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& DEVELOPMENT CORPORATION

High yields and early bearing for WALNUTS

A report for the Rural Industries Research and Development Corporation

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Foreword

The aims of the project were to raise the yield of quality walnuts from 1.5 to 4t ha^{-1}, decrease the time to reach commercial yields from 10 to 4 years and facilitate the expansion of the walnut industry. These objectives were met by a new management system for walnuts using soil modification, improved irrigation technology, close spacing of trees and the best cultivar available. An opportunity for commercial production of walnut timber was also tested.

The project provides evidence that walnuts can perform well on shallow, fragile soil if the soil is managed carefully. The results lead to the conclusion that a deep, non-stratified soil, however desirable, is not essential for successful walnut production. No additional gains in tree vigour and nut yield could be shown with the inclusion of subsoil modification through the application of gypsum and ripping. There was no evidence to suggest that loosening the subsoil by ripping affected the size and extent of the root system of walnut trees. Commercial orchards, direct-seeded with black walnut rootstock followed by patch budding to a desired cultivar, produced cheap trees (<$3.00 each), were easy to plant and avoided the slow growth often associated with trees transplanted from a nursery. Black walnut seedlings were patch budded >2m above the ground with the aim to produce both walnuts for several decades and a quality timber log from the black walnut trunk.

Walnut production from the Tatura project indicated that commercial yields of 0.3t ha^{-1} are attainable four years after planting grafted trees. In years five and six walnut yields were 1.3t ha^{-1} and 1.9t ha^{-1} respectively. These figures compare well with those from the USA, France and South Africa. The walnut yield of 1.9t ha^{-1} in year 6 exceeds the district mean of 1.5t ha^{-1} and is well placed to reach the projected yield of 4t ha^{-1} when the orchard reaches maturity at 10 to 12 years of age. The outcomes of this project provide the vital first step and identify a great opportunity for expansion of the Australian walnut industry. The information is highly relevant and timely for Australia to increase the supply of walnuts for domestic consumption and explore global market opportunities.

This project was funded from RIRDC Core Funds which are provided by the Federal Government and is an addition to RIRDC's diverse range of over 450 research publications. It forms part of our New Plant Products R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

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Peter Core
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Executive Summary

Many parts of Australia have a Mediterranean climate that is suitable for growing walnuts. Walnut production is attractive to investors because it is highly mechanised, orchards are low in maintenance, are productive for at least 40 years and once harvested the nuts will keep for up to two years. Irrigation areas, which currently support productive deciduous fruit industries, could also support a profitable walnut industry.

Presently, Australian walnuts have an average farm gate price of $5,000/tonne and the return has remained stable over the last 5 years, as the demand for nuts greatly exceeds the supply. In many parts of Australia, the Mediterranean climate and, compared with other competing countries, clean air and water as well as fewer pests and diseases are important factors which favour walnut production. The Australian Walnut industry needs to expand because it is small by comparison to other nut industries producing a total of 110 tonnes in 1999, whilst we imported 2,500 tonnes of walnuts worth close to $10 million. The two greatest barriers limiting the expansion of the industry are the low yields and long lead-time to produce the first commercial crop.

In 1998, a financial analysis was commissioned by RIRDC and conducted by agricultural consultants Hassall and Associates on eight relatively well-known industries. Tea tree oil, walnuts and olives, in order of profitability, were the top three with the best potential for returning strong results in terms of benefit/cost ratio, net present value and internal rate of return.

Traditional, walnut nursery trees may cost up to $32.00 each and, for hedgerow planting with tree densities of up to 550 trees ha^{-1} (6x3m spacing), require an investment of up to $17,600.00 ha^{-1}. Alternatively, direct-seeding of the rootstock followed by field budding is cheap (<$3.00) and quick plus it allows the seedling tree to develop an undisturbed taproot in situ and thus avoids the transplant shock associated with nursery stock.

The aims of the project were to raise the yield of quality walnuts from 1.5 to 4t ha^{-1}, decrease the time to reach commercial yields from 10 to 4 years and facilitate the expansion of the walnut industry. These objectives were met by a new management system for walnuts using soil modification, improved irrigation technology, close spacing of trees and the best cultivar available. An opportunity for commercial production of walnut timber was also tested.

Traditionally, walnut orchards are located on deep, well-drained, non-stratified soils. In contrast, many orchards of south-eastern Australia are on red-brown earths, that are renowned for properties, which limit root growth beyond the shallow (0.15m) A-horizon. This study challenged the perception that walnuts require topsoil of at least 1m depth. Instead, our objective was to produce good tree performance on a shallow, marginal soil where the physical, chemical and biological properties of the soil were modified to approach optimum levels.

The walnut trees in the project trial demonstrated that walnuts could perform well on the shallow, fragile soils if the soil is managed carefully. The results lead to the conclusion that a deep, non-stratified soil, however desirable, is not essential for successful walnut production. Whilst it is acknowledged that deep soils of uniform texture do provide useful buffering against poor irrigation practice or wet weather flooding, in the absence of these soils, a move to shallower soils need not have a negative impact on productivity. The trend towards high-density planting has led to a restriction in the size of the tree canopy, and a corresponding decrease in the size of the root system of each tree, is further evidence that a walnut orchard can be productive on a shallow soil.

On selected commercial orchards, rootstock seed was sown in the field and patch budded to produce trees for less than $3.00 each and demonstrated a considerable saving in one of the largest costs in establishing a walnut orchard. This showed farmers that it was faster and cheaper to sow seed than transplant trees and, if seedlings were patch budded >2m above the ground, the orchard could produce walnuts for several decades and then a timber log from the black walnut trunk. Seedling uniformity and vigour was high when two to three seeds were sown at each tree site, the best seedling was selected and the others in the group removed.

Walnut production from the Tatura project demonstrated that commercial yields of 0.3t ha^{-1} are attainable four years after planting grafted trees. In years five and six walnut yields were 1.3t ha^{-1} and 1.9t ha^{-1} respectively. The walnut yield of 1.9t ha^{-1} in year 6 exceeds the district mean of 1.5t ha^{-1} for mature trees. These figures compare well with yields from the USA, France and the projected figures from an economic analysis conducted in South Africa. The prospects are high for reaching the target yield of 4t ha^{-1} in 10 to12 years when the orchard reaches maturity. Higher yields are obtainable but good quality, large nuts (>30mm) are preferred even at the expense of a yield reduction.

The progress of the walnut project and the subsequent expansion of the walnut industry have attracted considerable public attention. Many people who firmly believed that walnuts take a long time to bear and only grew in the mountains are surprised to hear that walnuts will bear nuts in three years and will flourish on the flat plains in many parts of Australia. The outcomes that stem from the project are that approximately 200ha of new plantings have commenced in and around the Goulburn and Murray Valleys with approximately 1000ha planned for Victoria in the coming years. Other states are expanding their walnut industries and Tasmania alone has 400ha of new plantings with another 400ha planned for the future.

Value adding through on-farm processing has yet to be exploited in this country and when adopted will open up opportunities for a whole range of high-value, walnut products. Walnut kernel, oil, spread, liqueur, pickles, tea, herbal remedies, dyes and timber are but to name a few. A high-density hedgerow orchard, with the best management of soil and water, of the best known cultivars, harvested mechanically, and directed towards value-added products could put Australian walnuts at the forefront of quality walnut production.

These research outcomes provide the first step towards removing the real or perceived barriers to, and provide a sound basis for, extending the Australian walnut industry to a higher level. Australia, with its walnut industry in the expansion phase, has a great opportunity to capitalise on these latest findings, plus borrow the best knowledge and technology from other countries, and rise to be at the cutting edge of walnut production. This would put the Australian walnut industry on a very firm foundation for not only supplying the domestic needs but also allow us to compete on global markets. Future gains in walnut productivity could be attained through better canopy management, tree propagation and through advances in irrigation scheduling.

1. Setting the Scene

1.1 Introduction

Internationally, confidence in walnut production, is at an all time high with countries like the USA, China, France, Spain, Turkey Chile and Italy all expanding their industries. South Africa, through its Industrial Development Corporation of South Africa Ltd. has just completed an economic feasibility study for a proposed 600ha project to establish a new walnut industry. The South Africans have budgeted for a yield profile with the first commercial harvest in year 5 and a projected yield of 0.91 t ha^{-1} which will increase to 4.48 t ha^{-1} in year 10 when the walnut trees reach maturity. The figures from the South African study were arrived at independently but align closely with the aims of the project conducted at ISIA, Tatura. A financial analysis by agricultural consultants Hassall and Associates (1999), on eight promising new rural industries, ranked walnut production in Australia second to tea tree oil as the most profitable enterprise and ahead of olive oil production. Walnuts reported an internal rate of return of 12% and a benefit/cost ratio @ 7% of 1.54 based on a yield of 0.5t ha^{-1} (year 5) to 3.3t ha^{-1} (year 10).

Walnuts (*Julgans regia*) are thought to do best on fertile, deep, well-drained, non-stratified, loamy soils. In deep soils a few roots have been reported to grow to a depth of 3 metres but even in these soils, >75% of the roots are found in the upper 60-100cm of soil (Probesting 1943, Catlin and Schreader 1985). Subsoil ripping, prior to planting a walnut orchard, is common in California even though field trials conducted on a sandy loam with a depth of topsoil ranging from 0.6m to 1.2m deep showed no significant effect on tree vigour nor on walnut yield (Edstrom *et al.* 1998). The trial was slip plowed (ripped) to a depth of 1.8m, planted as a hedgerow at a tree density of 500 trees ha^{-1} and irrigated by two drip lines on each treeline. By USA standards, the shallow soil was considered as marginal for walnuts even though the trial continues to produce high yields of walnuts 12 years after planting. In the USA, as an alternative to deep ripping, a backhoe pit dug to a depth of 1.8m to 3m and refilled for each tree site, is used in preparing the soil for a new walnut orchard (Begg *et al.*, 1998). Based on the evidence from the USA, it is not clear why deep tillage continues to be widely used when there is little scientific fact to support it.

In many parts of Australia, the Mediterranean climate and, compared with other competing countries, clean air and water as well as fewer pests and diseases are important factors which favour walnut production (Chiba 1993). The Australian walnut industry needs to expand because it is small by comparison to other nut industries producing around 110 tonnes in 1999, whilst we imported 2,500 tonnes of walnuts worth close to $10 million. The two greatest barriers which limit the expansion of the industry are the low yields and the long lead-time to produce the first commercial crop. The pome and stone fruit industries faced the same problems some thirty years ago. The fragile, shallow soils that underlie many irrigation areas, were recognised as a major constraint to orchard performance. Further restrictions were tree densities that were too low, canopy management was poor and irrigation was inefficient based on border-check flood. An integrated research program at ISIA, produced the Tatura Trellis, a high-density orchard which owes much of its success to a soil management system developed at the same time. The result was a dramatic turn around in fruit growing which gave shorter lead-times and higher yields than ever before.

Up until the last 10 years, Australian walnut production was based on cultivars that were introduced in the early 1900's or seedling trees, planted on a wide (15m x 15m) spacing, that were not irrigated but relied on rainfall. Production fluctuated from year to year depending on the annual rainfall and the yield and quality of nuts was low in years of drought. Harvesting and processing was done entirely by hand and marketing was largely done on the farm by selling directly to the consumer. The early cultivars often took 8-10 years to produce a commercial crop then as the orchard reached maturity at 15 years of age the yields were often low (<1.5t ha^{-1}).

Australia has an estimated 80-120ha of walnut trees planted for timber with the largest planting of 33ha located at Alexandra, Victoria (Meggitt 1989). The eastern black walnut (*Juglans nigra*) is the most valuable timber species in temperate North America. Black walnut trees, grown in plantations, with a 5.5m clear log 45-60cm diameter of top quality veneer, have sold for around $1,500 each at 40-55 years of age. Large, isolated specimen trees have sold for more than $20,000. The species is ideal for agroforestry because of its characteristic late leafing in spring and early leaf fall in autumn. Nut producing species are often grafted to black walnut rootstock because of its hardiness and resistance to root rots. Some walnut growers have planted black walnut seed or seedlings directly into the orchard, allowed the tree to grow to three metres, and then grafted a nut species at a height of two metres above the ground. The intention was to produce walnuts for several decades and then a timber log from the black walnut trunk when the orchard is removed.

Many orchards in California are established in areas with well-structured, fertile topsoils that extend to a depth of 12m. In contrast, many orchards of south-eastern Australia are on red-brown earths, that are renowned for properties which limit root growth beyond the shallow (0.15m) A-horizon. Red-brown earths are a major soil type which underlie the Goulburn, Murray irrigation regions. Irrigation has provided stability to orchard production, and together with the Mediterranean climate and flat land, has provided a sound foundation for other horticultural industries to flourish. The region already supports around 10,000ha of pome and stone fruit orchards and produces around 250,000t of fruit annually.

The walnut project capitalised on over 60 years of research on fruit trees at ISA, Tatura by extending current knowledge to a management system for walnuts. The soil management system for orchards, developed at ISIA, Tatura, has evolved over many decades to its present state where some ten steps are involved to modify the soil and enhance its performance before the orchard is planted. Presently in the Goulburn Valley, most orchard land undergoes extensive modification before planting. The system of soil management continues to evolve as more information is discovered and will benefit the best soils as well as the poorest. The project attempted to show that walnut trees can be grown on shallow, poorly-structured surface soils provided the soils are first modified so that water, oxygen, mechanical resistance and nutrients are at levels that are not limiting to root growth. The aims of the project include a deep ripped treatment to test the effect of subsoil modification on local soils which have a shallow (0.15m) topsoil and a poor structure compared with soils in the USA.

Under the guidelines of the Tatura system of soil management, we increased the volume of soil by moving the topsoil from the traffic line onto the treeline to create a bank in the area where tree root activity is highest. We created a soft stable soil by changing the sodic sub-soil to calcic by the addition of gypsum ($Ca\ So_4.2H_2O$). Using a special winged tine, we tilled the subsoil to a depth of 80cm to create a well-aggregated subsoil, make more water available for tree roots and create better aeration. We kept biological activity high and stabilised the soil on the treelines to keep it soft and porous by growing ryegrass and by using straw mulch. We used tensiometers in the soil to determine the best time to irrigate to keep the soil soft for continued root growth and to supply the water required for tree growth.

In consultation with researchers at the University of California, we selected a walnut cultivar (*Juglans regia* cv. Chandler) and a black walnut rootstock (*Juglans hindsii*) that showed the most promising performance and assessed them as to their suitability under Australian conditions. We planted trees closer (6m x 3m) than traditional spacing (15m x 15m) and trained the trees to induce earlier bearing and produce high yields.

2. Literature Review

2.1 A description of the soil

The report covers the first six years of soil and tree measurements in a bid to determine whether walnut trees will perform similar to other tree crops grown successfully on red-brown earths. Many irrigated orchard crops are grown on red-brown earths that cover a large area of northern Victoria and southern New South Wales. The soil is widely used under many irrigated cereals, pasture and horticultural crops which suggests that these soils are suitable for walnut production if managed properly. The subsoil of red-brown earths has a low permeability (<27mm hr^{-1}), a high clay content (>50%) and an exchangeable sodium percentage >6% (Taylor and Olsson 1987). The common morphological feature of red-brown earths is an abrupt texture change between the A and B-horizons. The subsoil in the B-horizon has physical and chemical properties that can restrict root growth in an orchard and may reduce tree growth and yield. There have been earlier reports of these soils becoming waterlogged during winter that resulted in restricted growth of trees and low yields of peaches (Skene and Poutsma. 1962, Taylor and Olsson 1987, Tisdall *et al.* 1984). The dispersive nature and massive structure of the B-horizon has been shown to limit root growth in many horticultural crops. Applications of gypsum and ripping has been shown to increase the permeability of the soil and stimulate a significant increase in root length at a depth of 15-60cm (Taylor and Olsson 1987). In peach and pear trees in a red-brown earth, on an unmodified soil, root length concentrations were highest in surface soils but were restricted by the massive B-horizon (Cockroft and Wallbrink 1966).

2.2 Soil-water and air

Roots require adequate aeration to carry out their function just as leaves need adequate amounts of oxygen and carbon dioxide for photosynthesis and respiration to occur. The distribution of voids, pores and channels between soil particles is therefore important for maintaining adequate oxygen levels (Hamblin 1985). Poor growth of roots can result from a shortage of oxygen when concentration falls below 10%, while carbon dioxide levels do not seem to effect root growth even when in concentrations of up to 40%. In a soil management trial conducted on a peach orchard at ISIA Tatura, 30t ha^{-1} of straw was incorporated into a 37cm deep soil layer. Nine years after the incorporation of the straw into the soil, oxygen concentrations exceeded 10% and root lengths to 60cm depth were 60% greater than that of peach trees in adjacent control blocks (Tisdall *et al.* 1984). Total content of air in the soil is known as the air-filled porosity and for active root systems should not be less than 10% (Collis-George 1990).

The rate of uptake of water from the soil depends largely on the root length per unit volume of soil or the root-length density (Chootummatat *et al.* 1989, Bohm 1979, Fernandez *et al.* 1991), the relative permeability of the soil (Hillel 1980) and rooting depth (Mason 1984). Chootummatat *et al* (1989) identified that high root densities in the surface soil deplete the available water rapidly while deeper roots can extract water from a much larger volume of subsoil.

2.3 Soil strength

Bulk Density is a measure of the ratio of mass of dried soil to the total undisturbed soil volume and takes into account the total amount of solids and pores put together. Bulk density is affected by the packing or compaction of soil particles as well as by the amount of swelling and shrinkage of soils

(Hillel 1980). Root penetration and branching has shown to be increased when the bulk density is decreased and the soil-water content increased (Unger *et al.* 1981).

The rate of root penetration is not only effected by the distribution of pores and clay particles in the soil profile but also by the strength of the soil. In peanuts, root elongation has been reduced by 50% at a penetrometer resistance of 2Mpa, while cotton root elongation has been reduced by 50% in soils with a penetrometer resistance of only 0.7MPa (Bowen 1981). Abrupt changes in texture such as a change from sandy loam topsoil to clay subsoil create a hard soil interface that is a feature of red-brown earths. Hard layers, sometimes called plough pans because they occur at the depth of tilled layers, can be induced through poor tillage practices or hardening can occur through slumping if the soil is saturated for long periods of time.

2.4 Tree root ecology and physiology

The function of the root system in mature walnut trees is to absorb water and nutrients, provide anchorage and synthesise and store carbohydrates. The framework of structural roots (>2mm diam.), tends to extend laterally and vertically. From the structural roots, finer roots (<2mm) branch laterally, dividing into finer roots. Fine roots have a greater surface area per volume and are able to absorb more water and nutrients more effectively, than structural roots. Fine roots (<2mm) have been shown to make about 75% of the total root length in 4 year old apple trees, with woody roots (>1mm) making up less than 2% of the total root length (Huges and Gandar 1993).

2.5 Root mass

Root development and function is important in the plant for the absorption of essential nutrients and water. Red-brown earths that were modified to increase the soil volume available for root exploration has been widely published (Taylor and Olsson 1987, Cockroft and Wallbrink 1966, Mason *et al* 1984). Gypsum applied to the soil has shown to increase water intake (Loveday 1980) and deep ripping of the soil initiates structural change of the massive B-horizon leading to improved root growth (Tisdall *et al.* 1984). Bohm (1979) used root mass to measure photosynthate storage in the plant. Recent experiments showed that combined root mass of structural roots >2mm and fine roots <2mm in diameter represented more than 90% of the structural roots (Hughes and Gandar 1993). The root mass has been determined for orchard trees (Cockroft and Wallbrink 1966) but the accuracy of the final mass depends on removing all adhering water after washing.

2.6 Root length

Most deciduous trees (apples, pears, olives etc.), have a low mean RLD between 0.2-0.6cm cm^{-3} (Hughes and Gandar 1991). Root lengths per unit volume of soil or Root Length Density (RLD) for this study were determined by volume in the method used by Hughes and Gandar (1993) who took the total length of roots at each depth and divided it by the volume of soil. Soil adhering to roots should not exceed 4% and does not introduce a large error if root washing is done thoroughly (Bohm 1979).

Root length is often used for calculating the water uptake of roots (Bohm 1979, Fernandez *et al.* 1991, Hughes and Gandar 1993, Taylor and Olsson 1987 and Petrie and Hall 1992). Bohm (1979) shows that root length is important for studying nutrient uptake by plant roots. Nye and Tinker (1977) demonstrated that root weight and length increased at high levels of soil water content that in turn increased phosphorous uptake. On a sandy loam in a drip irrigation experiment, olive tree roots were concentrated near the drippers to 60cm depth where the most abundant roots were <0.5mm in diameter. In clay soils, root length densities for olive trees were lower near the drippers as a result of the soil remaining saturated for a longer period of time (Fenandez *et al.* 1991). The soil temperature near the surface can be too high (>35^oC) and limit root growth because for many plant species the rate of elongation of roots is at an optimum at temperatures between 20^oC and 30^oC (Voorhees 1981).

There is no single correct technique, for measuring root lengths. One of the most popular is the Newman line intersect method which has been used to measure olive roots (Fernandez *et al.* 1991), and cowpea and millet roots (Petrie and Hall 1992). This involves counting the number of intersections between roots, spread on a flat surface inscribed with grid lines 1.0cm apart. The method is an accurate visual technique, but time consuming. Tisdall *et al.* (1984) calculated root length of peaches by multiplying root mass (in milligrams) by a factor of 30, while Chootummatat *et al.* (1989) used a root-length, scanning machine.

2.7 Soil ameliorants

When gypsum ($CaSo_{4.}$ $2H_2O$) is applied to the soil, dispersed clay particles flocculate (stick together) creating aggregates (crumbs) of soil that in turn increase the air-filled porosity and water holding capacity of the soil by providing larger spaces between aggregates. Gypsum does not form new aggregates in the soil it merely clusters random clay particles together. After gypsum is applied to the soil it has shown to leach from the soil at the rate of 1 t ha^{-1} per 125mm-360mm of rainfall (Tisdall and Huett 1987). Therefore small quantities of gypsum need to be added annually or a large reserve is needed. Many dispersive soils (high in Na^+) have a massive structure due to limited air spaces between clay particles. The application of gypsum is only a short-term solution but for a longer term solution organic matter should be included. Organic matter can create and maintain larger aggregates in the soil due to organic bonds that bind small soil particles together (Panagiotopoulos and Gardner 1990).

2.8 Subsoiling techniques

Soils that are hard and compacted are sometimes tilled or deep-ripped to improve root development (Begg *et al.*, 1998). Soils that have a high clay content and low permeability to water through the soil profile may also be improved by deep tillage to produce deep cracks and fissures to create an air-filled porosity in the soil near 21%. Adding gypsum, before ripping a soil, has shown to flocculate clay particles, reduce the repacking of aggregates, improve the drainage of the soil and increase the vigour of peach trees (Rengasamy 1983, 1986, Tisdall and Huet 1987). The attachment of wings to the bottom of tines has shown to give better control over the tilth produced, to improve the aggregate size distribution and to loosen the soil (Spoor 1975, Spoor and Godwin 1978, Bowen 1981).

2.9 Planting densities

In the first few years of a new walnut orchard the nut production is directly related to the number of trees planted to the hectare (Sibbett *et al.*1998). The short-term objective is to have the maximum number of trees possible to get the highest return in the shortest possible time. A mature orchard reaches its maximum production when the total land surface is completely covered with walnut tree canopies with sufficient spaces between them to allow light to penetrate to the lower braches to maintain productive fruiting wood. Nyke and Tinker (1977) revealed that high density planting of apples resulted in greater root competition and higher root densities in the topsoil, which lead to higher initial yields. Huges and Gandar (1991) demonstrated that roots of apple trees in 5x4 metre spacing completely explored the root soil volume to <1m depth at low mean root densities of 0.2-0.3cm cm^{-3}.

3. Objectives

3.1 What is the yield potential and how long before the first crop?

The primary objective of this project was to demonstrate that walnuts could be managed to decrease the lead-time for commercial yields from ten to four years after planting and to raise production in a mature orchard from 1.5 to 4t ha^{-1}.

3.2 Can shallow soils be modified to suit walnut production?

The secondary objective was to investigate whether subsoil ripping did increase the extent and depth of rooting and hence the productivity of the walnut trees. This study attempted to challenge the perception that walnuts require topsoil of at least 1m depth. Our objective was to produce good tree performance on a shallow, marginal soil where the physical, chemical and biological properties of the soil were modified to approach optimum levels. Two systems of subsoil management were compared where in one treatment the soil had gypsum applied and then deep ripped with a tined implement and the second treatment where no gypsum or ripping was used.

4. Methodology

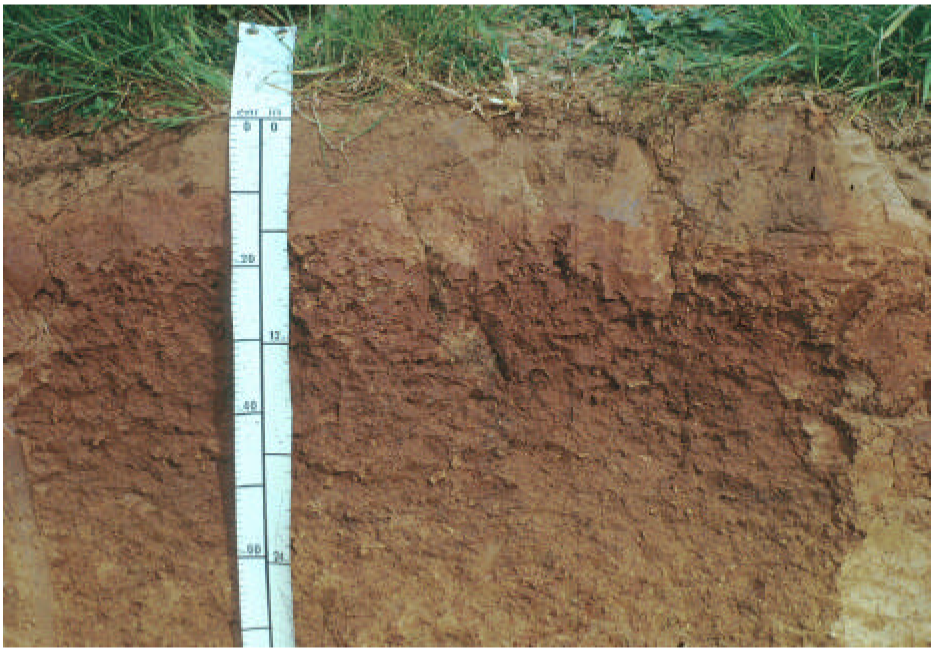
4.1 Specifications for soil preparation

The strategy, used standards from the scientific literature for soil properties, that has been successful for pome and stone fruit and field crops, and is now being extended to walnut trees (Spoor 1975, Spoor and Godwin 1978, Tisdall *et al.* 1978 Bowen 1981, Tisdall and Huet 1987, Tisdall and Adem 1989, Adem 1995)(Table 1). Water and nutrients were supplied on demand at levels that were non-limiting to the growth of tree roots.

Table 1. Specifications for soil properties which are non-limiting to orchard tree roots.

Purpose	Property	Specification
Controlled traffic	Wheel compaction	<25 %
Water management	Matric suction	10 to 40kPa
	Aggregate size	>0.5 mm
Root growth	Air-filled porosity	10 %
	Aggregate size	1-20 mm
	Penetrometer resistance	<1.5 MPa
	Bulk density	1.2 -1.5 g cm^{-3}
Soil stability	Organic carbon	>2 %
	Water stable aggregation	>75 %
	Clay mechanical dispersion	<1.0 %

At ISIA, Tatura, the walnut orchard was established on a duplex, red-brown earth classified as a Shepparton fine sandy loam (Skene and Poutsama 1962). The pH in a virgin soil is neutral in the topsoil layers and slightly to moderately alkaline in the subsoil layers but have become acidic under crops particularly when nitrogen fertilisers were applied. The topsoil was hilled into a bank 0.5m high along the treeline. Gypsum ($CaSO_{4.}\ 2H_2O$) was spread in a strip 2m wide on the treeline at the rate of 10t ha^{-1} (calculated over a 2m strip) to reduce the clay mechanical dispersion to <1.0%. The whole orchard was sown to ryegrass (*Lolium perenne*) to increase the number of biopores and help keep the air-filled porosity of the surface soil close to 10%. A ripper, with winged-tines (0.6m wide) operated at 0.8m depth, tilled the subsoil at the Lower Plastic Limit to create >80% of aggregates 1 to 20mm in diameter. Ryegrass roots were used to maintain the water-stable aggregation of the soil >75%. Straw-mulch 2m wide and 0.1m thick supplied organic matter, raised organic carbon levels to >2% and reduced water loss. Irrigation scheduling was determined by tensiometers whilst microjet sprinklers were used to keep the soil wetted to between 10 and 40kPa matric suction. Soil hardness, as measured by penetrometer resistance (30^0cone, 6mm in diameter), was <1.5Mpa at a matric suction of <90kPa. Wheel compaction was kept <25% of the land surface by keeping tractor traffic away from the treeline at all times.



A profile of a red-brown earth showing the shallow topsoil and clay subsoil

A road grader hills the soil to create a treeline bank

Gypsum is spread in a two metre wide strip along the treelines

Subsoil on the treelines is modified using a ripper fitted with winged tines

4.2 Setting up the orchard trial

The following series of steps were used in setting up the walnut trial

1. In autumn, the orchard treelines were pegged out accurately and the irrigation mains installed, running across the treelines.
2. Lime at 2t ha^{-1} (determined by a soil test to achieve a target pH of 6.5) was spread over the whole area and incorporated with a rotary-hoe.
3. A Road Grader was used to move the topsoil from the centre of the traffic line to the treeline to create a bank approximately 0.5m high.
4. Irrigation laterals and microjet sprinklers (output 5-10mm hr^{-1}) were installed and the plot irrigated for 3 hours.
5. When the soil had drained to around Field Capacity (10kPa matric suction), the entire orchard was cultivated with a power harrow and the soil surface smoothed.
6. Gypsum at 10t ha^{-1} (calculated over a 2m strip) was applied in a 2m wide strip along the treeline.
7. The orchard was sown to perennial ryegrass and irrigated for 2 hours.
8. In late winter, the ryegrass sward was mown close to the ground.
9. A winged-tine ripper was used to till the subsoil from a depth of 20cm to 80cm below the original surface of the soil, in 3 passes, in increments of 20cm.
10. The 2m wide strip was cultivated (0.2m depth) with a power harrow and the soil surface smoothed.
11. The trees were planted and the soil around the tree was not compacted but watered lightly to prevent slumping of the soil.
12. A mulch of straw (0.1m thick) was applied in a 2 m wide strip on the treeline.
13. In spring/summer, herbicides were used to control weeds in a 2m wide strip on the treeline.
14. In spring/summer, the orchard was slashed and the clippings delivered onto the treeline to supplement the straw mulch.

Soil under the straw mulch showing earthworm activity

4.3 Root Sampling

Two soil cores were taken for root samples at 1m radial distance from the butt of the second tree and of the fourth tree of each experimental unit along the tree rows. The root distribution was determined at six depths (0-15cm, 15-30cm, 30-45cm, 45-60cm, 60-75cm and 75-90cm) using a 32mm diameter sampler to take an intact core of soil. Samples were placed in containers containing a solution of the dispersive agent Calgon (Sodium hexametaphosphate) for 12 hours. Roots and Calgon solution were placed in a root washing machine (described by Smucker *et al*., 1982) to remove all soil. Total root lengths for fine (<2mm diam.) roots were measured using a root-length, automatic scanner (Commonwealth Aircraft Corporation Ltd, Melbourne), average RLD in samples were obtained by dividing total root lengths by core volumes. All roots were weighed including the roots >2 mm diameter. Roots were oven-dried at 60^{0}C for 24 hours and weighed. Root length densities were calculated by dividing dry weights by core volumes.

4.4 Soil-water content and bulk density

Two soil cores (73mm diameter by 63mm height) were taken for both soil-water content and bulk density making up a total of 40 x 3 depths = 120 samples were taken. Gravimetric water content was calculated from the water loss after the samples were oven dried at 105^{0}C. Bulk density (g cm^{-3}) of the sample was calculated by taking the dry weight of the soil sample and dividing it by the volume of the soil.

4.5 Tree management and measurement

Grafted, two-year old walnut trees (*Juglans regia* cv. Chandler) on black walnut (*Juglans hindsii*) rootstock were planted at the same depth as in the nursery. After planting, the tops of the trees were cut to two thirds (approximately 1m above ground level) of their original height and pruned to a single rod. Thereafter the trees received minimal pruning in line with present commercial practice in walnut orchards in Australia. Three guard trees were planted between each experimental unit of five Chandler trees. Six pollinator trees (cv. Franquette) were included in the guard trees in the first row of the plot. On advice from a DNRE Biometrician, no guard rows were deemed necessary between the plot rows because the treatments applied were confined to a 2m wide strip on the treeline leaving a 2m wide buffer (guard) zone between the treatments (rows 6m apart). Beginning in spring at bud-burst, six fortnightly applications of Bordeaux mixture (1kg copper sulphate, 1kg slaked lime per 100 litres of water) were applied to control the walnut blight (*Xanthomonas campestris* pv. *Juglandis)*. Tree butt circumference was measured using a tape measure, 30cm above the ground, on all trees. To determine if there were differences in tree size between each half of the walnut orchard, butt circumference measurements of rows 1 and 2 were separated from rows 3 and 4 statistically. At harvest, the nuts were by picked up by hand in three passes and then air-dried in a 1.2m x 1.2m x 0.75m fruit bin mounted over an electric fan. The yield was based on nuts dried to a moisture content of approximately 8%.


Chandler walnuts just prior to harvest


Chandler walnuts on modified soil in the Tatura trial

4.6 Experimental design and analysis

The plot consisted of 155 walnut trees that were divided into 20 experimental units, each unit containing 5 trees with 3 guard trees between each treatment. A row-column design was chosen because the entire experimental area has a uniform soil type and water applied to the walnuts over 4 years, has been uniform. Each treatment occurred at least once in each row and once only in each column. The design allowed the option to model two sight trends if necessary as a randomised block design. There were ten replicated experimental units for each treatment of gypsum and ripping and ten replicated units with no gypsum and ripping. In each experimental unit two samples for each measurement were taken, which gave 40 samples in total. Data analysis was set up in Excel 5.0 spreadsheet according to the computer program Genstat 5 Release 3.2 (1995) and the significance calculated using the Random Estimated Likelihood (REML) method. Response variables were "grav" (Gravimetric water), "pB" (Bulk density), "root" (Root length), "rwts" (root weights) and "buttsall" (butt circumference), transposed where appropriate to homogenise variances. The program selected random models to detect any significant differences between rows and/or/by columns. There are four random model combinations: 1)columns, 2) rows, 3) rows + columns +Row x Col or 4) Row x Col.

5. Results

5.1 Movement of gypsum

After a period of four months from the time gypsum was applied, there was a significant level of gypsum in the subsoil to a depth of 95cm compared with the control (Table2).

Table 2: Calcium concentration (me kg^{-1},1:5) in the soil profile four months after a surface application of gypsum (Yes G) compared with no gypsum (No G).

Depth (cm)	Yes G (me kg^{-1},1:5)	No G (me kg^{-1},1:5)	s.e.d.*	P
0 –20	10.9	2.1	2.7	*
20 – 35	2.9	2.4	0.8	NS
35 – 50	2.0	1.6	0.3	*
50 – 65	1.5	1.3	0.3	NS
65 – 80	1.5	0.9	0.2	*
80 – 95	1.1	0.8	0.2	*

***Significant at 0.05 probability level, NS not significant.**

Before the soil was deep ripped, samples taken to trace the movement of gypsum showed that to a depth of 80cm the concentration of calcium (from the gypsum) in the subsoil was 1.5me kg^{-1} (1:5 extract) and at the bottom of the layer to be deep-ripped. This supports the view that gypsum is relatively soluble and that it does not need to be incorporated into the soil.

5.2 Soil-water content

The water content of the soil was measured to establish whether there were any areas in the orchard that were subject to localised waterlogging (saturated soil) which may have affected tree growth. The soil-water content was significantly different ($P<0.01$) at 15-20cm depth in the soil treated with gypsum and ripped (Yes GR) compared with the non-treated soil (No GR) but there was no difference at the 45-50cm and 60-70cm depths in the soil (Table 3).

Table 3: Mean soil-water content at 3 soil depths.

Depth (cm)	No GR	Yes GR	LSD *	LSD **	P
15-20	0.18	0.22	0.03	0.04	*, **
45-50	0.19	0.20	0.02	-	NS
60-70	0.18	0.18	0.02	-	NS

*, ** Significant at 0.05 and 0.01 probability levels , respectively; NS not significant. Least Significant difference (LSD). No GR (control), Yes GR (treatment).

Across all soil samples at 15-20cm depth, there was no clear relationship of the butt circumference of the tree with the water content of the soil and sample position eg. sample position 1,1 (row 1, column 1) at the time of sampling (Fig. 2).

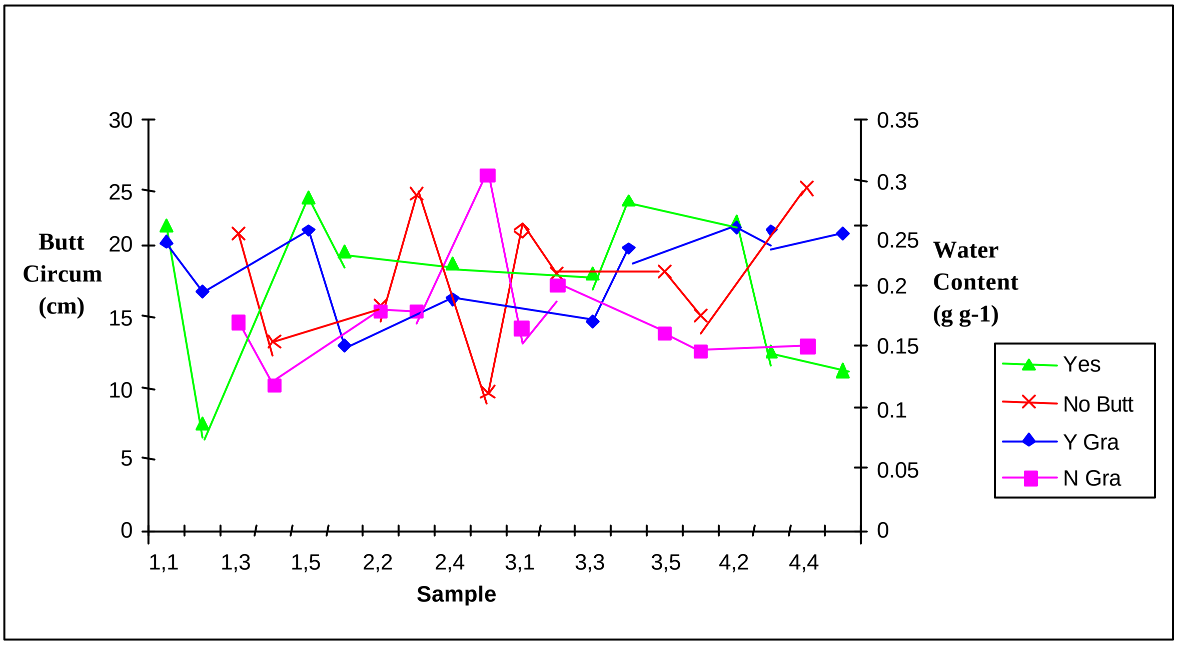


Figure 1. The relationship of mean butt circumference, mean gravimetric water content at 15-20cm depth and sample position of experimental design. Thus sample position 1,1 (row 1, column 1).

5.3 Soil bulk density

There were no significant differences in bulk densities between the gypsum and ripping treatment (Yes GR) and the control (No GR) at three depths in the soil (Table 4).

Table 4: The effect of gypsum (Yes GR) on the mean bulk density (g cm^{-3})at 3 depths in the soil.

Depth (cm)	Yes GR	No GR	LSD*	P
15-30	1.50	1.57	0.08	NS
30-45	1.67	1.72	0.06	NS
45-60	1.71	1.75	0.07	NS

*, Significant at 0.05 probability levels; NS not significant. Least Significant difference (LSD). No GR (control), Yes GR (treatment).

When the bulk density data were plotted, the soil treated with gypsum and ripping (Yes GR) had a slightly lower bulk densities than No GR but no significant difference could be shown (Figure 2).

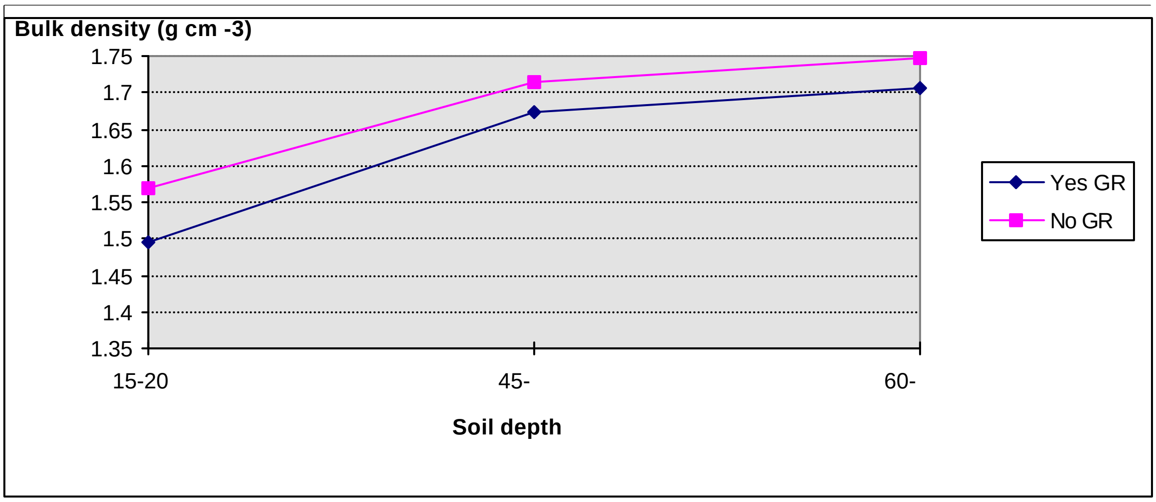


Figure 2. The effect of gypsum (Yes GR) on the mean bulk density (g cm^{-3}) of soil.

Contrary to expectations, the bulk density for Yes GR was not significantly lower, especially at depths between 30-60cm where the treatment was predicted to have the greatest effect. In a more intensive study at a depth of 45-50cm, the clay showed no differences in bulk density between Yes GR and No GR treatments (Figure 3).

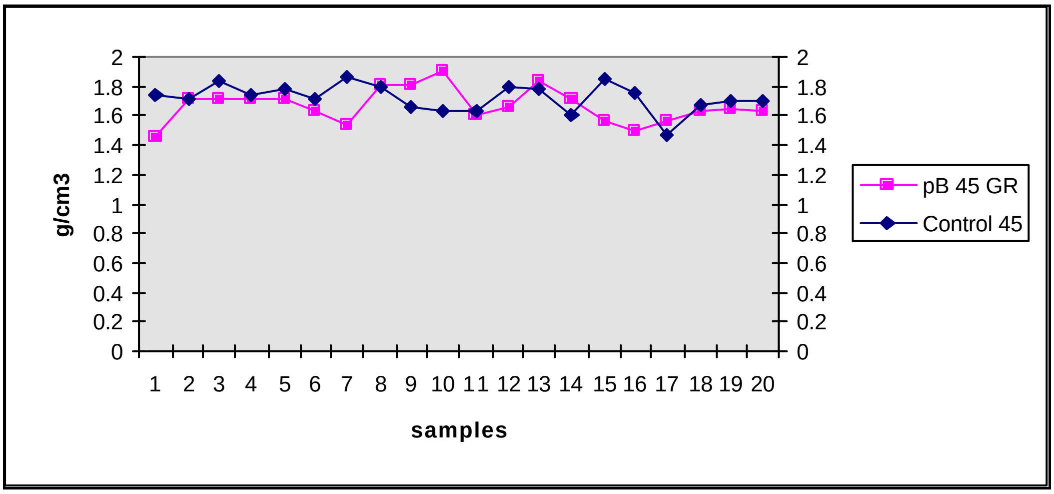


Figure 3. A line scatter graph of all bulk density (g cm^{-3}) data for both Yes GR (pB 45 GR) and No GR (control 45) at depth 45-50cm

5.4 Root length

Root lengths for Yes GR at 0-15cm depth recorded a lower mean root length than No GR (Table 5). The following 5 depths (15-30, 30-45, 45-60, 60-75, 75-90cm) for Yes GR had greater root lengths than No GR. Below this depth (60-75cm) the clay layer in the subsoil appeared to restrict root length in both treatments.

Table 5: The effect of gypsum and Ripping (Yes GR) on mean root length (m).

Depth (cm)	Yes GR (m)	No GR (m)	LSD *	P
0-15	16.32	17.94	4.47	NS
15-30	13.06	11.54	3.27	NS
30-45	7.49	5.86	2.46	NS
45-60	5.25	5.2	1.69	NS
60-75	4.44	4.00	2.21	NS
75-90	1.69	1.46	0.91	NS

*, ** Significant at 0.05 and 0.01 probability levels , respectively; NS not significant. Least Significant difference (LSD). No GR (control), Yes GR (treatment).

Root length in both Yes GR and No GR decreased with a corresponding increase in depth in the soil (Fig. 4). Mean root-length density (RLD) was 6.6cm cm^{-3} and 6.3cm cm^{-3} for Yes GR and No GR respectively. Predicted means calculated for six root volumes, down the soil profile to 90cm deep indicate that at 15-45cm, root length was longest in gypsum and ripping treatments compared with the control but overall there was no significant difference between treatments in all of the root volumes.

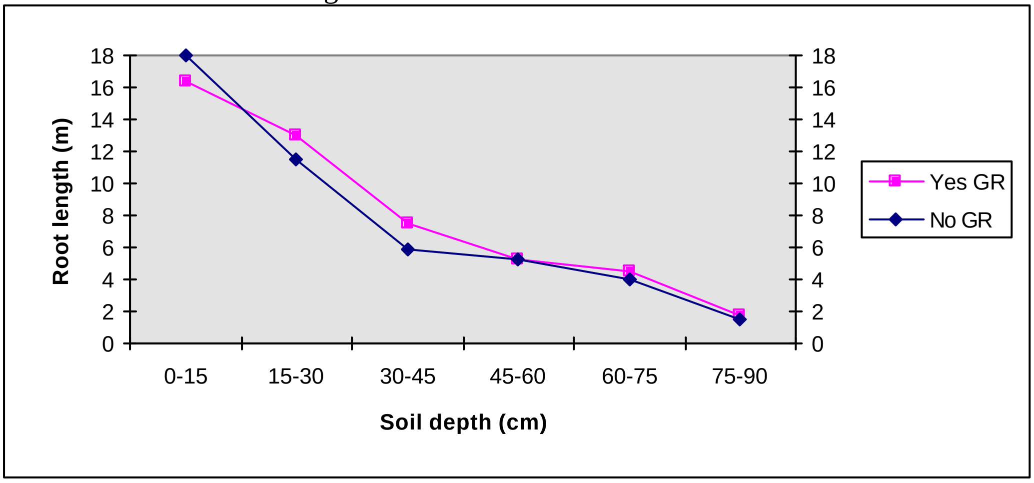


Figure 4. The effect of gypsum and ripping (Yes GR) on mean root length (m).

5.5 Root distribution

The total length of structural roots >2mm was measured, although most samples contained very few of these roots. Of the structural roots sampled, the total length for Yes GR and No GR were similar with 5.65cm and 5.8cm respectively. The distribution of these roots across the entire experiment was uneven where in No GR the roots are mainly limited to rows 1 and 2 (North) rather than rows 3 and 4 (South) as apposed to Yes GR which is more evenly spread over all rows (Fig. 5&6). In both Yes GR and No GR, the greatest lengths of structural root appeared to be restricted to Root 30 (15-30 cm), Root 45 (30-45cm) and Root 60 (45-60cm).

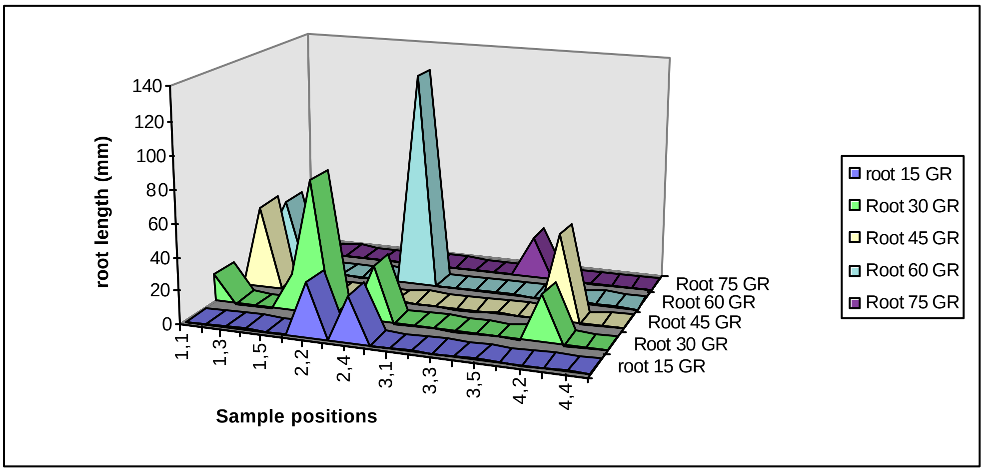


Figure 5. Distribution of structural roots (>2mm) for GR treatments for all rows and columns at 5 rooting depths.

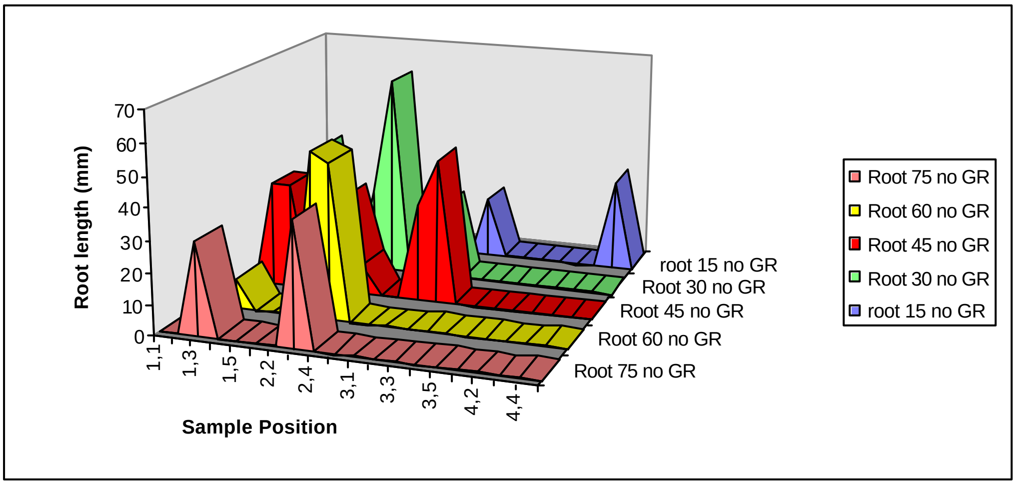


Figure 6. Distribution of structural roots (>2mm) for no GR treatments for all rows and columns at 5 rooting depths.

5.6 Root mass

Root mass at 6 sample depths were not significantly different (P>0.05) between the Yes GR and No GR treatments. The greatest differences in root mass were found at depths of 15-30cm and 60-75cm, than at any other depth (Table 6).

Table 6: The effect of gypsum and ripping (Yes GR) on mean root mass.

Depth (cm)	Yes GR	No GR	LSD *	P *
0-15	0.34	0.32	0.08	NS
15-30	0.43	0.36	0.29	NS
30-45	0.10	0.09	0.05	NS
45-60	0.08	0.07	0.04	NS
60-75	0.06	0.11	0.07	NS
75-90	0.03	0.03	0.03	NS

Significance at 0.05 (*) probability levels (P) ; NS not significant. Least Significant difference (LSD). No GR (control), Yes GR (treatment).

Mean root mass (fig. 7) shows that gypsum and ripped plots Yes GR had a slightly higher or the same root mass in all but the 60-75cm soil depth. The 60-75cm soil depth for No GR has a higher root mass because perhaps the more (heavier) structural roots >2 mm that were observed in this sample may have created a bias in the result.

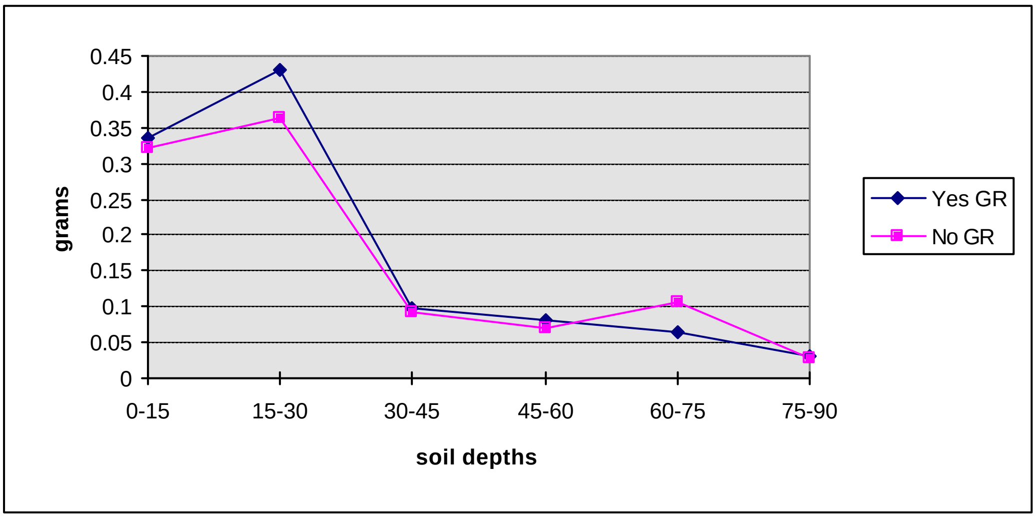


Figure 7. The effect of gypsum and ripping (Yes GR) on mean root mass.

5.7 Tree growth

The butt circumference of all trees was measured to determine if the growth of the tree was influenced by the gypsum and ripping (Yes GR) treatment. The mean butt circumference of the walnut trees was calculated in two different ways. The first was by taking the mean of all butts in each in rows 1 and 2 compared with rows 3 and 4. The second way was using all 100 absolute butt circumference measurements (buttsall) and analysing the data to determine whether there was a significance difference in tree growth. Overall there was no significant difference between butt circumference measurements for either procedure (Table 7).

Table 7: The effect of gypsum and ripping (Yes GR) on mean butt circumference.

Tree Butt Circumference (cm)	Yes GR	No GR	LSD*	P*
mean d.f 18	18.2	18.3	5.2	NS
Buttsall rows 1,2 d.f 48	19.7	16.0	4.4	NS
Buttall rows 3,4 d.f 48	17.7	19.6	6.4	NS

Significance level P= 0.05 (*); NS not significant. Least Significant difference (LSD). Degrees of Freedom (d.f)

There were no significant differences (P>0.05) in butt circumferences of all the walnut trees when statistically analysed together as buttsall. Butt circumference measurements were slightly higher in rows 1 and 2 in the soil treated with gypsum and ripping but the opposite occurred in rows 3 and 4 where butt circumference measurements were highest in the control (No GR). Mean butt circumference plotted over the whole growing season showed similar trends for both the modified soil area and the control (Fig.8). Illustrated by the slope of each curve, the results indicate that growth rates in both groups of trees were similar.

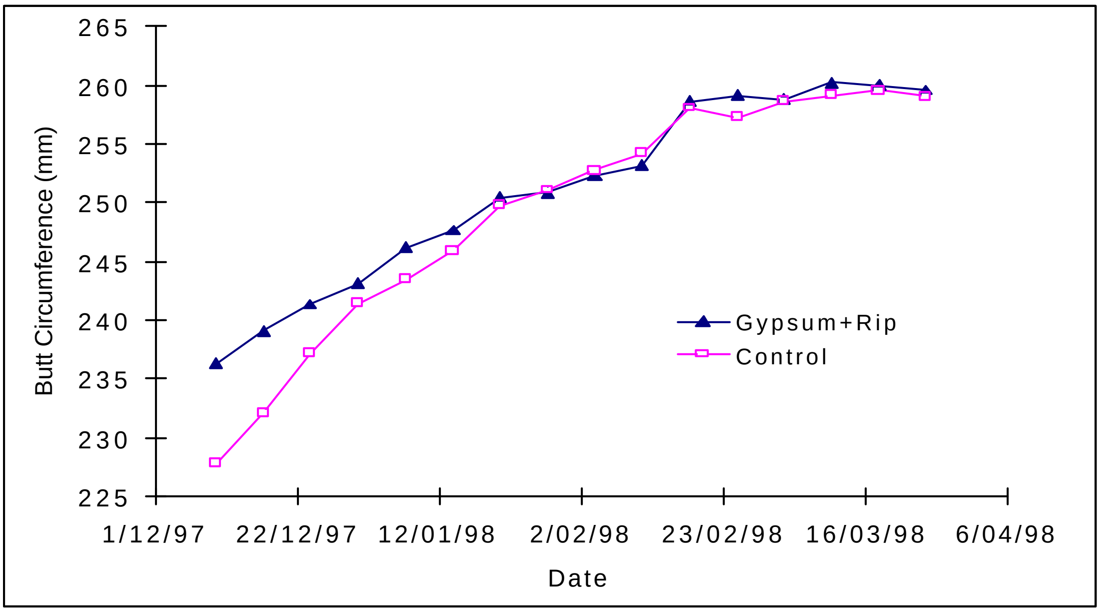


Figure 8. The effect of gypsum and ripping (Gypsum+Rip) on mean butt circumference of walnut trees.

5.8 Available water

The availability (to the tree root) of water or matric suction was monitored by tensiometers at 4 depths, (15cm, 30cm, 45cm and 60cm) in the soil throughout the growing season and used as a guide to determine irrigation scheduling (Fig.9). The soil was kept wetted to a matric suction of between 10 and 40kPa as prescribed by the specifications on soil management in the methodology section. Tensiometers were used in each experimental unit to measure matric potential, three times per week just before an irrigation event. The tensiometers proved to be sensitive to changes in soil water illustrated by the changes in matric suction in one or two days after irrigation was applied. The wet end of the scale was at 10kPa matric suction or Field Capacity when the soil has drained under the effects of gravity and contains optimum levels of stored water and oxygen. The dry end of the scale was chosen as 40kPa matric suction where the tree reacted to water stress, and where if irrigation or rainfall does not occur, a reduction in tree growth is expected.

The results show that overall the gypsum and ripping treatments (Yes GR) were generally wetter than the control at all four depths monitored. At 15cm depth the higher fluctuations in matric suction reflect the amount of root activity in this layer as the soil was wet up by sprinklers and dried by the tree roots. When this was compared with the matric suction at 60cm depth the amplitude of the fluctuations was less, particularly in the gypsum and ripping treatment, indicating less root activity.

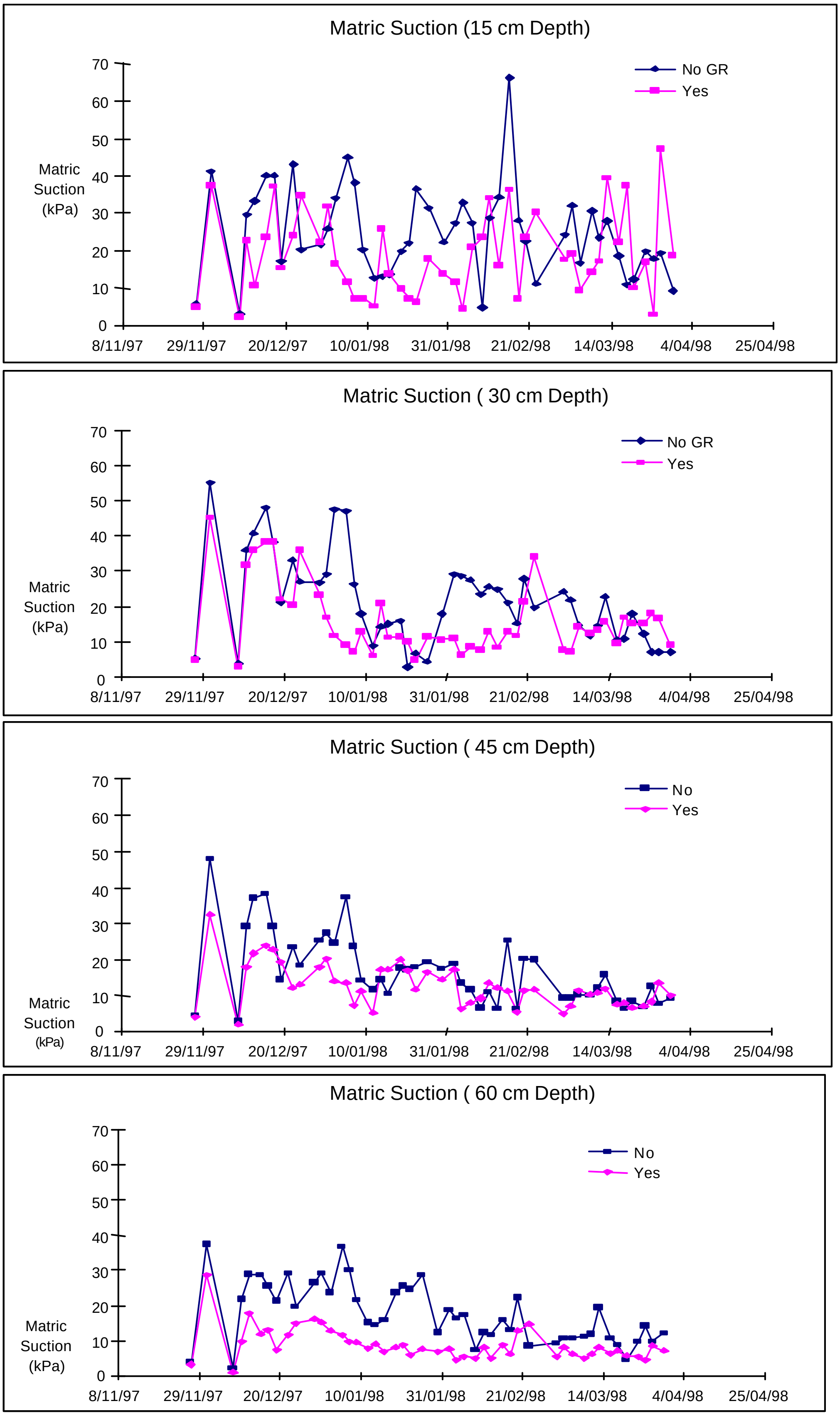


Figure 9. Matric suction (available water) monitored at 4 depths, (15cm, 30cm, 45cm and 60cm) in the soil throughout the growing season.

5.9 Walnut yield

There were no significant differences in walnut yield between the modified subsoil and the control for any of the three successive walnut harvests (Table 8). The trees were planted in 1993 and commenced commercial yields in 1997 (year 4) and produced up to 0.3t ha^{-1} in that year, 1.3t ha^{-1} in year 5 and 1.9t ha^{-1} in year 6. The results are promising when compared with the results from two walnut trials in California where the first commercial harvest on a marginal soil and a deep soil was not until year 5 and year 7, where the trees yielded 0.5t ha^{-1} and 1.3t ha^{-1} respectively (Table9). The Tatura trial results relate well to the projected yield profile for the walnut industry in South Africa who predict the first commercial harvest in year 5 with a projected yield of 0.91t ha^{-1} and a yield of 4.48t ha^{-1} in year 10 when the trees reach maturity.

Table 8. The effect of subsoil modification by gypsum and ripping on Chandler walnut yield (Trees planted 1993)

Treatment	Nut Yield 1997 (t ha^{-1}) year 4	Nut Yield 1998 (t ha^{-1}) year 5	Nut Yield 1999 (t ha^{-1}) year 6
Yes Gypsum & Ripping	0.2	1.2	1.7
No Gypsum & Ripping	0.3	1.3	1.9
LSD	0.1	0.1	0.3
P*	NS	NS	NS

*Significance at 0.05 probability levels, NS not significant

Table 9. Walnut yield (cv. Chandler) on two Californian soils. (Trees planted in 1986)

Treatment	Nut yield 1988 (t ha^{-1}) year 4	Nut yield 1989 (t ha^{-1}) year 5	Nut yield 1990 (t ha^{-1}) year 6	Nut yield 1991 (t ha^{-1}) year 7	Nut yield 1992 (t ha^{-1}) year 8	Nut yield 1993 (t ha^{-1}) year 9
*Chandler walnuts on a marginal soil	nil	0.5	0.8	2.1	2.8	4.0
**Chandler walnuts on a deep soil	nil	nil	nil	1.3	1.5	2.4

*Reil (1997), **Edstrom *et al.* (1998)

6. Economic Analysis

A financial analysis, based on information supplied from the Tatura project and industry predictions, was commissioned by RIRDC and conducted by Hassall and Associates (Table 10). Two important inputs to which the analysis was sensitive to were the aims of the project, walnut yield and lead time until the first commercial crop was harvested. The economic analysis of walnut production was one of eight crops from new or rediscovered industries with potential for growth namely, cashews, coffee, Geraldton wax flower, lychee, olive, peppermint and tea tree oil. Of the eight crops, ranked in order of showing the best potential, tea tree oil, walnuts and olives gave the best returns in terms of benefit/cost ratio, net present value and internal rate of return. The analyses are based on the best industry information and assumptions that were applicable at the time of the analysis. They are also analyses of hypothetical new ventures because the industries are young and model enterprises, using the latest production techniques and are yet to reach maturity. Some figures may appear conservative as is the case with the farm gate price for walnuts at $4.00/kg which, under present market forces, is more likely to be $5.00/kg.

No attempt was made to include returns based on value-added product through on-farm processing. This is an area of marketing that has yet to be exploited in this country and when it happens it will open up opportunities for a whole range of high-value, walnut products. Walnut kernel, oil, spread, liqueur, pickles, tea, herbal remedies, dyes and timber are but to name a few. Advances in science and technology have not only improved the balance sheet through the use of better cultivars, efficient management, early bearing and high yields but also in terms of water use efficiency, tree propagation and mechanisation.

Table 10. A financial analysis of walnut production in Australia (Hassall and Associates 1999).

Key Assumptions:	
Enterprise scale	10ha
Geographic location	Victoria
Initial investment	$335,200
Typical recurrent input costs	$16,087
Key yield factors	Progress from 0.5t/ha (year 5) to 3.3t/ha (year 10). May reach 4.5t/ha
Farm gate (or other) prices	$4 per kg
Discount rate	7%
Inflation rate (if any)	n/a
Analysis period	20 years
Present Value @7% over 20 years:	
Investment inputs	$389,013
Recurrent inputs	$211,330
Revenues	$866,102
Residual values	$37,336
Net Present Value of enterprise @7%	$303,096
Financial Analysis Results:	
Return on recurrent inputs	451% static state
Return on investment and recurrent inputs	105% static state
Internal rate of return	12%
Benefit Cost Ratio @7%	1.54
Breakeven on cumulative discounted basis after:	15 years
Threshold Analysis Results:	
Net Present Value of Enterprise equals ZERO when…..	
Yield/Prices decrease by (%)	35%
Investment Expenditure increases by (%)	78%

Recurrent Inputs increase by (%)	143%

6.1 Extension activities

The walnut project DAV-73A has provided a focus for the walnut industry and provided a home for R&D at ISIA, Tatura. The Australian Walnut Industry Association now consider ISIA, Tatura to be the centre of walnut research in Australia. At the commencement of the project in 1993, there were approximately 40 members in the Australian Walnut Industry Association. Today, the membership is well over 100 people, many of whom are from areas outside Victoria. Each year for the past six years, a two-day seminar, the first held at Mt Hotham and the others at Tatura, was held as a day for reporting and demonstration for the walnut industry. These events attracted walnut growers from Western Australia, South Australia, New South Wales and Tasmania. Reporting to the industry was also done through presentation of papers at the Australian Nut Industry Council national conference held each year (Adem, 1993a, 1993b, 1994a, 1994b, 1994c, 1994d, 1995, 1996a, 1996b, 1997, 1999, Adem and Aumann, 1994,1995).

Extension advice delivered by this author through farm visits has enhanced linkages with the grass roots members of the industry. The visits also served as a vehicle for forming a collective overview of industry problems and concerns as well as provided a communication network with the walnut industry. At the beginning of the project, few walnut growers had ever visited another country to see walnut production in other parts of the world. Networks established by the author have encouraged people in the industry to visit centres of excellence in the USA and France Italy and Spain to learn Best Management Practice from overseas researchers and growers. This author has visited these centres and brought back literature, photos, research findings and notes from interviews as well as visual experiences to share with the Australian walnut industry members (appendix 10.1,10.2). Networks established during and after the visits have opened up regular email, letter and fax communication. A direct benefit of these study tours has been a number of visits by some of the most highly acclaimed researchers in the world. Overseas, Australian scientists are held in high regard and have reciprocated in the exchange of information particularly through their expertise in high-density orchards, irrigation and soil management (Adem, 1994, Adem and Aumann, 1995, Adem, 1998). Visiting scientists to Australia were encouraged to speak to local walnut growers and give advice on walnut production, processing and marketing thus reinforcing our own extension messages.

The publicity given to the progress of walnut research and the expansion of the walnut industry has attracted considerable public attention. Radio interviews and press releases have stirred the public interest and dispelled many of the misconceptions about growing walnuts. Many people who firmly believed that walnuts take a long time to bear and only grew in the mountains are surprised to hear that walnuts will bear nuts in three years and will flourish on the flat plains of northern Victoria. The number of enquiries from the public has continued to grow from people who wish to become involved in the walnut industry. Since the project began, approximately 200ha of new plantings have commenced in and around the Goulburn Valley with approximately 1000ha planned for Victoria in the coming years. Other states are expanding their walnut industry and Tasmania alone has 400ha of new plantings with another 400ha planned for the future.

Considerable borrowing of expertise and technology from the well-established pome and stone fruit industries of the Goulburn Valley has allowed the walnut industry to capitalise on earlier advances in research and adapt it to walnut production. Much of the technology on pruning, irrigation and soil management is generic to fruit and nut crops and by selective borrowing from other tree crop industries immediate benefits to the walnut industry have been achieved at little or no cost. Soil modification, irrigation scheduling and tree canopy management are but to name a few of the techniques adopted. An example of an important extension exercise was to advise the walnut industry on the techniques of direct-seeding and patch budding. Demonstration and practical classes for groups have been held annually as well as a supply of written material on this subject provided. Information, gathered from overseas visits, has added to the depth of knowledge on tree propagation and has been presented to the Australian growers through seminars, demonstrations and written material. Most of the growers who have recently entered the walnut industry have no farming experience so that farm visits have been an important component of training to assist growers develop their skills in sound horticultural practices.

As a result of extension activities in this project, direct-seeding of black walnut rootstock followed by patch budding to produce a scion of the desired cultivar is fast becoming a popular method of establishing an orchard in Australia. Traditional, two-year-old nursery trees may cost up to $32 each and for hedgerow planting, tree densities of up to 550 trees/ha and an investment of up to $17,600/ha is required. Direct-seeding and patch budding in the field has produced trees for less than $3 each and represented a considerable saving in one of the largest costs in the establishment of a walnut orchard. Direct-seeding has had several other advantages in that it allowed the seedling tree to develop an undisturbed taproot in situ and avoided the transplant shock associated with nursery grown stock. It is faster and cheaper to sow seed than transplant trees. Seedling survival is high when two to three seeds were sown at each tree site and selection of the best seedling and removing the others in each group improved the uniformity and vigour of the orchard.

Exciting new advances in R&D made in the project have created a new generation of walnut investors with plantations of 12,000 to 50,000 trees in contrast to the traditional growers with 100 to 1,000 trees. New plantings are of high yielding, early-bearing cultivars planted in hedgerows that quadruple tree numbers compared with traditional planting for the same area of land. The present project has demonstrated a soil and water management system which allowed walnuts to be grown as hedgerows on shallow, clay-pan soils and demonstrated the suitability of the new high yielding cultivars eg. Chandler, in south-eastern Australia.

Direct-seeding a black walnut rootstock into the orchard

A one-year old rootstock patch budded in the field

7. Discussion

Based on the results of the project, walnuts can be managed to induce early bearing (within 4 years) and produce high yields (1.9t ha^{-1} in year 6) equivalent to similar plantings of the same cultivar in the USA. The performance of the walnut trees also confirms that walnuts will perform well on modified topsoil in a similar way to previous results with pome and stone fruit. No additional gains in tree vigour and nut yield could be shown with the inclusion of subsoil modification through the application of gypsum and ripping. There was no evidence to suggest that loosening the subsoil by ripping affected the size and extent of the root system of walnut trees. Deep, non-stratified soils do provide other benefits such as improved drainage through the soil profile and increased water storage. The hilled up topsoil in the Tatura system also improves drainage through increased run-off of surface water and the dependence on water storage in the soil is decreased with increased irrigation frequency.

The study demonstrated that the subsoil modification did not significantly increase root length, root mass, bulk density, butt circumference nor nut yield compared with the control. The result appears to contradict earlier studies and question the value of subsoil modification. The gypsum application of 10t ha^{-1} on the treated area was twice that of the highest rate of 5t ha^{-1} normally recommended for these soils. The period of four months allowed for calcium in solution to be carried down the profile is generous compared with commercial practice where gypsum is applied as little as one day before deep-ripping.

The root studies suggested that some interesting trends were beginning to emerge but further research was needed to explain the full effects of soil modification the root behaviour of walnut trees. Measurements of root length and root mass did show that, in both the modified subsoil and in the control, more roots occupied the soil from the surface to a depth of 30-45cm than below this to 75-90cm. This supports the argument that a shallow root system can support a walnut orchard and could explain why the gypsum and ripping of the subsoil showed no measurable effect on tree vigour (butt circumference) and yield. Both treatments at the 15-30cm depth, showed that this zone contained the highest root mass and suggested that a high proportion of the total root system was present at this depth. Therefore, it is reasonable to assume that it is these roots which largely determine the growth response of the tree. Soil modification below this depth will only affect a smaller portion of the total root system and arguably with little or no effect on the growth and nut yield of the tree.

Gypsum and ripping (Yes GR) had a significant effect on soil-water content at a depth of 15-20cm compared with the control (No GR). High levels of water content at the 15-20cm depth of soil for Yes GR indicated the presence of increased pore space for stored water. Bulk densities were lower for Yes GR treatments than No GR at all 3 depths suggesting that porosity had increased slightly, but the differences were not significant. The straw mulch used in the walnut trees on all treatments showed signs of a high amount of earthworm activity, which is thought to complement the Yes GR treatment, increasing the amount of pore spaces produced in the A-horizon while not in the B-horizon. The straw mulch may have effectively masked the effect of the subsoil treatment by creating favourable conditions for root growth close to the soil surface. This may have encouraged roots to develop at shallower depths (<30cm) at the expense of deeper roots. Tisdall *et al.* (1978) showed surface mulches applied under orchard trees increased earth worm populations from 150-2000m^{-2} and saw a four-fold increase in pores empting at Field Capacity. Tisdall *et al.* (1984) also showed that where surface mulches were applied to peach trees on a Shepparton fine sandy loam, 6 years after establishment, infiltration rates of 50mm of water in 6 minutes were recorded which is approximately 14 times the average in commercial orchards. Straw mulches are not widely used on commercial orchards and in their absence the surface soil dries faster, becomes hotter, contains fewer tree roots and encourages tree roots to develop deeper in the soil. The response to adding gypsum and ripping may be quite different where mulches are not used and poor irrigation allows the surface soil to become dry and unable to support tree root growth.

High levels of soil-water content for Yes GR treatments of the walnut orchard supports the viewpoint that the A-horizon has a higher infiltration rate. Mehanni (1974) showed a significant increase in hydraulic conductivity at saturation in the depth interval 20-30cm in a red-brown earth under flood irrigated lucerne and white clover, 2 years after ripping to 45cm depth. Soil-water content taken at depth 45-50cm and 60-70cm for Yes GR and No GR showed no significant differences. In the surface soil for Yes GR, cracks in the soil were noticed that could have greatly increased water entry during irrigation and consequently led to significantly high soil-water content at 15-20cm depth. Taylor and Olsson (1987) reported that gypsum may contribute to the formation of cracks in soils that would increase water entry.

Root lengths for Yes GR and No GR were not significantly different perhaps because irrigation was scheduled to maintain matric suction at the prescribed optimum level (10kPa-40kPa) in each treatment. Firstly, this approach was taken to test the effect of the soil modification on walnut roots whilst water available to the root was held constant. Secondly, the soil was kept wetted in this range to try to keep soil strength at a low (<1.5Mpa) level to encourage roots to penetrate to depth in the soil profile.

After 4 years from establishment, the treatment Yes GR had a slightly greater mean root length density (RLD) of 6.6cm cm^{-3} compared to 6.3cm cm^{-3} for No GR down the soil profile to 90cm depth, but the differences were not significant. In apple trees, the root distribution occupied soil volumes to at least 1 metre depth 4 years after establishment (Hughes and Gandar 1993). The mean RLD found in the Tatura project were 6 times higher than kiwifruit root systems with densities of 0.9-1.1cm cm^{-3}, twenty times that of pears and peaches with an RLD of 0.3-0.6cm cm^{-3} and 30 times higher of apples with an RLD of 0.2cm cm^{-3} (Hughes and Gandar 1993). The high level of root density in the walnuts compared with other tree crops may have been due to the genetic makeup of the walnut but a more likely explanation is the improved root environment achieved through meeting the target specifications for the surface soil. Root lengths were between 0.8-5.8m long at 90cm depth, for all treatments, indicating that a few roots grew at greater depths. There appeared to be more structural roots in rows 1 and 2 compared to 3 and 4 but the evidence was inconclusive since not all samples taken contained structural roots.

Root mass was not significantly different indicating that Yes GR did not effect the spatial distribution of structural roots down the soil profile compared with the control. At depths >30cm, the clay subsoil did appear to reduce root mass and length slightly. Structural root lengths >2mm, for Yes GR and No GR, were found in very few of the core samples taken.

Measurements of butt circumference tended to be greater in rows 1 and 2 compared to 3 and 4, yet there was no significant difference between rows. Three of the experimental units for Yes GR, had stunted trees where the mean butt circumferences were <15cm. This suggested that the smaller trees (<15cm), irrigated with the same levels of irrigation water as the large trees (>15cm), had suffered from the effects of a saturated soil (waterlogging). Walnuts are very sensitive to waterlogging which leads to reduced root nutrient and water uptake and root mortality (Mapelli *et al.*1997). A saturated soil can kill the terminal parts of new walnut roots within one to three days (Catlin 1998). In the No GR treatment there were 4 large trees (>20cm), that had a low soil-water content (<0.2g g^{-1}) in the A, B, and C-horizons, which indicated that roots had extracted water from all three horizons and may have suffered water stress. The evidence highlights the importance of efficient irrigation that gives uniform application of water and is scheduled accurately.

8. Implications

Walnut production from the Tatura project indicated that commercial yields of 0.3t ha^{-1} are attainable three years after planting grafted trees. In years four and five, walnut yields were up to 1.3t ha^{-1} and 1.9t ha^{-1} respectively. These figures compare well with yields from the USA, France and the projected figures from an economic analysis conducted in South Africa. The prospects are high for developing yields even further than those shown through the experience gained in the present project. Future advances could be through better canopy management, better quality tree propagation and through advances in irrigation scheduling.

Diversification of Australian agriculture has been fuelled by economic pressures on farms as well as by consumer demand on the domestic and global market for new and enhanced food products. In 1998, RIDC commissioned a financial analysis report by agricultural consultants Hassall and Associates on eight relatively well-known industries. The analysis was based on figures from the walnut project and the walnut industry. Eight industries, cashews, coffee, Geraldton wax flower, lychee, olive, peppermint, tea tree oil and walnuts were examined. Three industries, tea tree oil, walnuts and olives showed the best potential, returning strong results in terms of benefit/cost ratio, net present value and internal rate of return.

Walnut production is attractive to investors because it is highly mechanised, orchards are low in maintenance, are productive for at least 40 years and once harvested the nuts will keep for up to two years. Many parts of Australia have a Mediterranean climate that is suitable for growing walnuts. Irrigation areas, which currently support productive deciduous fruit industries, could also support a profitable walnut industry. Compared with the USA, Australia has the advantage of fewer pests and diseases of walnuts, clean air and water, and a reduced threat of urbanisation.

The results of the walnut project confirm that walnut trees will perform on the shallow, fragile soils of the Murray-Goulburn Valley if the soil is managed carefully. The results lead to the conclusion that a deep, non-stratified soil, however desirable, is not essential for successful walnut production. Whilst it is acknowledged that deep soils of uniform texture do provide useful buffering against poor irrigation practice or wet weather flooding, in the absence of these soils, a move to shallower soils need not have a negative impact on productivity. The trend towards high-density planting has led to a restriction in the size of the tree canopy and a corresponding decrease in the size of the root system of each tree is further evidence that a walnut orchard can be productive on a shallow soil.

Specifications for the desired soil properties were documented and a step-by-step guide for setting up the orchard supplied. The soil properties measured in the surface soil of the walnut trial were equal to or approach the standards in the table of specifications in the section on methodology. The results are encouraging because the ability to grow walnuts where the bulk of the root system is confined to the surface soil may suit many Australian soils that are shallow and have poor structure or have large amounts of free lime at a depth of 60cm. Shallow rooting is encouraged through the use of hilled tree lines, surface mulches and frequent irrigation, which then allows the farmer to manage the root system and tree productivity to a finer degree, by turning the root activity (and tree canopy) on and off through controlled irrigation scheduling.

Study tours to the USA, France and Spain provided an excellent opportunity to learn from some of the best walnut producers in the world. A wealth of ideas, facts and figures collected and the networks established with key researchers, farmers and manufacturers has brought immediate benefits to the Australian walnut industry. To operate in isolation without the guidance, experience and support of the people that have travelled this path before would be slow and costly. Some of clear messages that are outcomes of the overseas visits are that, Australia has fewer pests, has clean air and water and less population pressure to limit the expansion of the walnut industry. The industries of most other countries are based on very old plantings with the inherent problems of old cultivars, small land holdings, wide tree spacing, poor tree shape and generally an outdated infrastructure. For these countries to replant and restructure is too costly because of the loss of production from removing trees of up to 100 years of age, and a lack of consolidated orchard land. Value-adding of walnuts through cracking and oil extraction is popular particularly in European where it is done on-farm or through small cooperatives. French manufacturers have developed a range of harvesting and processing machinery to supply from the smallest producer through to the large corporate farms. Australia, with its walnut industry in the expansion phase, has an opportunity to capitalise on the latest innovations and rise to be at the cutting edge of technology by borrowing the best knowledge and technology from other countries. This would put the Australian walnut industry on a very firm foundation for not only supplying its own domestic needs but also allow it to compete on global markets. A high-density hedgerow orchard, with the best management of soil and water, of the best known cultivars, harvested mechanically, and directed towards value-added products could put Australian walnuts at the forefront of quality walnut production.

9. APPENDICES

9.1 Study tour of the Walnut Industry of California

The purpose of this study tour (2 September to 10 October 1994) was to visit the University of California, which has the most technologically advanced walnut program in the world. California produces almost all of the walnuts grown in the USA. The university directs most of the research and extension in walnuts with offices in most of the counties in California. The walnut industry in California is more than 200 years old and the USA is the world's largest producer of walnuts with a total production of 250,000 tonnes.

The Australian walnut industry desperately needed guidance from the best walnut experts in the world. The industry has too few growers, most trees were over 50 years old and in decline, planted too far apart limited by soil problems, affected by disease and of the wrong cultivars. To try to resurrect the industry by ourselves with our own resources would have been inefficient instead we chose to accept the guidance, assistance and offers of collaboration from the researchers in the USA who have successfully travelled the same path before us.

The University of California Centres Visited

Davis (Centre of walnut Research), and the following county offices: Parlier, Riverside, Butte, Colusa, Sacremento, Sutter, Yolo, Yuba, Lake, Napa, Santa Cruz, Fresno, Merced, San Joaquin, Stanislaus, Tulare

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Historically, the first English or Persian walnuts (Juglans regia) were probably brought to California by the Mission fathers in 1770 from South America. The earliest pioneers raised seedling trees which produced small round nuts with hard shells. Some of the earliest orchards were established in what now is the centre of Los Angeles. W.E. Stuart at Knights Ferry, Stanislaus County is credited with planting the first seeds imported from France. Two of the most popular rootstocks in use today are the Black Walnuts *J. hindsii* and *J. nigra*, both native to the USA. A cross between *J. hindsii* and *J. regia* results in a vigorous first generation hybrid called Paradox.

The bulk of walnut production (99%) is produced in California and the rest in Oregon and Washington. Hartley followed by franquette, Vina and Payne are the main in-shell varieties produced, accounting for one third of total production. The gross production of in-shell walnuts is around 250,000 tonnes of which two thirds is consumed domestically. Per capita consumption is approximately 220g. Annually, about 50,000 tonnes of in-shell and 13,500 tonnes of kernel from Californian walnuts are exported worldwide.

The walnut improvement program is based at UC Davis in California. The selection and breeding program was initiated by Eugene F. Serr and Harold I. Forde in 1948. The aim of the program was to increase yield and quality through desirable traits of lateral bud fruitfulness, late leafing, good shell seal, high kernel percentage and light kernel colour. The breakthrough came in 1975 and 27 years later when two cultivars Chandler and Howard were the result of the evaluation of 128 potential offspring. To this day, Chandler and Howard remain as two of the most successful cultivars that exhibit the desired characteristics for walnut production with Chandler representing close to 90% of new nursery stock.

The original improvement program for walnuts ended in 1978 when Forde retired although as a result of that early program two promising new cultivars, Tulare and Cisco, have been recently released. In 1982 a new genetic improvement program was initiated in a joint venture between UC Davis, the USDA and the Walnut Marketing Board. Improved walnut yield and quality are still the target traits plus rootstock improvement to resist *Phytophthora* root rot and Blackline disease. Paradox rootstock is the most resistant to Phytophthora whilst *J. regia* and *J. hindsii* are more susceptible. *J. nigra, J. ailantafolia* (Japanese walnut) and *Pterocarya stenoptera* (Wingnut) are resistant species. To increase the genetic diversity the UC Davis breeding program uses introduced germplasm and new varieties from around the world. In addition to the original aims of the program, the rising popularity of high-density hedgerow orchards has sparked the search for new traits to include upright growth habit, small stature, precocity and intermediate to large nut size.

The walnut nursery industry in California is largely based on traditional methods of propagation which involve the budding and grafting of seedling rootstocks. The most common rootstock *is J. hindsii* whilst the most popular is Paradox. The commercial nut *J. regia* is sometimes used because of its tolerance to Blackline disease. In the first half of the twentieth century, many farmers direct-seeded their orchards by planting four or five rootstock seeds at each tree site. When the seedlings emerged, the most vigorous was retained and the rest were removed. The seedlings were then grafted, often more than a metre from the ground, to provide a trunk of highly prised black walnut timber when the orchard was removed. The practice of direct-seeding of walnut orchards is still practiced in California today and represents the cheapest method of establishing a walnut orchard. Often, nursery sites are fumigated before planting. Rootstock seed is stratified by placing the washed seed in boxes of coarse sand and subjecting them to temperatures between 1 and 4^0C for at least two months. The storage at low temperature ensures a high and even germination when the seed is eventually sown in the field. Walnuts are a difficult species to reproduce vegetatively from cuttings. Californian nurserymen and researchers have had mixed success (30-80%) from the considerable resources invested in producing Paradox rootstocks from cuttings. Similarly, mixed results were attained from hardwood and semihardwood cuttings of popular cultivars used to produce trees on their own roots. Patch budding in late summer or whip-and-tongue grafting in late winter are the preferred propagation methods although shield and T-budding is also practiced. Propagation of walnut trees by tissue culture or micropropagation has not developed to a high level, has limited commercial application and is largely in the domain of research at UC Davis or at specialist nurseries.

Mechanical harvesting of walnuts is highly developed in California with the majority of the crop harvested in three steps, tree-shaking to remove nuts, sweeping of nuts on the ground into windrows and the picking up of nuts with a harvester. Experienced operators using modern equipment can shake three to four trees per minute. Under ideal conditions, the sweeper and harvester can be operated at several kilometres per hour making the whole harvesting operation fast and efficient. The shake and pick up method allows nuts to be harvested earlier and faster than letting the nuts fall out of their hulls naturally but has resulted in a large proportion of nuts which are removed with their green hulls firmly attached. The widespread use of machinery has made walnut production profitable and less dependent on labour than many other tree crops. The USA system of harvesting relies on a one-pass operation where all nuts are shaken from the tree and the nuts along with leaves, sticks and some soil are swept along the ground into windrows. The harvester picks up the windrow, separates the nuts from the trash with the aid of a chain elevator and a fan, and delivers the cleaned nuts to a hopper. A separate fan at the rear of the harvester blows nuts off the treeline into the adjacent row to be picked up by the next pass of the harvester. The dust created by the sweeping of the orchard floor plus the trash removal and treeline clearing by the harvester has led to a serious environmental problem for the industry in the USA. Recently, legislation introduced into the USA has limited the use of harvesting operations which create dust in the environment.

On Californian orchards, processing of walnuts involves removing the green hull (hulling) by feeding the nuts through a drum fitted with rotating plates or blades which scrape off the hull, a process assisted by water sprayed over the nuts. Damaged nuts are removed by hand on a sorting table or additionally by an air separator. The cleaned nuts pass into drying bins to reduce their moisture content to around 8% using heated air at <43^0C and at an airflow of 0.85 metre^3 min^{-1} metre-^{3}.Drying with heated air needs to be done carefully as it has the effect of reducing the quality of walnuts particularly when the air temperature exceeds 43^0C. Californian walnut growers tend to concentrate on nut production alone leaving the processing and value adding to centralised cooperatives. There are a few exceptions where cracking of nuts is done on-farm ranging from small operations where the product is hand-sorted to large automated processes where electronic sorting is employed. There appears to be little marketing of walnuts direct to the public as farm gate sales. Value added products such as walnut oil, chocolate-coated walnuts and walnut biscuits do not appear to be as popular in shops as they are in Europe.

Diamond Walnut Growers, Inc. processes almost 50% of the total crop of around 250,000 tonnes produced in the USA making it the largest processor of walnuts in the world. Diamond is a cooperative supplied by around 2,200 growers. Based at Stockton, California, the plant receives up to 4,000 tonnes of walnuts per day during the peak harvest period. Diamond has the capacity for up 65,000 tonnes of walnut kernel in cold storage and exports walnut products to more than 100 countries. Diamond is an industry leader in the technology of shell separation from kernel. Air separators carry out the preliminary sorting followed by colour separation that employs the latest in laser, fiber optics and computer technology and finally acoustic sorting, a device developed and patented by the company. The Diamond company boasts their products are guaranteed to contain less than one shell fragment per 90 kg of walnut kernel.

California has a strong manufacturing base for orchard machinery, illustrated by the number and variety of specialist manufacturers of walnut harvesting and processing equipment. Walnut harvesting equipment was first developed in the late 1940s with the advent of the first Ramacher harvester. Since that time, Flory, Weiss/McNair, Compton and Weldcraft all produce harvesters in either tractor drawn or self-propelled versions. Sweeping equipment is manufactured by Coe Orchard Equipment, FMC, Flory, Kilby, Nut Hustler, Ramacher and Weiss/McNair. Tree shakers are manufactured by Best Manufacturing, Compton, FMC, Nut Hustler, OMC, and Westech. Walnut hullers, shellers and separators are produced by Agsco, Davebilt, Hul-It, Jesse, Kamper, LMC, Mid-State, Minturn, Oliver, Peerless, Ripon, Trans-West, Wizard, and West Link.

;A walnut hedgerow orchard in the USA

A harvester picks up walnuts in the USA

9.2. Study tour of the Walnut Industries of France and Spain

The aim of this study tour (20 September to 5 October 1998) was to visit two important centres of walnut research in Bordeaux, France and Reus, Spain. France produces around 25,000t of walnuts annually and next to California, has the second largest walnut breeding program in the world with new lateral bearing cultivars suitable for high rainfall areas. Spain produces less than 10,000t annually and like Australia, is trying to revitalise its walnut industry with help from France and California.

Centres Visited

- Institut National de la Recherche Agronomique (INRA),
- Station de Recherches Fruitieres de Bordeaux, Bordeaux.
- Station Experimetale de la Noix, Creysse.
- Pepinieres du Domaine de Lalanne, St. Maixant.
- Departament d'Arboricultura Mediterrania (IRTA), Reus (Tarragona).
- Nous de Palau, El Palau D'Anglesola.

Key Contact Persons

- France: E. Germain, M. Vercesi, J. Leymat, J-P. Prunet, T. Ginebre and Y. Bergougnoux
- Spain: N. Aleta Soler, F. Vergas and J. Tous

Walnut production in France at the turn of the century was 100,000t but has been declining ever since to its present production of 25,000t. France has an area of 13,750ha under walnut production with close to 2m trees planted on around 9,000 properties most of which are small holdings. Trees are mostly planted on deep alluvial soils in the Garonne, Dordogne, Lot, Perigord and Drome valleys. The annual rainfall in these regions is 700 to 800 mm annually allowing rain-fed production although 10% of orchards are under microjet or drip irrigation mainly in newer plantings or for better yields.

The French Ministry of Agriculture provides cash incentives of 8,500Fr. for non-irrigated and 17,000Fr. for irrigated orchards to farmers to plant walnuts. To qualify, the farmers must plant a minimum of 0.5ha, use certified plant material of the recommended cultivars and sell their crop to a cooperative. Around 30% of walnut growers belong to cooperatives, others sell their niuts to specialised merchants.

Over 83% of trees are grafted onto *Juglans regia* rootstocks with the remaining on *Juglans nigra*. *J. nigra* has been popular for the last 25 years but is no longer used because of its susceptibility to Cherry Leaf Roller Virus (CLRV) the causitive agent of Blackline, a widespread disease in France.

In 1960, the Institut National de la Recherche Agronomique (INRA) in Bordeaux embarked on a new research program aimed at revitalising the French walnut industry. Rapid progress has been made in the walnut industry since with the initiation of a breeding program aimed at improving the genetic characteristics of both cultivars and rootstocks. High density plantings, improved control of pests and diseases and mechanisation of harvesting and processing have contributed to the success of the program. Traditionally orchards were planted at 12x12m then 10x10m but now hedgerow orchards are planted at 8x4m or 7x5m spacing.

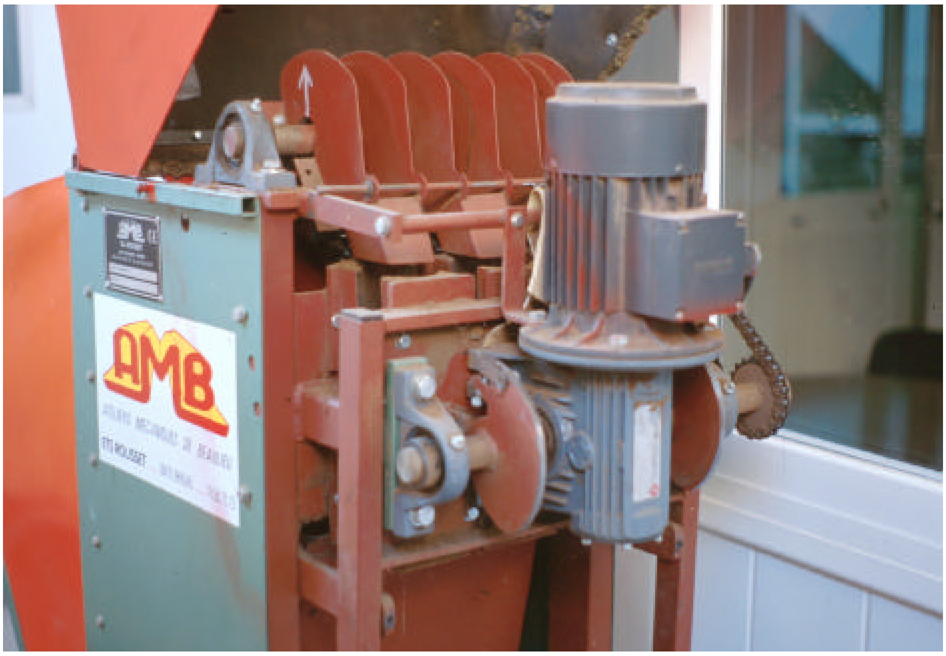
More than half the trees are the variety Franquette and in some areas can be as high as 90%. Franqette has quality nuts but the trees are slow to bear and yields are low because the nuts are borne on the tips of one-year-old shoots. Other popular cultivars are Corne, Marbot, Grandjean, Parisienne and Mayette. The newer lateral bearing walnuts produce nuts not only on terminal buds but also on the majority of the axillary buds on the current seasons growth. Until recently the major source of lateral bearing cultivars was from the walnut breeding program at UC Davis, California. Under the higher rainfall areas of France the Californian cultivars did not perform well and suffered from Walnut Blight. Lara, a new lateral-bearing cultivar selected in France has been successfully planted in hedgerows. In 1997, under a national breeding program headed by Eric Germain at INRA, around 50 new selections with lateral-bearing, blight resistance and quality characteristics have been made. Two of the latest selections which have been released to walnut growers in France are Fernor and Fernette. In-shell walnuts sell for around 10Fr./kg or A$3.00/kg but the target price is 8Fr. which is just below the price paid for US walnuts at 9Fr./kg.

There are around 12 nurseries in France producing over 100,000 trees per year by patch budding, whip and tongue grafting or side grafting. Virus-free scion wood is used and the quality of trees is very high. At INRA, the second strategy of Eric Germain's breeding program is to produce a vigorous rootstock hybrid to balance vigour and yield in lateral bearers, to avoid yield decline after a few fruiting years and to provide resistance to CLRV. This has been achieved by backcrossing hybrids of *J. nigra* x *J. regia*, *J. major* x *J. regia* or *J. hindsii* x *J. regia* with *J. regia* to obtain in the second generation, vigorous clones tolerant to CLRV.

Mechanisation of harvesting and processing is well established in France. Ateliers Mecaniques de Beaulieu manufacture a self-propelled nut harvester with an efficient nut pick-up system capable of operating in long grass and leaf litter. The same company produces a small cracking plant to separate walnut kernel from the shell. The cracker is small and affordable by even the smallest orchard and is available in modular form ranging from a single cracking head to multiple units. A small air-leg to separate kernel from the shell is also available.

In the walnut production areas of the Bordeaux region, value adding is widespread and highly developed. Food outlets from the smallest bakery, through to restaurants and supermarkets carry a large range of walnut-enhanced foods. The Bordeaux region lives up to its reputation of one of the finest gourmet regions of France when one is witness to the wide range walnut products, together with attractive packaging and clever presentation, provided to temp the palate of the consumer. Farmers individually or as part of a small cooperative value add by cracking walnuts, by hand or through the use of machinery, to extract the kernel and oil from the kernel. In-shell nuts, the kernel, walnut leaves for producing tea, the hull for a commercial dye, the packing tissue for herbal remedies, the ground shell as a commercial abrasive, walnut oil and quality walnut timber are all produced from the walnut orchard. Oil mills using stone wheels and accompanying batch presses to extract walnut oil are still widely used in France. Modern stainless steel mills are also used but the traditional methods have a rustic charm that appeals to some producers and consumers.

A harvester picks up walnuts from the orchard floor in France



A three row, walnut cracker made in France

Walnuts are native to Spain but widespread planting is thought to have occurred during the expansion of the Roman Empire. The walnut industry in Spain is small, producing around 9,000 t when compared with that of France. Most of the older plantings are seedling trees until the introduction of French cultivars started in 1972 and the importation of Californian cultivars in the last few years. Spain is attempting to expand its walnut industry in line with the new developments in technology in both France and the USA, two countries they depend on heavily for scientific input to their industry.

The Institut de Recerca I Tecnologia Agromentaries (IRTA) is located in Catalonia in north-eastern Spain on the Mediterranean coast. The institute of Mas Bove in Reus was set up in 1985 for the scientific investigation and the application of technology to the agricultural and agro-food fields. IRTA has centres at Reus, Amposta, Barcelona and Girona. Many soils in Catalonia are poorly-structured, shallow, calcareous, stony and suffer from hard pans. The region is very dry and irrigation water is limited. Mas Bove has two departments with one devoted to research on temperate fruits and the other to nutrition of chickens. Research in horticulture includes walnuts, olives, almonds, hazelnuts, carob, figs, pomegranates, pecans and pistachios.

At the Mas Bove Institute, the walnut program began in 1973 under the leadership of Neus Aleta to address the issues of a lack of genetic material, the need for selected clones and adaptation of foreign material. The breeding program aims to select cultivars which are lateral bearers, produce high quality nuts, high yields and resistant to Walnut Blight. Canopy management through pruning trials are also being investigated. Spain has three nurseries producing high quality trees from virus-tested scion wood. The walnut industry in Spain has not reached the level of production of that in France. Walnut crops are generally secondary crops to farmers with many trees planted on the edges of fields to supplement the income from other farming practices. Blackline is widespread with 28-50% of trees affected so J. regia lines are the preferred rootstock but more vigorous hybrids are being sought. Walnut timber is in strong demand stimulating a joint European Community research effort in 1993 into identifying, cloning and planting of suitable selections. Around 2,000 ha of walnut timber is planted in the European Community each year.

Planting distances in hedgerow orchards can range from 8x8 m, 7x5 m, 7x4 m to 7x3.5 m. The aim is to reach a production level of around 4t/ha in 8 years. Higher yields are obtainable but good quality, large nuts (>30 mm) are preferred even at the expense of a yield reduction. Spain and Germany are Europe's greatest consumers of walnuts with Spain importing over 80% of total its walnut consumption from the USA. In Spain in 1997, the average price paid for in-shell walnuts was between 400 to 640 pasetas/kg or A$1.50 to A$2.50/kg.

Processing of walnuts has been assisted by the use of machinery, imported from France, to carry out cracking and sorting. The equipment though small, has enabled family-owned businesses to process nuts from their own as well as from other orchards. Hand sorting is still popular and cost effective as labour is recruited on a seasonal rather than on a full time basis.

The study tours have both provided an excellent insight into research, production and processing in the walnut industry in the USA, France and Spain. The scientific research at the Universities and Institutes is of a very high standard and there is considerable exchange of information throughout the USA, Europe and North and South America. Clearly the Australian industry is at a gross disadvantage, geographically in this regard. The visits have provided not only a first- hand look at what must be considered privileged information but also access to literature not available in Australia. The timely visits created opportunities to meet world-class scientists, establish networks and put forward proposals for international scientists to spend time in Australia assisting us with our walnut program. It cannot be emphasised enough that study tours of this nature to learn from the best in the world are both cost-effective and efficient.

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