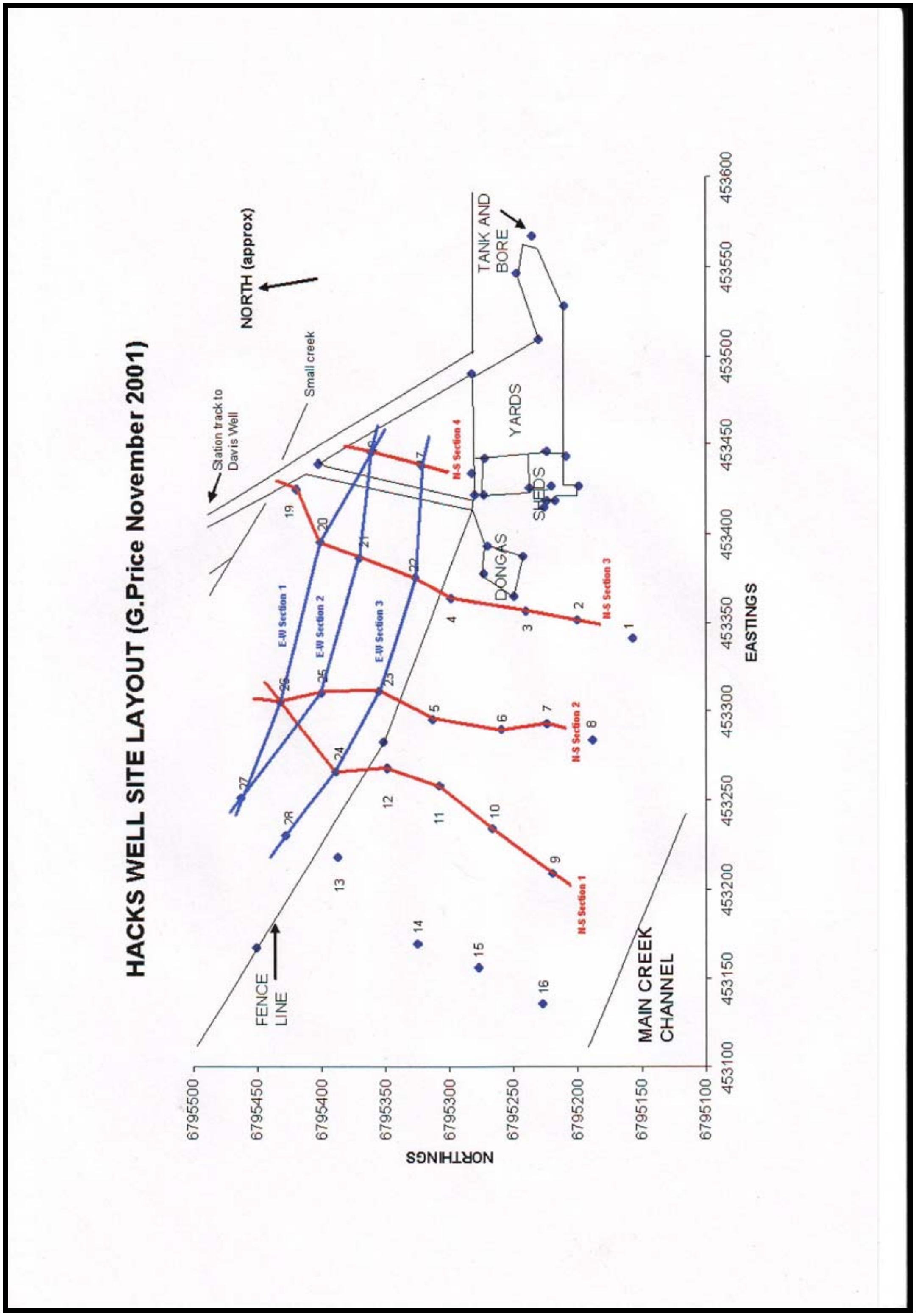


FIGURE A1.2: Layout of soil profiles constructed from soil pit mapping at Hacks Well (Site 3).
NB: Red lines represent N-S sections (Figure A1.3). Blue lines represent E-W sections (Figure A1.4).

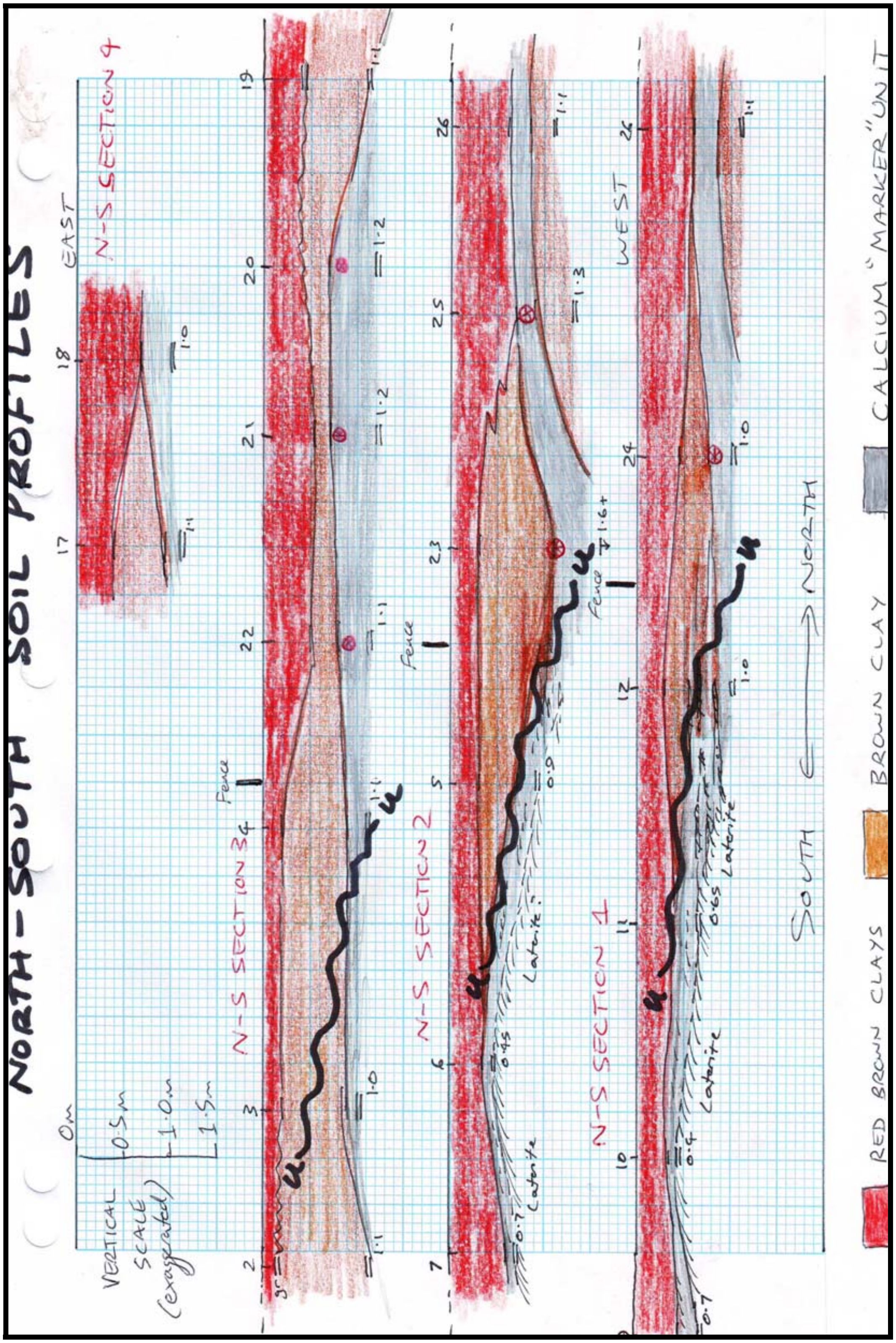


FIGURE A1.3: North-south oriented soil profiles (Red lines) constructed from Hacks Well soil mapping program. Individual soil pit holes denoted by number.

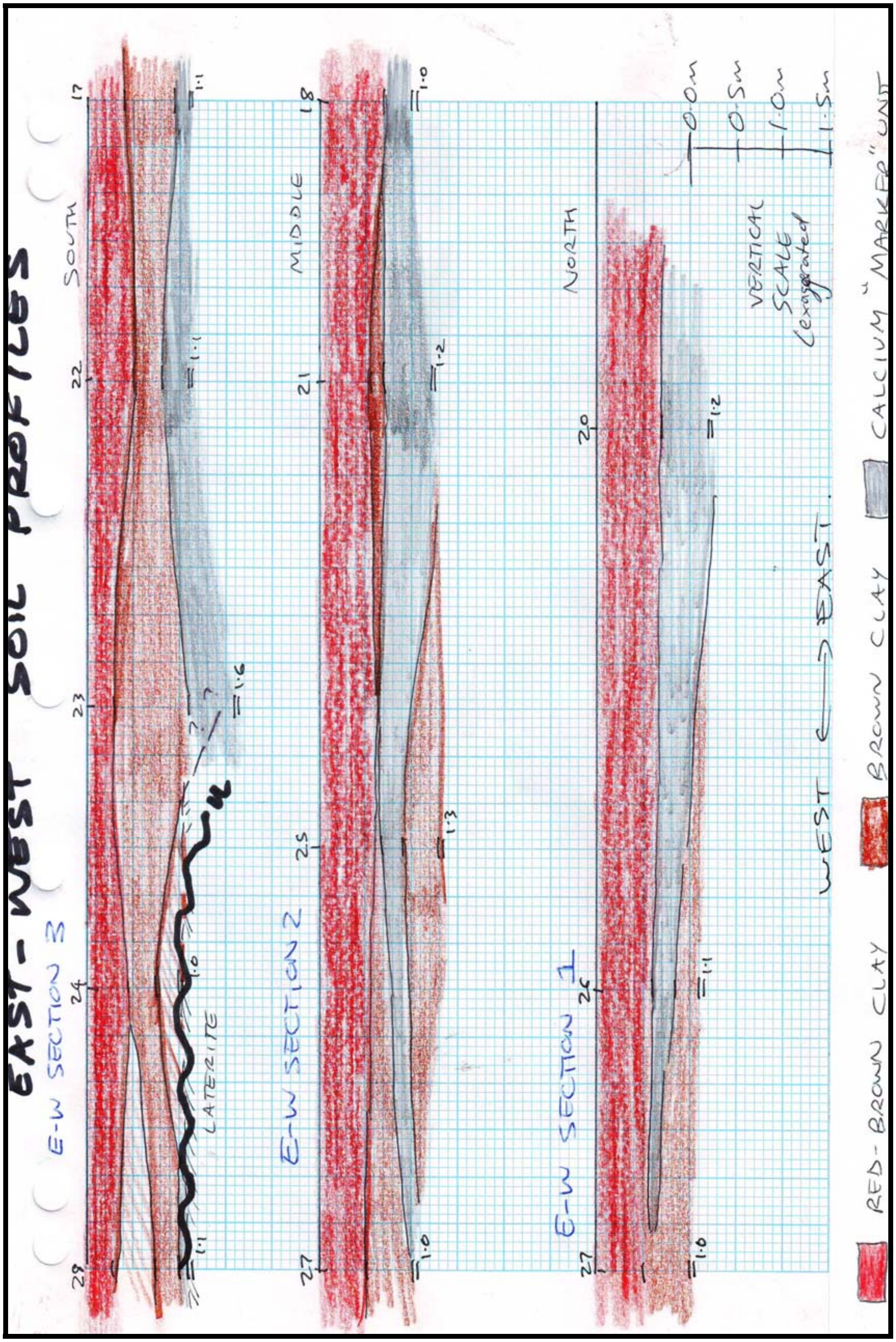


FIGURE A1.4: East-west oriented soil profiles (Blue lines) constructed from Hacks Well soil mapping program. Individual soil pit holes denoted by number.

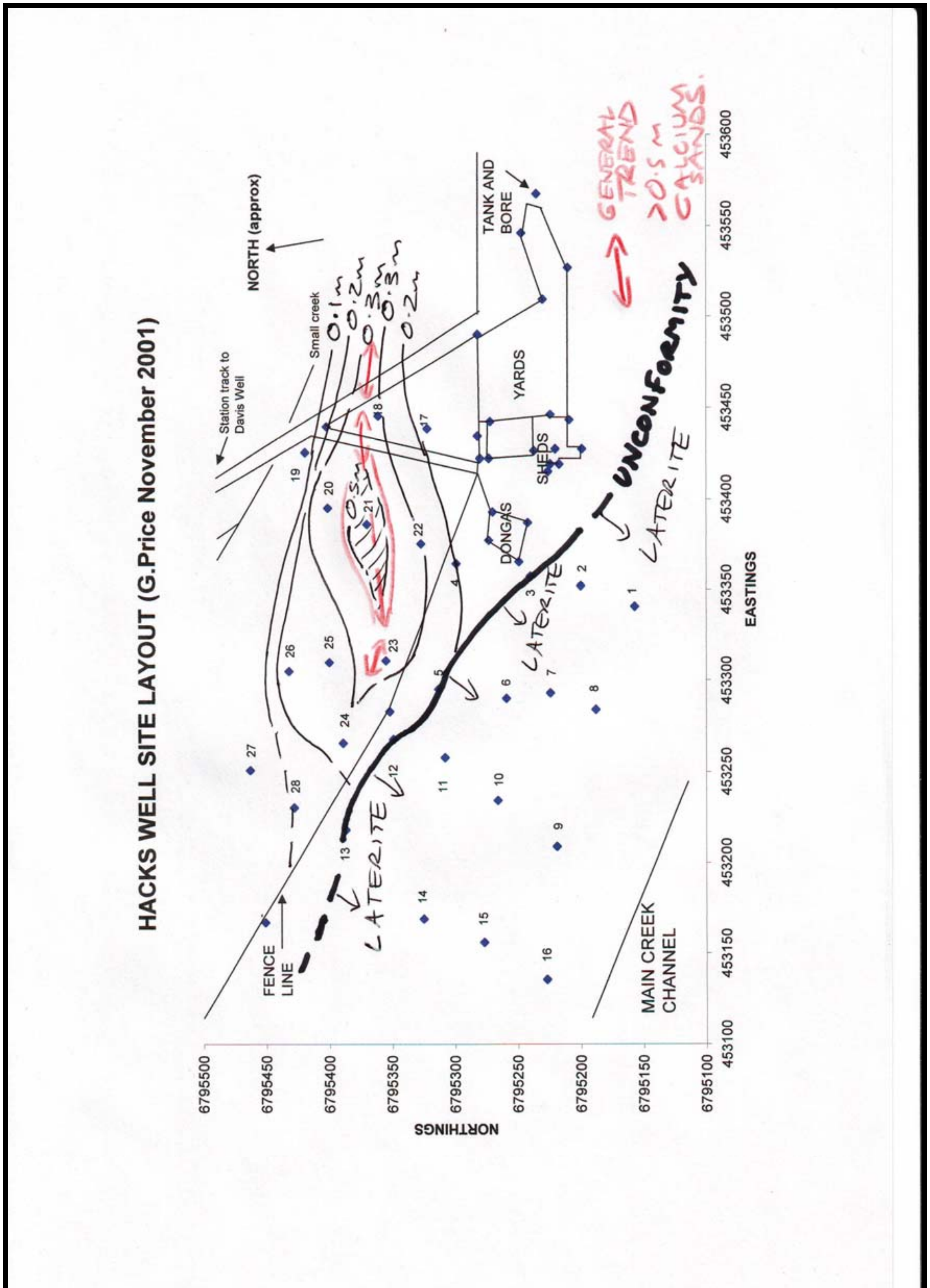


FIGURE A1.5: Hand-contoured map showing thickness and trend of the calcium-rich "marker" horizon located north of unconformity at Hacks Well (Site 3). Lines indicate thickness of calcium-rich horizon. **NB:** Interpretation based on mapping data and north-south/east-west soil sections.

TABLE A1.2 : Soil analysis data for A-horizon samples from Hacks Well (Site 3).

COSTEAN NUMBER APPROX DEPTH OF SAMPLE		20 30cm	21 30cm	22 30cm	23 20cm	24 30cm	25 30cm
Nitrate Nitrogen	mg/kg	60	132	2	2	104	30
Ammonium Nitrogen	mg/kg	3	7	1	1	6	2
Phosphorus Colwell	mg/kg	5	4	1	2	3	7
Potassium Colwell	mg/kg	282	216	107	216	176	275
Sulphur	mg/kg	9	19.9	3.9	3	23.5	7.5
Organic carbon	%	0.17	0.21	0.15	0.22	0.2	0.2
Reactive iron	mg/kg	475	493	440	549	505	444
Conductivity	dS/m	0.282	0.369	0.062	0.051	0.256	0.159
pH level ($CaCl_2$)	pH	7.5	7.4	7.6	7.6	7.7	7.7
pH level (H_2O)	pH	8.1	8	8.7	8.5	8.2	8.5
DTPA copper	mg/kg	0.96	1.22	0.73	0.69	1.16	1.23
DTPA zinc	mg/kg	0.21	0.22	0.35	0.1	0.11	0.21
DTPA manganese	mg/kg	4.55	4.41	2.84	2.82	2.18	3.93
DTPA iron	mg/kg	6.02	5.01	6.03	8.74	5.12	5.09
Exc. Calcium	meq/100g	9.38	10.53	4.29	3.4	11.07	10.28
Exc. Magnesium	meq/100g	2.13	3.21	1.69	1.26	2.29	2.88
Exc. Sodium	meq/100g	0.22	0.5	0.2	0.08	0.3	0.52
Exc. Potassium	meq/100g	0.7	0.54	0.27	0.53	0.48	0.68
Boron hot $CaCl_2$	mg/kg	0.4	0.5	0.3	0.3	0.3	0.4
Chloride	mg/kg	61	82	4	3	96	58

TABLE A1.3: Soil analysis data for B-horizon samples from Hacks Well (Site 3).

COSTEAN NUMBER APPROX DEPTH OF SAMPLE		20 80cm	21 80cm	22 90cm	23 1.1m	24 80cm	25 80cm
Nitrate Nitrogen	mg/kg	13	6	9	6	82	68
Ammonium Nitrogen	mg/kg	2	2	1	1	2	3
Phosphorus Colwell	mg/kg	4	2	3	4	5	3
Potassium Colwell	mg/kg	176	90	143	122	73	186
Sulphur	mg/kg	6.4	8.1	11.6	3.7	7.3	29.1
Organic carbon	%	0.24	0.15	0.17	0.1	0.21	0.22
Reactive iron	mg/kg	196	280	265	382	172	192
Conductivity	dS/m	0.111	0.117	0.119	0.068	0.34	0.509
pH level ($CaCl_2$)	pH	7.4	7.8	8	7.9	7.8	7.7
pH level (H_2O)	pH	8.3	8.8	9	8.7	8.3	8.3
DTPA copper	mg/kg	0.61	0.52	0.47	0.53	0.66	0.71
DTPA zinc	mg/kg	0.12	0.2	0.11	0.27	0.17	0.22
DTPA manganese	mg/kg	1.31	1.92	1.53	2.93	1.93	1.71
DTPA iron	mg/kg	2.91	6.61	5.56	11.76	6.35	7.18
Exc. Calcium	meq/100g	9.69	7.63	8.79	4.42	10.46	14.95
Exc. Magnesium	meq/100g	1.91	1.82	3.68	1.68	2.07	4.96
Exc. Sodium	meq/100g	0.21	0.38	0.92	0.19	0.36	1.65
Exc. Potassium	meq/100g	0.44	0.23	0.36	0.3	0.18	0.47
Boron hot $CaCl_2$	mg/kg	0.4	0.4	0.7	0.3	0.4	0.7
Chloride	mg/kg	11	19	38	9	265	656

NB: "DTPA" refers to extraction technique employed by CSBP laboratory, result confirms extractable concentration of relevant cation only. "Exc." refers to exchangeable concentration of cation only.

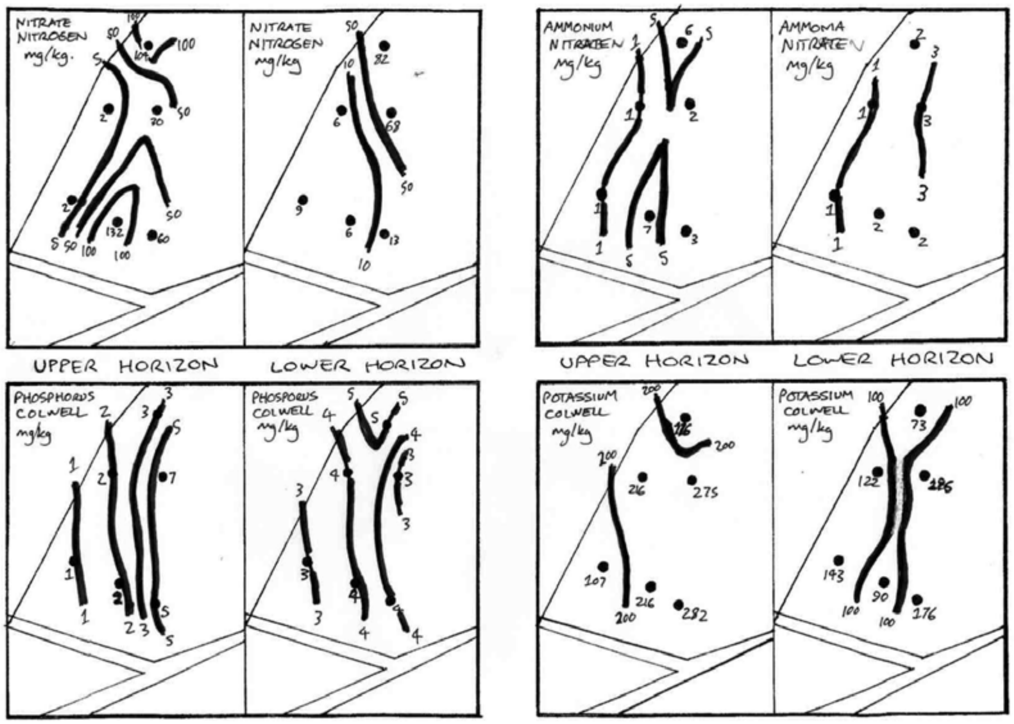


FIGURE A1.6-9: Hand-contoured maps showing concentrations of nitrate/ammonium nitrogen, phosphorus and potassium colwell.

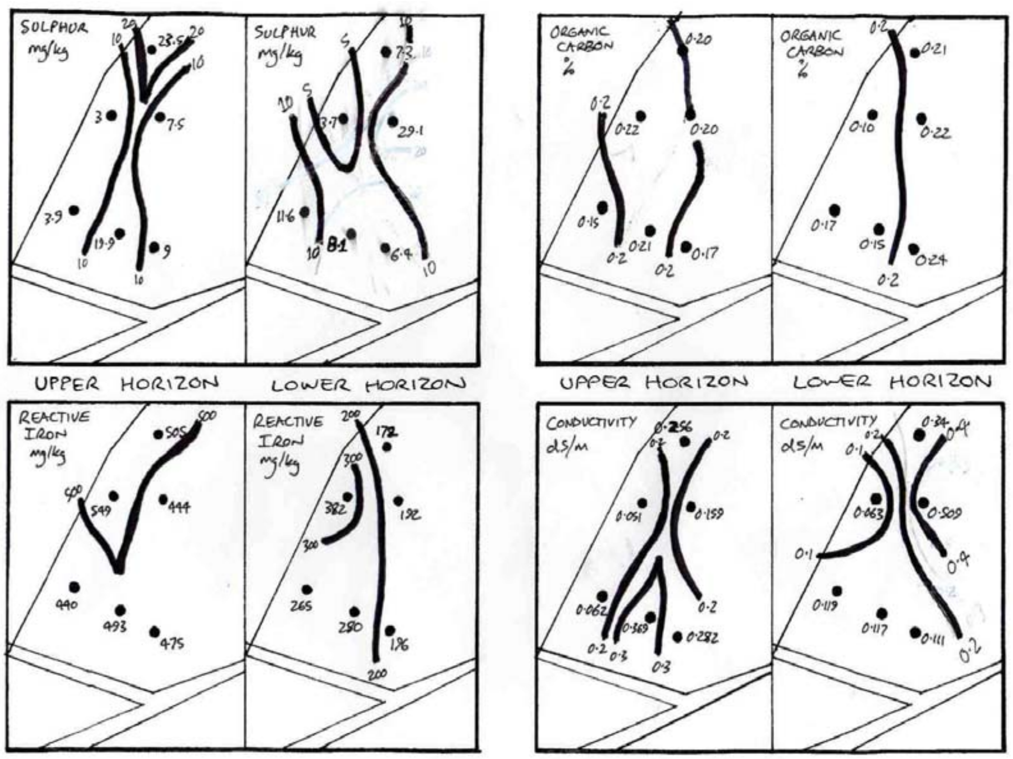


FIGURE A1.10-13: Hand-contoured maps showing concentrations of sulphur, organic carbon, reactive iron and conductivity readings.

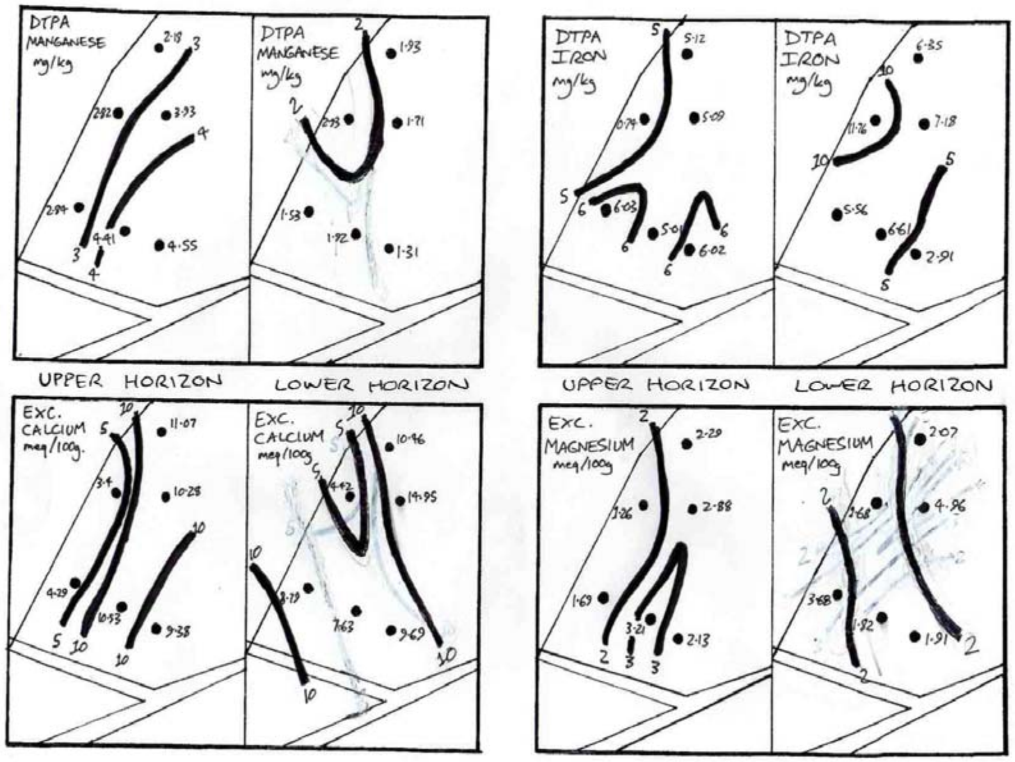


FIGURE A1.14-17: Hand-contoured maps showing concentrations of DTPA manganese/iron, exch. calcium/magnesium.

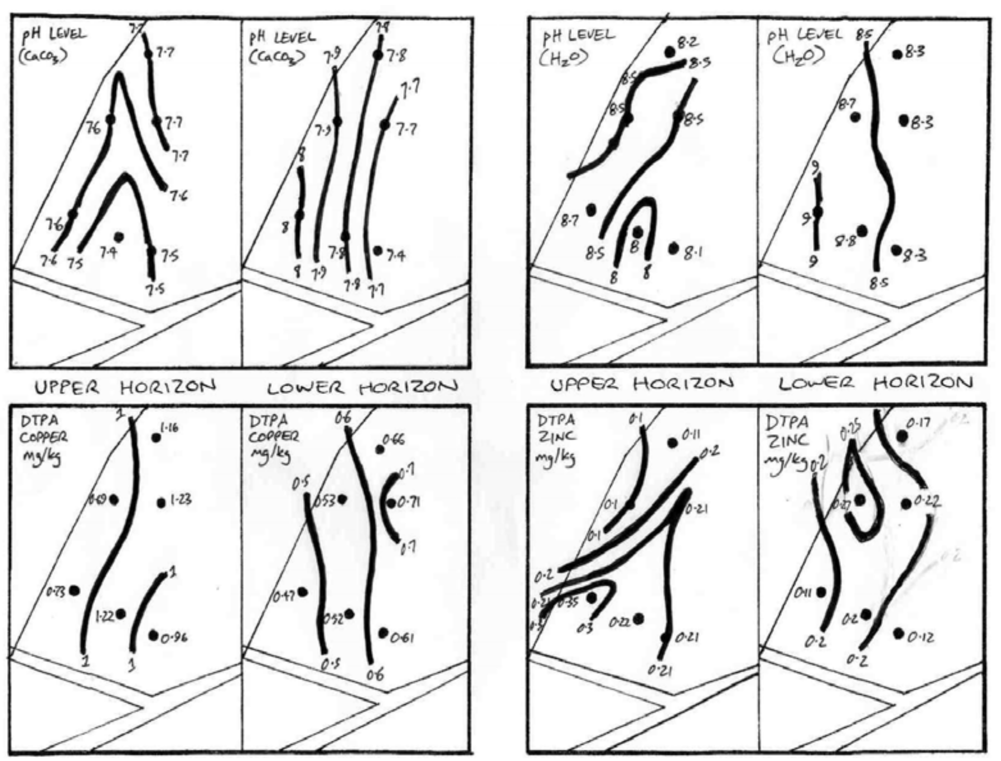


FIGURE A1.18-21: Hand-contoured maps showing pH (CaCO3/H20) and concentrations of DTPA copper/zinc.

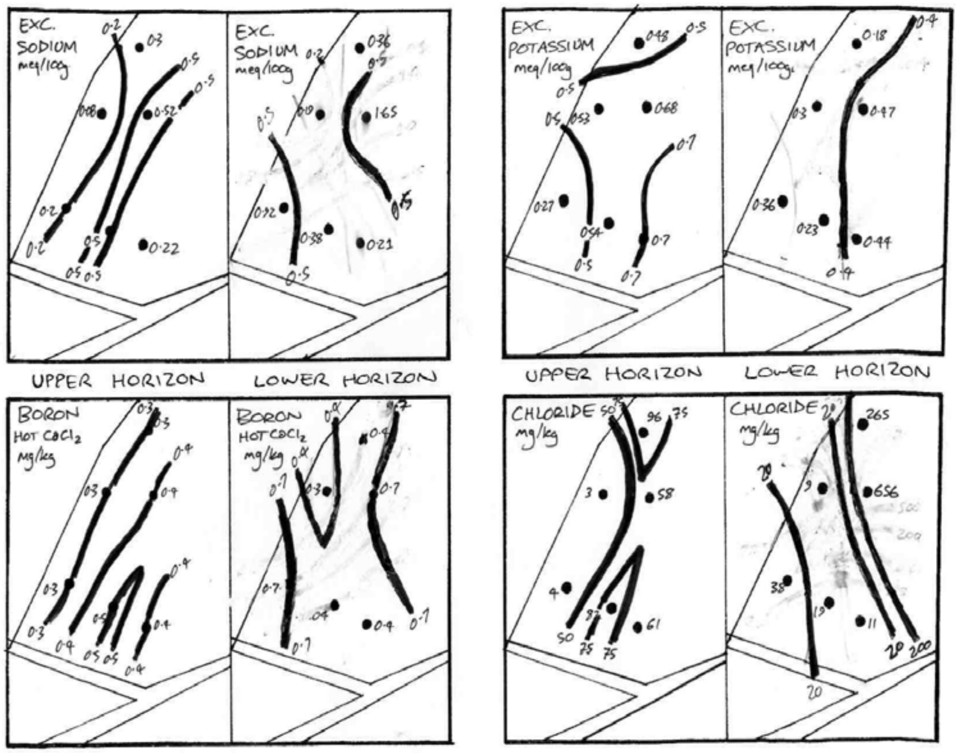


FIGURE A1.22-25: Hand-contoured maps showing pH (CaCO3/H20) and concentrations of DTPA copper/zinc.

Grove establishment

All stock was supplied by Olea Nurseries (Mandurah, WA). The trees were all approximately one year old and when inspected, were noted to be in good condition when they arrived on-site during October 2001. All trees were re-potted during November-December 2001. Each pot was filled with a mixture comprising the following:

1) 40% commercial potting mixture (Black and White brand),
2) 50% clay soil from local Hacks Well site,
3) 10% sand soil from local source.

Pots then remained on-site in the Sustainability compound at Granny Smith until the site preparation works were completed at Hack Well. A watering system, consisting of a single sprinkler connected to a tap-timer was installed and set to water all trees for approximately 20 minutes/day.

Site preparation

According to the original schedule for the Hacks Well experiment, the completion of site preparation works was proposed to commence during February-March 2002, with planting of trees to follow immediately after this work was completed (during the winter season). Due to unforeseen delays commencement of site preparation work was delayed for more than 3 months.

The 3 grove sites was paced out and marked with pegs and flagging in preparation for site clearing During July 2002. The grove areas were subsequently cleared by backhoe. During August 2002, the remaining earthworks were completed on-site and fencing of all three compounds then commenced. Groves were fenced with a combination of ring-lock and barbed wire (fence height of 1 m) to reduce the risk of grazing by fauna. The north and middle groves were fenced as one compound, with the south grove being fenced separately.

Individual tree sites where measured with a hand-tape and marked by pin-marker. Tree sites were excavated by backhoe immediately before planting. Holes were dug to 1m. depth in the north, but were shallower in the south owing to the laterite contact. Fertiliser was added to holes before trees were planted and mixed by the backhoe bucket. Due to a lack of supply during planting, no fertiliser was added to holes in the south grove.

Tree health

The original schedule for the Hacks Well trial, involved all plants being transplanted and left for a period of several months until the end of the summer season (from December to March) in preparation for planting at the start of autumn. This period of time that trees remained in their pots was considerably longer than the original schedule however (planting was originally scheduled for autumn-winter).

Fluctuations occurred in the water supply quality used to irrigate the trees whilst in the Sustainability compound, with water quality being noted to fluxuate between potable to highly saline during this period (pers. comm. Lamont, 2002). Both issues impacted on tree health and a high level of mortality was recorded amongst tree stock before planting occurred. Mortality rate for cv *Verdale* was around 30%, compared to about 10% for cvs *New Norcia Mission* and *Barnea*. The high mortality that occurred between December 2001 and August 2002 subsequently impacted on the design of the experiment (only 53 trees of cv *Verdale* remained, which was 1 tree short of the 54 required to complete the Latin square design).

Tree planting

All surviving trees were prepared for planting during the final week in August 2002. Trees were soaked for a period of 24 hours to reduce transplant shock. On 1st September 2002, planting of trees commenced at Hacks Well trial site. A total of 161 trees were planted by a small team of volunteers from the Exploration Department of Placer Granny Smith during 1½ days. At each site, a small hole was dug by shovel in the area that had been previously excavated by backhoe. Trees were placed according to the Latin-square design at each grove and soil was then molded around the base of the tree. Following planting, sites were watered by hand-held hose supplied by a water tank mounted on a 4WD vehicle.

Water supply

At each grove, a reticulated water supply was installed immediately after trees were planted. Water was supplied by main supply lines (40 mm poly-pipe), connected to a grid of 19 mm poly-pipe along each individual row. At each tree site a single supply was installed (9 mm flexible line) and a single drip-feeder was attached. Owing to the close proximity of the yard bore, this was chosen as the primary water supply for all of the groves from the start of the experiment. An electric pump was fitted to the bore, which was powered by a portable electric generator. From this bore, water was then pumped to the main supply tanks at the grove site via a single 40 mm pipeline. This main supply comprised of two large poly-tanks (total capacity 47,000 L) placed on an earth-filled stand (0.5 m above surrounding ground level).

Differential water supply

The supply tanks were elevated only 0.5 m above the ground level. The long length of the main supply lines to each grove resulted in a differential water supply. To compensate for the low water pressure, a petrol-powered water pump was fitted to the water line at the tank outlet during February 2003. The installation of this pump resulted in a considerable increase in the water supply pressure and greatly reduced the differential water supply across the three grove sites.

APPENDIX 2: TIP EXTENSION DATA

Trial site#1; Davis Well grove

TABLE A2.1: Summary of growth in branch tips (cm) for 10 selected trees at Davis Well (Site 1), between March 2001 and October 2003.

Cultivar	ROW	TREE	11/03/01 TO 26/08/01	12/04/01 TO 11/03/01	26/03/02 TO 12/04/01	22/05/02 TO 26/03/02	17/07/02 TO 22/05/02	21/09/02 TO 17/07/02	12/11/02 TO 21/09/02	19/02/03 TO 12/11/02	20/05/03 TO 19/02/03	14/10/03 TO 20/05/03	22/04/04 TO 14/10/03
N.N. Mission (1)	5	8	7	4.4	5	1	0.3	0	1	1.7	0.5	0	5.5
N.N. Mission (2)	7	1	6	4.2	4.5	0.6	0	0	0	3	3	0.5	3.5
Verdale (1)	7	5	2.1	13.4	10.8	1	0	0	0	0.2	2.2	0.25	0
Verdale (2)	11	8	0.8	2	3.1	0.5	0	0	0.3	2.8	2.8	0.3	11.3
UC136A (1)	1	1	3.3	3.9	8.7	0.8	0.5	0	0.1	0.4	1	0.2	3.8
UC136A (2)	1	8	12.4	7.2	7	10.5	0	0.5	0	0.2	0.1	1.3	3.5
Ascolana (1)	10	3	2.9	6.8	7.1	1	0.3	0.3	3	1.8	0	0	0
Ascolana (2)	4	4	2.2	4.6	10.9	6.6	0.8	0	0.3	1.1	3.1	0.5	8.5
Manzanil. (1)	11	2	5.9	5.5	5.1	1	0.1	0.1	1.5	3	1.3	0.3	5
Manzanil. (2)	4	7	2.6	5.4	6.4	0.8	0.4	0.2	2.8	7.1	3.1	0.5	3.5
MEAN VALUE:			**4.5**	**5.7**	**6.9**	**2.4**	**0.2**	**0.1**	**0.9**	**2.1**	**1.7**	**0.4**	**4.5**
STANDARD DEVIATION:			**3.42**	**3.07**	**2.62**	**3.38**	**0.26**	**0.17**	**1.17**	**2.07**	**1.28**	**0.38**	**3.44**

Trial site#2; Jubilee Well grove

TABLE A2.2: Summary of growth in branch tips (cm) for 10 selected trees at Jubilee Well (Site 2), between March 2001 and October 2003.

Cultivar	ROW	TREE	11/03/01 TO 25/08/01	12/05/01 TO 11/03/01	27/03/02 TO 12/05/01	23/05/02 TO 27/03/02	19/07/02 TO 23/05/02	21/09/02 TO 19/07/02	13/12/02 TO 21/09/02	20/02/03 TO 13/12/02	28/04/03 TO 20/02/03	16/10/03 TO 28/04/03	21/04/04 TO 16/10/03
Nabtari	1	3	2.6	3.5	1.9	0.3	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Leccino	1	14	9.5	3.5	5.8	0.3	0.0	0.0	0.5	1.0	0.5	0.5	10.0
Pendo-lino	3	14	11.6	9.7	4.6	0.2	0.2	0.0	0.5	0.3	0.0	0.0	0.0
Manza-nillo	2	12	9.5	3.9	5.9	0.8	0.2	0.4	2.2	1.4	1.0	0.0	5.3
Kalamata	2	1	7.8	0.5	1.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Ascolana	4	4	3.4	1.6	3.0	0.2	0.2	0.0	1.4	2.6	0.0	0.0	0.0
Verdale	5	9	4.3	7.5	10.3	1.8	0.0	0.0	0.8	0.3	0.4	0.3	5.5
Barouni	5	13	9.3	3.1	11.4	0.2	0.2	0.0	2.2	1.6	1.2	0.0	3.0
N.N. Mission 1	6	12	5.7	3.0	0.4	0.8	0.2	0.0	0.3	0.4	0.4	0.3	0.0
N.N. Mission 2	7	7	8.9	5.3	8.4	1.3	0.3	0.0	0.0	4.0	1.0	1.0	4.0
MEAN VALUE:			**7.3**	**4.2**	**5.3**	**0.6**	**0.1**	**0.1**	**0.9**	**1.2**	**0.4**	**0.2**	**2.8**
STANDARD DEVIATION:			**3.05**	**2.72**	**3.78**	**0.57**	**0.11**	**0.19**	**0.82**	**1.30**	**0.47**	**0.33**	**3.43**

APPENDIX 3: LEAF MATTER ANALYSIS

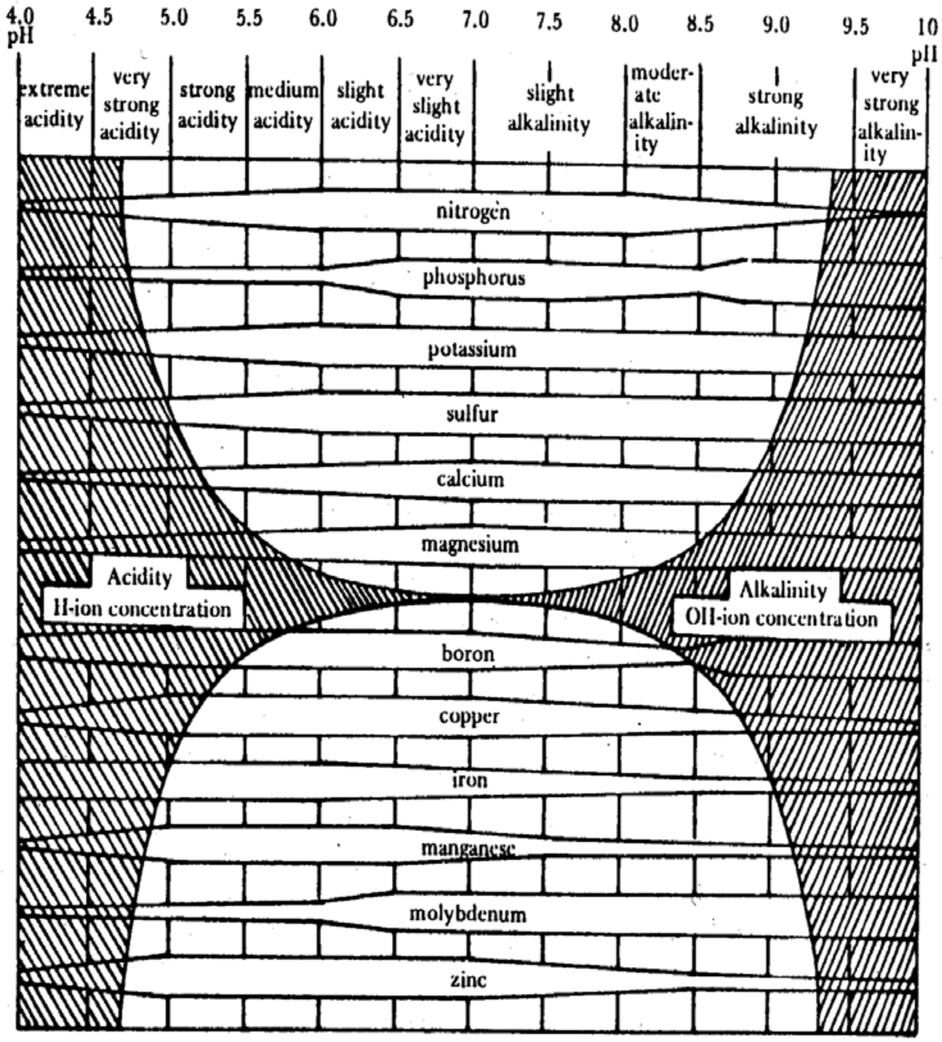


Fig. 7. Effect of soil pH on the availability of plant nutrient elements. The width of the band for each element indicates the relative favorableness of this pH value to the presence of the elements in readily available forms (the wider the band the more favorable the influence). It does not necessarily indicate the actual amount present since this is influenced by other factors, such as cropping and fertilization.

Emil Truog. 1953. *Mineral nutrition of plants.* p. 41.

FIGURE A3.1: Effect of soil pH on availability of plant nutrients (Troug, 1953).

Trial site#1; Davis Well grove

TABLE A3.1; Major/trace element analysis results from Davis Well (Site 1) for September 2001 (CSBP, 2001).

ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.674	Level adequate	1.588	Borderline adequate
Phosphorus	%	0.1-0.3 adequate	0.146	Level adequate	0.117	Borderline adequate
Potassium	%	0.4-0.8 marginal >0.8 adequate	0.987	Level adequate	1.122	Level adequate
Sulfur	%	No figures	0.166		0.127	
Sodium	%	>0.2 toxic	0.072	Level below toxic	0.022	Level below toxic
Calcium	%	>1.0 adequate	0.873	Level deficient	0.509	Level deficient
Magnesium	%	>0.1 adequate	0.166	Level adequate	0.127	Level adequate
Chloride	%	>0.5 toxic	0.177	Level elevated, but below toxic	0.215	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	6.12	Level adequate	5.72	Level adequate
Zinc	mg/kg	10-30 adequate	54.31	Level adequate	26.69	Level adequate
Manganese	mg/kg	>20 adequate	50.5	Level adequate	33.8	Level adequate
Iron	mg/kg	No figures	241.8		112.1	
Nitrate	mg/kg	No figures	51.8		45.4	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	18.79	Borderline marginal-adequate	20.41	Borderline adequate

TABLE A3.2; Major/trace element analysis results from Davis Well (Site 1) for February 2002 (CSBP, 2002).

ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.771	Level adequate	1.847	Level adequate
Phosphorus	%	0.1-0.3 adequate	0.108	Borderline adequate	0.151	Level adequate
Potassium	%	0.4-0.8 marginal >0.8 adequate	1.231	Level adequate	1.706	Level adequate
Sulfur	%	No figures	0.216		0.173	
Sodium	%	>0.2 toxic	0.097	Level elevated, but below toxic	0.011	Level elevated, but below toxic
Calcium	%	>1.0 adequate	1.512	Level adequate	0.745	Level deficient
Magnesium	%	>0.1 adequate	0.270	Level adequate	0.216	Level adequate
Chloride	%	>0.5 toxic	0.173	Level elevated, but below toxic	0.338	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	6.26	Level adequate	14.26	Level adequate
Zinc	mg/kg	10-30 adequate	33.26	Level adequate	28.73	Level adequate
Manganese	mg/kg	>20 adequate	73.70	Level adequate	45.0	Level adequate
Iron	mg/kg	No figures	249.5		67.1	
Nitrate	mg/kg	No figures	43.2		43.2	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	43.74	Level adequate	36.72	Level adequate

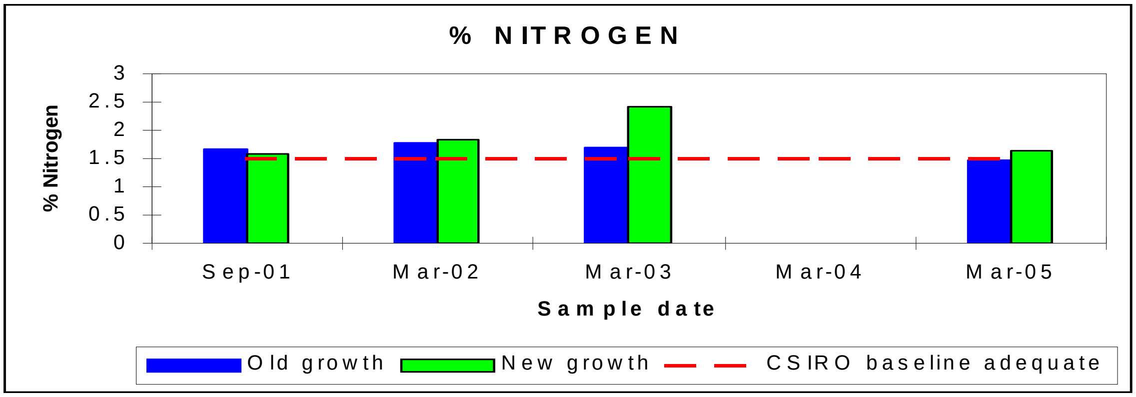
TABLE A3.3; Major/trace element analysis results from Davis Well (Site 1) for February 2003 (CSBP, 2003).

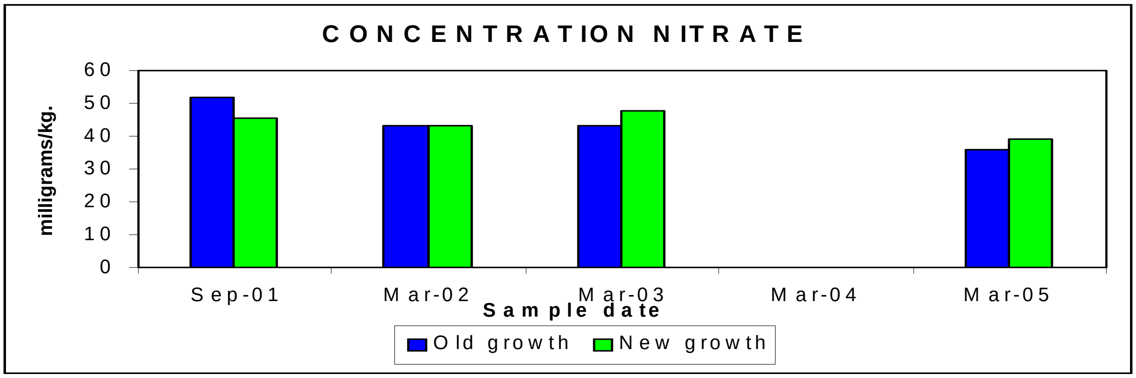
ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.685	Level adequate	2.419	Level adequate
Phosphorus	%	0.1-0.3 adequate	0.086	Level deficient	0.212	Level adequate
Potassium	%	0.4-0.8 marginal >0.8 adequate	0.886	Level adequate	1.567	Level adequate
Sulfur	%	No figures	0.173		0.191	
Sodium	%	>0.2 toxic	0.011	Level elevated, but below toxic	0.011	Level elevated, but below toxic
Calcium	%	>1.0 adequate	1.490	Level adequate	0.518	Level deficient
Magnesium	%	>0.1 adequate	0.216	Level adequate	0.148	Level adequate
Chloride	%	>0.5 toxic	0.145	Level elevated, but below toxic	0.249	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	4.00	Borderline adequate	13.45	Level adequate
Zinc	mg/kg	10-30 adequate	29.16	Level adequate	33.46	Level adequate
Manganese	mg/kg	>20 adequate	69.80	Level adequate	36.60	Level adequate
Iron	mg/kg	No figures	160.8		98.5	
Nitrate	mg/kg	No figures	43.20		47.50	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	35.32	Level adequate	42.12	Level adequate

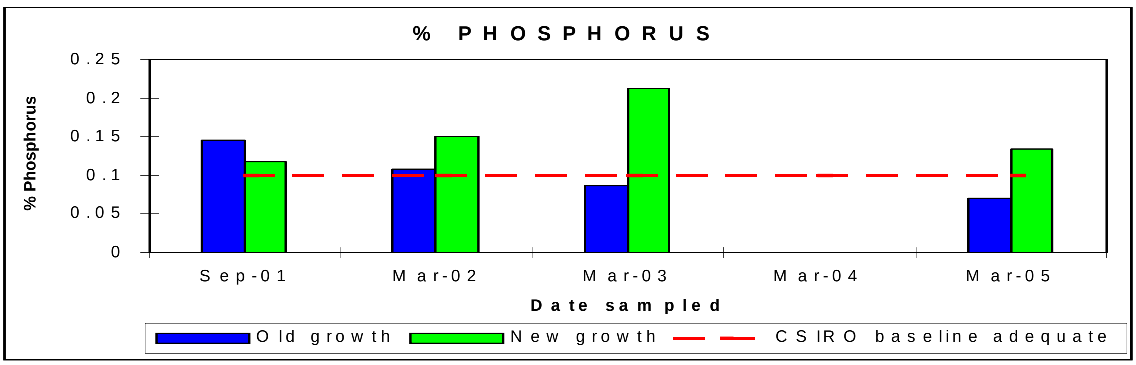
TABLE A3.4; Major/trace element analysis results from Davis Well (Site 1) for February 2005 (CSBP, 2005).

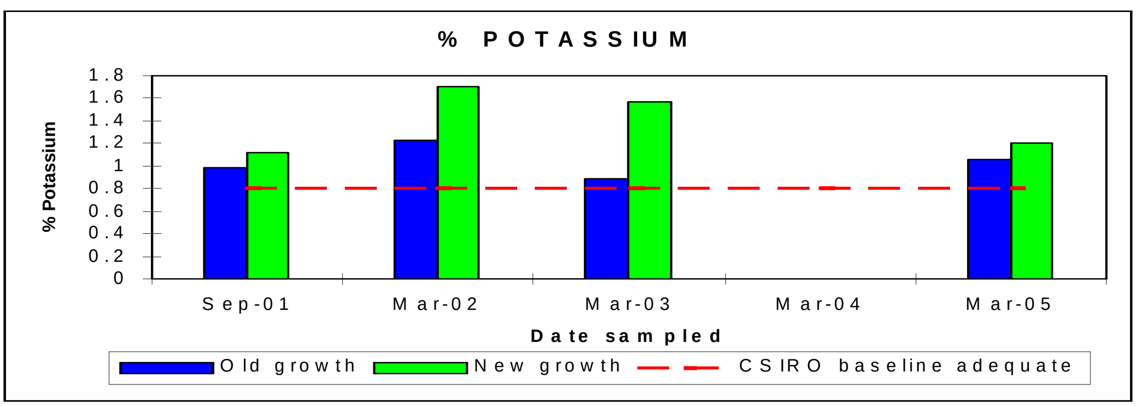
ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.47	Borderline deficient- adequate	1.63	Level adequate
Phosphorus	%	0.1-0.3 adequate	0.071	Level deficient	0.134	Level adequate
Potassium	%	0.4-0.8 marginal >0.8 adequate	1.06	Level adequate	1.206	Level adequate
Sulfur	%	No figures	0.184		0.166	
Sodium	%	>0.2 toxic	0.042	Level elevated, but below toxic	0.014	Level below toxic
Calcium	%	>1.0 adequate	1.88	Level adequate	0.669	Level deficient
Magnesium	%	>0.1 adequate	0.234	Level adequate	0.162	Level adequate
Chloride	%	>0.5 toxic	0.057	Level below toxic	0.136	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	3.58	Level deficient	9.17	Level adequate
Zinc	mg/kg	10-30 adequate	20.31	Level adequate	20.71	Level adequate
Manganese	mg/kg	>20 adequate	67.4	Level adequate	37.5	Level adequate
Iron	mg/kg	No figures	113.2		65.6	
Nitrate	mg/kg	No figures	36		39	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	25.5	Level adequate	26.1	Level adequate

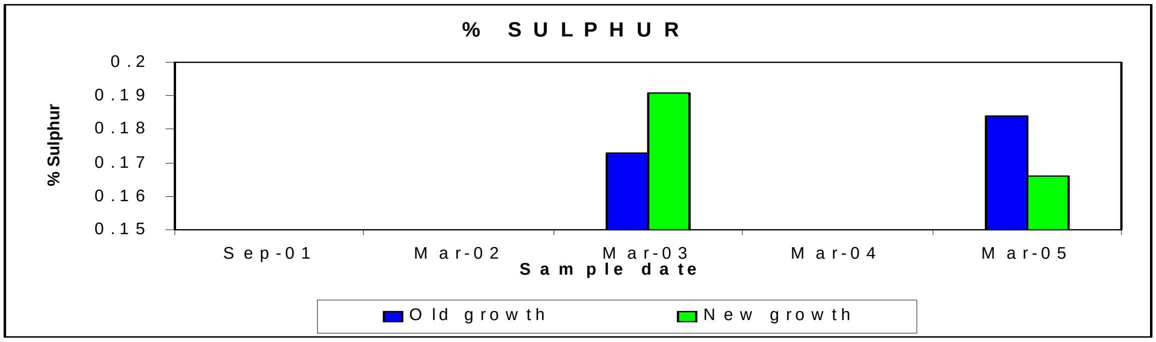
FIGURES A3.2-15: Major and trace element plots for leaf matter samples over the duration of the trial period from Davis Well grove (Site 1).



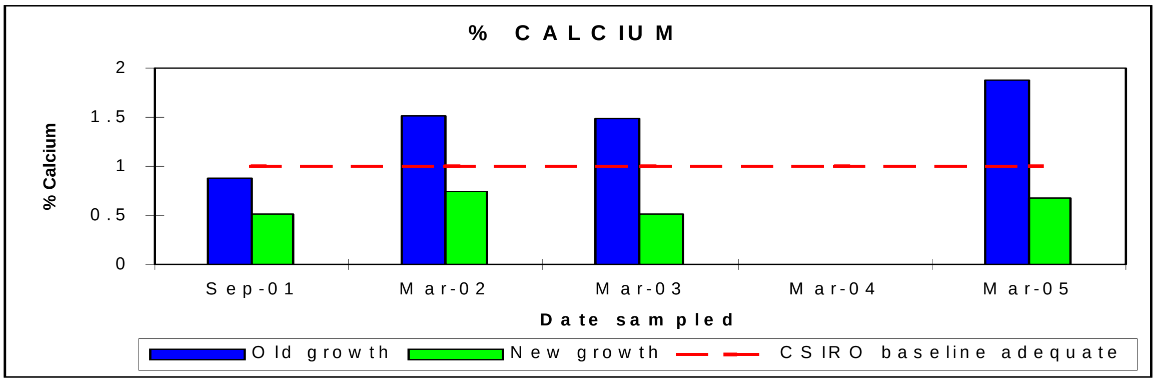




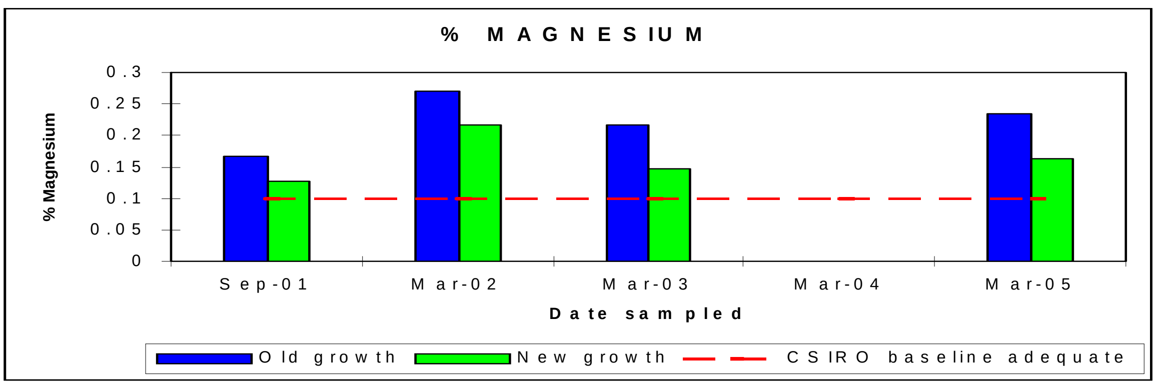




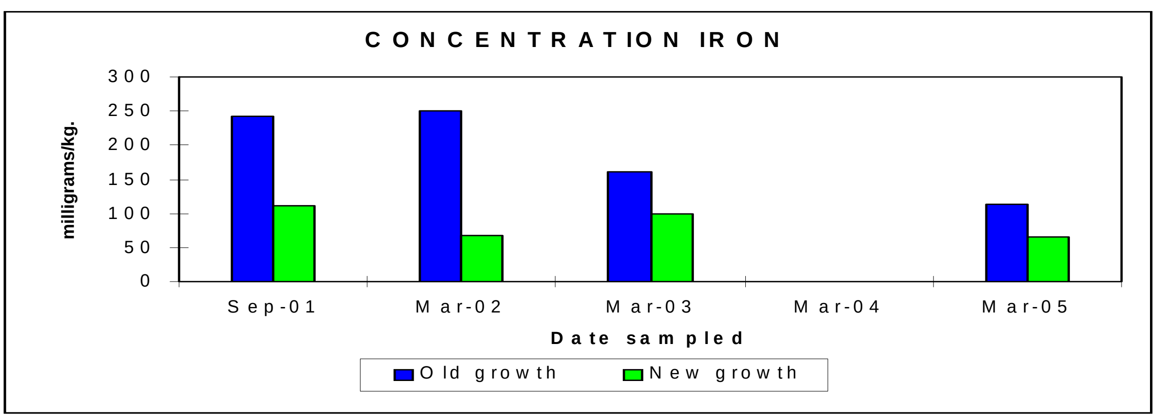
% SULPHUR
% Sulphur
0.2
0.19
0.18
0.17
0.16
0.15
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Sample date
Old growth
New growth



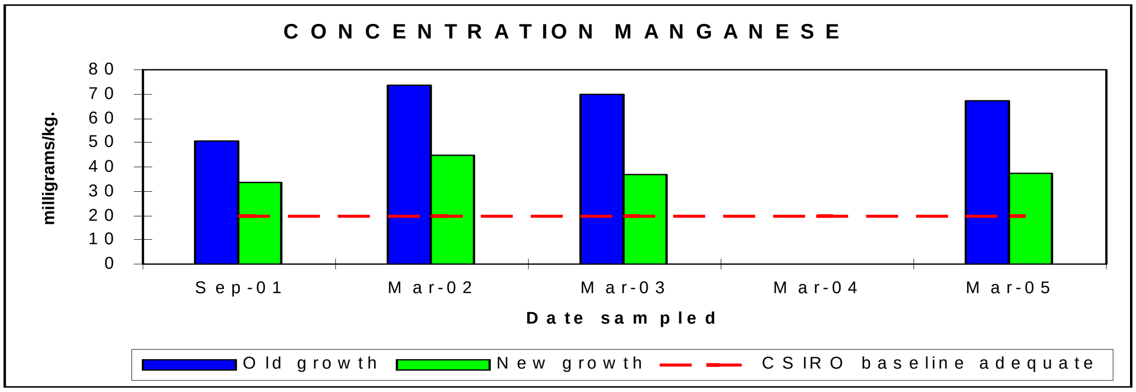
% CALCIUM
% Calcium
2
1.5
1
0.5
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate

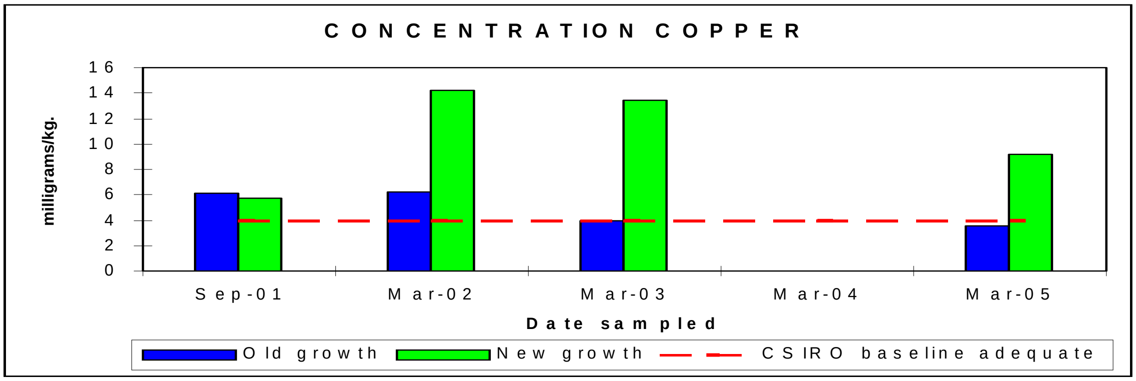


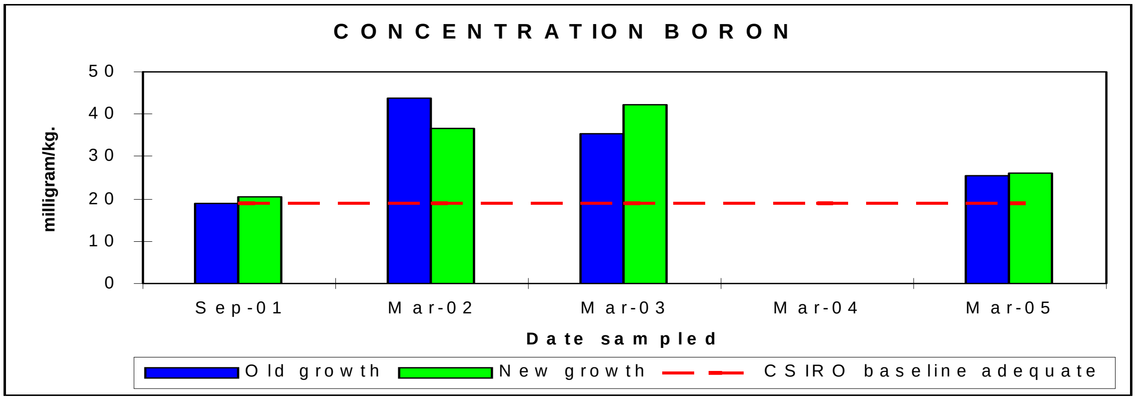
% MAGNESIUM
% Magnesium
0.3
0.25
0.2
0.15
0.1
0.05
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate

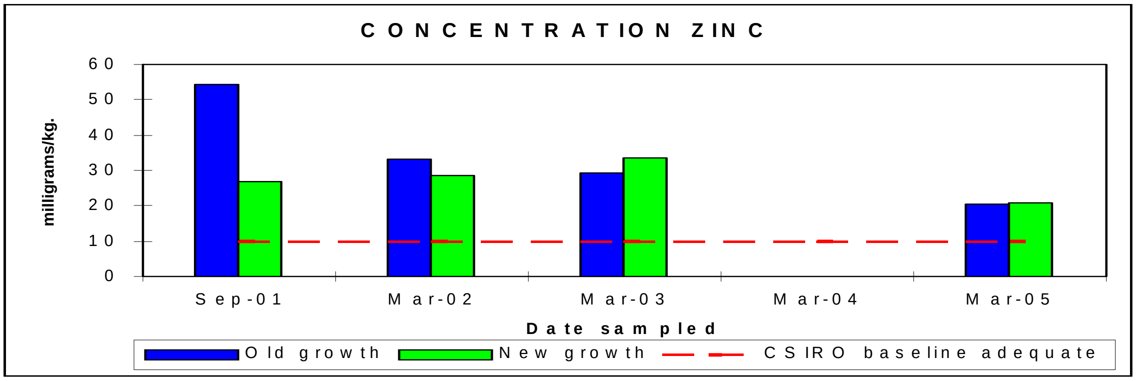


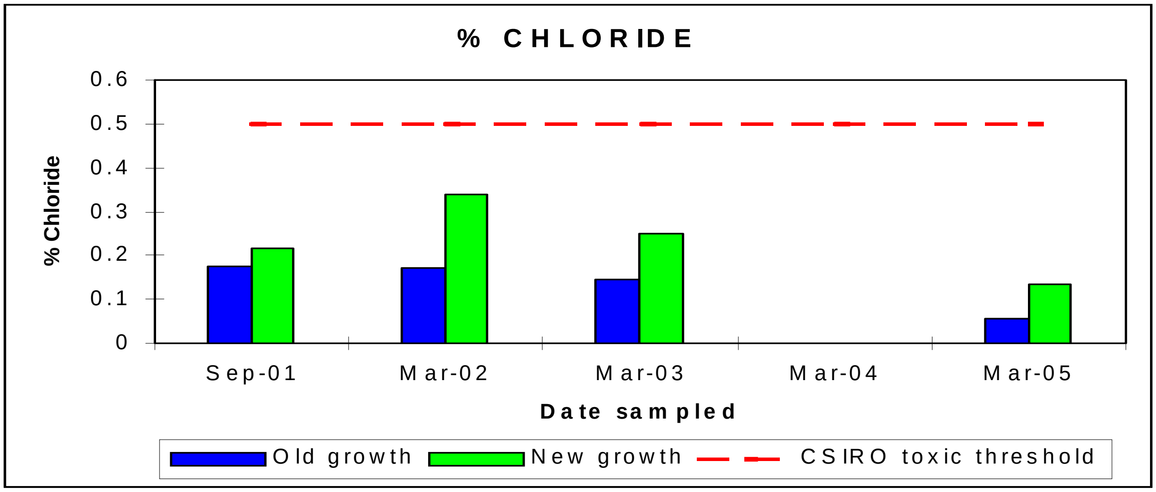
CONCENTRATION IRON
milligrams/kg.
300
250
200
150
100
50
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth

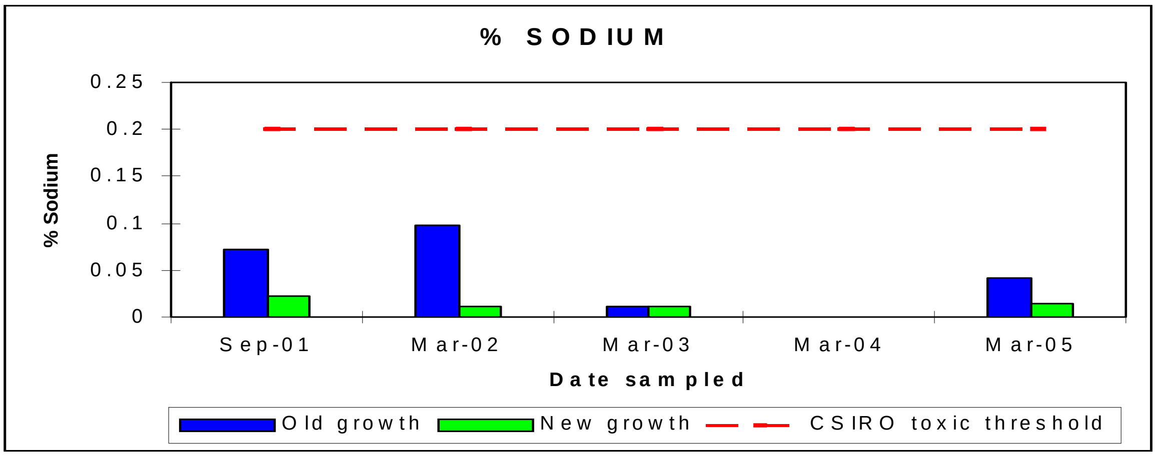

CONCENTRATION MANGANESE
milligrams/kg.
0
10
20
30
40
50
60
70
80
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


CONCENTRATION COPPER
milligrams/kg.
0
2
4
6
8
10
12
14
16
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


CONCENTRATION BORON
milligram/kg.
0
10
20
30
40
50
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


CONCENTRATION ZINC
milligrams/kg.
0
10
20
30
40
50
60
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


% CHLORIDE
% Chloride
0.6
0.5
0.4
0.3
0.2
0.1
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO toxic threshold


% SODIUM
% Sodium
0.25
0.2
0.15
0.1
0.05
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO toxic threshold

Jubilee Well grove (Site 2)

TABLE A3.5; Major/trace element analysis results from Jubilee Well (Site 2) for September 2001 (CSBP, 2001).

ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.652	Level adequate	1.274	Level deficient
Phosphorus	%	0.1-0.3 adequate	0.089	Level deficient	0.094	Level deficient
Potassium	%	0.4-0.8 marginal >0.8 adequate	1.157	Level adequate	1.215	Level adequate
Sulfur	%	No figures	0.176		0.114	
Sodium	%	>0.2 toxic	0.066	Level elevated, but below toxic	0.021	Level below toxic
Calcium	%	>1.0 adequate	0.991	Level deficient	0.571	Level deficient
Magnesium	%	>0.1 adequate	0.144	Level adequate	0.104	Level adequate
Chloride	%	>0.5 toxic	0.131	Level elevated, but below toxic	0.249	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	4.55	Level adequate	5.71	Level adequate
Zinc	mg/kg	10-30 adequate	26.45	Level adequate	63.34	Level adequate
Manganese	mg/kg	>20 adequate	51.6	Level adequate	30.8	Level adequate
Iron	mg/kg	No figures	112.3		68.0	
Nitrate	mg/kg	No figures	41.0		40.0	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	18.58	Borderline adequate	24.3	Level adequate

TABLE A3.6; Major/trace element analysis results from Jubilee Well (Site 2) for February 2002 (CSBP, 2002).

ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.48	Level adequate	1.501	Level adequate
Phosphorus	%	0.1-0.3 adequate	0.076	Level deficient	0.097	Level borderline deficient
Potassium	%	0.4-0.8 marginal >0.8 adequate	1.609	Level adequate	1.566	Level adequate
Sulfur	%	No figures	0.238		0.140	
Sodium	%	>0.2 toxic	0.108	Level elevated, but below toxic	0.022	Level below toxic
Calcium	%	>1.0 adequate	2.29	Level adequate	0.886	Level deficient
Magnesium	%	>0.1 adequate	0.259	Level adequate	0.205	Level adequate
Chloride	%	>0.5 toxic	0.149	Level elevated, but below toxic	0.151	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	5.40	Level adequate	9.83	Level adequate
Zinc	mg/kg	10-30 adequate	21.38	Level adequate	16.31	Level adequate
Manganese	mg/kg	>20 adequate	78.7	Level adequate	33.30	Level adequate
Iron	mg/kg	No figures	111.9		48.6	
Nitrate	mg/kg	No figures	43.2		43.2	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	30.13	Level adequate	33.05	Level adequate

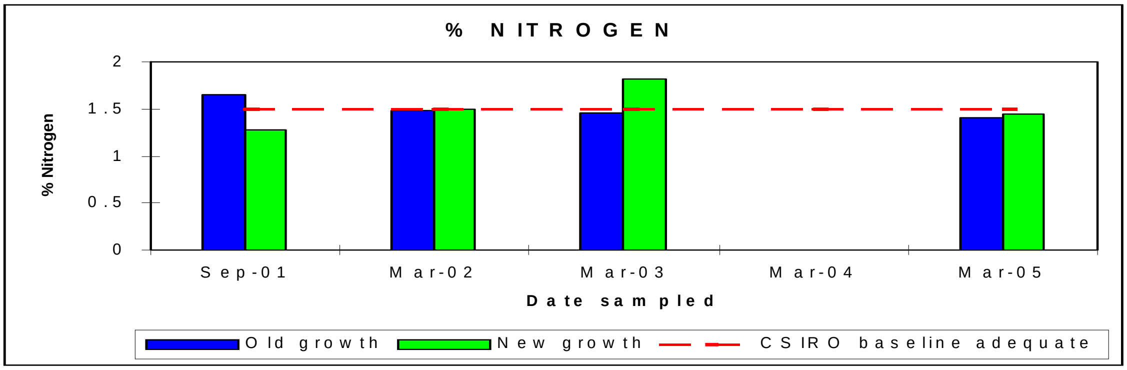
TABLE A3.7; Major/trace element analysis results from Jubilee Well (Site 2) for February 2003 (CSBP, 2003).

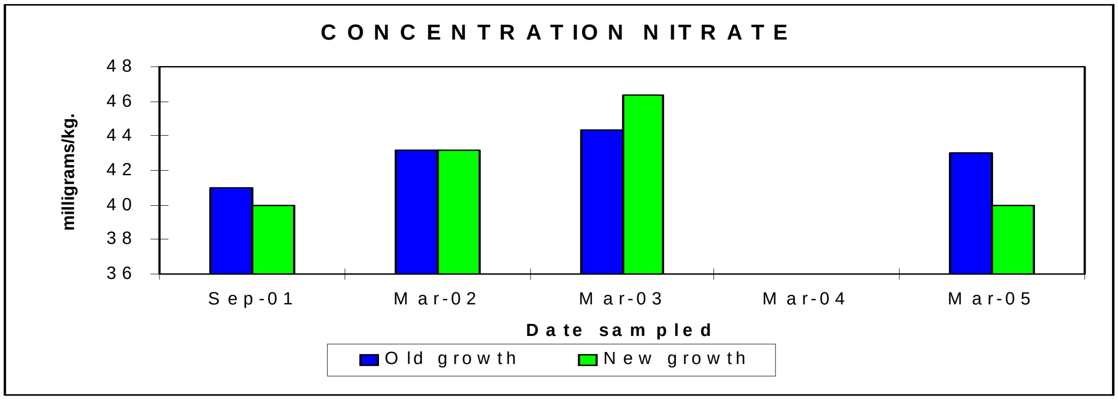
ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.458	Level adequate	1.814	Level adequate
Phosphorus	%	0.1-0.3 adequate	0.060	Level deficient	0.124	Level adequate
Potassium	%	0.4-0.8 marginal >0.8 adequate	1.128	Level adequate	1.339	Level adequate
Sulfur	%	No figures	0.168		0.168	
Sodium	%	>0.2 toxic	0.060	Level elevated, but below toxic	0.023	Level below toxic
Calcium	%	>1.0 adequate	1.764	Level adequate	0.945	Level borderline deficient
Magnesium	%	>0.1 adequate	0.204	Level adequate	0.214	Level adequate
Chloride	%	>0.5 toxic	0.106	Level elevated, but below toxic	0.183	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	4.20	Level borderline adequate	11.13	Level adequate
Zinc	mg/kg	10-30 adequate	16.39	Level adequate	20.81	Level adequate
Manganese	mg/kg	>20 adequate	60.8	Level adequate	40.5	Level adequate
Iron	mg/kg	No figures	78.7		179.9	
Nitrate	mg/kg	No figures	44.3		46.4	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	29.81	Level adequate	40.28	Level adequate

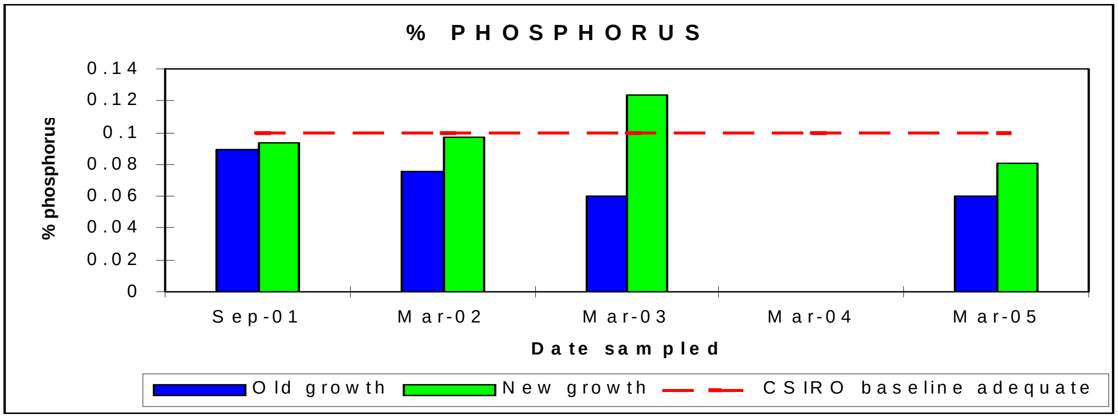
TABLE A3.8; Major/trace element analysis results for from Jubilee Well (Site 2) February 2005 (CSBP, 2005).

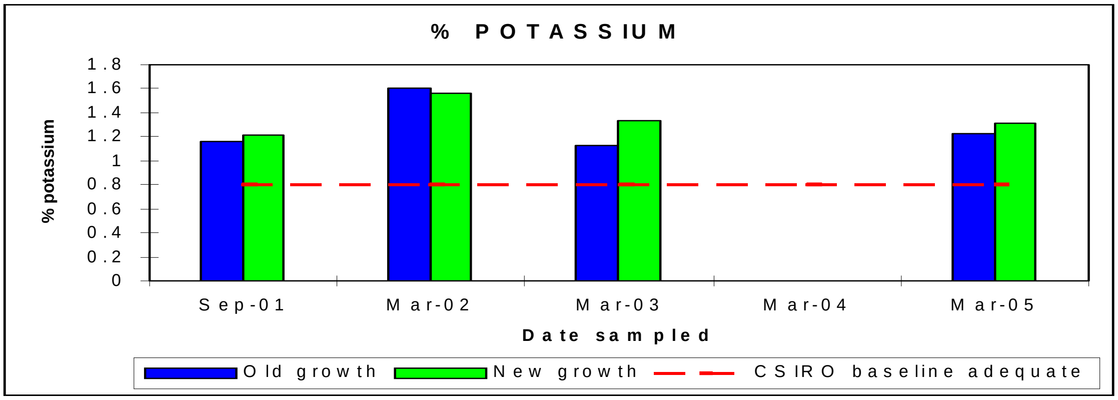
ELEMENT	UNIT	CSIRO Baseline figure	OLD GROWTH	COMMENTS	NEW GROWTH	COMMENTS
Total Nitrogen	%	<1.4 deficient 1.5-2.0 adequate	1.41	Level borderline adequate	1.45	Level borderline adequate
Phosphorus	%	0.1-0.3 adequate	0.06	Level adequate	0.081	Level deficient
Potassium	%	0.4-0.8 marginal >0.8 adequate	1.227	Level adequate	1.316	Level adequate
Sulfur	%	No figures	0.176		0.151	
Sodium	%	>0.2 toxic	0.052	Level elevated, but below toxic	0.044	Level below toxic
Calcium	%	>1.0 adequate	1.507	Level adequate	0.986	Level borderline deficient
Magnesium	%	>0.1 adequate	0.177	Level adequate	0.152	Level adequate
Chloride	%	>0.5 toxic	0.077	Level elevated, but below toxic	0.142	Level elevated, but below toxic
Copper	mg/kg	>4.0 adequate	3.7	Level borderline deficient	6.13	Level adequate
Zinc	mg/kg	10-30 adequate	10.98	Level borderline adequate	14	Level adequate
Manganese	mg/kg	>20 adequate	61.7	Level adequate	34.5	Level adequate
Iron	mg/kg	No figures	93.8		51.5	
Nitrate	mg/kg	No figures	43		40	
Boron	mg/kg	14-18 marginal 19-150 adequate >185 toxic	21.4	Level adequate	27.5	Level adequate

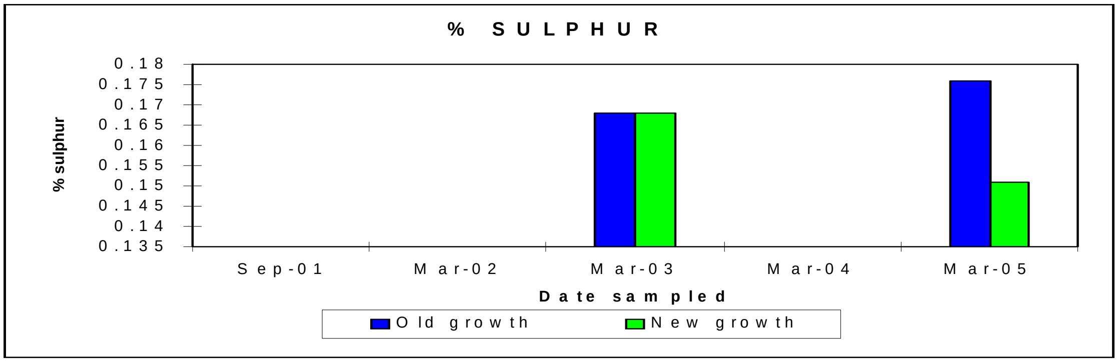
FIGURES A3.16-29: Major and trace element plots for leaf matter samples over the duration of the trial period from Jubilee Well grove (Site 2).

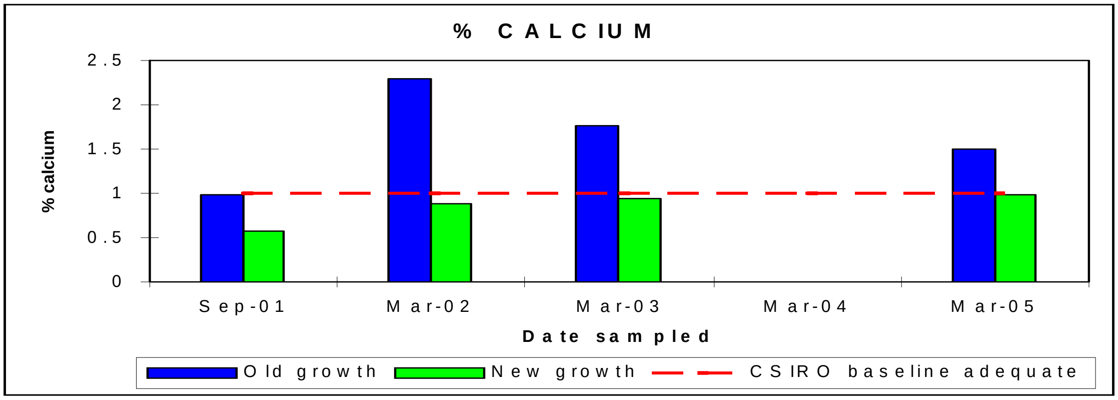


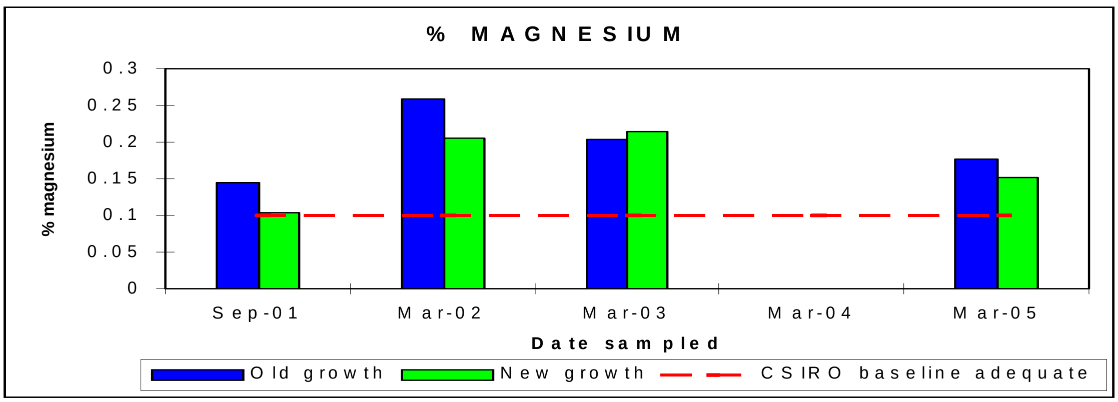


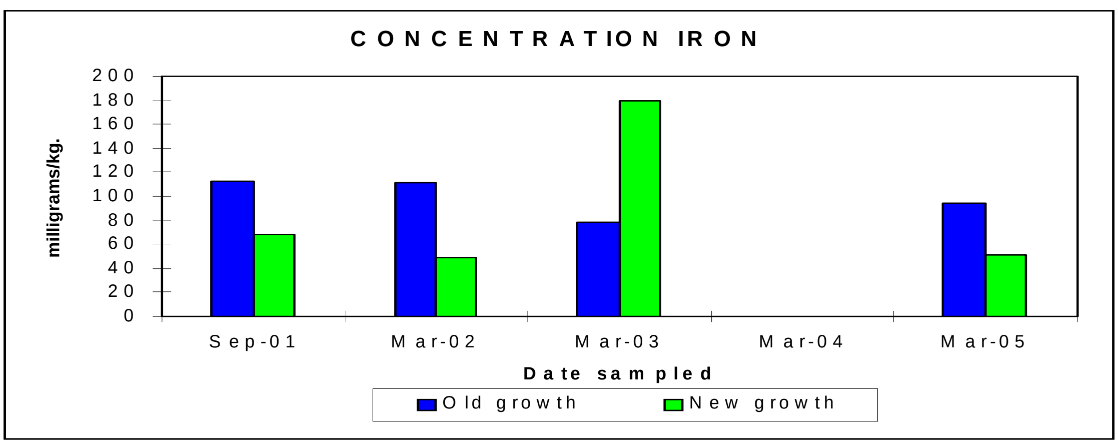


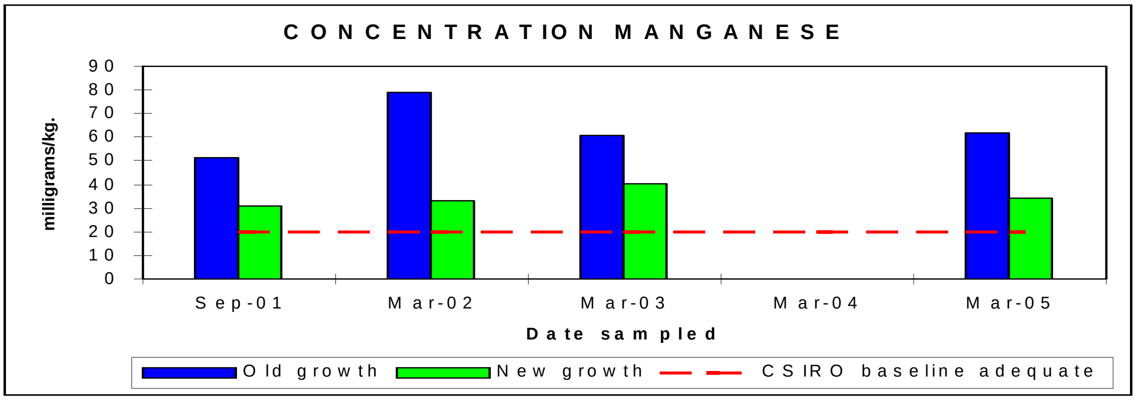


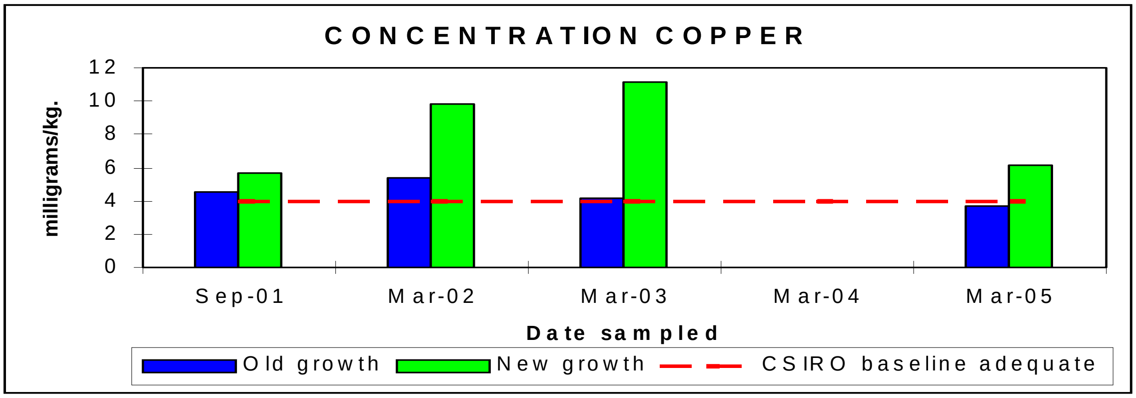

% SULPHUR
% sulphur
0.18
0.175
0.17
0.165
0.16
0.155
0.15
0.145
0.14
0.135
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth

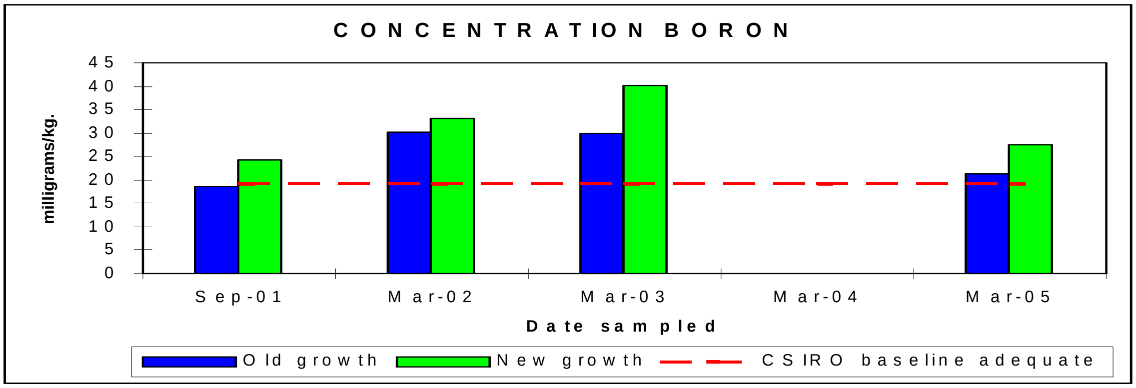

% CALCIUM
% calcium
2.5
2
1.5
1
0.5
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate

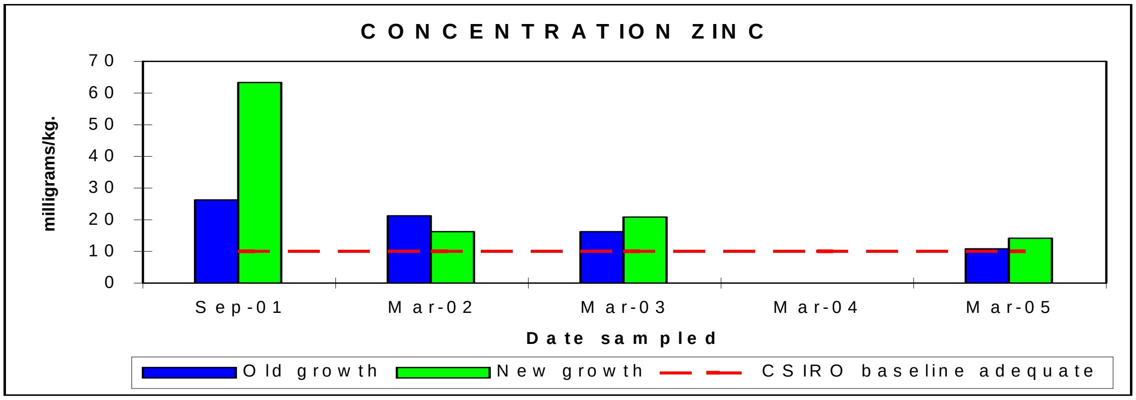

% MAGNESIUM
% magnesium
0.3
0.25
0.2
0.15
0.1
0.05
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate

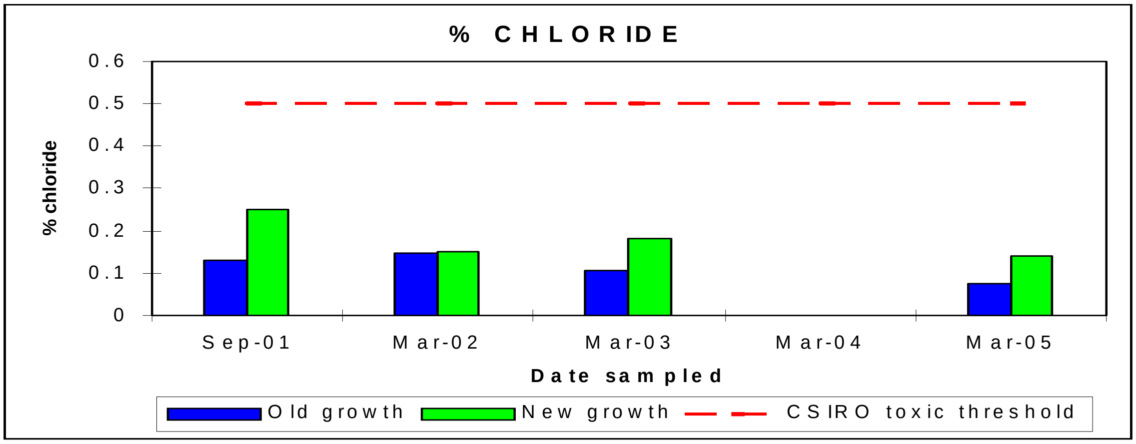

CONCENTRATION IRON
milligrams/kg.
200
180
160
140
120
100
80
60
40
20
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth

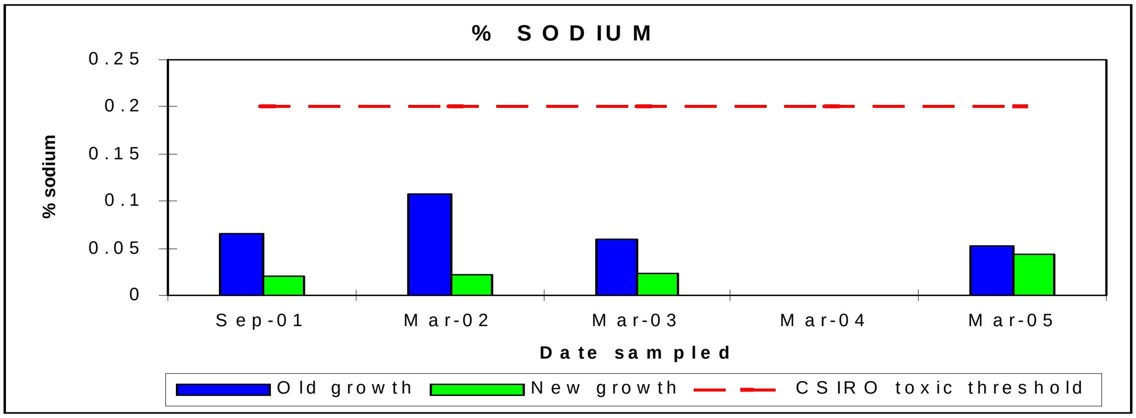

CONCENTRATION MANGANESE
milligrams/kg.
90
80
70
60
50
40
30
20
10
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


CONCENTRATION COPPER
milligrams/kg.
12
10
8
6
4
2
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


CONCENTRATION BORON
milligrams/kg.
45
40
35
30
25
20
15
10
5
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


CONCENTRATION ZINC
milligrams/kg.
70
60
50
40
30
20
10
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO baseline adequate


% CHLORIDE
% chloride
0.6
0.5
0.4
0.3
0.2
0.1
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO toxic threshold


% SODIUM
% sodium
0.25
0.2
0.15
0.1
0.05
0
Sep-01
Mar-02
Mar-03
Mar-04
Mar-05
Date sampled
Old growth
New growth
CSIRO toxic threshold

Hacks Well groves (Site 3)

TABLE A3.9 Major/trace element analysis results from Hacks Well (Site 3) for February 2003 (CSBP, 2003).

ELEMENT	UNITS	NORTH	MIDDLE	SOUTH
Total Nitrogen	%	2.095	1.901	2.549
Phosphorus	%	0.176	0.130	0.238
Potassium	%	1.432	1.116	2.225
Sulfur	%	0.200	0.176	0.216
Sodium	%	0.058	0.094	0.346
Calcium	%	1.034	1.550	0.605
Magnesium	%	0.212	0.246	0.216
Chloride	%	0.296	0.333	0.107
Copper	mg/kg	5.520	4.00	12.10
Zinc	mg/kg	25.54	24.57	31.54
Manganese	mg/kg	57.90	71.0	46.40
Iron	mg/kg	446.9	353.2	831.0
Nitrate	mg/kg	47.5	46.4	43.2
Boron	mg/kg	54.97	54.54	110.16

TABLE A3.10 Major/trace element analysis results for north grove, Hacks Well (Site 3) for February 2005 (CSBP, 2005).

ELEMENT	UNITS	OLD GROWTH	NEW GROWTH
Total Nitrogen	%	1.67	1.97
Phosphorus	%	0.09	0.151
Potassium	%	1.006	1.448
Sulfur	%	0.176	0.165
Sodium	%	0.015	0.012
Calcium	%	2.83	0.777
Magnesium	%	0.193	0.135
Chloride	%	0.058	0.199
Copper	mg/kg	4.48	11.16
Zinc	mg/kg	22.79	23.36
Manganese	mg/kg	65.5	31.9
Iron	mg/kg	143.3	92.7
Nitrate	mg/kg	38	41
Boron	mg/kg	28.1	35

TABLE A3.11 Major/trace element analysis results for middle grove, Hacks Well (Site 3) for February 2005 (CSBP, 2005).

ELEMENT	UNITS	OLD GROWTH	NEW GROWTH
Total Nitrogen	%	1.67	1.87
Phosphorus	%	0.089	0.14
Potassium	%	1.167	1.353
Sulfur	%	0.185	0.159
Sodium	%	0.019	0.019
Calcium	%	2.672	0.851
Magnesium	%	0.208	0.152
Chloride	%	0.056	0.191
Copper	mg/kg	5.02	9.59
Zinc	mg/kg	19.34	21.17
Manganese	mg/kg	63.7	34.4
Iron	mg/kg	150.1	122.6
Nitrate	mg/kg	39	39
Boron	mg/kg	26.2	33.4

TABLE A3.12 Major/trace element analysis results for south grove, Hacks Well (Site 3) for February 2005 (CSBP, 2005).

ELEMENT	UNITS	OLD GROWTH	NEW GROWTH
Total Nitrogen	%	1.73	1.85
Phosphorus	%	0.107	0.169
Potassium	%	1.076	1.452
Sulfur	%	0.182	0.17
Sodium	%	0.028	0.014
Calcium	%	2.036	0.582
Magnesium	%	0.185	0.147
Chloride	%	0.07	0.221
Copper	mg/kg	6.52	11.51
Zinc	mg/kg	23.02	31.73
Manganese	mg/kg	61.1	32.7
Iron	mg/kg	164.9	79.1
Nitrate	mg/kg	39	41
Boron	mg/kg	25.2	34.6

APPENDIX 4: FLOWER AND FRUIT FORMATION

Trial site#1; Davis Well grove

TABLE A4.1: Summary of flower and olive fruit formation at Davis Well (Site 1), between September 2001 and February 2002.

CULTIVAR	ALIVE TREE POP'N	MEAN %LIMBS WITH FLOWER	MEAN %LIMBS WITH FRUIT	TOTAL U'RIPE OLIVES	TOTAL RIPE OLIVES	TOTAL OLIVES	TOTAL WEIGHT (grams)	AVERAGE OLIVES PER TREE
ASCOLANA	10	24% (5 trees)	3% (2 trees)	20	1	21 (2 trees)	105	2.1
NEW NORCIA MISSION	16	<1% (1 tree)	0%	0	0	0	0	0
VERDALE	21	3% (2 trees)	<1% (1 tree)	10	0	10 (1 tree)	50	0.5
MANZANILLO	17	5% (3 trees)	1% (1 tree)	20	0	20 (1 tree)	100	1.2
UC136A	15	0%	0%	0	0	0	0	0
TOTAL:	**76**			**50**	**1**	**51**	**255**	

Important note;
1) Tree mortalities recorded 14th October 2001.
2) Measurement of % flower formation recorded 14th October 2001, percentage calculated over living tree population.
3) Measurement of % fruit formation recorded on 4th December 2001, percentage calculated over living tree population.
4) Fruit production checked on 4th December 2001, with fruit recorded as "unripe" production (not including surviving Ascolana).
5) Fruit production checked on 26th March 2002, with final fruit production recorded as "ripe" production.

TABLE A4.2: Summary of flower and olive fruit formation at Davis Well (Site 1), between September 2002 and February 2003.

CULTIVAR	ALIVE TREE POP'N	MEAN %LIMBS WITH FLOWER	MEAN %LIMBS WITH FRUIT	TOTAL U'RIPE OLIVES	TOTAL RIPE OLIVES	TOTAL OLIVES	TOTAL WEIGHT (grams)	AVERAGE OLIVES PER TREE
ASCOLANA	10	5% (3 trees)	<1% (1 tree)	5	0	5	25	0.5
NEW NORCIA MISSION	15	0%	0%	0	0	0	0	0
VERDALE	19	0%	0%	0	0	0	0	0
MANZANILLO	18	0%	0%	0	0	0	0	0
UC136A	12	0%	0%	0	0	0	0	0
TOTAL:	**74**			**5**	**0**	**5**	**25**	

Important note;
1) Tree mortalities recorded 20th September 2002.
2) Measurement of % flower formation recorded 20th September 2002, percentage calculated over living tree population.
3) Measurement of % fruit formation recorded on 11th December 2002, percentage calculated over living tree population.
4) Fruit production checked on 11th December 2002, with fruit production recorded as "unripe" production.

TABLE A4.3: Summary of flower and olive fruit formation at Davis Well (Site 1), between September 2003 and April 2004.

CULTIVAR	ALIVE TREE POP'N	MEAN %LIMBS WITH FLOWER	MEAN %LIMBS WITH FRUIT	TOTAL U'RIPE OLIVES	TOTAL RIPE OLIVES	TOTAL OLIVES	TOTAL WEIGHT (grams)	AVERAGE OLIVES PER TREE
ASCOLANA	10	6% (1 tree)	n/r	0	0	0	0	0
NEW NORCIA MISSION	15	0%	n/r	0	0	0	0	0
VERDALE	19	0%	n/r	0	0	0	0	0
MANZANILLO	18	19% (6 trees)	n/r	0	0	0	0	0
UC136A	12	0%	n/r	0	0	0	0	0
TOTAL:	**74**			**0**	**0**	**0**	**0**	

Important note;
1) Tree mortalities recorded 14th October 2003.
2) Measurement of % flower formation recorded 14th October 2003, percentage calculated over living tree population.
3) Measurement of % fruit formation not recorded (denoted "n/r").
4) All trees at grove checked on 22nd April 2004, with <u>no fruit production being recorded.</u>

TABLE A4.4: Summary of flower and olive fruit formation at Davis Well (Site 1), between September 2004 and February 2005.

CULTIVAR	ALIVE TREE POP'N	MEAN %LIMBS WITH FLOWER	MEAN %LIMBS WITH FRUIT	TOTAL U'RIPE OLIVES	TOTAL RIPE OLIVES	TOTAL OLIVES	TOTAL WEIGHT (grams)	AVERAGE OLIVES PER TREE
ASCOLANA	10	9% (1 tree)	n/r	0	0	0	0	0
NEW NORCIA MISSION	15	2% (1 tree)	n/r	0	0	0	0	0
VERDALE	19	11% (3 trees)	n/r	0	0	0	0	0
MANZANILLO	18	6% (2 trees)	n/r	0	0	0	0	0
UC136A	12	7% (1 tree)	n/r	0	0	0	0	0
TOTAL:	**74**			**0**	**0**	**0**	**0**	

Important note;
1) Tree mortalities recorded 16th October 2004.
2) Measurement of % flower formation recorded 16th October 2004, percentage calculated over living tree population.
3) Measurement of % fruit formation not recorded (denoted "n/r").
4) All trees at grove checked during March 2005, with <u>no fruit production being recorded.</u>

Site#2; Jubilee Well trial grove

TABLE A4.5: Summary of flower and olive fruit formation at Jubilee Well (Site 2), between September 2001 and March 2002.

CULTIVAR	ALIVE TREE POP'N	MEAN %LIMBS WITH FLOWER	MEAN %LIMBS WITH FRUIT	TOTAL U'RIPE +RIPE OLIVES	TOTAL O'RIPE +FALLEN OLIVES	TOTAL OLIVES	TOTAL WEIGHT (grams)	AVERAGE OLIVES PER TREE
ASCOLANA	25	15% (10 trees)	3% (9 trees)	65	5	70 (6 trees)	200	2.8
KALAMATA	10	31% (9 trees)	8% (5 trees)	30	1	31 (5 trees)	110	3.1
JUMBO KALAMATA?	1	10% (1 tree)	10% (1 tree)	3	22	23 (1 tree)	236	23
PENDOLINO	2	33% (1 tree)	3% (1 tree)	12	1	13 (1 tree)	20	6.5
OLEA MISSION	3	10% (2 trees)	10% (2 trees)	110	53	163 (2 trees)	420	54.3
NEW NORCIA MISSION	23	23% (21 trees)	19% (18trees)	732	466	1198 (18 trees)	2445	52.1
VERDALE	9	42% (8 trees)	27% (7 trees)	416	151	567 (7 trees)	2750	63
NABTARI	6	52% (6 trees)	45% (6 trees)	186	79	265 (6 trees)	1270	44.2
LECCINO	**7**	13% (2 trees)	6% (2 trees)	12	1	13 (2 trees)	45	1.9
BAROUNI	6	0%	0%	0	0	0	0	0
MANZANILLO	2	0%	0%	0	0	0	0	0
TOTAL:	**94**			**1585**	**758**	**2343**	**7496**	

Important note;
1) Tree mortalities recorded 13th October 2001.
2) Measurement of % flower formation recorded 13th October 2001, percentage calculated over living tree population.
3) Measurement of % fruit formation recorded on 5th December 2001, percentage calculated over living tree population.
4) Fruit production collected and weighed on 14th March 2002.

TABLE A4.6: Summary of flower and olive fruit formation Jubilee Well (Site 2), between September 2003 and February 2004.

CULTIVAR	ALIVE TREE POP'N	MEAN %LIMBS WITH FLOWER	MEAN %LIMBS WITH FRUIT	TOTAL RIPE OLIVES	TOTAL FALLEN OLIVES	TOTAL OLIVES	TOTAL WEIGHT (grams)	AVERAGE OLIVES PER TREE
ASCOLANA	25	1% (1 tree)	n/r	0	0	0	0	0
KALAMATA	10	0%	n/r	0	0	0	0	0
JUMBO KALAMATA?	1	65% (1 tree)	n/r	0	0	0	0	0
PENDOLINO	2	0%	n/r	0	0	0	0	0
OLEA MISSION	3	0%	n/r	0	0	0	0	0
NEW NORCIA MISSION	23	10% (7 trees)	n/r	2	2	4 (1 tree)	20	0.2
VERDALE	9	2% (1 tree)	n/r	0	10	10 (1 tree)	50	1.1
NABTARI	6	0%	n/r	0	0	0	0	0
LECCINO	**7**	<1% (1 tree)	n/r	0	0	0	0	0
BAROUNI	6	0%	n/r	0	0	0	0	0
MANZANILLO	2	45% (1 tree)	n/r	0	0	0	0	0
TOTAL:	**94**			**2**	**12**	**14**	**70**	

Important note;
1) Tree mortalities recorded 16th September 2003.
2) Measurement of % flower formation recorded 16th September 2003, percentage calculated over living tree population.
3) No measurement or recording of % fruit formation was completed (denoted as "n/r").
4) Fruit production recorded on 21st April 2004, with total weight calculated from estimated weight of 5grams/olive.

TABLE A4.7: Summary of flower and olive fruit formation Jubilee Well (Site 2), between September 2004 and February 2005.

CULTIVAR	ALIVE TREE POP'N	MEAN %LIMBS WITH FLOWER	MEAN %LIMBS WITH FRUIT	TOTAL RIPE OLIVES	TOTAL FALLEN OLIVES	TOTAL OLIVES	TOTAL WEIGHT (grams)	AVERAGE OLIVES PER TREE
ASCOLANA	25	82% (12 trees)	n/r	20	5	25 (1 tree)	125	1
KALAMATA	6	48% (5 trees)	n/r	4	6	10 (3 trees)	50	1.7
JUMBO KALAMATA?	1	95% (1 tree)	n/r	40	3	43 (1 tree)	215	43
PENDOLINO	2	25% (2 trees)	n/r	0	0	0	0	0
OLEA MISSION	3	73% (3 trees)	n/r	70	9	79 (2 trees)	395	26.3
NEW NORCIA MISSION	23	69% (21 trees)	n/r	393	62	455 (15 trees)	2275	19.8
VERDALE	9	84% (9 trees)	n/r	240	34	274 (9 trees)	1370	30.4
NABTARI	6	95% (6 trees)	n/r	50	12	62 (5 trees)	310	10.3
LECCINO	**7**	68% (8 trees)	n/r	601	122	723 (7 trees)	3615	103.3
BAROUNI	6	50% (6 trees)	n/r	60	0	60 (2 trees)	300	10
MANZANILLO	2	95% (2 trees)	n/r	40	4	44 (2 trees)	220	22
TOTAL:	**94**			**1518**	**257**	**1775**	**8875**	

Important note;
1) Tree mortalities recorded 15th October 2004.
2) Measurement of % flower formation recorded 15th October 2004, percentage calculated over living tree population.
3) No measurement or recording of % fruit formation was completed (denoted as "n/r").
4) Fruit production recorded during 15th March 2005, with total weight calculated from estimated weight of 5grams/olive.

Site#3; Hacks Well groves (Site 3)

TABLE A4.8: Summary of flower formation for Hacks Well groves (Site 3), between September and December 2003.

	NORTH GROVE		MIDDLE GROVE		SOUTH GROVE	
CULTIVAR	**LIVE TREE POP'N**	**% LIMBS WITH FLOWER**	**LIVE TREE POP'N**	**% LIMBS WITH FLOWER**	**LIVE TREE POP'N**	**% LIMBS WITH FLOWER**
BARNEA	12	2%	10	0%	13	0%
NN MISSION	10	0%	16	0%	9	0%
VERDALE	10	3%	8	4%	2	0%

Important note;
1) Tree mortalities recorded 14th October 2003.
2) Measurement of % flower formation recorded 14th October 2003, percentage calculated over living tree population.
3) All flowers removed 14th October 2004 before fruit formation.

TABLE A4.9: Summary of flower formation Hacks Well groves (Site 3), between September and December 2004.

	NORTH GROVE		MIDDLE GROVE		SOUTH GROVE	
CULTIVAR	**LIVE TREE POP'N**	**% LIMBS WITH FLOWER**	**LIVE TREE POP'N**	**% LIMBS WITH FLOWER**	**LIVE TREE POP'N**	**% LIMBS WITH FLOWER**
BARNEA	12	63%	10	27%	13	6%
NN MISSION	10	8%	16	4%	8	0%
VERDALE	10	22%	6	19%	nil	

Important note;
1) Tree mortalities recorded 14th October 2004.
2) Measurement of % flower formation recorded 14th October 2004, percentage calculated over living tree population.
3) Fruit development examined during March 2005, no fruit formation was observed.
4) No measurements for cultivar *Verdale* at south grove, due to mortality of all trees.

APPENDIX 5: OTHER LITERATURE

Adv. Hort. Sci., 2002 16(3-4): 131-137

Preliminary report on the growing potential of the European olive (*Olea europaea* L.) under Australian arid-zone conditions

G. Price*, E.G. Barrett-Lennard, J.E.D. Fox***, S.G. Kailis******

* *Sustainability Department, Placer Granny Smith Pty. Limited, P.O. Box 33, Laverton Western Australia 6440, Australia.*

** *Western Australian Department of Agriculture, South Perth, Western Australia 6151, Australia.*

*** *Mulga Research Centre, Curtin University, Department of Environmental Biology, GPO Box U1987, Perth, Western Australia 6845, Australia.*

**** *Faculty of Natural and Agricultural Sciences, University of Western Australia, Crawley, Western Australia 6009, Australia.*

Key words: cultivar, mortality, saline conditions, sodic clays.

Abstract: **Trials of the European olive (Olea europaea) were undertaken to assess growth performance and commercial potential in an arid climate with saline ground water. Eighty-eight trees of five different cultivars were planted on a clay soil at the first trial site. A total of ninety-eight trees comprising eleven different cultivars were planted in sandy soil at the second site. A significantly higher mortality rate occurred at the first site. A significant quantity of fruit was produced by some cultivars at the second site. Ripening of fruit occurred earlier than at other olive growing areas. The European olive has potential as a possible future commercial crop in arid environments in Australia. A future randomised block trial is planned, to assess growth performance in contrasting soil profiles.**

1. Introduction

This paper describes the growth of the European olive (*Olea europaea* L.) under arid conditions. Decline in global markets for traditional arid-zone products, such as wool, is stimulating the search for new economical and sustainable agricultural options in the more remote rural areas of Australia. Active promotion of economic diversity has been the focus of a number of different groups within the agricultural industry, in addition to key government agencies (Pastoral Wool Industry Taskforce, 1993). On Mount Weld pastoral station, situated in the arid zone of Western Australia, preliminary trials have been continuing for three years to test growth performance and evaluate the potential of the European olive.

Mount Weld pastoral station (latitude 29 degrees, longitude 122 degrees) has an area of ~800,000 ha and is located ~350 km north, north-east of the regional centre of Kalgoorlie, in the central south-east of Western Australia. Mount Weld (Fig. 1) is currently managed by a commercial organisation that operates

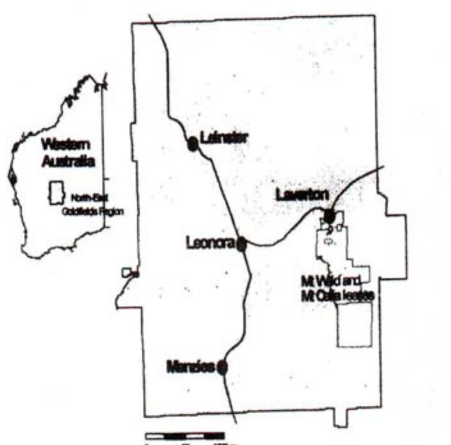


Fig. 1 - Map showing the location of Mount Weld Pastoral Station (James *et al.*, 2001).

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substantial gold mining at the station (James *et al.*, 2001). Mineral exploration and mining occurs on some areas of the station. Pastoralism is however, active on a much larger portion of the station and involves grazing of merino and demara sheep for wool and meat production.

Trials of potentially commercial crops are part of a biodiversity conservation plan for Mount Weld station (James *et al.*, 2001). This plan includes the testing of crops that have potential for sustainable land use in the future, and on enterprises that can play a role in the rehabilitation of degraded land. The preliminary trials of the European olive on Mount Weld pastoral station reported in this paper have been conducted according to the key principles of this biodiversity conservation plan.

Environment of Mount Weld pastoral station

Mount Weld pastoral station is well inland, being located more than 700 km from the southern and 1000 km from the western coastlines of Australia. Elevation is over 400 m above sea level. Long term averages of local climate recorded at the nearby weather station in Laverton are presented in figures 2 and 3. Mount Weld pastoral station has an arid climate (Gilligan, 1994). Mean annual rainfall in the area is between 200 and 250 mm per annum. Rainfall distribution is erratic but generally more regular in autumn and early winter than in spring and summer (Gilligan, 1994). Heavy rains that cause floods occur occasionally. The occurrence of flooding is commonly associated with rain-bearing depressions resulting from the breakdown of tropical cyclones as they travel across the region. On average, evaporation rates for the region exceed rainfall by a factor of more than ten.

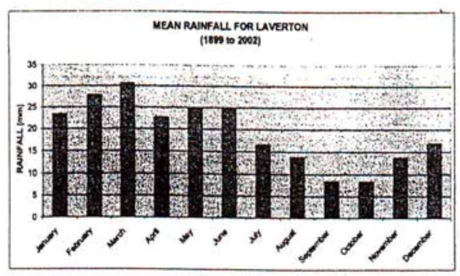

Fig. 2 - Long term averages of mean monthly rainfall for the Laverton town-site (Hollingshead, 2002).

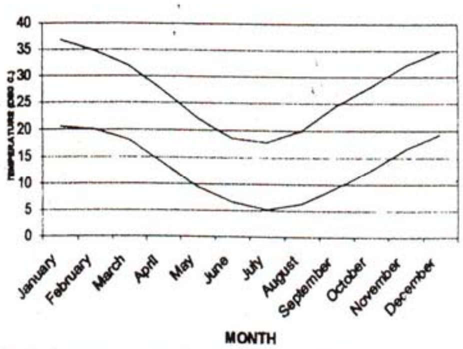

Fig. 3 - Long term averages for mean monthly maximum and minimum temperatures for the Laverton town-site (Hollingshead, 2002).

The hydrogeology of the region has been described by Allen (1994). Groundwater from wells and bores is commonly of low to moderate salinity (ranging from 0 to 5000 mgl^{-1} total dissolved solids), alkaline (pH 7 to 9) and contains high background levels of nitrate (above 30 mgl^{-1}). Around the edge and within the Lake Carey drainage system (a salt lake that borders the western side of Mount Weld pastoral station) groundwater is highly saline to hyper-saline (5,000 to 300,000 mgl^{-1} total dissolved solids).

Comparison with other olive growing regions

Mount Weld station receives less than half the annual rainfall of olive growing areas in Europe, such as in parts of Spain, Italy, Greece and coastal southern Australia. The level of precipitation is similar on average to the more arid olive growing regions of Morocco, Argentina and some drier areas of South Australia. There are also differences in rainfall frequency when compared to other areas. Most olive growing areas in southern Australia receive more regular rainfall than Laverton, with the bulk of rain falling in winter and spring. Average temperatures have a similar annual pattern to most other olive-growing areas worldwide, although they are generally warmer during winter than in the majority of other areas.

Why choose olives?

The European olive has been considered historically to be productive in hot and dry environments in the Mediterranean. The tree has a moderate tolerance to salinity (Maas, 1986). Successful cultivation of olives in Mediterranean climates and in areas subject to saline conditions has been described by Therios and Misolinos (1988) and Tattini *et al.* (1995, 1996). Many areas of Western Australia (Kailis, 1997) and southern Australia (Kailis and Sweeney, 2000), with Mediterranean-like conditions, are suitable for olive cultivation. Kailis (1997) notes the absence of commercial olives in the central interior of Western Australia, where climatic conditions are hot and dry. However, individual trees are known to grow well and fruit abundantly under dry-land conditions within the region. Small plantings of olive are found at various locations including the towns of Kalgoorlie and Menzies (Fig. 1). A single olive tree exists near the original homestead site on Mount Weld station within 30 km of the trial groves. While these plantings confirm the survival of European olive under typical dry land or arid conditions as suggested by Kailis (1997), little data was available on the growth of this species in the region. This study aimed to address this deficiency by gathering data on survival and rates of growth of commercial-scale plantings of the European olive in this region.

2. Materials and Methods

The two sites selected for preliminary planting of the European olive are located in areas previously subject to heavy grazing. They are also close to established water supplies sufficient to irrigate to a level of approximately 500 l hr^{-1}.

Site 1 (Davis Well)

Eighty-eight trees were planted at Site 1 (Davis Well) during the Spring of 1999. Soil at the site consists of a shallow profile (0.4 to 0.5 m) of red-brown sodic clay above a lateritic horizon. Excavation of the laterite to a depth of 0.7 m revealed a dominantly siliceous hardpan. Tree roots of indigenous flora exposed within the excavation had penetrated to this shallow depth along pre-existing fractures within the laterite. Personal observations suggest that the laterite was highly impermeable. The planting site was cleared of vegetation and the soil was ripped to 1 m before planting of the olive trees. Tree stock was two years old, propagated commercially from self-rooted cuttings. After consultations with a commercial nursery (Bazzani, Personal communication), the following cultivars were planted: New Norcia Mission (a 'Frantoio' clone, 17 trees), Ascolana (11 trees), Verdale (23 trees), UC13A6 (15 trees) and Manzanillo (22 trees). Eight trees per row were planted in a randomised pattern along eleven parallel rows (approximately 8 x 10 m grid). Trees were irrigated with groundwater (electrical conductivity 4.23 m S cm^{-1}, pH 9.0) through gravity-fed drip-feeders.

Site 2 (Jubilee Well)

Ninety-eight olive trees were planted at Site 2 (Jubilee Well) during autumn 2000. The soil profile consists of coarse sand to more than 1 m depth. The site was completely cleared of vegetation. Three year old commercially propagated trees were planted into 1 m deep holes in seven mounded rows. Cultivars planted include: New Norcia Mission (a 'Frantoio' clone, 25 trees), Ascolana (25 trees), Kalamata (10 trees), Verdale (9 trees), Nabtari (6 trees), Leccino (9 trees), Barouni (6 trees), Manzanillo (2 trees), Olea Mission (a 'Frantoio' clone, 3 trees), Pendolino (2 trees) and Jumbo Kalamata (1 tree). Planting order was arranged according to cultivar, with fourteen trees per row being planted in seven parallel rows (6 x 10 m grid). Trees were irrigated with groundwater (electrical conductivity 2.53 m S cm^{-1}, pH 8.4) through gravity-fed reticulated drip-feeders. Irrigation for both groves was stabilised to an average weekly volume of between 180 and 250 l per tree. Natural precipitation provided additional water. Irrigation however was curbed following heavy rainfall, particularly during the summer months.

Tree measurements

Measurements (tree height [m], crown girth [cm], trunk diameter [mm] of each individual tree and mortality were recorded every second month from planting until May 2002. Tree heights were measured using a tape-measure from ground level to the tallest shoot. Crown girth was calculated as the mean of two measurements (completed with a tape-measure) at right angles across the tree crown. Trunk diameter was measured with a vernier caliper, at a height of 10-15 cm above ground level.

Flowering and fruit measurements

Flowering and fruit formation rates were recorded for each individual tree during the summer of 2001/02. Fruit, harvested by hand, was also undertaken in March 2002 and assessed further.

Oil testing

Two composite samples were analysed by the Chemistry Centre of W.A., according to international and NATA protocols (Rothnie, 2002). The olives were randomly selected from fruit harvested from the cultivars New Norcia Mission and Verdale at Site 2. These varieties were two of the more productive cultivars. A delay of four days occurred before sample dispatch. At the laboratory, samples were prepared and analysed for oil content and percentage free fatty acid (FFA) in the oil. The oil fraction was extracted from the fruit by the soxhlet method using with hexane.

3. Results and Discussion

Olive tree mortality

Mortality during the first twelve months exceeded 10% at Davis Well (12 trees), as opposed to 1% at Jubilee Well (one tree). The higher mortality at Davis Well may have been caused by the different characteristics of the two soil profiles. The sodic clay at Davis Well is susceptible to water-logging. Water-logging was frequently observed at the soil surface at Davis Well when trees were watered through the irrigation system and also after periods of heavy rainfall (defined here as greater than 2-3 mm rainfall over 12 hours). In comparison, at Jubilee Well there was no evidence of water-logging in the highly permeable sandy soil. Since the end of the first year, no further tree mortality has been observed at Davis Well. Exposure of root sections of two trees at the Davis Well site showed that roots had mostly developed along the upper surface of the laterite at or below 0.4 m depth.

Growth performance of olive trees

Comparison of growth performance between the groves was complicated by the fact that tree placement was randomised at Davis Well but not at Jubilee Well, the different time of establishment of each grove, and the differences in both the number and selection of cultivars planted at each site. As a consequence of these differences, tree growth data were assessed independently at the two trial sites. Tree growth data for Davis

Well are presented in Table 1. On average, over the period from September 2000 to May 2002 (20 months), there was a 2.6-fold increase in trunk diameter and crown diameter and a 0.2-fold increase in tree height.

Statistical comparisons were completed for all cultivars at Davis Well. No significant difference was identified for the rate of growth in trunk diameter between different cultivars. Some significant differences however were identified in the rate of growth of the canopy (crown diameter) and tree height. With crown diameter, the biggest difference was identified within individual trees of cultivar Ascolana ($p \leq 0.05$). For changes of crown diameter between cultivars, a significant difference was also identified with the cultivar UC13A6, compared to 'New Norcia Mission' and 'Ascolana' ($p \leq 0.05$). For tree height, the most significant differences were between the cultivar Verdale, as compared to 'Manzanillo' and 'UC13A6' ($p \leq 0.05$).

Tree growth data for Jubilee Well are presented in Table 2. For trees at Jubilee Well, the most sensitive indicator of vegetative growth in the period from June 2000 to May 2002 (23 months) was trunk diameter (a 1.3-fold increase). There was a 0.9-fold increase in canopy diameter and a 0.2-fold increase in tree height over the same measurement period.

Some statistically significant differences were identified with all growth parameters for the cultivars grown at Jubilee Well. For the rate of growth of trunk diameters, a significant difference was identified between the cultivars Pendolino and Nabtari ($p \leq 0.05$). For growth of crown diameter, the most significant difference was identified in comparisons between trees of cultivar Pendolino, and all other cultivars, except for 'Manzanillo' and 'Jumbo Kalamata' ($p \leq 0.05$). For change of tree height, significant difference occurred with comparisons between cultivar Nabtari, and Leccino and Pedolino ($p \leq 0.05$). No other cultivars showed any significant differences.

Comparison between Davis and Jubilee Wells

For trunk diameter, the highest growth rate was identified in trees at Davis Well (a 2.6-fold increase), compared to trees at Jubilee Well (a 1.3-fold increase). For canopy diameter, the highest growth rate was identified in trees at Davis Well (a 2.6-fold increase), compared to trees at Jubilee Well (a 0.9-fold increase). For tree height however, growth rates were similar between both groves (a 0.24-fold increase for Jubilee Well, compared to a 0.17-fold increase for Davis Well).

Fruit formation during the 2001/2002 season

Data on the extent of flower formation, pollination and fruit formation were collected during the summer of 2001/02 at both sites. There was negligible fruit formation at Davis Well, but trees of most cultivars at Jubilee Well (Table 3) produced fruit. At Jubilee Well, fruit ripened during February-March which is several months earlier in the season than in olive growing areas in southern Western Australia (Courtin, personal communication). Fruit ripening rate is known to be a function of factors such as maturity, crop load, temperature and levels of solar radiation so there may be differences in subsequent years.

The most successful trees in terms of fruit production at Jubilee Well were of the cultivars Verdale, New Norcia Mission and Nabtari. At this site, a total of more than 1 kg of fruit was harvested from each of

Table 1 - Growth of olive cultivars at Site 1 (Davis Well)

Cultivar	Replicates	Sep-2000	May-2002	Increases
		Tree height (m)		
Ascolana	10	1.090 ± 0.047	1.30 ± 0.075	0.193
Manzanillo	18	1.228 ± 0.039	1.386 ± 0.036	0.129
New Norcia Mission	15	1.353 ± 0.034	1.57 ± 0.047	0.16
UC13A6	13	1.127 ± 0.087	1.273 ± 0.093	0.13
Verdale	19	1.066 ± 0.046	1.332 ± 0.06	0.249
Mean		1.176 ± 0.026	1.378 ± 0.029	0.172
		Trunk diameter (mm)		
Ascolana	10	6.5 ± 0.342	26.7 ± 2.836	3.108
Manzanillo	18	7.0 ± 0.181	26.444 ± 1.314	2.778
New Norcia Mission	15	8.8 ± 0.393	28.133 ± 1.771	2.197
UC13A6	13	7.462 ± 0.462	23.308 ± 2.277	2.124
Verdale	19	6.737 ± 0.285	26.737 ± 1.635	2.969
Mean		7.307 ± 0.171	26.347 ± 0.828	2.606
		Canopy diameter (m)		
Ascolana	10	0.325 ± 0.031	1.29 ± 0.13	2.969
Manzanillo	18	0.350 ± 0.024	1.292 ± 0.065	2.69
New Norcia Mission	15	0.327 ± 0.020	1.30 ± 0.070	2.98
UC13A6	13	0.358 ± 0.026	0.971 ± 0.090	1.715
Verdale	19	0.324 ± 0.027	1.179 ± 0.060	2.642
Mean		0.337 ± 0.011	1.209 ± 0.037	2.591

Values are the mean ± S.E.

Increases between September 2000 and May 2002 are shown in column 5 as a ratio of May 2002 data dived by September 2000 data.

Table 2 - Growth of olive cultivars at Site 2 (Jubilee Well)

Cultivar	Replicates	Sep-2000	May-2002	Increases
		Tree height (m)		
Ascolana	25	1.616 ± 0.033	1.97 ± 0.044	0.22
Barouni	6	1.342 ± 0.223	1.90 ± 0.242	0.42
Kalamata	10	1.47 ± 0.066	1.695 ± 0.113	0.15
Leccino	8	1.35 ± 0.113	2.131 ± 0.137	0.58
Manzanillo	2	1.275 ± 0.025	1.875 ± 0.025	0.47
Nabtari	6	1.617 ± 0.088	1.625 ± 0.048	0.01
New Norcia Mission	24	1.699 ± 0.041	2.029 ± 0.076	0.19
Olea Mission	3	1.683 ± 0.13	2.083 ± 0.224	0.24
Pendolino	2	1.10 ± 0.00	1.80 ± 0.20	0.64
Verdale	9	1.522 ± 0.077	1.894 ± 0.049	0.24
Jumbo Kalamata	1	1.95	2.40	0.23
Mean		1.565 ± 0.028	1.939 ± 0.035	0.24
		Trunk diameter (mm)		
Ascolana	25	16.08 ± 0.404	40.0 ± 0.95	1.488
Barouni	6	17.833 ± 1.537	40.333 ± 3.676	1.26
Kalamata	10	12.9 ± 0.722	29.7 ± 2.793	1.30
Leccino	8	15.5 ± 1.195	40.625 ± 4.127	1.62
Manzanillo	2	11.0 ± 1.0	34.5 ± 0.5	2.14
Nabtari	6	14.333 ± 0.494	29.5 ± 0.885	1.06
New Norcia Mission	24	20.208 ± 0.535	41.25 ± 2.205	1.04
Olea Mission	3	20.0 ± 1.528	41.667 ± 3.48	1.08
Pendolino	2	12.5 ± 0.5	46.0 ± 9.0	2.68
Verdale	9	13.667 ± 0.601	37.667 ± 1.481	1.76
Jumbo Kalamata	1	21.0	37.0	0.76
Mean		16.5 ± 0.368	38.469 ± 0.903	1.33
		Canopy diameter (m)		
Ascolana	25	0.668 ± 0.023	1.428 ± 0.033	1.14
Barouni	6	0.592 ± 0.04	1.358 ± 0.119	1.30
Kalamata	10	0.56 ± 0.048	1.033 ± 0.093	0.84
Leccino	8	0.66 ± 0.07	1.381 ± 0.129	1.10
Manzanillo	2	0.48 ± 0.075	1.30 ± 0.05	1.74
Nabtari	6	0.68 ± 0.038	1.158 ± 0.033	0.70
New Norcia Mission	24	0.80 ± 0.037	1.313 ± 0.066	0.64
Olea Mission	3	0.80 ± 0.058	1.367 ± 0.073	0.71
Pendolino	2	0.55 ± 0.10	1.925 ± 0.225	2.50
Verdale	9	0.61 ± 0.072	1.189 ± 0.057	0.96
Jumbo Kalamata	1	0.70	1.60	1.29
Mean		0.678 ± 0.018	1.318 ± 0.029	0.95

Increases between September 2000 and May 2002 are shown in column 5 as a ratio of May 2002 data dived by September 2000 data.

Table 3 - Comparison of fruit formation between Jubilee Well and Davis Well groves

	Sample population No of Trees		limbs with flower formation %		limbs with fruit formation %		Total number of olives formed		Total weight (grams)	
Cultivar	JW	DW	JW	DW	JW	DW	JW	DW	JW	DW
Ascolana	27	10	39	50	38	10	79	1	225	5
Kalamata	11		100		64		62		195	
Jumbo Kalamata	1		100		100		23		236	
Pendolino	2		50		50		13		20	
Olea Mission	3		67		67		163		420	
New Norcia Mission	25	16	76	7	68	0	1171	0	2380	0
Verdale	8	19	100	11	88	6	567	0	2750	0
Nabtari	7		86		86		265		1270	
Leccino	5		0		0		0		0	
Barouni	4		0		0		0		0	
Manzanillo	3	17	0	18	0	0	0	0	0	0
UC13A6		12		0		0		0		0
TOTAL	96	74					2343	1	7496	5

JW= Jubilee Well.
DW= Davis Well.

these three varieties during March. Smaller quantities of fruit (less than 1 kg) were harvested from cultivars Ascolana, Kalamata, Jumbo Kalamata, Pendolino and Olea Missiön. Cultivars Leccino, Barouni and Manzanillo did not flower, so no fruit were formed. As no prior experience was at hand for olive fruiting in the local area, the decision to harvest fruit at Jubilee Well was based on the majority of fruit being at the green-ripe stage and commencing to darken to a purple colour. The degree of ripening of the fruit varied considerably between different trees within different cultivars. The only exception was cultivar Kalamata, which exhibited even ripening at harvest time.

Small quantities of "shotberries", small parthenocarpic fruit of no commercial value formed alongside fully developed fruit on some trees in the cultivars New Norcia Mission, Verdale and Nabtari. The formation of shotberries has been described by Cuevas *et al.* (1994) as occurring when olive trees are exposed to daily temperatures higher than 30°C. This resulted in increased seed abortion and reduced fruit set. This has also been observed for grapes (Kliewer, 1977). The formation of shotberries on trees at Jubilee Well could have been due to this reason for the season 2001/02. At least some trees from each cultivar, except variety 'UC13A6', produced flowers at Davis Well. However, most flowers subsequently aborted.

Oil quality

Oil content (% w/w as fresh weight) and quality (% FFA in the oil) were measured on two composite samples of olives harvested from cultivars New Norcia Mission and Verdale from Site 2 (Table 4). Both samples contained relatively elevated levels of free fatty acid, which may be due in part, to the time between harvest and testing. Levels however were within those required for the extra virgin grade. Fresh fruit from the cultivar Verdale had higher flesh oil content than those from New Norcia Mission cultivar. In both cases the oil levels were comparable with those required for commercial olive oil production. Bearing in mind the preliminary nature of the data presented, long-term evaluation of oil levels in these two varieties will reveal the true situation.

Table 4 - Analysis of olive fruit from Jubilee Well

Sample details	Verdale	New Norcia Mission
Sample weight (grams)	70.9	98.8
Flesh weight (grams)	60.3	76.3
Stone weight (grams)	10.6	22.5
Flesh to stone ratio	5.7:1	3.4:1
Water % (flesh component)	35.5	51.1
Oil % (flesh component)	33.8	24.4
Free fatty acid % (oil)	0.5	0.8

4. Conclusions

These initial trials have shown successful growth of the European olive in the arid environment typical of Mount Weld pastoral station, with relatively low mortality. Mortality was higher at Davis Well than at Jubilee Well during the first year after grove establishment. This higher mortality was probably related to saturation of the soil and associated waterlogging. Growth patterns of roots appear to have responded to conditions of saturation observed in the clay soil profile at shallower depths at Davis Well.

Comparison of growth performance was complicated by differences between both groves. As a consequence tree growth figures were evaluated independently for each trial site.

Comparisons of growth rates between groves provided a general insight about growth performance at each site. In general, greater rates in tree trunk and canopy diameter were observed at Davis Well when compared to the trees at Jubilee Well. At the latter site a small change in the rate of increase in tree height was observed. The differences observed in growth performance possibly reflect the contrasting conditions at the two different trial sites. Collection of additional data over subsequent years will allow for a more vigorous statistical evaluation of the sites.

Fruit was produced by many trees from most cultivars at Jubilee Well, but not at Davis Well. The reasons for these differences are not yet completely clear. Nevertheless, the data presented indicate that olives will grow and produce fruit at selected arid zone locations in Western Australia. It is still uncertain as to the long-term productivity and oil quality. European olive growing may become a commercial crop in the Laverton area providing a medium to high value product, that could be processed locally ensuring social and economic benefits.

On the basis of preliminary data obtained to date, a third trial is planned at another site to take into account factors that would influence the statistical significance of the trial. Site 3 (Hacks Well) is located in the vicinity of the existing groves. The new trial will have a randomised block design, aimed at testing the growth performance of three different olive cultivars on three different soil profiles with two water regimes.

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EUROPEAN OLIVE (*OLEA EUROPAEA*) AS AN ECONOMIC AND SUSTAINABLE AGRICULTURAL OPTION FOR THE RANGELANDS

G. Price1[1], E. G. Barrett-Lennard[2], J. E. D. Fox[1] and S. G. Kailis[3]

[1]School of Environmental Biology, Curtin University of Technology, Bentley, WA.
[2]WA Department of Agriculture, South Perth, WA.
[1]Mulga Research Centre, Curtin University of Technology, Bentley, WA.
[3]Department of Plant Science, University of Western Australia, Crawley, WA.

INTRODUCTION

Decline in global markets for traditional arid-zone products, such as wool, is stimulating the search for new, economically attractive and sustainable agricultural/horticultural options in remote rural areas of Australia (Price *et al*. 2002). On Mount Weld pastoral station, situated in the semi-arid rangeland of Western Australia, trials involving European olive commenced in 1999.

In regions such as central Australia and the Goldfields, there is a history of individual plantings of European olive in semi-arid and arid rangeland environments. However, the absence of commercial quantities of European olive in the interior of Western Australia where climatic conditions are hot and dry, has been noted (Kailis 1997). Preliminary trials conducted on Mount Weld pastoral station aim to test growth of a semi-commercial quantity of European olive in hot and dry conditions, typical of semi-arid rangelands.

Mount Weld pastoral station is located south of Laverton, which is approximately 350 km north north-east of Kalgoorlie, in central south-east Western Australia. The station covers approximately 800,000 ha and is currently managed by Placerdome Asia Pacific, a company that conducts mining and mineral exploration activities as well as managing the pastoral operations on the station. Trials of potentially commercial crops are part of a biodiversity conservation plan for Mount Weld station (James *et al.* 2001). This plan includes the testing of crops that have potential for sustainable land use in the future, and of enterprises that can play a role in the rehabilitation of degraded land.

MATERIALS AND METHOD

Preliminary trials of European olive were conducted at two sites with contrasting soil types and soil profiles. The first site was established in 1999 at Davis Well where 88 trees from five cultivars were planted on soil with a shallow profile (0.4 - 0.5 m. of clay soil above laterite). The second site was established in 2000 at Jubilee Well where 98 trees from 11 cultivars were planted on a soil with a deeper profile (more than 1 m. of coarse, sandy soil).

Growth performance assessments were carried out regularly at both trial sites, including the measurement of tree height, crown girth, trunk diameter and an estimation of biomass using the Reference Unit Method (Kirmse and Norton 1985). Direct comparison of the growth performance at these two sites was complicated by the fact that tree placement was randomised at Davis Well but not at Jubilee Well, the two groves were established at different times, and the cultivars selected and numbers of each planted at the sites differed. As a consequence, tree performance was assessed independently at the two trial sites (Price *et al.* 2002).

RESULTS AND CONCLUSIONS

Although the growth performance of European olive at the two sites could not be compared statistically, differences in tree growth were apparent. Differences in biomass were identified (from Reference Unit Method results) between individual groves, as well as individual cultivars, between the period September 2002 to April 2004. Trees from 8 out of 11 cultivars growing at Jubilee Well produced small quantities of fruit during the 2001/02 spring-summer season (cultivars; *Ascolana, Kalamata, Jumbo Kalamata, Pendolino, Olea Mission, New Norcia Mission, Verdale* and *Nabtari*). At Davis Well by comparison during the 2001/02 spring-summer season, minimal fruit formation was observed on 2 trees only (cultivars; *Ascolana* and *Verdale*) (Price *et al.* 2002). Significantly, fruit ripening occurred earlier than at other more temperate olive growing areas in WA.

Importantly, preliminary trials of European olive on Mount Weld pastoral station highlight the fact that this crop may potentially be grown successfully in the semi-arid rangelands. The overall potential of European olive as a commercial crop, however, still needs further evaluation. Results from the first two trials conducted on Mount Weld pastoral station were encouraging, and a third grove was established in 2002 at 'Hacks Well', which is close to the two original sites and also on Mount Weld pastoral station.

The Hacks Well trial has been designed as a randomised block, to test potential variations in growth performance of European olive subjected to different soil and water conditions. Three different cultivars of European olive have been selected for this third trial, based on results from the preliminary trials at the Davis and Jubilee groves. Further assessment of growth performance and fruit production will be undertaken at the three trial sites on Mount Weld, and this will include detailed recording of fruit production from individual trees and laboratory testing of olive oil quality.

References

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