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BEST PRACTICE MANAGEMENT

FOR ESTABLISHING A WALNUT ORCHARD

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BEST PRACTICE MANAGEMENT

FOR ESTABLISHING A WALNUT ORCHARD

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Forward

The following manual on Best Practice Management for Establishing a Walnut Orchard was compiled by the author from his own publications and from other published literature. The manual does not describe all management systems available. The author has attempted to select, in his opinion, the best options at the time of writing. All of the techniques described in the text have been used by the author in practical field applications on commercial orchards and in research trials. The intention was to distill the considerable information on this topic into a concise document to guide the reader by providing much of the essential information needed in setting up a walnut orchard.

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1.0 Background

Walnuts appeal to many farmers, part-time farmers, retirees and investors because production is highly mechanised, orchards require low maintenance, are productive for at least 40 years and once harvested, nuts will keep for two years. Many parts of southern Australia have a Mediterranean-type climate ideally suited to the growing of walnuts. The irrigation areas which presently support a highly productive deciduous fruit industry could also support a profitable walnut industry. Compared with several other countries, Australia has the advantages of fewer pests and diseases of walnuts, clean air and water and a reduced threat from the urbanization of agricultural land.

Australia can become self-sufficient in walnuts, replace imports and allow export of quality nuts into the profitable European and Asian markets during winter in the northern hemisphere. In Australia, walnuts have been grown for over 70 years but the industry is small, with great opportunities for expansion. Walnut trees, managed under the latest technology, will produce nuts in their second or third year and commercial yields in the fourth or fifth year.

2.0 Climatic requirements

Walnuts perform best in a Mediterranean climate, between 600 and 800 hours of temperatures between 0°C and 10°C during winter (Winter Chill), a frost-free period during flowering and temperatures below 38°C during summer. Most of the walnut orchards are located in areas that have a Mediterranean type climate in the southern parts of Australia (Plate 1).

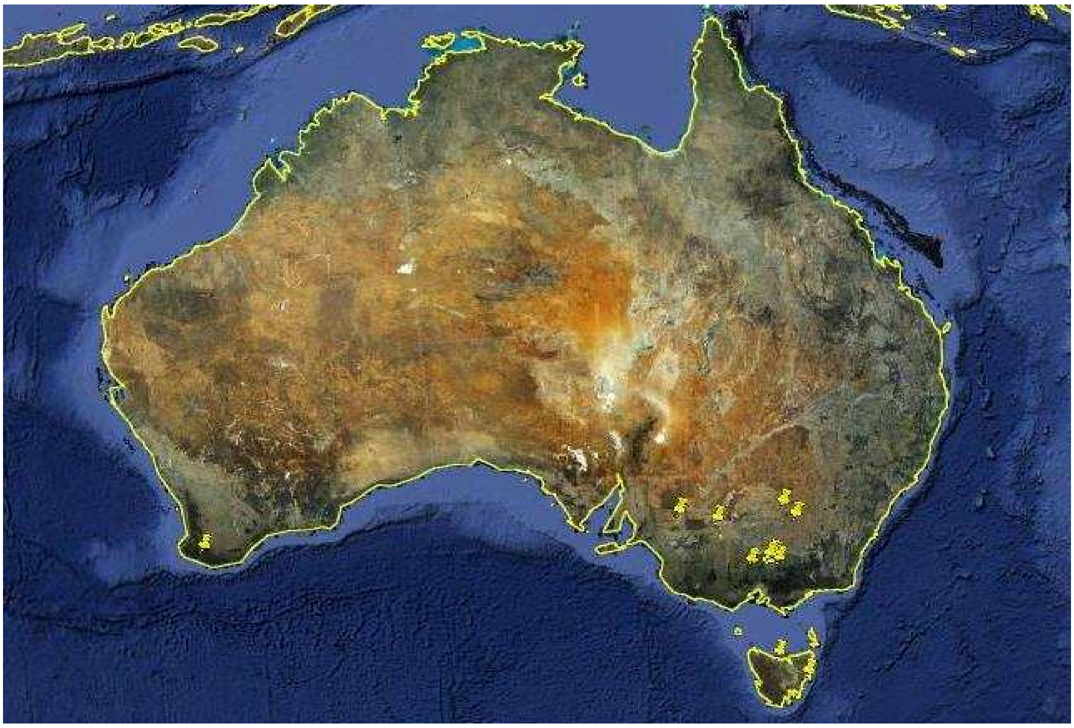

Plate 1. Map showing some areas where walnut are grown in Australia

3.0 Soils

Walnut trees are very demanding of soils especially in terms of texture (the proportions of silt, sand and clay) and structure (the porosity or spaces between soil particles), through which water, air and nutrients move to the roots. Soils need to be soft enough to allow the unrestricted growth of roots and yet stable enough to resist collapse of the structure under wetting and compaction. Deep, sandy loams or clay loams are often favored for walnut trees.

Soil structure defines the porosity, or the spaces between the particles, which make up the soil. The biological activity of roots and soil organisms will create pores, incorporate plant residues, decompose organic matter, soften soils and stabilize soil structure. The size of the pores determines their role (Table 1). Pores less than 0.2 micrometer (µm) (2/10,000mm) in diameter will hold water so tightly that the plant cannot extract water. Pores up to 30 micrometer (3/100mm) in diameter can store water against the pull of gravity – larger pores will drain soon after rain or irrigation. Growers do not need to measure porosity but growing cereals or grasses (eg, ryegrass) as a cover crop will create storage pores to store water at field capacity.

Mean pore diameter (µm) (1mm=1,000µm)	**Biological significance**
2,000-50,000	Ant nests and channels
500-3,500	Wormholes
300-10,000	Tap roots of dicotyledons
500-10,000	Nodal roots of cereals
1,000	Root plus root hair cylinder in clover
100-1,000	Seminal roots of cereals
50-100	Lateral roots of cereals
30	**Field capacity (-10 kPa)**
20-50	1st- and 2nd- order laterals of cereals

Table 1. Pore dimensions of biological origin (Hamblin, 1985).

Tilling the soil has been used for thousands of years to control weeds, loosen soil, improve porosity and create a root bed. One of the most important objectives of tillage is to create a range of aggregates 0.5–20mm in diameter, which in turn creates a range of pore sizes between soil particles, for drainage, the extension of the crop roots and the flow of water, nutrients and oxygen to the tree. Tillage is easy and can be done with a large range of implements.

On the negative side, tillage can pulverize soil, create clods, oxidize organic matter and deteriorate soil structure. The effect of tillage are, at best, temporary, because soils slump and become harder and more dense and where tilling continues, soil particles are ground finer, roots and fungi are killed and compaction occurs.

At times, growers may be required to till the soil, however the full consequences of tillage on production are not fully understood and often better alternatives (herbicides, mulches and cover crops) are preferred.

Many Australian soils used for horticulture have a shallow, loam topsoil (<20cm thick) underlain by a heavy clay. The clay restricts drainage of water down the profile and can create a water table at the topsoil-clay interface. Subsoil tillage, in some soils, can provide a safety valve, which allows excess water to drain away from the root zone of the tree. Soil drainage and safeguard against waterlogging can be provided by subsoil tillage and mounding. Mounding provides good surface runoff and effectively sheds excess water, which might otherwise enter the soil. Mounding has the added bonus of concentrating the best quality soil and at the same time deepening the topsoil along the tree line. Subsoil tillage is best done at the right water content, when the soil is most friable. A winged-tined ripper should be used, in several passes, progressively each times 20cm deeper than the previous one, until the desired depth is reached.

In irrigation regions of south-eastern Australia on shallow topsoils overlying hard, clay-pan subsoils, high yields from stone and pome fruit, and more recently walnuts, have been achieved by the adoption of the Tatura System of Soil Management. The Tatura system provides levels of water, air, stability and mechanical resistance in orchard soils that are non-limiting to tree productivity (Table 2).

Purpose	**Property**	**Specification**
Water management	Matric potential	-10 to -50 kPa
Root growth	Air-filled porosity	15-20 %
	Penetrometer resistance	<1.0 MPa
	Bulk density	1.0-1.3 g cm^{-3}
Soil stability	Organic carbon	>2 %
	Water stable aggregation	>75 %
	Clay mechanical dispersion	<1.0 %

Table 2. Soil specifications that are non-limiting to tree growth

In the Tatura System, to improve drainage and to optimise land use, the topsoil is hilled into a treeline bank approximately 0.5 m high (Plate 2). From soil tests, the specified amount of lime is incorporated and gypsum spread on the surface in a two metre wide strip on the treeline. Ryegrass is sown over the entire orchard. Where compacted (hardpan) subsoil is present, a ripper with a winged-tine is used to till the soil to a depth of 60 cm to create aggregates in the subsoil. The nut trees are planted and the bare soil, created by the tillage operation, is covered with straw mulch 2m wide (Plate 3).

Plate 2. A road grader mounds soil into a treeline bank

Plate 3. Straw is spread as mulch on the treeline

4.0 Steps recommended as a guide to setting up a new walnut orchard

1. In late summer/autumn, peg out the orchard treelines accurately and install the irrigation mains.
2. Use a road grader to move the topsoil from the centre of the traffic line to the treeline to create a bank approximately 0.5 m high.
3. For acid soils (pH <6.0), apply lime (amount determined by a soil test) in a 2 metre wide strip along the treeline and incorporate with a rotary-hoe.
4. Install irrigation laterals and microjet sprinklers (output 5-10 mm/hr) and irrigate for 4-5 hours.
5. When the soil has drained to around field capacity (2-3 days), cultivate the entire orchard with a tined implement, power harrow or a rotary hoe and smooth the soil surface.
6. For dispersive soils, apply gypsum (amount determined by a soil test) in a 2 metre wide strip along the treeline.
7. Sow the orchard to ryegrass or a ryegrass and clover mix and irrigate for 2-3 hours.
8. In late winter, mow the grass/clover sward close to the ground.
9. In compacted subsoils, use a winged-tine ripper to a depth of 60 cm in 3 passes in increments of 20 cm.
10. Cultivate the 2 metre wide strip with a tined implement, power harrow or a rotary hoe and smooth the soil surface.
11. Plant the trees without compacting the soil and water-in lightly to prevent slumping of the soil.
12. Apply a surface mulch of straw in a 2 metre wide strip on the treeline.
13. In spring/summer, use herbicides to control weeds in a 2 metre wide strip on the treeline.
14. Slash the orchard and deliver the clippings onto the treeline to supplement the straw mulch.

5.0 Tree density (spacing)

Tree spacing in walnut orchards can be from 10m x l0m, to 6m x 3m which gives approximately 100 to 550 trees per hectare respectively (Table 3). Where spacing within the tree row is <8m, pruning the trees into a hedge will be required from about year five and onwards. Trees that are to be harvested mechanically may need 0.5m of trunk before branching to allow the attachment of a trunk-shaker.

Tree spacing (m)	Row spacing (m)				
	6	7	8	9	10
3	556	476	417	370	333
4	417	357	313	278	250
5	333	286	250	222	200
6	278	238	208	185	167
7	238	204	179	159	143
8	208	179	156	139	125
9	185	159	139	123	111
10	167	143	125	111	100

Table 3. Number of trees per hectare for a range of row and tree spacings

6.0 Nutrition

For function and growth, plants obtain most of the mineral nutrients from the soil water solution. Soil minerals and organic matter, making up the bulk of the soil mass, act as a buffer or reserve of nutrients available to plant roots. Nutrients may be classified into three classes according to the needs of the plant and how the nutrient is available in different forms (Table 4.).

Class of nutrient	Element	Symbol	Form in fertiliser	Symbol
Primary	Nitrogen	N	Nitrate	$NH3^-$
	〃	〃	Nitrite	NO_2^-
	Phosphorous	P	Hydrogen phosphate	$HPO_4^=$
	Potassium	K	Potassium	K^+
Secondary	Calcium	Ca	Calcium	Ca^{++}
	Magnesium	Mg	Magnesium	Mg^{++}
	Sulfur	S	Sulphate	$SO_4^=$
Micronutrients	Iron	Fe	Ferrous	Fe^{++}
	〃	〃	Ferric	Fe^{+++}
	Manganese	Mn	Manganese	Mn^{++}
	Zinc	Zn	Zinc	Zn^{++}
	Copper	Cu	Cupric	Cu^{++}
	Boron	B	Borate	$H_2BO_3^-$
	Molybdenum	Mo	Molybdate	$MoO_4^=$
	Chlorine	Cl	Chloride	Cl^-

Table 4. Forms of nutrient elements found in soil solutions

6.1 Soil pH and nutrient availability

Soil pH affects both the availability and absorption of mineral nutrients (Plate 4). Measurements of soil pH can be a good guide to the diagnosis of nutrient deficiencies and should be corrected before nutrients are applied. Low pH (<5.5) may result in deficiencies of Ca, Mg, P or Mo and perhaps excesses of Mn, Fe or Al. High pH (>7.5) may result in deficiencies in Mn, Zn, Fe or Cu.

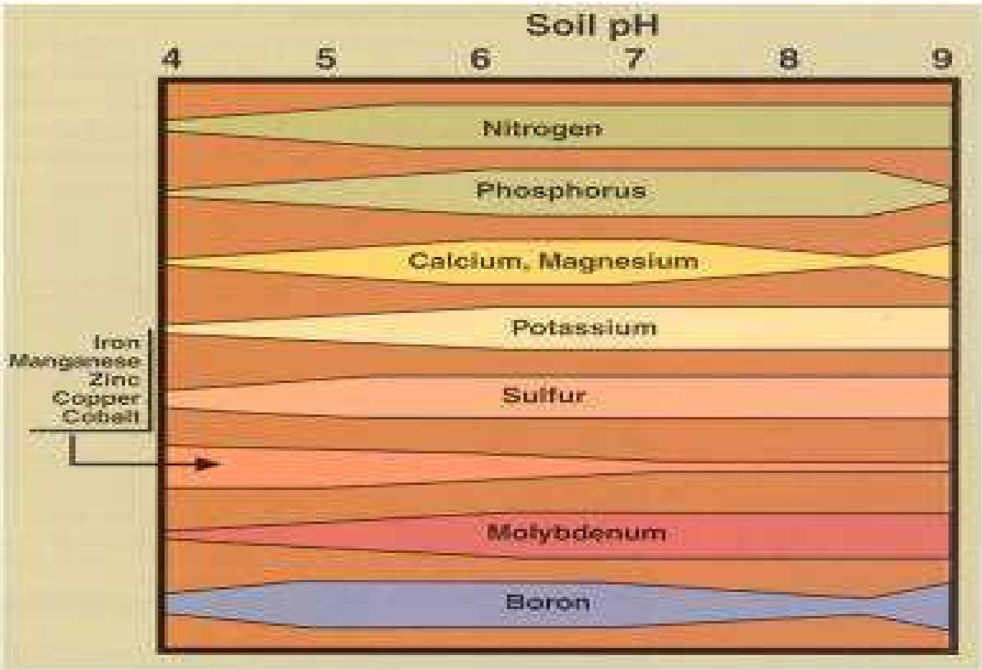

Plate 4. Chart of the effect of soil pH on nutrient availability

6.2 Fertilisers

Plants are major users of nitrogen and most horticultural crops become nitrogen deficient if N is withheld. Fertilisers containing N are widely used in orchards and, being a moderate expense in the overall production cost incurred in the business, can be applied too heavily or inappropriately. Inefficient application techniques will reduce the proportion of applied fertiliser taken up by the tree. Using more fertiliser than needed by the crop can not only waste money but can lead to excess vigour, soil acidification and contamination of groundwater. Nitrogen fertilisers can contain N in different forms that move through the soil at different rates giving rise to the term ‘mobility’ in the soil (Table 5).

Mobile component	Less mobile component
Urea	Ammonium
Nitrate	Potassium

Table 5. Mobility of fertilizers in soil

The ability of a fertilizer to dissolve in water is not always a good indicator of the mobility of the nutrient. Urea, a N source often used in fertigation, is easily dissolved, is very mobile and is easily leached past the rootzone of trees. Ammonium also dissolves in water but is much less mobile because it sticks to clay particles. Ammonium fertilizers such as MAP and ammonium sulphate are less likely to be leached past the rootzone. Ammonium nitrate breaks down to a nitrate component which is mobile and easily lost by leaching whilst the ammonium component binds strongly to clay particles. Calcium nitrate and potassium nitrate are both mobile and subject to leaching but may slowly increase soil pH (Table 6).

Fertilizer	Acidifying effect on soil
Ammonium sulphate	High
MAP	High
DAP	High
C.A.N.	Medium
Urea	Medium
Ammonium nitrate	Medium
N.P.K. (Urea based)	Medium
Organic manures	Medium
Calcium nitrate	Low
Potassium nitrate	Low

Table 6. Effect of different sources of nitrogen on soil acidity

6.3 Soil and plant analysis

Many Australian soils are deficient in N and P and in some soils K may also be low. Soil tests to determine nutrient levels are useful to establish broad levels of mineral elements available to the plant but it is often difficult to interpret these results. Soil tests are most useful to detect the presence of extremely deficient levels of N, P, K, Fe and B or toxic levels of Na, Cl and B. Soil tests can be carried each year before the start of the growing season. Fertilizer suppliers can advise on the application rates for fertilizers based on the performance of walnuts in a given area.

The best time for fertilizer application is in late winter-early spring when tree roots and shoots commence their rapid growth phase. Primary nutrients namely N, P and K are in greatest demand followed by secondary and micronutrients. A rule-of-thumb for N requirement of walnut trees is to apply fortnightly 30g of pure N per tree for every year of growth.

Nutrient levels can also be determined by leaf and sap analysis and then compared with standards that are recognized to be non-limiting to plant growth (Table 7). Leaf analysis is the preferred method and best undertaken in mid to late January by sampling trees at random in each block. Samples should consist of 50-100 of the current year's leaves including petioles from the base to the middle of non-fruiting shoots at various positions around the canopy. Walnut leaves to be collected for sampling should be from shoots of average vigour from trees of the same cultivar selected at random. Avoid sampling damaged or old leaves from the middle of the tree as this will affect leaf nutrient concentration.

Element	Normal concentration
Nitrogen (N)	2.2-3.2 %
Phosphorus (P)	0.1-0.3 %
Potassium (K)	>1.2 %
Calcium (Ca)	>1.0 %
Magnesium (Mg)	>0 3 %
Manganese (Mn)	>20 ppm
Boron (B)	36-200 ppm
Copper (Cu)	>4.0 ppm

Table 7. Nutrient levels (dry-weight) for walnut leaves

6.4 Fertigation using drippers and microjets

Fertigation is an efficient technique for using irrigation water as a carrier of fertilizer in solution to deliver a known concentration of nutrients to crops (Plate 5). Fertigation has the advantage of delivering nutrients from a point source to wherever irrigation is applied to the crop. The operation is simple because it uses the irrigation infrastructure already present without the costs associated with conventional spreading of fertilizers with tractor equipment. Nutrients in solution are in a form readily taken up by plant roots and there are fewer losses due to volatility of some compounds. Fertigation is a flexible method because small amounts of nutrients can be introduced at frequent intervals rather than in fewer large doses.

Plate 5. Fertigation tank (LHS) and irrigation filters (RHS)

Fertigation coupled with treeline irrigation gives the operator good control over the timing and dosage. However, if poorly managed, fertigation can lead to severe acidification of the soil profile. Where drippers or microjets are employed to wet the treeline only, tree roots are concentrated in this narrow strip and fertilizer uptake by the tree is both efficient and rapid. Fertigation should be done a day or two after a rainfall event or irrigation so that the fertilizer is applied whist the soil is still wet. When using fertigation, the irrigation run should be shorter than usual and the fertilizer applied in the last 30 to 60 minutes of the run.

6.5 Foliar application of nutrients

Nutrients applied as foliar sprays are a convenient way to quickly correct a nutrient deficiency and get a rapid response in the walnut tree (Table 7). Foliar sprays are a useful way to treat nutrient disorders in small areas of orchard or trees at random. However the response may be short-lived with little reserve held in the plant tissue and the amount of nutrient applied may be insufficient and limited to levels below that cause phytotoxicity. Foliar sprays compared with fertigation may be expensive in terms of the nature of the product required and the machinery needed to apply the nutrient. A long term and often cheaper solution is to add fertilizers to the soil to provide a reserve of nutrients that are picked up by walnut roots over time.

7.0 Tree water use

Depending on the location, walnut trees need approximately 5-10Ml per hectare of water per year during the growing season. The actual amount of water will depend on the soils and climate of the site. The timing and amount of rainfall is not reliable enough in rain-fed orchards to match the yield and quality of walnuts from an orchard irrigated by microjets or drippers (Plate 6). Even in higher rainfall areas, some provision for top irrigation is essential. The orchard is usually irrigated several times per week in summer to replace the water lost through transpiration. Tensiometers or other sensors in the soil are used to determine when and how long to irrigate and avoid waterlogging the trees (Plate 7).

Plate 6. Microjet irrigation

Plate 7. Soil matric potential is measured with tensiometers

7.1 Stem water potential (SWP)

Measurement of SWP in leaves relates directly to the water status of the tree and indirectly to soil water and atmospheric conditions (Plate 8). Tree water status is closely linked to vegetative growth and a sensitive indicator of water stress in orchard trees. SWP is best measured between 11:00am and 1:00pm by removing a young, fully expanded leaf from a shaded part of the tree and wrapping it in a damp cloth for around 10 seconds. The leaf is then placed in a pressure chamber with the petiole extending through a sealing stopper to the outside of the chamber.

The pressure is increased in the chamber by pumping it up until sap is forced out of the cut petiole surface and the pressure is recorded in Megapascals (Mpa) or Bars (Mpa x 10 = bar units). Readings should be taken on days when trees are likely to be under maximum stress, usually just before irrigation. The SWP should be kept at less than 10Bar to avoid water stress in walnut trees. Following this guideline will indicate when to begin irrigation in the orchard and can also be used to check the efficiency of the irrigation scheduling.

Plate 8. Stem water potential measured with a pressure chamber

7.2 Irrigation scheduling

Water management is one of the largest and most important inputs into a walnut project. The relatively dry climate of Australia combined with the shallow, generally clayey soils means that there is little storage of water in the soil. Following irrigation, there is only about a two or three day supply at optimum levels of water held in the soil in mid summer. This means the walnut trees are dependent on a regular irrigation, supplied on demand, and dictated by the prevailing weather conditions. Careful scheduling of irrigation based on a calculation of tree water use from weather data, monitoring of soil water status and measurement of the internal water potential of the tree are the tools to decide the amount and frequency of the irrigation applied.

7.3 Evapotranspiration (ET)

Evapotranspiration involves two processes - evaporation or water loss from the soil surface and transpiration or water loss from tree leaves. The processes occur simultaneously and there is no easy way of separating them. Weather factors including radiation, air temperature, humidity and wind speed affect evapotranspiration. Factors such as soil salinity, low fertility, hard pans, waterlogging as well as pest and diseases can affect transpiration.

7.4 Pan evaporation

Pan evaporation (E_{pan}) is the amount of water lost (evaporated) from a standard Class A Pan either located in the orchard, figures can be obtained from a local weather station or from the Bureau of Meteorology (www.bom.gov.au) (Plate 9).

Plate 9. Class A pan evaporimeter

7.5 Reference crop evapotranspiration (ET_o)

Crop evapotranspiration (ET) is the rate of water loss from a hypothetical grass reference crop not short of water. The use of a grass surface as a standard reference for all crops means that ET does not need to be calculated for each crop and stage of growth. ET_o values measured or calculated from weather data at different locations or seasons are comparable as they refer to the same grass surface reference. The Bureau of Meteorology can provide values of ET_o for selected weather stations in Australia. Where values of ET_o are not available, evaporation figures from a Class A pan can be adjusted to approximate ET_o by multiplying by a factor of 0.8.

$$\text{Class A pan adjusted (approximate } ET_o \text{)} = \text{Class A pan} \times 0.8$$

7.6 Effective area of shade

An accurate way to calculate tree water use from canopy size is based on the effective area of shade (Effective Canopy Cover) measurements of the percentage of shade under a walnut treeline.

$$\text{Area \% shade} = \frac{\text{Width of tree row shadow at noon} \times 100}{\text{Row spacing}}$$

7.7 Crop coefficient

The crop coefficient is used to make an adjustment to the Effective Canopy Cover based on theoretical evapotranspiration for a disease-free, well-fertilized walnut crop, grown on a large area, under optimal soil water conditions and achieving full production.

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$$\text{Crop Coefficient} = \frac{\text{Effective area of shade} \times 1.5}{100}$$

7.8 Irrigation scheduling

Tree water use and irrigation frequency can be calculated from long term records of Class A pan evaporation (Tables 8&9).

Tree Water Use (mm) = Crop Coefficient x Pan Evaporation x 0.8
Tree Water Use (L) = Crop Coefficient x Pan Evaporation x 0.8 x Row width x Tree spacing
100 mm of irrigation over 1 ha = 1ML/ha of water use.

Month	Evaporation Class A Pan (mm) A	Class A Pan Adjusted (mm) B=0.8xA	Effective Area of Shade (%) C	Crop Coefficient D=1.5xC/100	Tree Water Use (mm) E=BxD	Rainfall 2007-2008 (mm) F	Irrigation Requirement (mm) H=(E-F)x%IAE
Sept	109	87	20	0.3	26	7	24
Oct	187	150	30	0.5	67	7	75
Nov	199	159	40	0.6	96	40	69
Dec	238	190	50	0.8	143	61	102
Jan	282	226	50	0.8	169	64	132
Feb	205	164	50	0.8	123	6	146
Mar	185	148	40	0.6	89	17	90
Apr	70	56	40	0.6	34	11	28
May	45	36	20	0.3	11	35	0
TOTAL (mm)					757		667
TOTAL (ML/ha)					7.6		6.7

Table 8. Theoretical tree water use based on long term records

Location	Tatura		Tree Spacing (m)		3		
Block	Trial		Row Spacing (m)		6		
Variety	Chandler		Emitter Output (litre/hour)		30		
			Emitter Spacing (m)		3		
Rootstock	J hindsii		Laterals per Row		1		
Month	**Irrigation Run Time (hours)**	**Irrigation Amount (litre/tree) A**	**Class A Pan Adjusted (mm/day) B**	**Crop Coefficient C**	**Tree x Row Spacing (square m) D**	**Daily Water Use (litre/tree) E=BxCxE**	**Irrigation Frequency (day) F=Ax%IAE/E**
Sep	2.0	60	2.9	0.3	18.0	16	3
Oct	4.4	132	4.8	0.5	18.0	39	3
Nov	4.4	132	5.3	0.6	18.0	57	2
Dec	4.4	132	6.1	0.8	18.0	83	1
Jan	4.4	132	7.3	0.8	18.0	98	1
Feb	4.4	132	5.9	0.8	18.0	79	1
Mar	4.4	132	4.8	0.6	18.0	52	2
Apr	4.4	132	1.9	0.6	18.0	20	5
May	4.4	132	1.2	0.3	18.0	6	17

Table 9. Predicted tree water use and irrigation frequency

8.0 Cultivars (Varieties)

Walnuts belong to the order *Juglandales,* family *Juglandaceae.* The family consists of six genera, one of which is *Juglans* which in turn comprises many species of walnut. The common English or Persian walnut *(Juglans regia L.) is* the dominant commercial species. Up until the late l980's, Franquette made up 70% of trees planted in Australia, followed by Treve Mayette, Eureka, Myrtelford Jewell and Wilson's Wonder, all of which produce nuts from terminal buds (Table 10).

Cultivar	Pistillate flowers from lateral buds %	Blooming	Nut size gm/kernel	Kernel %	Light kernel colour %	Shell seal	Nut yield
Franquette	5	late	5.3	47	90	good	fair
Treve Mayette	0	late	-	-	78	poor	low
Eureka	0	late	7.7	50	40	good	moderate
Payne	88	early	5.7	50	68	good	high
Hartley	5	late	6.1	46	76	good	high
Serr	85	mid	5.8	50	70	good	low
Ashley	85	early	5.8	50	70	adequate	high
Sunland	82	mid	10.6	57	85	good	high
Chico	96	very early	5.2	47	60	good	very high
Vina	70	mid	6.3	49	90	good	high
Amigo	74	early	5.9	51	63	fair	high
Howard	89	late	6.6	49	96	good	very high
Chandler	89	late	6.5	49	100	adequate	very high
Tulare	72	mid/late	7.5	53	86	good	high
Lompoc	50	early	7.5	54	60	good	high

Table 10. A selection of the main cultivars available in Australia.

In the last 10-15 years, cultivars with lateral bearing habits have been imported from California. The cultivars bred at the University of California, Davis display high fruitfulness (80-90%) on lateral buds, kernel to shell percentage is close to 50%, with over 60% of kernels classified as light-coloured. Presently, the most popular cultivar in the USA is Chandler, a heavy bearer, producing quality nuts. The cultivar is suitable for dry climates, and compared with Franquette, requires less winter-chill to break dormancy. Walnuts are both self and cross-fertilized but the pollen release and stigma receptivity often fail to coincide. For this reason, approximately 5% of the walnut orchard should be planted to suitable pollinators. At the time of writing, Chandler, Tulare and Howard are the most popular cultivars and Cisco as a pollinator.

9.0 Rootstocks, budding and grafting

Northern Californian Black *(Juglans hindsii)* and Eastern Californian Black *(Juglans nigra),* are both used as rootstocks for *J. regia* in Australia. Paradox hybrids *(J. hindsii x J. regia)* and Royal hybrids *(J. nigra x J. regia),* used as rootstocks in the USA because of their increased vigour, are generally not available in Australia. The hybrid rootstock Paradox, the rootstock of choice in the USA, is rarely used in this country due to its scarcity.

Black Walnut fruit is collected when the outer flesh (hull) is ripe and appears black. The fruit is tumbled with water in a concrete mixer to remove the flesh, thereby separating the seed. The seed is then stratified; a process of storing the moist seed at below 10^0C. This is usually achieved by placing the washed seed in a plastic bag which is then stored in a refrigerator. An alternative method is to store the seed in damp, coarse sand outside and away from direct sunlight (Plate 10). The stratification period takes around two to three months and serves to induce dormancy in the seed preparing it for germination. Proper stratification of walnut seed will promote a higher uniformity of germination.

An alternative method used in the USA and Australia is to plant pre-germinated, black walnut seed directly into the treeline in the orchard (Plate 11). The rootstock is grown for one or two years and then patch-budded in mid-summer. The result is an inexpensive tree that avoids the problem of transplant-shock associated with bare-rooted trees transplanted from a nursery. A further method is to propagate black walnut seed in pots in a greenhouse. The rootstock seedlings are then planted in the field and then patch-budded (Plates 12&13). Alternatively, they are patch-budded in the greenhouse ready to be planted in the orchard at any time once the graft union has taken.

In many parts of the world, the practice of direct seeding walnuts and grafting or budding in situ has been carried out for centuries. Planting grafted nursery stock is the traditional method for establishing a walnut orchard where tree uniformity and timeliness are prime considerations. Direct seeding may be considered cheaper because the cost of the grower's time in caring for the trees is not always considered and the practice of field budding, unless performed skillfully, can result in uneven trees.

Direct-seeding has had several other advantages in that it allows the seedling tree to develop an undisturbed taproot in situ and avoids the transplant shock often associated with nursery stock. It was faster and cheaper to sow seed, but the lead-time until nut production may be longer when compared with transplanted trees. Seedling survival is highest and the uniformity and vigour of the orchard improved when two to three seeds were sown at each tree site and the best seedling retained whilst the others are removed.

Plate 10. Black walnut seed stratified in boxes of sand.

Plate 11. Direct-seeding a black walnut rootstock into the orchard

Plate 12. Planting black walnut seedlings

Plate 13. A walnut rootstock patch-budded in the field

To address some of the problems associated with direct seeding of the rootstock directly into the orchard, seed can be sown in coarse sand in plastic sleeves that measure 500mm in length by 100mm in diameter (Plate 14). A metal staple in the bottom of the sleeve allows drainage but prevents the sand from falling out. The sleeves are placed together in a nursery area until the walnut seedlings emerge. The seedlings are then sorted for health and vigour and the best ones selected for planting. A hole, 100mm in diameter and 100mm deep, is dug at each tree site and, after removing the staple, the seedling is planted with the sleeve in place. A spring-steel stake (2.5m long and 8mm diameter) is placed inside the sleeve to provide support to the tree. The sleeve thus becomes an effective guard against wind, herbicide drift and animal pests plus it provided a warm, moist microclimate to assist seedling early growth.

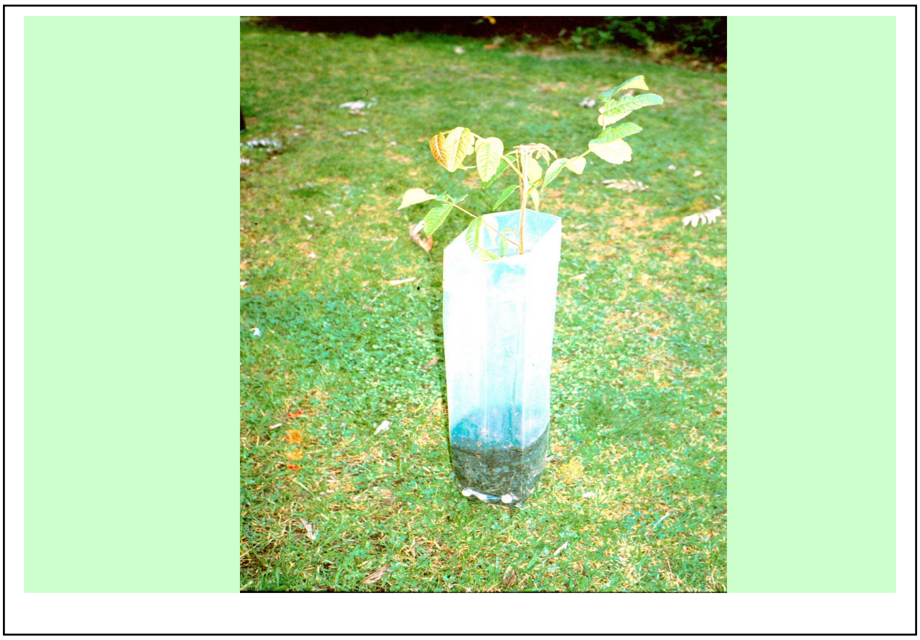

Plate 14. A walnut rootstock seedling propagated in a plastic sleeve.

The technique provides a useful microclimate within the transparent, polyethylene, plastic sleeve that encourages early seed germination and improved seedling emergence. The system is more reliable than the direct seeding method, minimising the labour input and reducing tree losses. Other benefits included the ability to transplant a small, delicate seedlings from the nursery into the field and control weeds using herbicides whilst the tree seedling is safely protected inside the tree guard.

10.0 Tree training

Studies of light interception provided the best scientific basis for tree spacing, tree size and canopy shape for the production of assimilates and conversion into economic yield. The two main objectives are to firstly optimise the sunlight falling on the trees as opposed to falling on the ground and secondly to optimise light distribution within the tree canopy.

The amount of intercepted sunlight in the orchard has a strong bearing on tree water use and walnut production per hectare. Sunlight has a profound effect on shoot growth, flower formation, nut set, nut development and nut quality. In a Multi-leader walnut tree, unpruned and separated from neighbouring trees, production is limited by the shadow it casts upon itself. At a distance of more than say 1.5m in from the edge of the canopy, light levels can fall to less than 30% resulting in little or no nut production. The shape of the tree also has an effect on the volume to surface area ratio of the canopy. Ideally, a well-planned orchard should intercept 70-80% of sunlight falling on the land. Traffic lanes for machinery make up the rest of the land area. Sunlight interception is also influenced by tree height and therefore the maximum tree height in summer should not exceed 80% of the row width.

Sunlight as the energy source drives photosynthesis in the orchard that produces the products, carbohydrates and energy-containing molecules for tree growth and fruit production. Photosynthesis is optimal at temperatures between 15^0C and 30^0C with drastic reductions at below 5^0C and above 35^0C. Stomates on leaves exposed to full sunlight open as light intensity increases, reaching a maximum by mid-morning. By the afternoon temperatures may be excessive and stomates close to reduce water loss. Carbon in the form of CO_2 is taken up during photosynthesis and converted to carbohydrate that then serves as an energy source for maintenance or the growth of new plant parts. Carbon is lost in crop harvest, pruning or leaf loss, and sometimes due to the effects of pest and disease.

Walnut trees trained to a Central Leader shape have the potential to yield higher and for longer than a Multi-leader tree. Multi-leader trees severely shade both the interior and the lower parts of the tree as the tree gets older whereas Central Leader or pyramid-shaped trees have better light interception even with age (Fig 1). Central leader trees allow sunlight to penetrate to the base of the canopy and cause less shading.

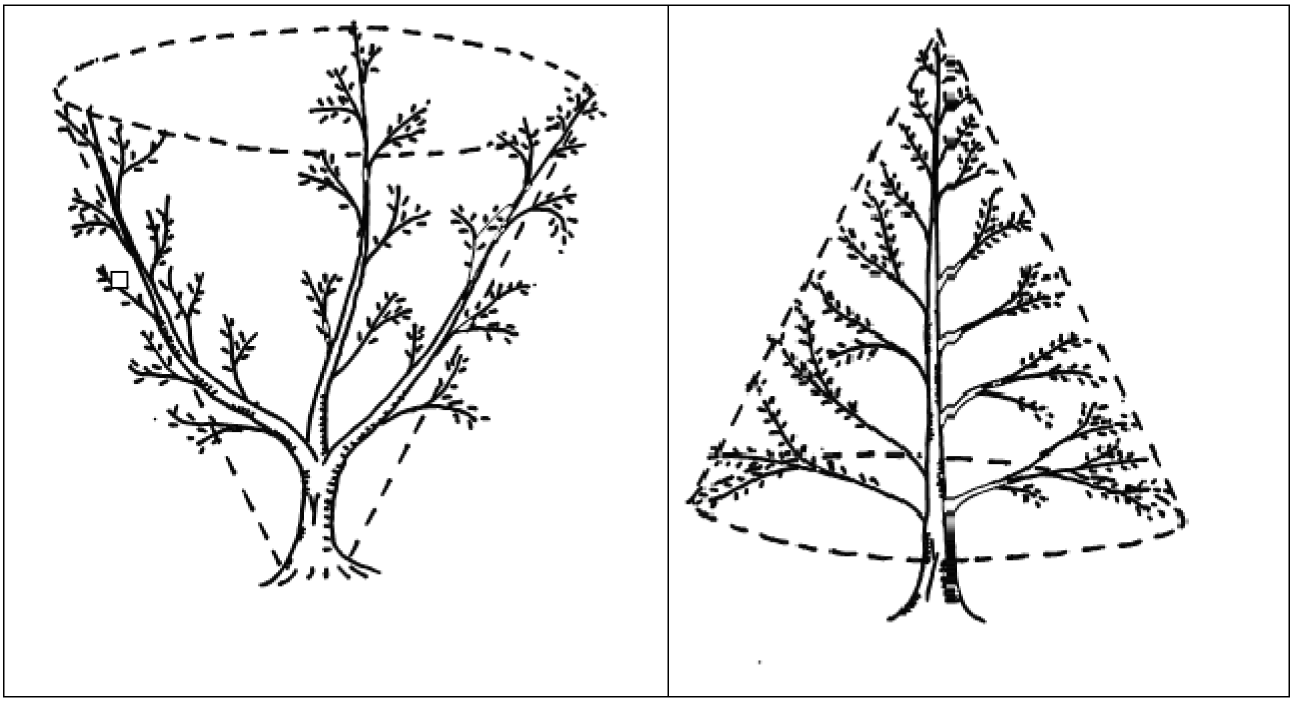

Fig 1. Multi-leader (LHS) and Central Leader (RHS) training systems

In a hedgerow orchard, walnut trees are planted equal to or closer than the width of the tree row to form a continuous canopy. A hedgerow design for efficient interception of solar radiation can be calculated based on the effects of tree size, shape, spacing and row direction (Table 11). Increasing the planting density, and thus improving light interception per hectare, has been one of the best ways to increase productivity in walnut orchards.

Row width (m) A	Alleyway width (m) B	Tree canopy width C=A-B (m)	Canopy width with poor light penetration D=C-(2x1.5m)	Optimum tree height E=Ax80% (m)
6	2	4	1	4.8
7	2	5	2	5.6
8	2	6	3	6.4
9	2	7	4	7.2
10	2	8	5	8.0

Table 11. The effect of row width, canopy width and tree height on light penetration

Large Multi-leader trees that extend over the traffic lane in the orchard have very high light interception but at the same time fruit production is low because a high proportion of the tree canopy is shaded (Fig 2). Leaves that are more than 1.5 metres from the outer canopy surface have light levels that are too low for flower bud development and nut set. These shaded leaves become an energy drain or a liability to the tree.

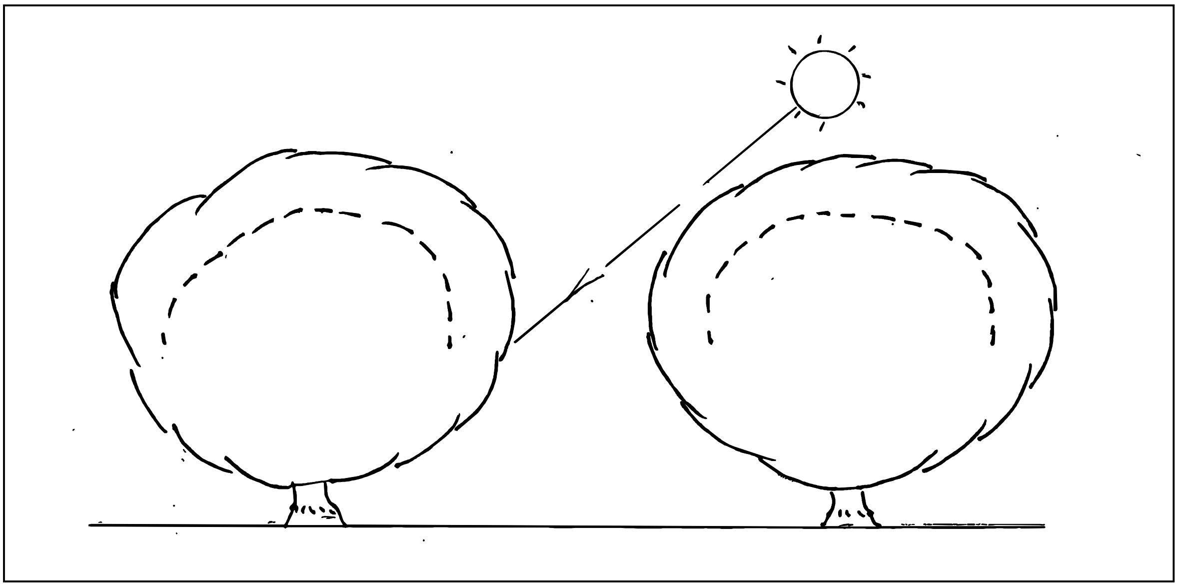

Fig 2. Multi-leader trees have high light interception and low light distribution
(Dotted line represents the limit of effective light penetration to 1.5m)

Angled hedgerows (eg. Central Leader trees) have better light distribution than trees hedged with vertical sides (Fig 3&4). The natural growth habit of many fruit trees, in the unpruned state, is paraboloid with the height almost equal to the width. A 20^0 wall angle (70^0 to the horizontal) is close to the natural slope of the side of the tree at mid-height. If a walnut orchard has a 6m row spacing, a minimum of 2m was allowed as an alleyway for machinery and the canopy wall was angled at 20^0, the trees should be no higher than 4.8m to achieve optimum light interception.

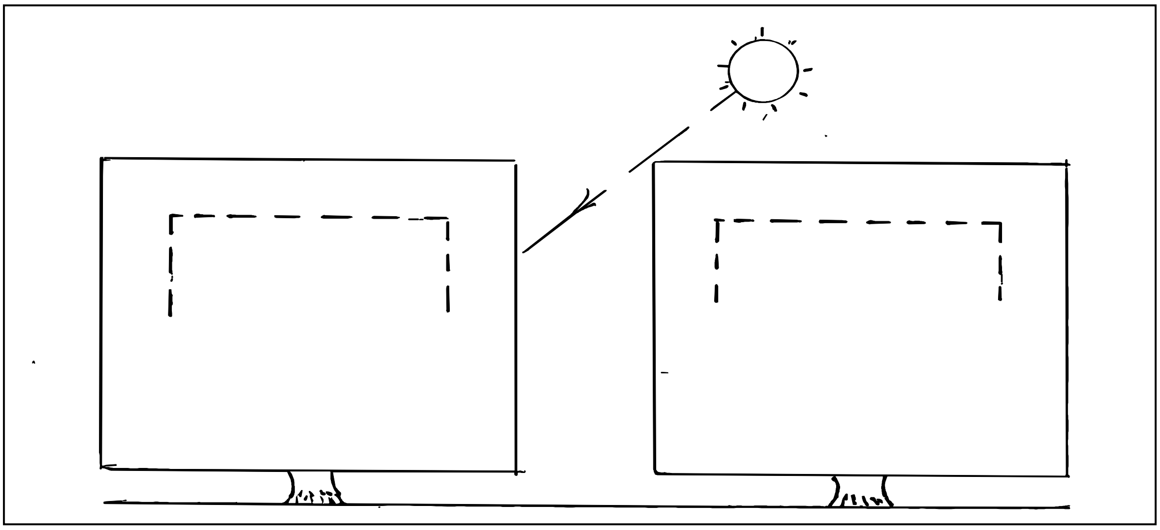

Fig 3. Hedged trees have high light interception and low light distribution

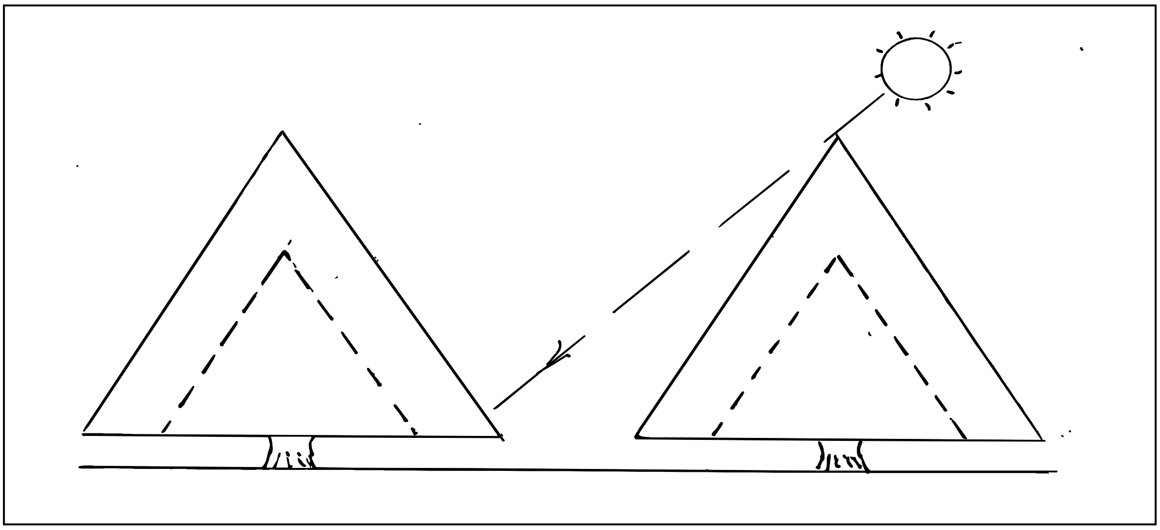

Fig 4. Central Leader trees have high light interception and high light distribution.

10.1 Pruning

Pruning is a dwarfing process and the apparent vigour induced by hard cutting of shoots is simply the tree attempting to grow back what has been cut off. The quickest way to grow a tree is to avoid heading cuts (shoots cut by 25-50%) and to leave the leaders alone. Shoots removed from a tree by pruning should be viewed as a loss of energy that the tree has expended. Skilled training of the tree canopy involves directing tree growth into a canopy to provide a strong framework, optimizes light interception and maximizes fruit production. The best way to do this is to remove unwanted growth before the tree has committed a lot of energy and resources. If the shoot placement is correct but the angle is wrong, bracing or tying of the shoot at the correct angle is an efficient way to train the tree without wasting growth.

10.2 The central leader tree

Many species of nut trees have an apically dominant structure and grow naturally into a Central Leader tree. This tree shape is one of the most efficient for light interception and crop production. Proponents of The Central Leader trees claim that less feeder leaves are needed per fruit for its development and more fruit can be produced per unit stem diameter. On the negative side are claims that Central Leader trees are harder to prune, more mistakes are made and the risk of sunburn may be higher. Walnut trees trained to a Central Leader shape have the potential to yield higher, for longer and are better suited to mechanical harvesting than either a vase-shaped or a Multi-leader tree.

10.3 The three-to-one rule

In a Central Leader tree, failure to remove branches greater than one-third the diameter of the main stem (3:1 Rule) and multiple branching at one point will result in reduced apical dominance and a weak or stunted central axis in the tree (Fig 5). If we consider the framework of the tree as a system of branched pipes carrying water from the roots to the tips of each shoot, our aim is to conduct the bulk of the water to the tip of the central pipe (stem) to maintain apical dominance. Branch pipes that have a diameter close to that of the main pipe, or where we have too many pipes originating from the one point, draw too much water from the main pipe. By keeping branch pipes to less than one-third (i.e. 3-to-1) the diameter of the main and only one branch at each point, we maintain apical dominance of the flow of water.

10.4 Pruning at planting

When planting a new orchard, strong laterals and those with a narrow angle to the trunk should be removed. This maintains apical dominance and restores the balance between shoots and roots. Cutting of the scion helps to restore the top-to-root ratio of the tree where major root loss has occurred in cutting of the taproot or in potted trees where fine roots may be lost through drying. In spring and early summer, a single shoot is allowed to develop and competing shoots are removed (by thinning cuts) or restricted by pinching out the growing tips. The remaining shoot develops into a single rod to form the central leader (axis) of the tree.

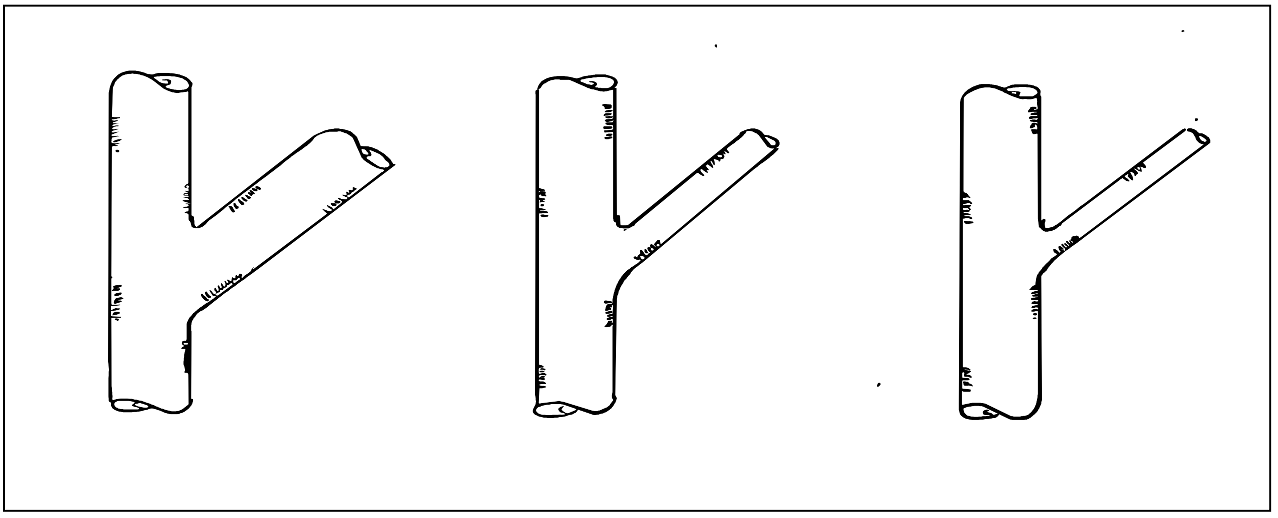

Fig 5. Ratio of stem to branch size: Incorrect 1:1 (left) & 1:2 (centre); correct 3:1 (right).

10.5 Limb bending

Limb bending is a technique employed to maintain apical dominance in a Central Leader tree by keeping the leading shoot uppermost and spreading other shoots away from the vertical. Bending (or bending and twisting) as opposed to pruning of limbs, is an economical way of reducing carbon loss through removal of wood, is quick and can induce early bearing in young trees (Plate 15). Limb bending concentrates the auxins produced in the apical bud to encourage growth in the uppermost shoot.

Walnut trees at the INRA research station near Bordeaux, France showed significant, earlier bearing and higher yields when scaffold limbs were bent from a near vertical to a horizontal position. When the trees were three years of age, limbs were bent, either by hand or through the use of poles with a hook at one end. Bending was done just beyond the elastic point of the wood so that the limb remained in the desired position. The best time for the operation is in mid-summer when the limbs were heavily laden with fruit.

Plate 15. Limb bending has increased fruitfulness and reduced vigour in walnut trees

10.6 Girdling, scoring, notching, cincturing and pinching

Girdling, scoring, notching and cincturing are all less invasive methods than pruning and serve to stimulate bud break, promote shoot growth or even reduce the vigour of a tree (Plate 16&17).

Girdling involves the removal of a 5 to 10mm strip of bark from around the circumference of a limb. Girdling in the winter and spring months can increase yields in some cultivars whilst in late summer or autumn girdling has no effect. Girdling has also been shown to reduce alternate bearing in some cultivars.

Scoring is a cut made with a knife, a saw or a chainsaw but unlike girdling the cut is made for one quarter to one half of the circumference of a limb. The width of the cut may vary from 1 to 10mm where the narrower cuts are designed to heal quickly and be effective for the current season whilst the larger cuts may be effective for several years.

Notching and cincturing is a cut made a few millimeters above a bud around half the circumference of the limb in order to stimulate bud break. The cut can be made with a knife but weakening the limb should be avoided by not cutting too deeply past the cambium layer beneath the bark. A 30mm wide, steel spatula with a 90^0 vee-notch in the end of the blade is a useful tool for this method.

Pinching has been described as the manual removal of the distal part of a current season's shoot before lignification to stimulate the emergence of new lateral shoots (Plate 18). Pinching is also an effective way to regulate the growth of vigorous shoots by removing the terminal bud. This method is fast, does not require tools and preserves the photosynthetic (leaf) area. When done in a timely fashion, pinching is far less invasive to the tree and easier than pruning.

Plate 16. Scoring trunks with a vee-notched tool

Plate 17. Shoots induced by scoring

Plate 18. Pinching out unwanted shoots

10.7 Alternate bearing

Alternate bearing in walnut trees is the event of a heavy crop in one year followed by little or no crop in the next. The physiological mechanism for this pattern is not well understood but it is thought to involve nutrition, soil water status, time of harvest, pruning and climate. Alternate bearing increases with tree age and once started it becomes more difficult to manage. Some control of alternate bearing has been achieved by girdling branches of some cultivars (see section on girdling).

11.0 Pest and disease control

In Australia, there are few pests and diseases which affect walnut production making the walnut an ideal crop for organic production. In contrast, orchards in California can be affected by more than 20 insects and 10 diseases as well as nematodes. Codling moth *(Laspeyresia pomonella)*, a major pest of apples and pears in Australia and the USA, is rarely a problem in walnuts in this country but affects crops in the USA.

Walnut blight *(Xanthomonas campestris pv juglandis; syn. X. arboricola* pv. *juglandis)*, a bacterium affecting flowers, leaves**,** shoots and nuts, is a major problem of walnuts throughout the world including Australia. Walnut trees are particularly susceptible at flowering, especially during wet weather in spring and early summer.

Symptoms appear on current season's growth as dark lesions, 3-6 cm long on infected shoots. Brown to black spots, with lighter coloured edges, appear on leaves and severe infections may cause leaf drop. Infected catkins shrivel, darken and become distorted. On female flowers and nuts, the first symptoms are small, water-soaked spots, which expand rapidly. Nuts infected at an early stage will have shrivelled kernels and drop prematurely. In older nuts, the hull sticks to the shell with black, sunken areas on the surface of the hull and the kernel turns black. The disease develops rapidly when the daily average temperatures are between 12^0–20^0C for 13–14 hours and leaves are wet for between 8–12 hours.

The disease can be managed by spraying the trees with copper-based sprays and by planting late-flowering cultivars to avoid the worst infection period. The amount of metallic copper recommended is 4.5 kg/ha. A fungacide is sometimes added to the copper spray to improve control of walnut blight.

The first spray should be applied at the bud-break of the terminal pistillate flowers. Effective blight control requires all susceptible surfaces to be protected by a bactericide. If possible, spray before there is rain. Spraying after rain only gives protection for subsequent rain that may follow. In a low rainfall season, two to three applications during bloom may control blight, but in a wet season sprays repeated at 7–10 day intervals through bloom, or until rainfall stops, are necessary.

Phytophthora Root Rot is a major disease of fruit, nut and ornamental trees the world over. Three species affect walnut trees, namely *Phytophthora cinnamomii, P. cactorum* and *P. citricola.* These fungi are present in most orchard soils and spread quickly through mobile spores when the soil is saturated, especially in warm weather. Infected leaves turn yellow and drop and the trees may die within a few years.

Eradication of *Phythophthora* from infected soil is very difficult and success of control of the spread of infection in the tree depends on early detection. Recently infected trees show slow bud development and shoot growth in the spring. Careful soil management that includes an organic mulch as well as careful irrigation and drainage will reduce the risk of infection.

12.0 Bird pest management

In Victorian walnut orchards, long-billed corellas, sulphur-crested cockatoos and galahs are causing substantial crop losses and damage by tearing and breaking young shoots and leaves. Effective management depends on careful, daily monitoring of the presence and behavior of birds, particularly the scout birds that discover the food source and attract the rest of their flock. There is a wide variety of bird scaring devices, from scarecrows, gas guns, glittering strips and helium-filled balloons, which are placed in the orchards. Usually more than one type of deterrent will have to be installed. Birds do get accustomed to the techniques employed and become less frightened by it so the source of sound, altering the direction of the speakers, or the intervals between repeating sounds will make the system more effective.

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