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RESEARCH & DEVELOPMENT CORPORATION

Alley Farming in Australia

Current research and
future directions

A report for the
Rural Industries Research & Development Corporation
by
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“Alley Farming in Australia: Current Research and Future Directions”

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Foreword

Trees have the potential to increase sustainability and productivity of agriculture. Alley farming, also known as alley cropping, is a form of agroforestry where crops and pastures are cultivated in the alleys between spaced rows of trees or shrubs.

It has been researched in developing countries of the tropics and is now being trialed and practised by farmers in Australia, usually at wider spacing than in the tropics.

Tree planting on farms is becoming more widespread and popular. However, more research is needed to allow adaptation of our farming systems to make the best economic and ecological use of trees.

This publication considers some of the key research issues relating to alley farming in Australia. It looks at the history of alley farming around the world, current practice and the characteristics of the success stories.

It analyses the economics of alley farming and the challenges of appropriate research and development in Australia.

The report results from one of a series of projects within the RIRDC / LWRRDC / FWPRDC Joint Agroforestry Program which aims to develop practical agroforestry and farm forestry systems for the combined purposes of commercial production of forest products, increased agricultural productivity, and sustainable management of natural resources within the agricultural environment.

Peter Core

Managing Director

Rural Industries Research and Development Corporation

ALLEY FARMING IN AUSTRALIA: CURRENT RESEARCH AND FUTURE DIRECTIONS

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EXECUTIVE SUMMARY

The executive summary has been compiled under the headings as set out in the Table of Contents. Further information on any topic is contained under the same heading in the body of the text. See Table of Contents for page numbers.

Section 1. SETTING THE SCENE

1.1 General Introduction

Most annual crops and pastures are yield-limited by rainfall, yet do not use as much water as the pre-existing vegetation. If substantial portions of the landscape are re-planted to trees to control rising water tables, competition by trees for scarce resources is likely to be high. Acceptable agroforestry strategies must minimise the disruption to annual based farming systems while fulfilling the ecological imperatives.

1.2 A brief history of alley farming world wide

Alley cropping research generated enormous enthusiasm world wide in the early 80's as a new productive and sustainable farming system. Fifteen years later there are doubts about its productivity. Once alley cropping research moved out of the wet tropics, tree/crop competition made it unacceptable. Problems of experimental design have also clouded some of the early optimism. Today research is focussing on “smarter agroforestry designs”, with emphasis on tree root distribution and phenology.

Section 2. ALLEY FARMING IN AUSTRALIA

2.1 Current commercial practice

Alley farming is being practised in the south-west of Western Australia (about 10,000 ha), south eastern South Australia (several hundred hectares), the mallee and Wimmera of Victoria (less than 100 hectares) and in south eastern Queensland (less than 100 hectares). Some 5,000 ha of this has been planted specifically to control rising water tables in the wheatbelt of Western Australia while the rest are multipurpose plantings for fodder, timber, wind protection and soil improvement.

2.2 Research projects; past, in progress and planned

Thirty eight research projects were identified as being related to alley farming. Only seven of these involved studies of resource competition at the tree/crop interface; six of the seven are focussing on above ground competition (four of those being sites in the National Windbreaks Program) and one on below ground competition. Thirty of these studies are at the tree/crop scale, seven at the catchment scale and one looking at whole farm economic impact.

2.3 Literature review

Twenty two Australian publications on alley farming were identified by this study. Half of those were concerned with the Leucaena alley cropping system in northern Australia, and were mainly experimental reports. The other half dealt with a range of alley farming systems in southern Australia and were predominantly descriptive or speculative with only two reporting on experiments.

2.4 Characteristics of major successes

Only one example of an alley farming system could be found that has been studied in sufficient detail to clearly identify it as economically and ecologically successful. This is a timber/pasture alley system in a high rainfall environment where the tree species is of high value and where there appears to be abundant water at depth.

2.5 Constraints to adoption

Uncertainty over the impact of alley farming on crop and pasture production and environmental factors, the capital cost of establishment, the lag time between establishment and benefit, the complexity and indivisibility (all-or nothing-nature) of the technology and the visual impact on the landscape were all cited as constraints to adoption by people contacted during this study.

Section 3. THEORETICAL FRAMEWORK FOR RESEARCH

3.1 How much land should be planted to trees

This depends on how much water trees use, which in turn depends on tree location, arrangement, rooting depth, soil type and climate. Perhaps the greatest unknown is the amount of water different tree species can use from partially saline watertables. The limited number of catchment studies in Australia suggest at least one quarter of the landscape needs to be planted to trees to stabilise watertables and up to half to radically turn the problem around.

3.2 How should trees be positioned in the landscape

Planting of uppermost parts of catchments is least disruptive to agriculture. Tree productivity and water use will be higher in strip plantings lower in the catchment where there is a contribution of water from up slope. Plantings in discharge areas lower in the catchment are likely to be salted out unless salt can be exported from the root zone.

3.3 The tree crop interface

Alley cropping gives one of the longest tree/crop interface lengths of all agroforestry options. If the interaction at the tree/crop interface is positive (i.e. value of crop + tree products increased), then we should maximise the length of the interface. However if the reason for tree planting is to counter land degradation, but trees compete strongly with the crops, the interface should be kept as short as possible, without compromising the job of lowering the water table or protecting the soil.

3.4 Alley cropping case study

Quantification of competition at the tree/crop interface is the most important information needed to design an alley farming system.

3.5 Tree rooting patterns

Agroforestry systems can only be viable if temporal, spatial and functional niche differentiation is used to reduce competition between tree and annual crops.

3.6 The use of models in agroforestry

There are many existing models which address aspects of agroforestry. Model development in Australia should focus on salt/watertable/tree water use interactions by strips or isolated trees and competition between tree and crop root systems. More information is needed about how efficiently different trees species extract water from depth.

3.7 Designing an Alley Farming System

Design and species selection will depend largely on the depth and salinity of the watertable (where water tables are high) or the vertical and horizontal root distribution of the trees (where water tables are below rooting depth but rising).

3.8 What about perennial pastures?

In situations where soils are deep and have a high water holding capacity, strategic rotations between crops and perennial pasture species like lucerne may be sufficient to prevent significant deep drainage. Simultaneous cropping and trees (alley cropping) is required when drainage is rapid or root exploration of the subsoil is slow.

Section 4. ECONOMIC ANALYSIS OF ALLEY FARMING

4.1 How alley farming can effect crop yield

Crop yield at a commercial alley farming site dropped off close to the alleys. This highlighted the importance of understanding tree/crop interactions, the width and spacing of the tree lines and the economic value of the tree crop when determining the economic impact of the practice at the paddock level. The important criteria for tree selection are high economic value (T) and low competition effects (Y1). Important aspects of management are design to limit the area of lost arable land (D), and possibly root pruning.

4.2 Whole farm economic modelling of alley farming

A whole farm economic study of tagasaste alley farming in the coastal sandplain area of Western Australia showed that where trees of high economic value are involved, alley farming will be selected over other land use options without having to factor in the positive environmental impact of the trees.

Section 5. CHALLENGES FOR R&D IN AUSTRALIA

5.1 Scaling between levels of inquiry

A single farmer cannot address environmental issues arising on a regional or catchment scale. Questions such as “what proportion of the catchment must be planted to trees” and “where in the catchment should the trees be located” should first be addressed at the regional scale. The arrangement of those trees with crops on a farm requires knowledge of how trees and crops interact. The solutions must be consistent across scales.

5.2 Maximising complementarity in tree/crop systems

Alley cropping may be practiced because the trees provide a new product (eg fodder), enhance the growth of crops through shelter (windbreaks) and/or protect the resource base (eg. lower watertables). To optimise the alley cropping design we need to know how to minimise the competition between trees and crops and maximise their complementarity. Information is required on how different tree species interact with water tables as a function of their depth and salinity. Coupled water and salt transport models are needed in conjunction with well designed field trials. Where the watertable is deep, we need to know how water and nutrients will be allocated between trees and crops in the interfacial zone. We need information on how effectively trees remove water from deep in the soil profile with respect to potential evaporation. These issues require the development of theoretical frameworks in conjunction with field trials to provide data for models which can extend the information to other soils/climates.

5.3 A checklist for alley farming research

The section concludes with a list of considerations as a check to whether alley farming would be an appropriate agroforestry system for a given environment.

RECOMMENDATIONS

- Research is needed to ensure consistency between regional, catchment, farm and paddock scales in deciding the proportion of the landscape planted to trees and their distribution.
- Research (modelling, experimental) is needed to characterise the tree crop interface of a variety of different species x soil x environment combinations. The data will be used as a predictive tool to assess various agroforestry designs.
- Research (mainly experimental) is needed to characterise tree water use from water tables of different depth and salinity and the efficiency of uptake of good quality water by trees from unsaturated subsoils.
- Experiments will require long lead time to set up and will need to be carried out in different environments. Identification of existing field experiments which can be expanded and coordinated to address the above issues would be the most sensible way forward.

Section 1.

SETTING THE SCENE

This study was undertaken in two parts. Richard Stirzaker reviewed international experience of alley cropping (which included a week at the International Centre for Research in Agroforestry in Nairobi, Kenya) and also put together a theoretical framework for alley farming research. The focus is on understanding how trees and crop interact, the way we should approach experimental work and the data required for modelling alley farming. This information is contained in section 1 and section 3 of the report.

Ted Lefroy reviewed the commercial practice of alley farming in Australia, current research underway and economic appraisals in the Australia context. This was done through telephone interviews with over fifty researchers, extension personnel and landholders, a visit to the Murray Mallee and Lower South East of South Australia and a search of databases and bibliographies, and is contained in sections 2 and 4 of this report.

We have attempted to bring all this information together in section 5, and in so doing recommend strategies for future research into alley farming in Australia.

This report does not cover the effects that strips of trees have on modifying crop microclimates or shelter for stock. These issues are being addressed by The National Windbreak Program. The report also does not cover how forestry practice would need to be modified when growing trees in strips as opposed to plantations.

1.1 General Introduction

Farming systems based on introduced shallow-rooted annual crops and pastures are the mainstay of Australian agriculture. However the replacement of trees and native pastures with annual species has set in train slow and subtle changes to the hydrology of the landscape. The cumulative effect of these changes goes unnoticed at first, but becomes catastrophic when saline watertables rise to within the rooting zone of crops, or break out at the surface. Salinity is perhaps the most feared consequence of tree clearing, but there are many others; these include accelerated wind and water erosion, nutrient leaching and loss of biodiversity.

The paradox of Australian agriculture is that most crops and pastures are yield-limited by rainfall and nutrients, yet our agricultural systems are not efficiently capturing these resources in the first place; rising watertables and subsoil acidity (caused in part by the leaching of nitrate with associated cations) present clear evidence of this. These problems are not easily amenable to agrochemical or engineering solutions. The consequence of a changed hydrology over a vast area is essentially a biological problem that, as far as possible, requires biological solutions i.e. the re-introduction of trees and other deep rooted species into the landscape. Land holders would then be faced with the same problem that confronted them before the land was cleared, that competition by trees for scarce resources was unacceptably high. The aim of agroforestry system is to maximise the positive interactions between trees and annual species and minimise the negative ones.

Farm forestry is being encouraged in Australia, but adoption is slow because farming with annual species is perceived to be more profitable. Some farmers have diversified to include timber production in their operation so as to spread risk. There are two other reasons for planting trees. Trees can enhance the productivity of existing operations. Examples include the planting of windbreaks to improve water use efficiency of crops, and fodder trees to fill seasonal feed gaps for animals. The second reason for tree planting is to maintain the

productivity of a farm by addressing the results of land degradation. Examples here include tree planting to reduce erosion or to manage rising watertables. Agroforestry design must balance the benefits of trees (direct value of trees and the enhancement of other farm enterprises) and the problem of tree plantings (displacement of crops, competition for water, light and nutrients) with the cost of doing nothing (land degradation).

Alley cropping is one form of agroforestry, defined as a system where crops and pastures are cultivated in the alleys between spaced rows of trees and shrubs (Kang *et al.* 1990). It can fulfil many of the desirable requirements of trees described above. An important aspect of alley cropping is that there is a wide distribution of trees across a landscape. This increases the chance of capturing water which would have otherwise contributed to deep drainage. On the negative side, there is a large area of overlap between tree and crop root zones which would increase the competition between trees and annual species. Thus much of this review focusses on water issues, both reducing recharge and competition between crops and trees. In the words of Pedro Sanchez, the Director General of ICRAF, "Alley cropping is like playing with fire, because it has strongly positive and strongly negative interactions and thus requires precise fine tuning in every situation"

1.2 A Brief History of Alley Cropping world wide

Formal research into alley cropping started as late as the late 1970's, at the International Institute of Tropical Agriculture in Nigeria. Kang *et al.* (1990) record three factors which led to the development of this technology. First, multi-purpose trees and shrubs already played a major role in traditional farming systems in the tropics. Second, the traditional shifting cultivation was resulting in forests being cleared many times faster than they were being replanted. Third, there were large areas of infertile soils that erode and acidify under modern agricultural methods, making crop production unsustainable.

In the wet tropics, cropping took place for only a few years after clearing before infertility and weed invasion made it impossible. The natural forest regeneration did restore soil fertility, but, as population pressure grew, it took an unacceptably long time to do so. In order to shorten the fallow period, farmers selectively retained certain trees during clearing and planted other trees after the cropping period, and so created improved or managed rotations. The development of alley cropping required a conceptual leap from the established rotation practice; tree and crop phases were now separated in space, rather than time, a situation which has many advantages as well as attendant difficulties.

On leached soils with rainfall exceeding 1000 mm, field crops were limited by nutrients, rather than water, and the main role of the trees was to provide nutrients for the crop. Kang *et al.* (1990) lists the desirable characteristics of a tree for alley cropping; ease of establishment, deep root systems, fast growth, tolerance to pruning and ability to coppice, ability to fix nitrogen and nutritious to browsing stock. At least 5 to 10 t ha⁻¹ y⁻¹ of prunings are needed to provide these nutrients, even for modest grain yields. To achieve this amount of prunings, tree rows were often spacing only 4 to 6 m apart, and cut back several times per year to prevent shading of the crops.

Research results from IITA showed that *Leucaena*/maize alley cropping could sustain maize yields of 2 t ha⁻¹, and higher yields with the application of fertiliser (Kang *et al.* 1981). Spurred on by encouraging results at IITA, alley cropping research spread to other parts of Africa (Arap-Sang, 1986), India (Singh *et al.* 1986; Rao *et al.* 1991), South America (Szott *et al.* 1991), the Philippines (Maclean *et al.* 1992) and Indonesia (Parera 1986), supported by a massive injection of funds from donor nations. Ten years later, experiences from around the world are mixed at best and frequently disappointing. This raised the question - was alley-

cropping being tested in the wrong environments; were there problems with the way experiments had been carried out, or was the whole concept technically flawed (Ong 1994; Coe 1994)?

Today, it appears that alley cropping may have a role in the wet tropics with non-acid subsoils or on sloping land, but is marginal in comparison to a cereal/legume rotation when annual rainfall is less than 1000 mm. Alley cropping is also not suitable in low base status soils, because the trees do not grow fast enough and there are not enough nutrients to recycle through the trees to the crops. In most situations the trees are too competitive and cannot be pruned frequently enough; crops were shaded and a large proportion of nutrients released from prunings was recaptured by the trees before the crops could take them up. There were certainly some design flaws in major alley cropping experiments. Ong (1994, personal communication 1995), re-evaluated 7 major long term alley cropping trials from around the world. A recurring problem was that experimenters assumed that there was little competition between trees and crops in a humid environment. Control plots were taken as plots which received no tree prunings, but closer examination showed that these "control plots" were riddled with roots from alley treatments 20 m or more away.

Given that alley cropping has largely failed in semi-arid India and Africa, it seems strange that it should be considered in even drier parts of Australia. However, apart from Leucaena/pasture systems in Northern Australia, alley cropping appears to have arisen *de novo* in response to a peculiar suite of local problems, with little influence from the work in other parts of the world. The driving force behind alley cropping in tropical regions was to reduce erosion, provide nitrogen from legume shrubs and to recycle cations from depth; nutrients, not water, limited yield. A suite of environmental problems has accompanied tree clearing in Australia, with rising water tables arguably the most important in Southern Australia. Despite the differences between the Australian environment and the environment where alley cropping research has been carried, several lessons have been learnt which are pertinent to the Australian situation.

These hard lessons have also opened the way for new ideas which are being followed up at ICRAF. The first of these was to select trees based on their below-ground characteristics rather than their above-ground productivity. An example is the comparison between *Eucalyptus camaldulensis* (called "Drinkwater" in Swahili) and *Grevillea robusta*, considered by farmers to be a good tree. Researchers found out that *Grevillea robusta* had a root system that could penetrate acid subsoils and was capable of extracting phosphorus from low P soils by way of its proteoid roots (Harwood and Booth 1992). Another line of progress has been the investigation of quick measures of root distribution. Based on fractal models, a relation is expected between the diameter of roots at the stem base and the total length of roots, given a few parameters about the branching pattern which can be obtained from small samples made close to the trunk (van Noordwijk *et al.* 1994). Finally there is the search for trees displaying unusual phenology. An example is *Paulownia tormentosa*, which is intercropped with wheat in more than 2 million hectares throughout China at a density of 40-70 tree ha⁻¹. *Paulownia* is a fast growing tree which breaks into leaf very late in the season, when the wheat is already in head (Yunyin and Dalmacio 1991). These ideas have been encapsulated in the Alley farming equation (Ong 1995, see section 3.3), which provides a framework for quantifying competition and complementarity between trees and crops.

Section 2.

ALLEY FARMING IN AUSTRALIA

Alley farming is a farming system where crops and pastures are cultivated in the alleys between rows of trees and shrubs

(after Kang et al 1990)

2.1 Commercial practice

In surveying alley farming practice and research in Australia, it became apparent that there is overlap between alley farming as defined above and windbreak or shelter belt systems, which have been the subject of research in Australia for some time (Bird 1992). These two forms of agroforestry can be regarded as lying on a continuum; at one end of this continuum are windbreak systems with belts of tall, long lived tree species spaced hundreds of metres apart. The primary goal is to moderate the above ground growing conditions of crops, pastures and animals.

At the other end of this continuum are alley farming systems featuring rows of lower growing, short lived shrub species spaced tens of metres apart, the purpose being to add the commercial value, water use and soil conservation role of trees and shrubs to cropping systems. Between these extremes lie a range of multipurpose systems designed with differing emphasis on shelter, water use and the economic value of the trees and shrubs.

Two distinct forms of alley farming currently exist in Australia. In southern Australia, the prime motivating factors for the development and adoption of alley farming has been salinity and wind erosion. The first examples were developed in Western Australia with interest spreading to South Australia and Victoria through farmer visits organised by extension workers and Landcare groups. This development occurred quite independently of alley cropping in the tropics and took place mainly on farms, initiated by farmers, with little formal research support (Lefroy 1994).

In northern Australia, alley farming research and the promotion of alley cropping systems based on *Leucaena* (*Leucaena leucocephala*) is a direct consequence of research in Africa and Asia (Gutteridge 1988). The intention of these systems is to use fast growing leguminous shrubs to improve soil nitrogen status and reduce soil erosion. It is difficult to see these systems having wide-spread application to Australian agriculture for two main reasons. Firstly because recent research, referred to in the previous section of this report, has cast serious doubt on this alley cropping system due to the highly competitive nature of this shrub species. Secondly because the close spacings (5-10 metres) necessary to produce the nutrient cycling benefits and the frequent tree pruning necessary to return mulch to the inter row crops and limit shading are practices unsuited to broad acre extensive farming systems.

Alley farming is currently being practised commercially in the south-west of Western Australia (about 10,000 ha), south eastern South Australia (several hundred hectares), the mallee and Wimmera of Victoria (less than 100 hectares) and in south eastern Queensland (less than 100 hectares). Some 5,000 ha of this has been planted specifically in an attempt to control rising water tables in the wheatbelt of Western Australia. The scale of the salinity problem facing the Western Australian wheatbelt is such that this has happened without evidence of the effectiveness or economic consequences of this approach. The remaining areas have been established primarily for the shelter value and commercial value of the trees while the limited interest in Queensland is on the basis of improving soil fertility and fodder supply. This section reviews the current state of commercial practice.

Western Australia

Four different styles of the alley farming concept can be found in Western Australia. These have been described by Lefroy and Scott (1994) as timberbelt alley farming in the high rainfall South-West, saline alley farming in the wheatbelt, sandplain alley farming on the light soils of wheatbelt and coastal sandplains and 'mallee-alleys' for the experimental production of eucalyptus oil in the wheatbelt.

Timberbelt alley farming

This form of alley farming first developed from wide-spaced agroforestry experiments established in the late 1970's. The wide-spaced agroforestry system allows simultaneous production of high value trees and pasture. It has been used for centuries in southern Spain and Portugal for cork production and grazing, and more recently in New Zealand for timber and sheep production. A disadvantage of this design is the long period from planting until the trees can withstand grazing. This means there is little or no income from the land for four or five years. Richard Moore, Department of Conservation and Land Management forester, saw the alley farming layout as a solution to this problem as it would allow income from cropping or hay production between the rows of trees during those early years. In 1981, he planted an experimental area of pines (*Pinus radiata*) and eucalypts (*Eucalyptus saligna* and *E. accedens*) in four-row belts separated by 20 metre alleys near Bowelling in the Collie River catchment. The tree rows were planted parallel and oriented north-south to minimise shading of the pasture.

Bridgetown farmers David and Di Jenkins used the same approach when they planted a paddock in 1987 to three-row belts of mixed *Eucalyptus globulus* and *E. saligna*, leaving 25 metre alleys between. The Jenkins chose this type of agroforestry for several reasons. First, they wanted to maintain hay production and grazing while they added the trees as an extra source of income (high value saw logs and pulp from the thinnings). Second they wanted to minimise drought stress on the trees by spacing them out. Finally, they needed some way to increase water use over much of their farm to prevent the waterlogging and salinity that was beginning to show up in the valley floor.

Measurements of tree growth and sheep carrying capacity after six years indicated that this paddock had produced 78 per cent of the timber production expected from a plantation of this age, and 52 per cent of its carrying capacity as a pure pasture paddock over that period (Lefroy and Scott 1994). This level of timber production was confirmed in year seven when the stand was thinned (Jenkins pers. comm.). This complementarity between the tall deep-rooted summer-active trees and the shallow-rooted winter-active annual pasture can be expressed by calculating the Land Equivalent Ratio* for this paddock. This ratio shows that it would take 30% more land to produce the same amount of pasture and the same amount of timber in separate monocultures. At the same time, the trees have begun to lower the watertables in the valley floor. Some catchment studies suggest that the greatest impact on rising groundwater levels would come from planting trees in wide spaced rows over much of the landscape, rather than trying to identify specific recharge areas and concentrating them there. This endorses the Jenkins' approach. On cultivated land, an alternative to the narrow alleys with a north-south orientation is to plant below contour banks.

Some unexpected advantages of this system have shown up recently. First, there was a graphic demonstration of the lower fire risk of the alley farming approach in late 1991. Low fuel levels in the agroforestry area (due to grazing) and low wind velocity because of the trees meant that a fire burning across an adjacent open pasture paddock slowed markedly at the edge of the agroforestry area enabling control. Second, the low tree density of 450 stems per hectare has protected the trees from drought when compared to plantations. Nearby plantations, which normally have densities of about 1200 trees per hectare, have suffered up

to 30 per cent loss over recent dry summers. In commercial terms, this form of alley farming is obviously best suited to the high rainfall part of the south-west where timber production is viable. Spreading trees out into wide-spaced rows does raise the possibility of growing trees for timber in lower rainfall areas than would be recommended for tree plantations. In ecological terms, timber alley farming roughly mimics the eucalypt forest that formerly occupied these sites.

An estimated 200 ha of this style of narrow timberbelt alley farming has been established recently in the high rainfall area of WA using Tasmanian bluegum and *Pinus radiata*. In addition to the narrow alley format, the use of a wider contour tree planting pattern based on the Keyline system of Yeomans (1958) has been pioneered in the south west of WA by Ron Watkins at Frankland (Watkins 1991), originally with *Eucalyptus maculata* and more recently with Tasmanian bluegum.

*The Land Equivalent Ratio is a means of determining if there is any advantage in growing plants in mixtures rather than monocultures. To calculate the Land Equivalent Ratio, divide the yield of each crop in the mixture by its yield in monoculture in the same environment and add these fractions. The example below uses measurements from the Jenkins' timber alley farming taken at year six in a ten year tree rotation:

$$\begin{array}{rcccl} \frac{\text{Yield of trees in alley farming}}{\text{Yield of trees in plantation}} & + & \frac{\text{Yield of pasture in alley farming}}{\text{Yield of pasture in monoculture}} & = & \text{Land Equivalent Ratio} \\ \\ \frac{92 \text{ cubic metres/ha}}{118 \text{ cubic metres/ha}} & + & \frac{6.5 \text{ ewes/ha/year (mean over 6 years)}}{12.5 \text{ ewes/ha/year}} & = & \\ .78 & + & .52 & = & 1.30 \end{array}$$

The amount by which this ratio exceeds 1 indicates the percentage increase in land area necessary to produce the same amount in separate monocultures as in a mixture. In this case, it would take 30% more land to grow the same amount of timber and pasture in separate monocultures. When the ratio is greater than one, it indicates that there is more efficient use of resources (light, water or nutrients) in the mixture, either because the crops are using different resources or drawing on the same resources at different times. This can occur if the plants have different structures (such as height and rooting depth), different growing seasons or different resource needs (such as legumes and non-legumes). In this case, it is due to the compatibility of the tall, deep-rooted summer active eucalypts and the shallow-rooted, winter-active annual pastures in an environment with abundant water at depth.

Saline alley farming

Saline alley farming began with attempts to use trees as water pumps to lower saline water tables. The best documented example is at the Boundain property of Graeme Wilson, near Narrogin. This site receives about 500 mm of annual rainfall, and is one of several plantings of this type around the Narrogin region. Department of Agriculture researcher Ric Engels and adviser Tim Negus designed the planting at this site in 1981 to test the effectiveness of this simple concept. At the time, there was considerable scepticism that trees would even survive on these salt flats, let alone control watertables. These watertables were 1 to 3 metres below ground, with water quality of 500 to 3,000 mS/m, or about 2,750 to 16,500 parts per million. The experiment involved planting different species of salt tolerant trees, the swamp oak (*Casuarina obesa*), flat-topped yate (*Eucalyptus occidentalis*), salt river gum (*E. sargentii*), York gum (*E. loxophleba*), Kondinin blackbutt (*E. kondininensis*), red river gum (*E. camaldulensis*), and the swamp mallet (*E. spathulata*). The trees were planted five metres apart in single rows at 25 and 12.5 metre alley widths. These two alley widths gave tree densities of 80 and 160 stems per hectare respectively.

Watertable monitoring bores placed in the alley farmed areas and in an adjacent area not planted to trees showed that watertable draw-down in the alleys began in the fourth year after planting. The rate of draw down was similar at both the low and high tree densities. Sub-clover was successfully re-established in 1986 following leaching of salts from the soil surface after the groundwater began to recede. After that however, the story was not so encouraging. The trees, particularly the flat-topped yate, competed so strongly with the pasture that after a few years there was very little production in the alleys. Pruning the tree roots doubled pasture production in the alleys in the following season. The trees have fulfilled their role in terms of water use in this instance but have left the land with little commercial potential.

There are an estimated 5,000 ha of this type of alley farming in the medium to low rainfall areas of WA, commonly featuring a mixture of salt tolerant species of the genera *Eucalyptus*, *Acacia*, *Casuarina* and *Atriplex*. Major areas of activity are around Narrogin and Katanning in the 400 to 500 mm rainfall zone and in the central wheatbelt around Merredin in the 300 to 400 mm rainfall zone where there are an estimated 2,000 ha with one valley floor planting over a rising saline water table of 800 ha.

Sandplain alley farming

The term alley farming was first used in Western Australia to describe the approach that Dowerin farmers Dean, Sherren and Craig Melvin developed in an attempt to eliminate wind erosion and increase returns on some of their poorer sandplain country. In 1989, the Melvins brought together the results of two separate pieces of research when they began planting widely spaced rows of fodder shrubs across some of their worst sandplain.

The first of these was the work of Chris Oldham and his colleagues at the University of Western Australia when assessing the value of the leguminous shrub tagasaste as a browse plant for sheep and cattle. They had shown in grazing experiments with sheep that tagasaste could increase the carrying capacity of poor Badgingarra sandplain by a factor of six, from just over one dry sheep equivalent (dse) per hectare to eight. Cattle grazing the same tagasaste plantations produced in the order of 300 kg of liveweight per hectare per year.

The Melvins also drew on a windbreak study by Department of Agriculture adviser David Bicknell. On Gary and Jan English's farm at Esperance in 1988 and 1989, David recorded an increase in the yield of lupins and oats in the lee of a pine windbreak. That included allowing for the land taken up by the trees and the area of depressed yield that occurred within one to two tree heights of the windbreak. Influenced by these two experiences, the Melvins developed their alley farming system. They planted two to three rows of various fodder shrubs in north-south belts, initially with 30 metre wide alleys but more recently with alleys twice that width. The north-south orientation of the rows was to give protection against the most damaging winds, in their case north-westerlies, south-westerlies and easterlies.

A neighbour, John Thomas, has used a spiral design to control wind erosion, increase feed supply and make cultivation easier in an irregularly shaped paddock. The alley width in both cases is based on multiples of the widest implement. These paddocks, which normally could not produce a profitable wheat crop, have seen a marked increase in productivity. The Melvins claim a threefold increase in sheep carrying capacity and greatly reduced erosion risk associated with autumn grazing. With this layout, they have also maintained the option to crop. This means a greatly reduced risk of erosion with early lupin sowing and reduced spray drift, which in turn enables more timely crop spraying. The key questions are whether these benefits to crops outweigh the competitive effects of the trees in the *majority* of seasons.

This type of alley farming has been mainly taken up on the West Midlands sandplain region between Perth and Geraldton, with an estimated 3,000-4,000 ha established on some 50

properties. The tree species commonly used are tagasaste and *Acacia saligna*. Alley farming is being strongly advocated by regional extension staff of Agriculture WA as a means of controlling wind erosion, with a lot of attention being given to practicality of design and simplicity of establishment (Mitchell and Wiley 1995). Drilling programs in the region have indicated that water tables are rising in the order of 30 cm per year under the sandplain, but as they are still relatively deep in most areas, this is not as strong a motivating factor for the adoption of alley farming as protection from wind erosion (Russell Speed pers. comm.).

On the South coast sandplain between Albany and Esperance, landholder groups recently identified alley farming as a high priority for research and demonstration in an exercise coordinated by Agriculture WA in Albany (Don MacFarlane pers. comm.). Rapidly rising saline water tables were a major influence in this decision. While there are between 1000 and 2000 ha of wide spaced wind break plantings of pines and eucalypts on the Esperance sandplain, there are only a few hundred hectares of the narrower spaced alley farming plantings to date. This reflects the fact that there are more options available for water use and wind protection in the form of perennial pastures and timber species such as Tasmanian bluegums.

Mallee alleys

This form of alley farming is being examined by the Department of Conservation and Land Management and the Agriculture WA in collaboration with farmers at 30 sites on farms across the wheatbelt from Morowa to Esperance. The total area involved is approximately 1,500 ha. The aim is to test the feasibility of combining wide-spaced rows of mallee trees for eucalyptus oil production with conventional crops and pastures in the alleys. Under test is the assumption that spreading the trees out will result in faster and more uniform leaf and oil production than block plantings while still having an influence on ground water accessions and rising watertables. Shelter effects on crops and pastures in the alleys have been cited as possible benefits of this approach but are not being measured at these sites.

The use of eucalyptus oil in the industrial solvent market is being seen as an incentive for integrating deep rooted perennial plants into the wheatbelt landscape. The viability of a eucalyptus oil industry is uncertain at this stage because of the high production costs and a low world price, but this project has identified the improvements necessary in oil yield, harvest efficiency and extraction cost for an industry to be viable. A breeding program is under way to improve oil yield and various engineering approaches are being examined to improve harvest and extraction.

South Australia and Victoria

In 1992, 1993 and 1994, Primary Industry South Australia (PISA) staff and Landcare groups conducted farmer tours to WA to look at examples of alley farming and other approaches to farm revegetation. The establishment of several hundred hectares of close-spaced alley farming in south eastern Australia has resulted from these tours. The main interest has been shown by farmers in the Lower South East and Murray Valley of SA and the Wimmera and Mallee of Victoria. An Alley Farming Network was established in 1993 to keep interested landholders in touch with recent developments. This is coordinated by the Greening Australia Victoria representative in Nhill, Ron Dodds. GAV has produced six Alley Farming Network newsletters since July 1993, with a mailing list of 120. The term alley farming as used by this group includes wide spaced windbreak plantings, and there is currently more emphasis on trees for shelter and commercial value than water use.

Another consequence of this interest in alley farming in south eastern Australia was a collaborative research proposal between PISA, Agriculture Victoria and the Victorian

Department of Conservation and Natural Resources that is being supported by the Murray Darling Basin Commission. This currently employs scientists in Murray Bridge SA (Alex Knight), Walpeup, Victoria (Roger Lawes) and Bendigo (Darren McGrath) to carry out research into alley farming, coordinated by Greg Dalton, (PISA Murray Bridge). A major emphasis in this work is the water use potential of alley farming systems. The Alley Farming Network is being used as a means of information transfer for this project.

The most extensive example of alley farming in South Australia is a 160 ha planting on the property of Henry Angus at Meningie, South of Murray Bridge, in a 400 mm rainfall zone. This is a mixed planting of *Acacia saligna* and tagasaste established in 1993 on the Dean Melvin model following a visit to Western Australia. The primary purpose is wind protection with a secondary role of fodder supply. The alleys are 30 metres wide and established to lucerne. The high grazing pressure has meant that the tagasaste is gradually being grazed out.

A survey conducted in 1995 by Roseworthy Campus, University of Adelaide, identified 45 farmers who have established 1,200 ha of alley farming and fodder shrubs in South Australia (Ian Nuberg pers. comm.). Alley farming was not defined in the survey, so the responses covered a continuum from block plantings to wide spaced windbreaks. The range in alley widths was 2 m to 125 m with a mean of 32 m and a median of 20 m. Of the plantings considered by the landholders to be alley farming, 22 were for fodder supply, 11 for shelter, 4 for timber and 4 identified as multipurpose. The multipurpose nature of the plantings was further indicated by the fact that 19 out of the total 45 respondents identified salinity control as a reason for establishment. The tree and shrub species used were *Atriplex spp* (26), tagasaste (25), *Acacia spp.* (18) and *Eucalyptus spp.* (15). The inter-row was used for cropping in 13 cases and pasture in 32.

In Victoria, the main interest appears to be in the Wimmera around Horsham where there are a small number of sites at the windbreak end of agroforestry systems with mixed belts of eucalypt, acacia and casuarina species at 150 m to 200 m apart. In the mallee there are some wide spaced plantings of *Atriplex nummularia* and near the South Australian border at Harrow, a planting of tagasaste at 30 m spacings.

Queensland

There is growing interest in using *Leucaena* as a high protein fodder for cattle in areas where there are no well adapted pasture legumes. Much of this interest has been fuelled by the good performance of *Leucaena* during a run of below average rainfall seasons. There are also commercial plantings in Queensland (<100 ha) on the eastern Darling Downs at Greenwood and in the Lockyer Valley. These involve *Leucaena* at spacings between 5 and 10 m with vegetable crops in the alley. The trees are cut several times a year to provide mulch for the crops. These plantings are a direct result of research work by Gutteridge (1988) in the Lockyer Valley and at the Queensland University Redlands Bay Research Station which in turn are based on the *Leucaena* alley cropping systems described by Kang *et. al.* (1990) and others in Africa. Recently there has been increa

2.2 Research, past and present and planned

Thirty eight research projects in Australia were identified as having particular relevance to alley farming. The criteria used to identify these projects takes a broader definition of alley farming than the one used in reviewing the literature. This has been done to include work such as farm forestry and windbreak research that is not specifically identified as alley farming research but is relevant to the biological and economic assessment of alley farming.

Northern Territory

1. Katherine Research Station

Leucaena alley farming experiments comparing the nitrogen contribution of mulched Leucaena foliage to that of nitrogen fertiliser. (Z. H. Xu, see Xu *et. al.*, 1992a,b, 1993). Only about 4 to 14 % of the nitrogen contained in the Leucaena was recovered by a subsequent maize crop, compared to recoveries of between 24 to 79% from fertilisers.

Queensland

1. University of Queensland

Leucaena alley farming experiments at Redlands Bay Research Station and on a commercial property in the Lockyer Valley. Leucaena grown for the mulch value of the foliage at 5 to 10 m spacings with cereal and vegetable crops in the inter row. (Ross Gutteridge)

2. Biloela Research Station, Queensland Department of Primary Industries

a) Long term experiments with Leucaena at 2 to 6 m spacings with perennial grass based pastures in the inter row. Originally set up as a grazing experiment to assess the role of Leucaena and inter row pasture in finishing cattle over 60-80 days in autumn early winter (Bob Clem)

b) Alley farming experiment with *Albizzia lebbbeck*. Trees planted at wide spacings on the contour. Five years of crop during tree establishment followed by five years of pastures. (Bob Clem)

3. Queensland Department of Primary Industries, Atherton/RIRDC/LWRRDC

Experimental site assessing the effects of windbreaks on crop growth, one of four sites in the National Windbreaks Program. (R. Keenan)

4. CSIRO Division of Tropical Crops and Pastures/RIRDC/LWRRDC

Modelling crop growth and yield under environmental changes, a project that represents the crop modelling component of the National Windbreaks Program which has experimental sites at Atherton (Qld), Dookie (Vic), Roseworthy (SA) and Esperance (WA). (Peter Carberry)

New South Wales

1. University of New England/LWRRDC

The ecosystem function of trees in temperate pasture. Includes a comparison of water use under four different treatments; windbreaks (100 m spacing), and alley farming (40 m spacing) with improved pasture in the inter row compared to native pasture without trees and improved pasture without trees. Changes in soil moisture are being measured using neutron moisture meters and the SWIM model is being used to infer rates of water use by the different systems. A grid of piezometers is in place to measure impact at the catchment scale (approx. 50 ha) and infer the tree density required to have an impact on waterlogging. Other measurements include infiltration rates, pasture composition and microbial decomposition. Early indications are that the 100 m spacing is ineffective. (Nick Reid)

2. New South Wales Agriculture, Deniliquin/MDBC

Project on the integration of commercial shrub species into broadacre agriculture. Species include Jojoba, Blue mallee and broombush. Funded by Murray Darling Basin Commission. (Ian Hume)

ACT

1. CSIRO Division of Plant Industries/RIRDC

Investigating the ability of trees and shrubs to reduce the rate of soil acidification. Has demonstrated a wide range in the ash alkalinity of a range of species, and therefore their potential to bring cations up from depth and reduce soil acidification. (Peter Randall)

2. CSIRO Division of Plant Industries/RIRDC

Proceedings of a workshop reviewing the effects of agroforestry on soil amelioration. (Andrew Noble, CSIRO Townsville).

3. CSIRO Division of Environmental Mechanics/RIRDC

The impact of trees on winds, temperatures and evaporation rates in farmland. The development of a modelling framework to be used in the National Windbreaks Program which has experimental sites at Atherton (Qld), Dookie (Vic), Roseworthy (SA) and Esperance (WA). (Helen Cleugh)

4. CSIRO Division of Environmental Mechanics/Land and Water Care

Lucerne vegetable alley cropping to control leaching. Experimental work looking at the ability of lucerne to intercept water leaching below the root zone of inter row vegetable crops. (Richard Stirzaker)

Victoria

1. Rutherglen Research Station, Agriculture Victoria/GRDC

A comparison of three different approaches to controlling water logging in crops; lucerne ley, lucerne alley farming and alley farming with native trees and shrubs. The lucerne ley consists of 2, 3, and 4 years lucerne followed by crop compared to continuous lucerne, continuous pasture and crop lucerne rotation. The alley system compares the effectiveness of strips of lucerne that occupy 10%, 15% and 30% of arable land. (Phil Haines)

2. Department of Agriculture Victoria, Hamilton/RIRDC

Assessment of the effects of shelter belts on crop and pasture production in Victoria. One of four experimental sites in the National Windbreaks Program. (Rod Bird)

3. Department of Agriculture Victoria, Horsham/MDBC

Location of one of three major project sites to be established as part of the 'Low rainfall alley farming systems' project being conducted jointly by DAV and Department of Conservation and Natural Resources in Victoria and Primary Industries SA and University of Adelaide Roseworthy Campus. Crop productivity, stock management, fodder performance and water use to be measured under different alley treatments and a control at a 40 ha site. Potential tree species are to be assessed on the basis of growth rate, rooting patterns, competition and water use. The research officer, Roger Lawes, is based at Walpeup Research Station. (Gary O'Leary)

4. Department of Conservation and Natural Resources, Bendigo/MDBC

Location of a researcher (Daren McGrath) and one of the three major sites in the 'Low rainfall alley farming systems project' described above. (John Williamson)

5. Department of Conservation and Natural Resources, Creswick

Agroforestry experiments measuring timber and pasture production from various spacings and densities of *Pinus radiata*. (John Kellas)

6. Department of Agriculture Victoria, Hamilton

Fifty sites established as part of the Glenelg Region Integrated Farm Forestry project are being monitored for tree growth rates and timber production for a range of species and planting densities in the 600-1200 mm rainfall zone. (Don Jowett)

7. CSIRO Division of Forestry, Melbourne/RIRDC

Assessment of wood quality from young fast growing trees in woodlots, shelter belts and single row plantings on farms. (Gary Waugh)

South Australia

1. Primary Industries South Australia, Murray Bridge/MDBC

Location of the project manager and one of three researchers (Alex Knight) in the 'Low rainfall alley farming systems project' described above. (Greg Dalton)

2. University of Adelaide, Roseworthy Campus and the CSIRO Division of Water Resources/MDBC

PhD student (Tim Ellis) studying soil water regimes under alley farming systems and developing a water balance model in conjunction with the 'Low rainfall alley farming project'. (Ian Nuberg)

3. University of Adelaide, Roseworthy Campus/RIRDC

Effects of windbreaks on crop and pasture productivity in SA. One of four experimental sites in the National Windbreaks Program. (Ian Nuberg)

4. Primary Industry South Australia, Mt. Gambier

Thirteen year old experimental site measuring production of *Pinus radiata* in an alley layout (3 rows at 20 m spacing) and a wide spaced parkland layout. (Mick Underdown)

5. CSIRO Water Resources, Adelaide/MDBC

Catchment scale modelling to determine optimal revegetation strategies to address rising water tables. (Tom Hatton)

Western Australia

1. Agriculture WA, Esperance/RIRDC

The impact of trees on the physical environment and the productivity of farmland. One of four experimental sites in the National Windbreak Program. (Rob Sudmeyer)

2. Agriculture WA, Katanning/CSIRO/GRDC

Assessing the impact of trees, drains and perennial versus annual pastures on water logging on a duplex soil. Involves sufficient measurement to develop a water balance for a sloping site with 150 m between tree rows. (Brett Ward)

3. Agriculture WA, Moora/IWS

Comparison of carrying capacity and wool production between plantation density tagasaste (2000 stems/ha), alley farming with tagasaste in rows 30 m apart (500 stems/ha) with and without perennial grasses in the inter row and conventional annual pasture. (Tim Wiley)

4. Agriculture WA, Perth/RIRDC

Catchment scale modelling to assess the impact of a range of agroforestry strategies on salinity and water logging. Using a version of the MODFLOW model, this study of the East Yornaning catchment (450 mm annual rainfall) suggests that tree belts 100 m apart across the whole catchment would be more effective than either block planting all the free draining upland areas or all the valley floor. (Paul Raper)

5. Agriculture WA, Albany/IWS

One site that is part of WOOLPRO (wool production demonstration program) will be monitoring wool production from an alley farming/windbreak site in comparison to open pasture. (Colin McDonald)

6. Agriculture WA, Bunbury

Monitoring 69 bores in a catchment treated with contour and close spaced valley floor alley farming systems for impact on a rising saline water table. (Richard George)

7. Murdoch University/CSIRO

Hydrologic modelling to compare agroforestry strategies for the Kent River catchment. An honours project supervised from CSIRO that concluded that parkland planting rather than alley farming or block planting was the most efficient agroforestry approach to controlling water table rise in terms of the area of land occupied by trees (20%). (Justine Edwards, CALM Bridgetown)

8. Conservation and Land Management, Busselton, Agriculture WA, Bunbury/RIRDC

Assessing the influence of Tasmanian bluegums on pasture production. Involves measuring pasture composition and production in transects out from established plantings on a range of soil types and at different orientations with and without root pruning. (Richard Moore, CALM Busselton)

9. Conservation and Land Management, Perth/NLP

Assessment of oil yield from mallee eucalypts in block and alley plantings (10, 20 and 40 m spacings) at six sites from Morowa in the northern wheatbelt to Esperance on the south coast. Sites also monitored for impact on water tables. (John Bartle)

10. Conservation and Land Management, Narrogin

Measuring the impact of a range of large scale alley farming treatments including varying spacings and tree species on water tables in the Lake Toolbin catchment. (Ken Wallace)

11. University of WA, CALM/LWRRDC

Soil characteristics limiting the growth of Tasmanian bluegums. Using Time Domain Reflectometry, this project is examining the soil physical properties that are limiting the root growth and water use of bluegums at a number of sites in south western Australia. This research was prompted by recent drought deaths of four and five year old bluegum plantations. (Keith Smettem)

12. University of WA, CLIMA

a) Whole farm modelling of the impact of block and alley farming planting of tagasaste in the West Midlands region.

- b) Measuring the impact on lupin yield of alley farming and intercropping with a summer active perennial grass.
- c) Comparison of changes in stored soil water under conventional lupin/wheat rotation, plantation tagasaste and a lupin wheat rotation in an alley cropping system with rows of tagasaste 30 m apart. (Ted Lefroy)

Tasmania

1. University of Tasmania

Comparing alley farming and plantation systems of timber production from bluegums. (Rob Clarke)

2.3 Literature review

The bibliographies Agricola and CAB (1985-1995) and Australian Rural Research in Progress, Australian Biological Abstracts and STREAMLINE (1990-1995) were interrogated using the search command 'Alley farming or alley cropping and Australia or Queensland or Victoria or New South Wales or Tasmania or Northern Territory'.

Twenty entries were found which are reproduced in appendix 1 alphabetically by author. To these have been added two 1996 publications. Table 1 shows a break down of these 22 publications in terms of climatic zone (tropical and temperate Australia) and content (speculative, descriptive or experimental).

The lack of publications in Table 1 describing commercial alley farming systems in tropical Australia reflects the very low level of adoption of the concept in northern Australia to date. The

Table 1. Analysis of Australian publications on alley farming and alley cropping by climatic zone and subject matter, (1985-1996).

Climatic Zone	Subject Matter			
	speculative	descriptive	experimental	
Tropical	3	-	8	11
Temperate	2	5	4*	11
	5	5	12	22

* Two of these are notices of research in progress while two are 1996 publications. A small proportion of publications from southern Australia of an experimental nature reflects the fact that adoption is occurring in the belief that shelter and water use benefits will result but in the absence of empirical studies. For more details see Appendix 2.

2.4 Characteristics of major successes

Of the commercial examples of alley farming described above, only one has been established long enough and has involved sufficient data collection to enable an assessment of its biological and economic success to be made. That is the eucalypt/pasture alley farming system of David and Di Jenkins at Bridgetown in WA. Biologically, a Land Equivalent Ratio of 1.3 indicates that it has been more productive to grow the trees and pasture in a mixture at that site than to grow them in separate monocultures. Financially, the first thinning of seven year old trees for pulpwood in 1995 plus the income from grazing in the first six years indicates it is more profitable than pure pasture and suggests it may be as profitable as

plantation pulpwood production, depending on sawlog and pulpwood prices at maturity. The fact that it involves income diversification compared to the pure stand alternatives and that it appears to be achieving the environmental objective of lowering a rising water table add to this success.

The characteristics of this success are that it is in a high rainfall environment, it involves a high value tree species and the tree and pasture components are compatible as indicated by the Land Equivalent Ratio. A further important characteristic is that measurements have been made of the productivity of the mixture and each of the components in monoculture (pure pasture and plantation forestry) to enable an assessment to be made of its biological and economic success. This success is in some ways fortuitous as it was not known that the tree and pasture species would be compatible at the time of planting.

While the other commercial cases described have passed the tests of practicality and acceptability in the eyes of several hundred farmers, there has been no critical evaluation of their productivity or the processes involved. Some of the presumed benefits of alley farming that have influenced its adoption to date have yet to be clearly demonstrated, including the water use and shelter effects of trees. In the one season that measurements were made of crop yield in a tagasaste alley farming system at the Melvins' property in WA (Lefroy and Melvin 1996), the influence of the trees was to depress yield in the alley by 13% and across the whole paddock (including the land taken up by the trees) by 37% through increased incidence of frost. While this does not rule out the possibility of positive benefits of altered microclimate, it does indicate that this effect can be highly variable and judging the success or otherwise of alley farming systems requires either long term assessment of production as in the Jenkins case or sufficient understanding of the processes involved to allow modelling.

2.5 Constraints to adoption

A major constraint is the uncertainty surrounding the effects of alley farming systems on the agricultural component, the crops and pastures growing in the alley. While it is easy to assess the costs involved in terms of establishment and land lost to agricultural production, there is very little guidance available to estimate possible benefits. Until the nature of interactions at the tree/crop interface has been characterised for different species combinations in a range of environments, adoption is likely to be driven by environmental imperatives. This is the case in WA where rapidly rising water tables and wind erosion hazard are driving the adoption of alley farming at present, since perennial pastures are hard to establish. Some of these may yet prove to be ecologically ineffective, where an insufficient area of a catchment has been treated, or economically inefficient where the opportunity cost of crop or pasture displaced is not compensated for by the direct and indirect values of the trees.

Even when good information exists on the likely benefits and costs, significant constraints are the capital cost of establishment and the lag time between establishment and benefits. These two economic constraints are characteristic of all forms of agroforestry, and have been reduced somewhat in the case of fodder shrub based alley farming by the development of low cost establishment techniques such as direct seeding and bare rooted seedlings for some of the commonly used species. The lag time remains as a major constraint however and the impact of this has been demonstrated through investment analysis of adoption of windbreak systems in the WA wheatbelt (Kubicki *et. al.* 1993). Related to the issue of lag time is the episodic nature of significant climatic events. A severe wind event occurring soon after a windbreak system reaches an effective size has far more favourable implications for that investment than if the first major wind event occurs ten years after the trees reach an effective height.

Additional constraints are the complexity and indivisibility of the technology. Managing mixed perennial and annual systems is inevitably more complex, particular where grazing animals are involved, and this may inhibit adoption. Alley farming systems generally require more intensively managed rotational grazing systems which are made more difficult by the presence of trees inhibiting mustering. The practice also has to be applied on a fairly large scale to achieve the environmental benefits and cannot be adopted progressively as is the case with some crop and pasture technologies. Finally alley farming involves significant visual change to the landscape which has been cited as a source of resistance to adoption.

Section 3. THEORETICAL FRAMEWORK FOR RESEARCH

There are two reasons why farmers may decide to start alley cropping. They may find that it is more productive than a farming system based solely on annual species or they may be driven to it by the threat of land degradation. Regardless of the trigger point, the planting of trees will have both an effect on crop/pasture productivity and an effect on environmental quality. The success or failure of alley cropping hangs on its ability to achieve the environmental objectives such as water use and shelter, with minimal competition with the annual species. Trees and crops will compete for light, water and nutrients. Past and present work in Australia is heavily weighted towards above ground tree/crop interactions (Section 2). There has been almost no work carried out on below ground competition, which is likely to dominate in a semi-arid environment. This section examines how water would be partitioned between crops and trees in various agroforestry designs, since water is a major limiting factor in Australian agriculture.

3.1 How much land should be planted to trees ?

The amount of water used by native Australian trees has been the subject of debate. Eucalypts growing in other parts of the world have the reputation of being profligate - using all the available water even to the point of drying up wells used for drinking water (eg. Calder *et al.* 1993). At the other end of the scale, Eucalypts above saline water tables survive on $< 1 \text{ mm d}^{-1}$ through the year (Thorburn *et al.* 1993), and less than 3 mm d^{-1} in mountain forests (Vertessy *et al.* 1995). Dunin *et al.* (1996) invoke the concept of equilibrium evaporation to show that eucalypts are conservative users of water, whereas data from effluent irrigated trees show that maximum daily water use can be up around 8 mm d^{-1} , near the potential limit (eg, Myers *et al.* 1996) .

Annual tree water use is needed to determine what proportion of the landscape should be retired from conventional agriculture in order to secure the long-term sustainability of traditional annual cropping. The simplest approach is described by Stewart (1984), and requires only two pieces of information; the annual water use of crops and the annual water use of trees in a particular region. For example, soil water balance studies of Peck and Hurlle (1973) and Hillman (1981) found that the total annual water use by a crop was 405 mm when rainfall was 450 mm, which resulted in 45 mm of drainage. Figure 1 shows the proportion of the landscape that must be planted to trees, as a function of transpiration rate of the trees, in order to keep the water table at present levels or restore it to its level of 60 years ago in 30, 15 or 7.5 years. The output from Fig. 1 is self evident; a quick drop in water table levels when trees use relatively small amounts of water will necessitate reafforestation of a large proportion of a catchment. Figure 1 shows that if we want to reduce the water table to where it was 60 years ago within 30 years, and the evapotranspiration from trees is 1000 mm y^{-1} , then 20% of the landscape should be planted to trees.

Stewart's model was proposed for simple one dimensional flow in the West Australian context. Its accuracy depends mainly on the estimates of deep drainage, which are difficult to obtain from soil water balance measurements. It also assumes that trees have full access to a fresh water table. Despite these simplifications, there is evidence from Western Australia that tree clearing or planting can cause rapid fluctuations in watertable levels, as predicted by the model. For example, in a high rainfall area, thinning of the catchment canopy from

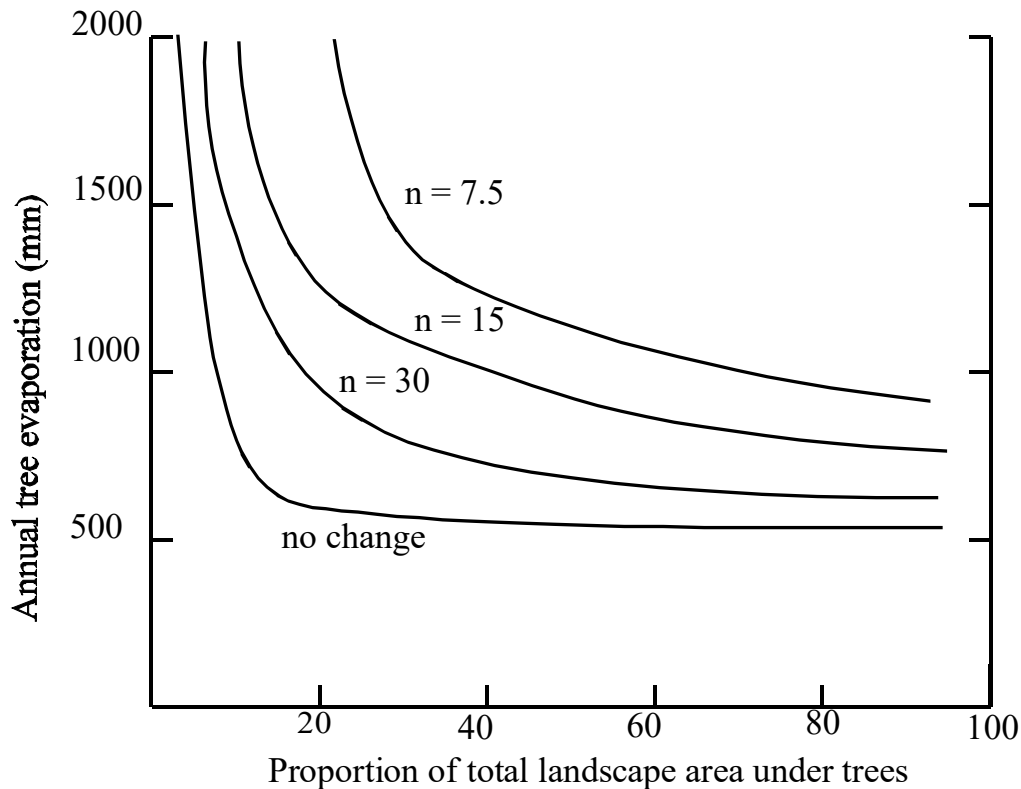


Figure 1. The proportion of the landscape which must be planted to trees as a function of annual tree water use to stabilise watertable levels (no change) or drop the water tables to the level of 60 years ago within 7.5, 15 or 30 years (redrawn from Stewart, 1984).

55% to 22% resulted in a 4 m rise in the watertable over eight years (Stoneman 1993). Conversely, Greenwood *et al.* (1992) increased canopy cover from 16% to 27 % and witnessed the disappearance of a saline seep. Seven years after planting trees, transpiration greatly exceeded the rainfall of 750 mm y^{-1} , whilst the annual pastures used a paltry 450 mm y^{-1} . The high rates of tree water could only be sustained while the trees were mining water left behind by previous crops. In the longer term, maximum tree water use would move towards total effective rainfall. Hingston *et al.* (1994) showed watertable depths fluctuating by up to 1.5 m between seasons under *Eucalyptus globulus* plantations; annual transpiration plus interception losses ranged from a low of 393 mm in a dry site to 1496 mm in a wetter site, where root depth exceeded 6 m and the tree's water use exceeded rainfall by 1008 mm over a two year period.

The large difference in rooting depths between trees, crops and pastures has been well documented in West Australia. Eucalypt roots in the study of Greenwood *et al.* (1992), reached depth of 12 m, in contrast to 0.8 m for pasture. At certain times of the year, tree roots were 3 to 5 m below the top of the watertable, but survived because of the large amount of dissolved oxygen in the water and low soil respiration rate at such depths. Sharma *et al.* (1987) showed that a eucalypt forest extracted water to 6 m and beyond, whereas winter annuals only used water from the top 1 m. Carbon *et al.* (1982) also found that winter annual pastures only used water to 1 m, but perennial grass pastures depleted soil water to a depth of 3 m. Lucerne depleted soil water to 6 m, the same depth as the trees. Deep drainage was lower under pine forest than eucalypt forest. Eastham *et al.* (1994) measured relatively low extraction rates by trees, though tree water use was substantially greater than that from annual pastures. In an environment where pan evaporation was 2300 mm y^{-1} and rainfall 350 mm y^{-1} , trees only removed a maximum of 30 mm per m of soil from the wet zone below 2 m.

Annual water use by the trees never exceeded 600 mm, but the trees were still young at the time of measurement.

Schofield (1990), also working in Western Australia, developed a model similar to that of Stewart (1984), but calibrated it using data from whole catchments rather than soil water balance studies in single locations. The model partitions the landscape into seepage areas, cropped or pasture areas, remnant vegetation and reafforested areas. The annual water use of each zone was estimated as the total rainfall minus stream flow from a range of catchments, which differed in their annual rainfall and proportion cleared for agricultural use. Schofield's model showed, for example, that 24% of a catchment must be reafforested in an area with a rainfall of 1032 mm and 18% in an region with a rainfall of 750 mm, in order to drop the water table by 200 mm y^{-1} .

In contrast to Western Australia, there are few examples of tree water use in South-Eastern Australia, and measurements below 2 m are rare or non existent. Myers and Talsma (1992) showed how a *Pinus radiata* plantation on a duplex soil in the Canberra region progressively dried the soil to at least 2 m. When irrigated, the annual water consumption was between 1100 and 1500 mm, 0.88 to 1.19 times pan evaporation. When unirrigated, water use was between 500 and 700 mm, equivalent to effective rainfall. Annual stand water use increased at a rate of 43 mm t^{-1} ha $^{-1}$ of foliage, within the range of 6 to 16 t ha $^{-1}$, illustrating the importance of maintaining maximum canopy development in situations where high water use is the main objective of reafforestation, by for example, correcting nutrient deficiencies. In the "Flushing Meadows" experiments near Wagga, trees irrigated with effluent used up to 8 mm d^{-1} , and had an annual crop factor between 0.84 and 0.93 times pan evaporation (Myers et al. 1996). On an equivalent leaf area basis, eucalypts used a similar amount of water to pines. No water was extracted from the very dense soil below 2 m (W. Bond pers. com. 1996).

Total water use of trees is difficult to measure using soil based measurements, particularly when roots are very deep or are accessing a watertable. Vertessy *et al.* (1995) used the heat pulse technique to measure water use by *Eucalyptus regnans* in southern Victoria. Dunin *et al.* (1985) used a lysimeter in the Kioloa State Forest NSW and showed that they could predict the water use of *Eucalyptus maculata* accurately from weather station data. Over a two year period, the trees used 1700 mm, which represented 60% of the available radiant energy and was marginally higher than the total rainfall of 1600 mm over the same period. They also showed that maximum daily water use by fertilised grassland could be up to 30% higher than forested land used, but over the longer term tree water use exceeded that of the pasture because they explored a greater depth of soil.

Hatton *et al.* (1996) used the model TOPOG_IRM, to predict the consequences of reafforesting catchments in the Murray-Darling Basin. They caution that complex models such as TOPOG require a great deal of data to parametise, may be confounded by complex geology, and that it is difficult to generalise outcomes to other catchments. However the exercise provided many useful insights into the relationships between climate and hydrogeology, and the effects that area and location of tree planting have on tree productivity and discharge of water and salt from the catchments. For example, in a presently cleared 160 ha catchment, there would be a mean watertable rise of 6 m within 10 years and discharge 150 tonnes of salt per year into the stream. If the entire catchment was planted to trees, the water tables would drop by 10 m in 10 years. The simulation predicted that about 30% of the catchment should be devoted to trees to keep water tables at their present levels. Half the MDB basin would need to be reafforested to reverse the salinity problem.

As in South-Eastern Australia, there is little experimental data on tree water use from Queensland. Eastham *et al.* (1990a) measured water extraction to 6 m by *Eucalyptus grandis*

on a red/yellow podsolic near Brisbane, and tried to partition water between trees and pasture as a function of tree density. In the Burdekin Catchment of North Queensland, Williams *et al.* (1993) measured the effect of clearing trees for *Stylosanthes* and native grass pastures on a red earth. Trees removed water from below 3.5 m, whereas pastures failed to remove any water below 2 m. Although there was no evidence of secondary salinity in the region, the authors argued that the same ingredients that were causing dryland salinity in Southern Australia were present in the north i.e. significant salt stores in the landscape, a concentrated wet season and the replacement of deep-rooted for shallower-rooted vegetation, leading to deep drainage. Thorburn *et al.* (1991) found that clearing Brigalow south west of Rockhampton had little effect on groundwater recharge. This was attributed to the slowly permeable soils and the fact that the Brigalow itself was shallow rooted.

Rooting depth, soil type and climate are major factors affecting the amount of water trees will use, but the greatest unknown is the relationship between tree water use from partially saline groundwater. The problem has two parts. First, salt increases the osmotic pressure of the soil water and makes it less available to the trees; there is some variability among species in their ability to tolerate this. Second, even in mildly saline environments trees concentrate the salt in their root zones. If the root zone is not partially leached from time to time, salt can build up to toxic levels within the rotation cycle of a plantation (Thorburn *et al.* 1995). This effect was encountered by Heuperman (1995) in the Shepparton Irrigation Region. The problem of saline watertables first manifested in deeper rooted orchard crops, and native tree planting was expected to provide an environmentally friendly solution. Ten years after planting, the trees had dropped the watertable to about 5 m below ground level, in contrast to the surrounding irrigated pastures, where the water table was 1 m below the surface, but tree water use had dropped to around 2 mm d⁻¹. The drawdown effect was restricted to, at most, 40 m from the edge of the afforested area. Water flowed from the surrounding country towards the trees, causing a build up in salt beneath them. A similar effect was reported by Whitfield *et al.* (undated) in the same region. They were able to control salt levels in the rooting zone by irrigation, but eucalypts still displayed, for the most part, conservative water use.

3.2 How should trees be positioned on the landscape?

The foregoing discussion mentioned four different ways of estimating tree water use; soil water balance studies with simple 1-D models, calibrated catchments, direct measurement of tree water use and complex models. Each method contains uncertainty, but there is also a degree of consistency in these widely differing approaches made in different parts of the country. Land managers should be thinking in terms of planting at least one quarter of the landscape to trees to stabilise watertables and up to half to radically turn the problem around. This is the base information needed; the next question is where to plant these trees so that annual agriculture can proceed with minimal tree competition without compromising the need to reduce discharge.

The first trees planted in agricultural landscapes are usually windbreaks. Ticknor (1988) found the spacing between windbreaks which will keep soil erosion below tolerable limits to be 200 m. Finch (1988) suggests that the leeward zone up to 30 times the height of the tree will provide protection for tolerant crops, falling to around six tree heights for very delicate horticultural crops. Generally, windbreaks can be effective when taking up as little as 5% of the land area. This is well below the proportion of the landscape that may have to be under trees in order to control and reverse watertables .

Fig. 2 shows six ways of arranging 25% tree cover on a notional area of land (Young 1987). Block plantings represent the strategy of planting out specified areas of the landscape, such as

recharge or discharge areas (Fig. 2a). Another example of a block planting for a different reason is leucaena plantings in the Burnett region of Queensland. Since the area is marginal for leucaena, one approach is to identify the best soils, fence them off and grow a pure stand of leucaena. The leucaena is then used as a protein bank when the native pasture is deficient. Fig. 2b shows a windbreak arrangement. If we consider the total area in Figs 2b to 2f as 100m x 100m paddocks, then the windbreaks would be about 6.25 m wide (double that when added to adjacent paddocks), separated by 87.5 m. Fig 2c shows a timber belt configuration, 17.5 m wide,

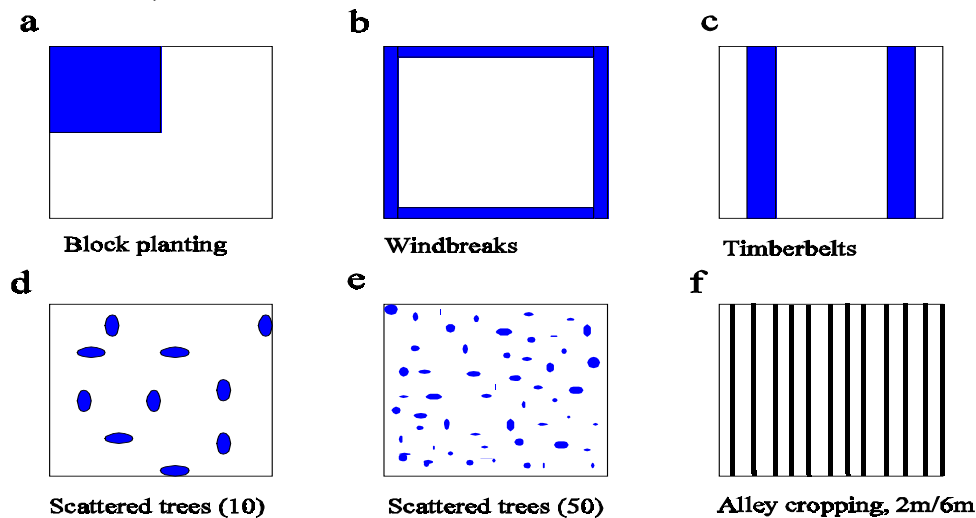


Figure 2. Six arrangements for putting 1 hectare of land under trees (redrawn from Young 1987).

separated by 37.5 m. This system has been used where valuable timber is produced in conjunction with improved pastures, as in the higher rainfall regions of South Western Australia. Figures 2d and 2e show examples of scattered trees in pastoral systems, where machinery is not used, and trees or shrubs do not have to be confined to certain areas. Fig 2f is an example of an alley cropping system commonly used in tropical areas. Most published information on tree crop interaction comes from this layout.

In some situations, farmers would want to plant trees on land which is least suitable for cropping or improved pasture. Upper parts of catchments with higher slopes and thinner soils generally export more water than flatter regions, and would provide the most obvious sites for tree planting. The cost of establishing trees in this terrain and the growth rates on the poorer upland soils may make this strategy uneconomic. In some regions, discharge areas have been planted to trees to stabilise areas where the soil quality has dropped to the point where crops can no longer be profitably grown. Tree planting will not be a long term solution here, unless salt can be exported from the discharge areas in some way. In practice, recharge and discharge areas are often difficult to identify. Recharge areas may be distributed across a wide area of the catchment, and discharge sites will be affected by features such as dykes, changes in bedrock level, changes in soil textures and breaks in the slope.

Hatton et al. (1996) used TOPOG_IRM to simulate three scenarios for tree planting in an upper Murrumbidgee catchment. Previous simulations had shown that 30% of the catchment should be reafforested to halt rising watertables. They calculated the effect on discharge of planting (1) the entire 30% in a single large block in the uppermost portions of the catchment (2), three blocks, each covering 10% of the catchment planted lower down the slope and (3) three strips of trees across the contour approximately 70 - 100 m in width. All three planting strategies were effective in halting the rise in watertables, although the strip planting gave the lowest surface runoff and best control of waterlogged regions. Tree growth was affected by

location in the catchment. The model showed that tree productivity from reafforestation of the upper catchment would eventually be governed by local rainfall rate. In contrast, productivity would be higher at sites lower in the catchment where there is a contribution of water from upslope. This extra water may be very important for high value trees which cannot be grown as plantation species in the < 800 mm zone. Salama *et al.* (1993) in a West Australian catchment came to a similar conclusion to the above study; they predicted that replanting 25% of the upper portions of a catchment was acceptable to manage watertable height.

A rather different scenario is described by Raper and de Broekert (1996) from a catchment in the Narrogin area of West Australia. They used the model MODFLOW to give steady state predictions of the areas under threat of becoming saline. Under traditional agriculture, 50% of the catchment would become saline. They then modelled the effect of a low density of trees (100 stems/ha) planted on the valley floors and upland areas, and found that both plantings were necessary i.e. low densities of trees needed to be planted over the whole catchment. Whereas a block planting of trees may control water tables in the previous examples, an alley cropping approach seems more suitable in the Narrogin catchment. The difference may reflect the real hydrology or be a consequence of the way the different models have been set up and parameterised.

3.3 The tree / crop interface

The most striking difference between Figs. 2a-2f is the length of the tree crop interface for the different strategies of putting 25% of the land under trees (Table 1). Huxley (1985) argues that if we can understand what is happening at the tree/crop interface, then we have got a long way in understanding how an agroforestry system will perform. According to Young (1987), if the interaction at the tree/crop interface is positive, then we should maximise the length of the interface. However if the reason for tree planting is to control watertables, but trees compete strongly with the crops, the interface should be kept as short as possible, without compromising the job of lowering the water table.

Table 2. The length of the tree crop interface for six arrangements of planting 25% of land to trees

Agroforestry practice	Design	Tree/crop interface (m per hectare)
Block planting	block 50 x 50	200
Windbreaks	Belts, 6.25 m wide	750
Timberbelts	2 belts, 12.5 m wide	450
Trees in field	10 trees, radius 8.9 m	560
Trees in field	100 trees, radius 2.8 m	1770
Alley cropping	Rows, 2 m tree, 6 m crop	2500

Fig. 3 gives some likely examples of the competition and complementarity at the tree/crop interface. Case A gives an example of an annual crop adjacent to a timber belt. Crop yield is reduced at the interface because of competition for water, nutrients or light by the tree, and tree growth is enhanced because of the access to these extra resources. At a distance of 2 to 10 times the height of the trees away from the tree line, yield may be higher than open paddock because of positive micro meteorological effects. Case B gives an example of perennial pasture adjacent to a timber belt. In this case the deep rooted pasture is little affected by the trees, but the trees are affected by competition from the pasture and/or exposure. In case C, both the tree and crop growth is enhanced at the interface. This may

occur where the tree and crop growth cycles are out of phase, so that only the beneficial interactions are expressed in each season. There are quality issues which must also be taken into account in the three cases above. Trees may produce more biomass at the interface, but increased branching of timber trees may also incur additional management costs, depending on the commercial purpose and species.

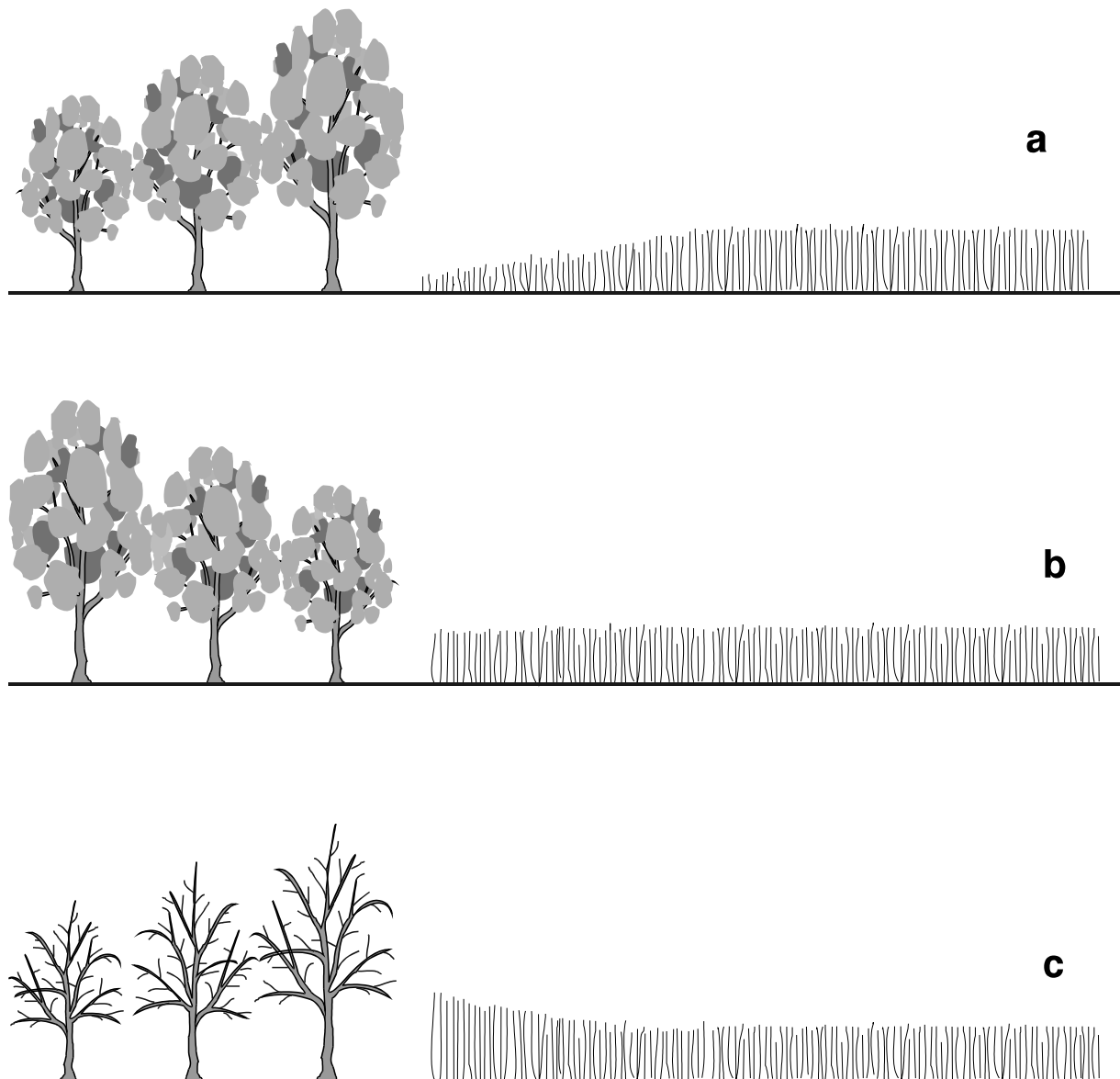


Figure 3. Possible outcomes at the tree/crop interface

Case A or B in Fig. 3 will occur when the tree and the crop are both drawing on limited resources from the same pool ie. when they are in competition. Case C occurs when there is a

complementary relationship between the tree and the crop. Complementarity occurs in a tree/crop mixture when the mixture

- i) uses a greater fraction of a limiting resource and/or
- ii) makes the more effective use of the same resource (Ong and Black 1994).

i) *Greater resource capture*

Trees can use more water than crops by virtue of spatial (deeper rooting habit) or of temporal complementarity (using off season water). A successful example in Australia comes from Connor *et al.* (1987), where a deep rooted perennial (pine) was growing with shallow rooted winter annuals (clover and ryegrass pasture). Pasture production was not affected by tree densities up to 277 stems/ha.

ii) *More efficient resource use*

Examples include the greater water use efficiency in the "quiet zone" in the lee of the windbreak (Frota *et al.* 1987), and the greater water use efficiency of certain C₃ plants growing in light shade. There may also be a functional complementarity eg. plants with proteoid roots being able to extract phosphorus from low P soils.

Case A, crop reduction close to trees, is by far the most commonly observed scenario. The skill in designing an agroforestry system is to exploit as many case C opportunities as possible while at the same time restricting competition as much as possible. Fig. 4 shows the yield of spring wheat behind a windbreak compiled from 49 separate studies (Kort 1988). The sharp drop in yield near the trees is more than compensated for by a large region of enhanced yield. This data set came from an environment where the weather was much colder than Australia and snow drifts piled up against the treebelts, providing additional water at the interface during the thaw.

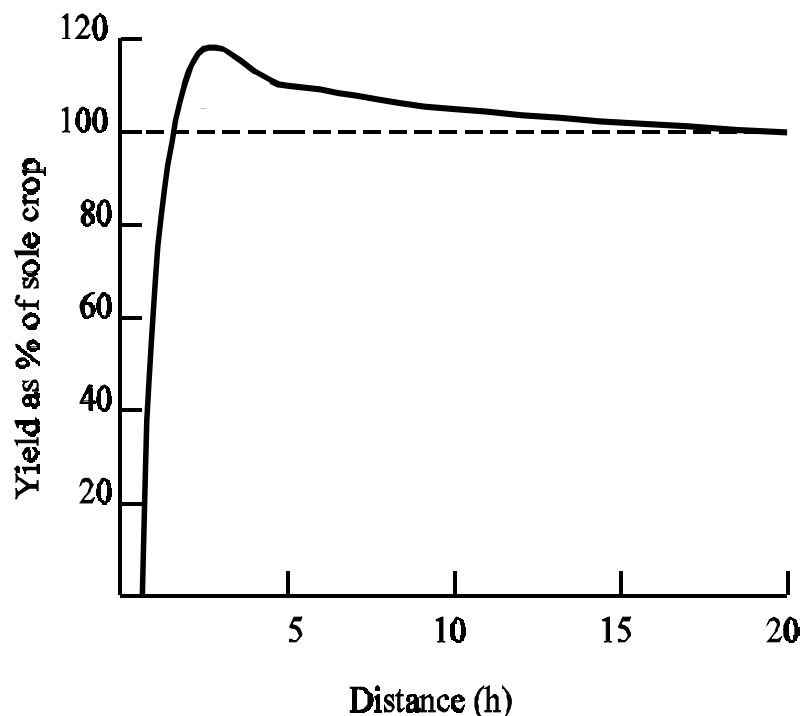


Figure 4. Yield, as a proportion of a sole crop, with distance away from a windbreak (h is height of windbreak). Redrawn from Kort (1988).

There is some evidence that similar effects can occur under Australian conditions Bird *et al.* (1992) and Nuberg *et al.* (1996) i.e. that the windbreak can produce a net yield benefit. The national windbreaks program is currently quantifying the microclimatic effects of windbreaks on crop yields around the country. We envisage that windbreak plantings alone will not be sufficient to control water tables; alley farming is a system that can deliver the required tree density but is likely to have a larger tree/crop interface than windbreaks. Thus our focus needs to be on how to predict and manipulate competition in the zone between the tree line and 5h (five tree heights) of Figure 4.

The complexity of separating above and below-ground effects near the tree line is evident in the example of Singh *et al.* (1989) shown in Fig. 5. Grain yield is expressed as a percentage of sole crop yield between two hedgerows, 10 m apart. In the original design, hedgerows were 5 m apart, but every second hedgerow was removed. A 0.5 m deep root barrier was installed at the left hand hedgerow. Crops near the LH hedgerow received 30-80% less light than unshaded plants, but this had no effect on cowpea and sorghum yield. Yield was enhanced in the mid position because of improved soil physical and nutrient conditions where the middle hedgerow was removed. Yield was reduced at the RH hedgerow with no root barrier. Castor, which had a longer growing season, was more seriously affected by the hedgerows than cowpeas or sorghum, because water below 0.5 m was critical. This and subsequent experiments led Ong (1995) to propose the following relationship

$$I = F + P + L \pm M - C$$

where I = the net benefit of alley cropping; F is the fertility effect of hedgerow clippings or manure from animals browsing the hedgerow; P is improvements to soil physical structure particularly infiltration; L is long term soil conservation effect, particularly erosion; M is the

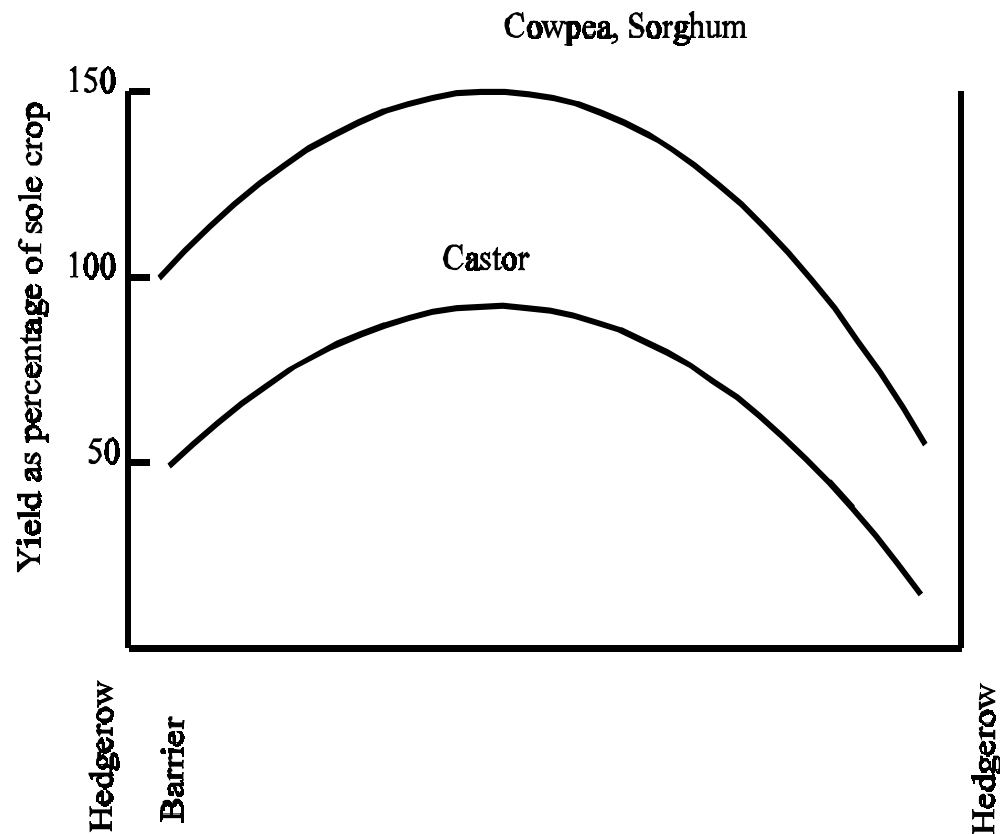


Figure 5. Yield as a proportion of sole crop of three crops with distance from a hedgerow. A 0.5 m deep root barrier was installed adjacent to the left hand hedgerow (redrawn from Singh *et al.* 1989).⁴

microclimate effect; and C is the competition between tree and crop. In terms of the Australian situation with fairly wide alleys, effects of F (fertility) and P (structure) may be relatively small in cropped zone between the trees. However if the location of the tree belts are rotated over time, the long term fertility and structural benefits could be enormous. The value of M (microclimate) is currently under study in the national windbreaks project. This leaves L, in our case the ecological imperative of controlling salinity, and C, tree competition as the fundamental parameters that must be quantified. These are dealt with in the next 3 sections.

3.4 Alley cropping case study

Figure 6 represents six zones likely to be present in an alley-cropped field. Zone A is reserved exclusively for trees, and the extraction of water would be fastest from near the top of the zone (A1) and decrease with depth, according to the distribution of roots and structure of the soil (A2). Tree roots would also extend laterally into zone B (in this example tree roots do not meet in the middle of the field). Zone B1 is the area of overlap between the shallow rooted crop and lateral roots from the trees. It represents the zone of potential competition. Zone B2 is occupied exclusively by tree roots, since the roots of an annual crop could not go this deep. Extraction of water by trees from zone B2 would both reduce accessions to the watertable and enhance tree growth. Zone C1 is occupied exclusively by the roots of the crop and zone C2 contains no roots.

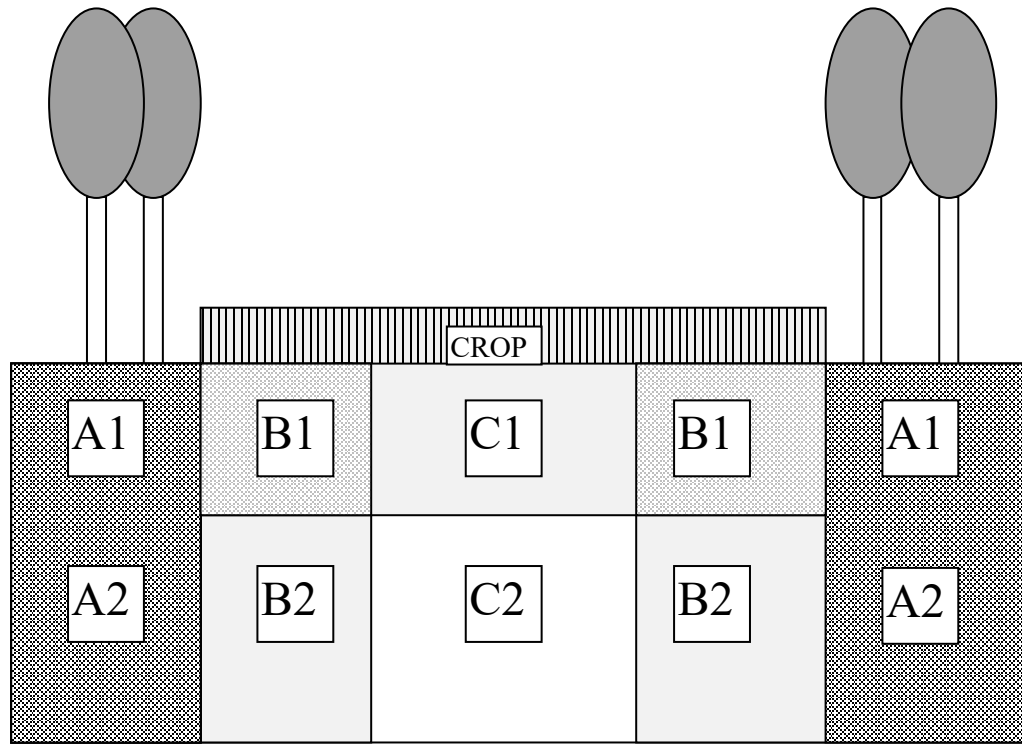


Figure 6. The six soil zones in an alley cropped field

An example of the rate at which water is extracted from each zone is shown in Figs 7a and 7b. This information was taken from an alley cropping experiment with lucerne and irrigated vegetables (Stirzaker 1996). Although the dimensions differ from a dryland alley cropping, the principles remain the same. In the following example the lucerne represents the "tree" and the vegetable crop represents a dryland grain crop or pasture.

The lucerne was planted two years before measurements began. At the time of planting both zones A1 and A2 were wet because of water left in the profile from previous crops. At the start of the measurement period the lucerne had dried all of zone A1 and A2 (Fig. 7a). During the next 540 days, pan evaporation was 2322 mm and rainfall was 850 mm. In addition, the whole site (lucerne and crop), was irrigated with 112 mm on day 130 and 149 mm on day 340. Apart from these perturbations caused by irrigation, zones A1 and A2 were generally dry. Thus during the first two years, the lucerne mined the water left behind by previous crops, and after that water use of lucerne was equal to rainfall plus irrigation.

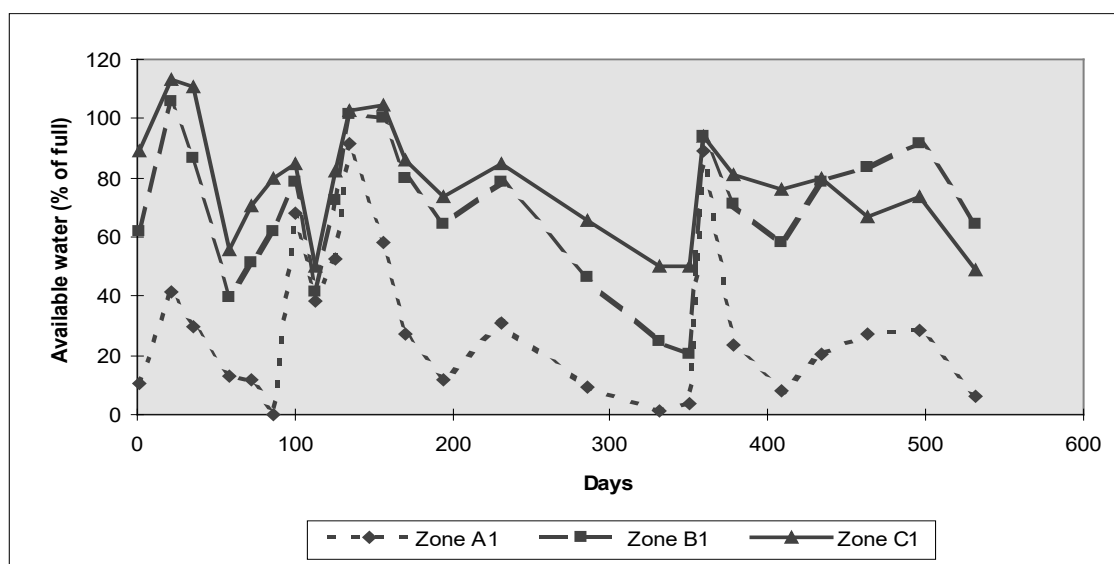


Figure 7a The amount of water in zone A1, B1 and C1 of Figure 6.

At day 0, a crop was planted in the alley between the lucerne rows (i.e. across zones B and C. At planting, zone B1, which contained some lucerne roots, had less water than zone C1 (60% full as opposed to 90% full). This difference remained for the first 100 days, and then disappeared following heavy rain around day 90. The crop was harvested on day 113, after which the total area received 112 mm of irrigation. Between days 113 and 340 no crop was grown and zones B and C were kept free of any weed growth. Zone C1 fell to 50% of full during this period (i.e. evaporation from the soil surface exceeded rainfall), and zone B1 fell to 20% of full. The extra 30 % lost from zone B1 was presumably used by the lucerne, assuming that the same amount of water was lost directly as evaporation from zones B1 and C1.

A second irrigation on day 340 filled the soil profiles in zones B1 and C1. At day 400, lucerne mulch from the strips on either side of the alley, was placed on the surface of zone B1. Under this regime, more water was stored in zone B1 than zone C1 because (i) evaporation was reduced from the soil surface of zone B1 and (ii) regular rainfall meant that the lucerne could satisfy most of its demand for water from zone A.

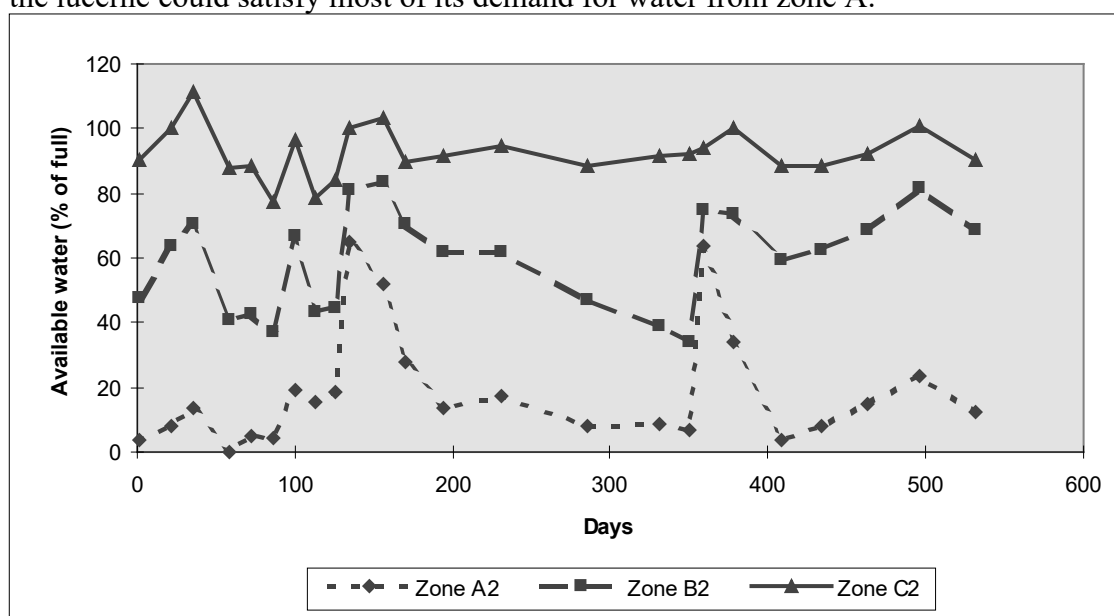


Figure 7b The amount of water in zones A2, B2 and C2 of Figure 6.

Comparisons of zones B1 and C1 give a measure of the competition for water in an alley crop system, and the expected crop yield loss in the absence of other factors. Comparisons between zones B2 and C2 reveal the long term sustainability of alley cropping and monocultures. The available water in zone C2 stayed relatively constant, since for most of the time the profile was full (Figure 7b). This meant that excess water from zone C1 (either from rainfall or irrigation) could not be stored, and would contribute to rising water tables. Zone B2 was never full and was thus able to act as a reservoir for surplus water.

The alley crop system fulfilled the ecological requirement admirably, but crop yields fluctuated. In some cases, vegetable yields in the alleys were over 30% greater than the sole crop. This was because the lucerne provided valuable mulch, nutrients and organic matter. In another case, at the other extreme, vegetable yield in the alley was reduced by 60% when the competition for water outweighed the benefits. The yields proved to be unpredictable because the competitiveness of the lucerne changed over the years. When the lucerne had used all the water in its own bed, it extracted water from vegetable beds at a rate of 0.25 mm/day/ m of soil depth. This rate declined with distance away from the lucerne row. The water "stolen" from the vegetables by lucerne during a 100 day vegetable crop was trivial, but the cumulative effect through the year meant that alley crops started the season drier than sole crops, and this had repercussions later in the season. In order to understand the system we need to know how much water the lucerne will extract from zones B1 and B2 of Fig 6, which in turn depended largely on the water available in zones A1 and A2. Figure 8 gives three "snapshots" of the two dimensional soil water profiles that develop in traditionally managed and an alley cropped fields.

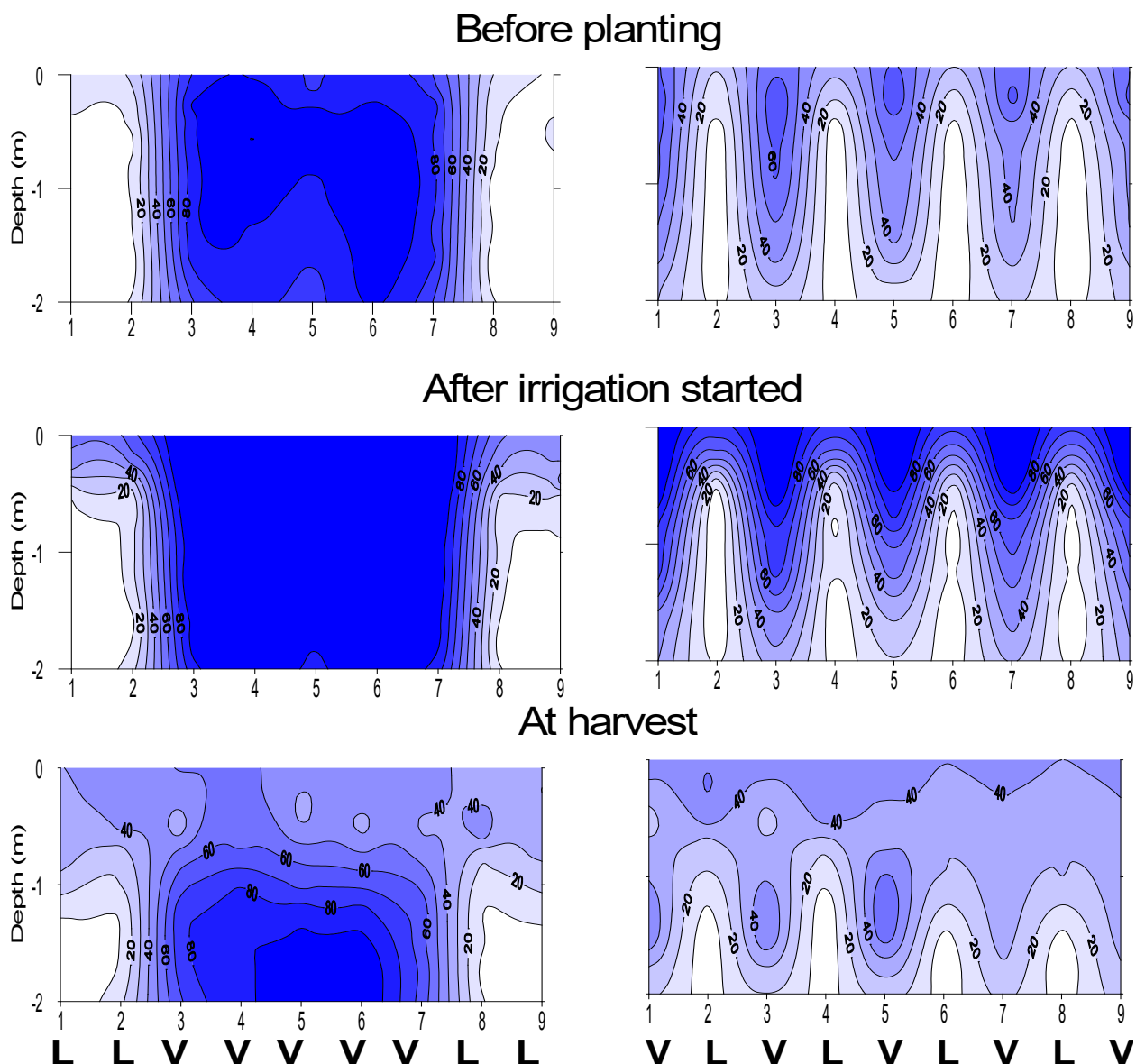


Figure 8. The diagram shows where the water goes in a traditionally managed or an alley cropped field before sowing, after irrigation commenced and at harvest. The horizontal axis shows a section across nine rows in the field and the vertical axis shows a soil profile 2 m deep. The rows are labelled L for lucerne and V for vegetables; the darkest shade means the soil is very wet and white is very dry. The left hand column shows five irrigated beds side by side (rows 3 to 7). Before the tomato crop was planted, soil was wet because water has been left behind from the previous vegetable crop. After irrigation started, water added to the soil met up with that stored in the subsoil, and drainage occurred. Irrigation ceased two weeks before harvest, and at harvest time the topsoil dried down substantially, but the sub soil remained wet. The right hand column shows alternating lucerne and vegetable beds. The location of the lucerne is obvious because it kept the soil dry (rows 2, 4, 6, 8). After irrigation started, the topsoil where the vegetable roots are was wet but the subsoil was relatively dry. At harvest both the top soil and subsoil are drier than the traditionally managed field.

3.5 Tree rooting patterns

Agroforestry systems can only be viable if temporal and spatial niche differentiation can be used to reduce competition between tree and annual crops. Jonnson *et al.* (1986) examined five tree species commonly used in agroforestry systems and found that the rooting patterns were too similar to maize to expect niche differentiation. Thus it is essential to understand the rooting behaviour of the trees before designing an agroforestry system.

The size of the exploration zone of a tree is given by the deepest roots and those furthest laterally from the trunk. The potential rate of exploitation is a function of the density in different parts of the explored zone and its water content, subject to the transpiration rate of the tree. Common generalisations about tree roots, such as rooting depth is related to tree height and lateral root growth is related to crown width are invalid (van Noordwijk 1996). Ideally, the rooting depth should be sufficiently large so that storage zone can accommodate unusually large rainfall events. The lateral spread will increase the amount of water available to the tree and the size of the tree/crop overlap zone. Roots from a Eucalyptus windbreak can extend at least 18 m into the cropped zone (Onyewotu *et al.* 1994). Roots of *Senna siamea* have been measured 15 m from the trunk (Hauser 1993), *Acacia seyal* 26 m from the trunk (Groot and Soumaré 1995) and *Faidherbia albida* 60 m from the trunk (Coe 1994).

Some empirical relationships between rooting patterns and tree growth have been observed by Hairiah and van Noordwijk 1986, cited in van Noordwijk 1996). Trees with deep tap roots and few superficial horizontal roots showed slow initial growth rates, and had shoot:root ratios in the range 0.4 - 2.5 (shoot biomass divided by root biomass). Deep rooted trees with extensive horizontal exploration had shoot:root ratios in the range of 2 - 6 (i.e. invested more photosynthate in above ground production), and had faster growth rates. Shallow rooted trees, with shoot:root ratios in the range of 2 - 30, also tend to be fast growing. The requirement for a deep rooted, fast growing tree with little horizontal root development, and therefore little competition with an adjacent crop, does not seem to be common or even possible.

The farmer acceptance of the *Paulownia* system in China and the *Grevillea* systems in Africa may be due to complementarity in the fine root distributions between trees and crops accompanied by favourable above ground morphology and phenology. There is a clear need to characterise important tree species in this way for the Australian environment. Some insights may be gained by using the fractal root excavation method mentioned earlier. The bulk of the information will have to be gleaned from carefully designed field trials.

3.6 Use of Models in Agroforestry

The last decade has seen the development of models of different complexity to help generalise experience from long term experiments, to other soils and climatic zones. Models could be particularly useful for alley cropping because we are dealing with soil profiles as deep as 10+ m (i.e. that of a tree), which may take years to fill up and dry down. Carry over effects from season to season will be much larger than for annual cropping systems. The outcome of alley cropping field trials, carried out for, say, three years, could be completely dominated by the rainfall of recent years and not give a reliable indication of long term sustainability and productivity of the system. Tree planting creates a new hydrologic equilibrium in a catchment which may take decades to stabilise, and may be overlooked in field trials.

There is a large array of models with at least some application to agroforestry. These include growth models such as BIOMASS, MAESTRO, GROWEST and GRASGRO, which predict growth and productivity of trees or pasture; soil and water models such as SWIM, PERFECT,

WATLOAD, HARMS, MODFLOW and the 2D tree water use model of Landsberg and McMurtrie (1984), which predicts the amount and distribution of water in the profile or the behaviour of watertables; integrated models such as TOPOG_IRM or the APSIM suite which predict both water movement and growth and farm scale economic models such as FARMTREE, SALTREC and MULBUD. Models used for prediction of light interception in hedgerow orchards can also be used to predict the shading of crops or pastures can pastures in the lee of tree alleys eg. Jackson and Palmer (1972).

The application of TOPOG and MODFLOW gave useful insights as to how an alley cropping system may perform as discussed in section 4. Another example comes from Williams *et al.* (1993) who used the physically based model SWIM to extend their data set to other soil types. They then used PERFECT to simulate drainage events over the last 100 years. Finally they assessed salinity risk from the digital Atlas of Australian Soils. Point EC measurements were correlated with certain soils and parent materials and recharge areas were identified by permeability codes of "high" or "good" drainage. Although the model predictions have not been tested (and cannot be in the case of historical drainage), the authors argue that short term experiments are of limited value where drainage events are so episodic, and that the appropriate use of simulation models can "transcend the tyranny of site and season variability that has plagued so many hydrological studies in Australia" (Williams *et al.* 1993).

To date there is no agroforestry model that can reliably partition resources between crops and trees. The Institute of Terrestrial Ecology in the UK is in the process of creating an agroforestry model by marrying existing tree crop and soil models. They have produced a new model called HyPAR, derived by combining the tested crop model, PARCH and the tree model HYBRID. The model partitions light and rainfall between the tree and the understorey, and simulates tree and crop growth. In soil layers where both tree and crop roots exist, the model assumes that trees have primary access to this water. For the immediate purposes of HyPAR (closely spaced small trees in a tropical environment), this assumption may be reasonable. It would be a major limitation in the Australian context, especially as tree roots may become very sparse with distance from large trees.

Aside from the value of models in organising and extrapolating information, there remain several black holes. An important one is how sparse roots systems take up water from deep in the subsoil, which is frequently the scenario tree root systems are operating in. There is evidence that physically based models, based on root distributions and the diffusivity of the soil, over-estimate water uptake from subsoils. Gardener's distributed sink hypothesis, which states that roots dry out upper layers completely before drying layers below, can reflect the real situation more closely. A second vital issues are the interactions between tree water use and the depth and salinity of the water table (Thorburn *et al.* 1995), since tree planting in Australia will be driven by the spectre of rising watertables. Resource capture between overlapping root systems is also poorly understood. Future modelling work in Australia should focus on these issues.

3.7 Designing an Alley Farming System

When contemplating alley farming designs, it is useful to consider two scenarios separately. The first scenario is shown in Figure 9a, where recharge is uniform over the landscape, water tables are deep and there is no lateral flow of water. In order to capture most of the water which is escaping from the bottom of the crop root zone, trees with a wide lateral rooting habit are needed. Since the tree rooted volume is large relative to tree leaf area, competition between the tree and crop will tend to be low. However the tree operates 12 months of the year, and would mean that the annual cropping season would commence with less stored water. In places like Western Australia, where there is a defined break of season, this may be

of little consequence. In Eastern Australia, where the carry over in water stored from one year to the next is very important, crops will suffer. Tree/crop competition will be reduced as tree rooting depth increases, but spaced trees tend to root more shallowly than densely planted stands (Eastham *et al.* 1990).

The second scenario is when the trees are tapping into a water table, and is shown in Figure 9 b. When the soil is saturated water will move relatively quickly to the absorbing roots and the alley spacing can be calculated using the Dupuit-Forcheimer approximation (Kirkham 1967); this is in contrast to the unsaturated case, where tree roots must grow towards the water. Using the above method, we can calculate the optimal spacing between alleys of trees for a given soil saturated hydraulic conductivity, and the width of the tree belt to dispose of the water. The analysis is complicated by sloping land and saline water tables, but these can also be built into the model. The saturated scenario is likely to be very important, since the easiest way to ensure tree/crop complementarity is to drive trees towards accessing watertables through tree species selection and spacing.

There are several variants of the cases detailed above. One common situation is the problem of perched water tables on duplex soil. Trees may be able to locally enhance the conductivity of the sub-soil and provide sinks for water moving laterally above the B horizon. Another strategy may be to plant trees on contour banks to catch overland flow and concentrate infiltration into the tree lines where root systems are very deep, and to flush away accumulated salts. Deep ripping around the edges of tree belts before sowing can reduce the tree/crop competition substantially (Onyewotu *et al.* 1994) in some cases and not in others (Hughes *et al.* 1994).

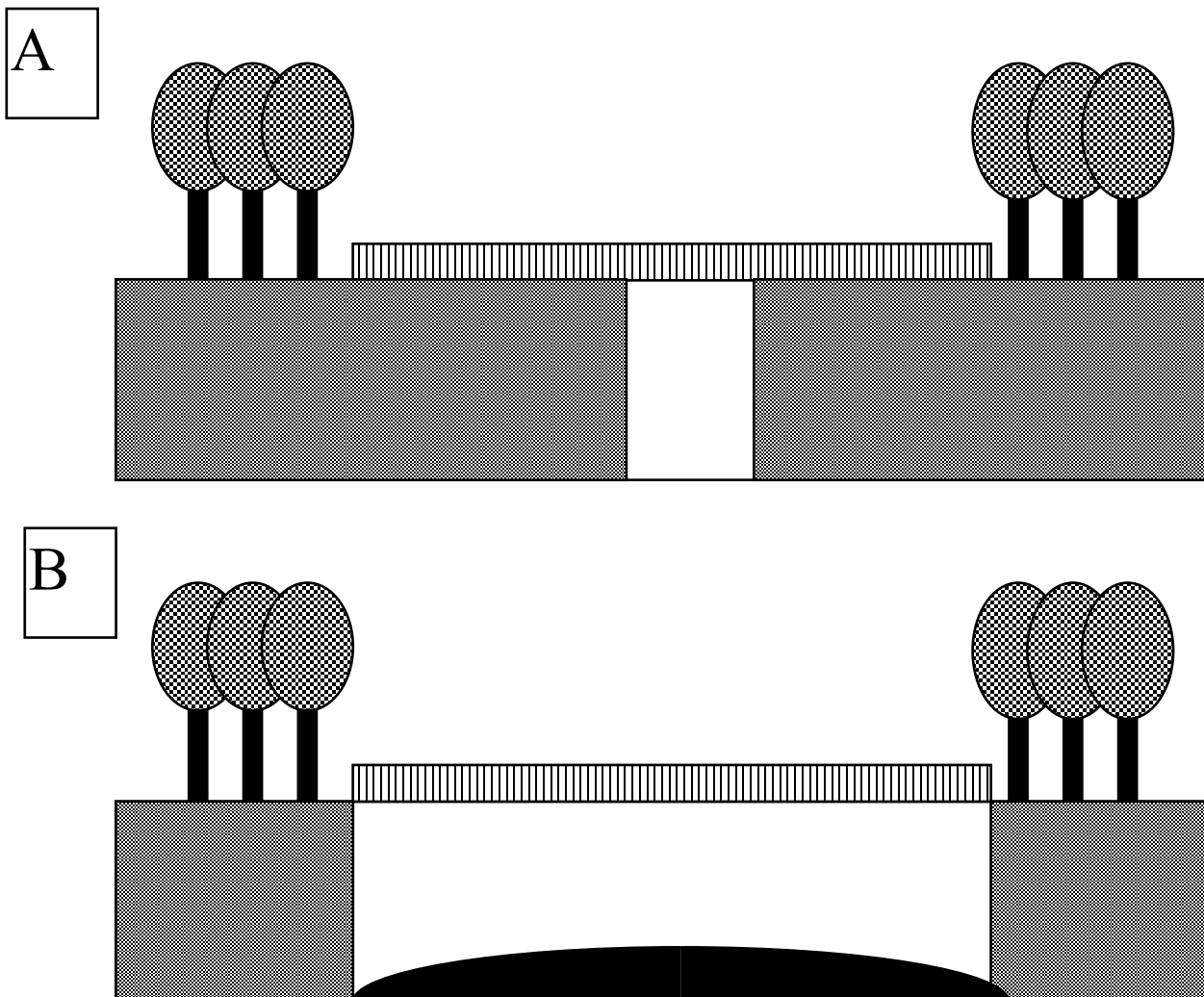


Figure 9. Choice of alley trees with a) wide lateral extension or b) narrow lateral extension in the presence of a watertable.

3.8 What about perennial pastures?

There are some perennial crops, particularly lucerne, which have very similar water use patterns to trees (eg. Carbon *et al.* 1982, Cransberg and McFarlane 1994). Planting perennial pastures will be more acceptable to farmers than planting trees. In agronomic circles there is an increasing realisation that pasture management is a powerful tool for increasing grain yield and protein levels. Lucerne is not an easy crop to manage, but the farmers who have mastered it are among the most profitable.

The essential difference between trees and a deep rooted crop such as lucerne, is that trees have a sparse root system operating year round, whereas lucerne must “mine” water from the subsoils, left behind by annual crops. If lucerne can be integrated into cropping systems in such a way as to achieve the part of the goal of managing recharge, the need to reafforest will be reduced to more economically realistic levels.

Section 4.

THE ECONOMICS OF ALLEY FARMING

In this section, two recent pieces of research are briefly summarised to illustrate the implications, first at the paddock scale and then at the farm scale, of adopting a sandplain alley farming system in the wheatbelt of WA. The first emphasises the importance of knowing the nature of interactions between trees and crops over a range of seasonal conditions. Although only one season's data is presented, it illustrates the implications of the competitive effects of trees, their commercial value and the particular layout used. The second emphasises the point that the full economic implications of alley farming for a mixed cropping and livestock enterprise only become apparent when examined at the whole farm scale. These include secondary effects such as better feed utilisation, reduced pressure on conventional annual pastures and more land use options.

4.1 How alley farming can effect crop yield

Measurements of lupin yield in a 40 ha alley farmed paddock on deep sand over gravel soil at Dowerin, 150 kilometres north east of Perth, were carried out in November 1993. The shrubs *Acacia saligna* and tagasaste (*Chamaecytisus proliferus*) had been planted in 1989 in alternating three row belts orientated north south and spaced 30 m apart. The paddock remained in pasture until 1993 when a lupin crop was sown in the first week of May.

Six replicated 20 m by 30 m plots were harvested in the alleys in strips parallel to the shrub rows with a 1.5 m wide plot harvester to produce continuous yield transects across the alleys. One open paddock plot away from the influence of the trees was also harvested.

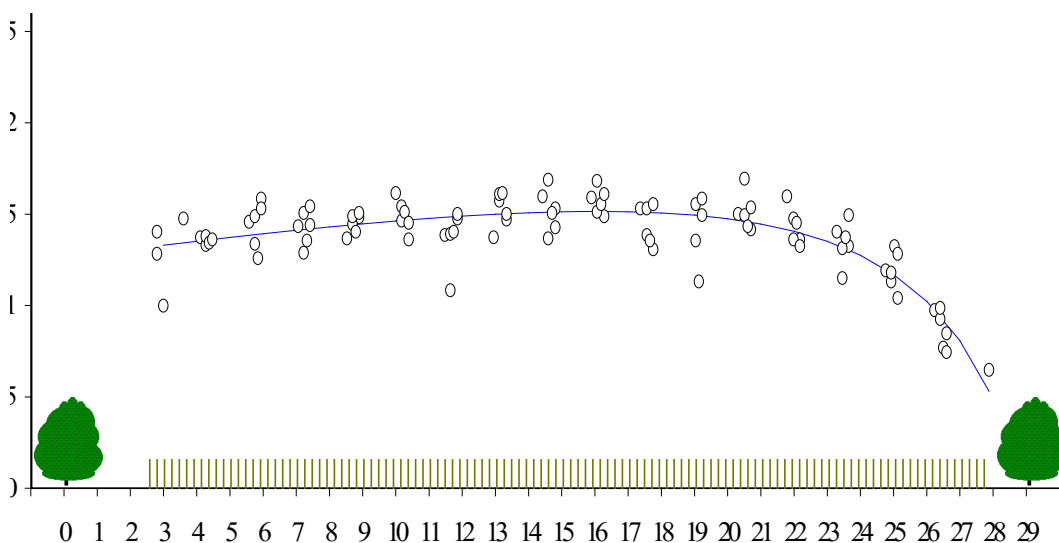


Figure 10. The influence of trees on the yield of lupins across a 30 m alley (6 reps)

Figure 10 shows that there was a strong directional trend in the influence of the trees on lupin yield. Lupin yield was markedly lower in the eastern lee (right hand side) of trees than in the western lee. Half the data points in Figure 10 are from plots that had tagasaste on the western side and acacia on the east. The other half are from plots with the reverse arrangement, indicating that the effect of trees on yield was directional and not species dependant. The net effect of the trees on lupin production at the paddock scale is shown in Figure 11. While the open paddock yield in Figure 11 cannot strictly be considered a control as it was later

discovered that different herbicide rates had been used in the alley farmed and open areas, it is included to illustrate the principle of the trade-offs are involved in alley farming.

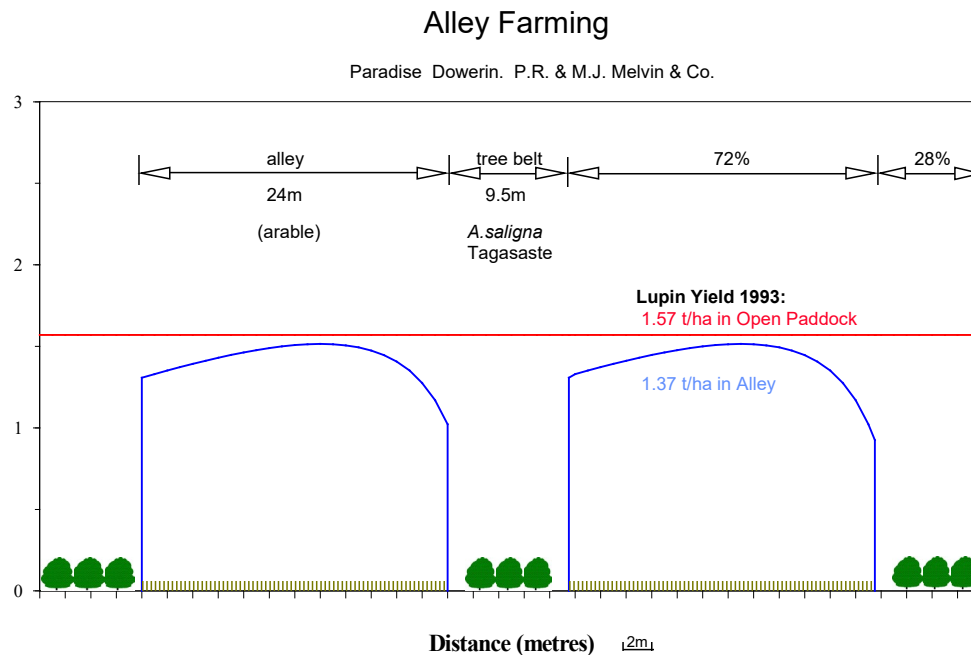


Figure 11. The influence of one alley farming design on lupin yield at the paddock scale.

The strongly directional trend in the effect of the trees on lupin yield was most likely due to frost damage. Frost damage was apparent in this and neighbouring lupin crops. It is possible that the trees restricted air movement across this paddock and so exaggerated this effect, particularly in the eastern lee of the tree rows where temperatures would have remained low for a longer period after sunrise. The fact that frost damage occurred in the eastern lee of both tagasaste and acacia rows suggests that this directional effect was not species dependant.

The yield depression in the alley illustrates the potentially negative effects of trees on crop yield and the need for long term studies that cover a wide range of seasonal conditions. A long term windbreak study in Nebraska reported that over six consecutive years of measurement, shelter effects on wheat yield varied from a 50% increase to a 44% decrease, with an average net effect of +15% (Brandle *et al.* 1988).

Even though this study lacked a satisfactory control, it is possible to derive from Figure 11 a simple break even equation to illustrate the principles involved in the net commercial effect of alley farming.

$$T + (Y_2 - Y_1) - D = \text{net benefit}$$

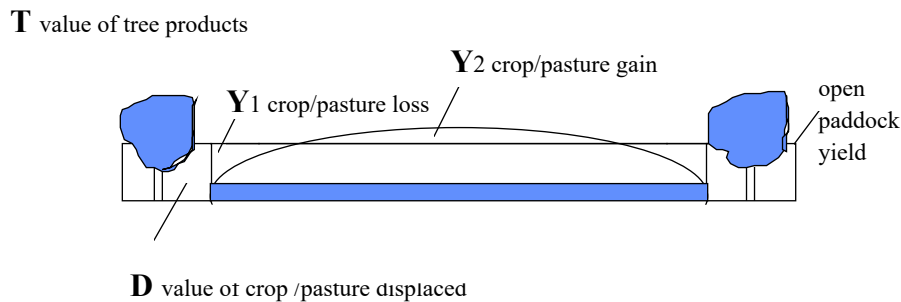


Figure 12. The break even equation for alley farming showing the relationship between the value of tree products (T), the negative effect of the trees on crop production (Y1), the positive effects of the trees on crop production (Y2) and the value of crop displaced by the trees (D).

The various positive and negative influences shown in Figure 12 need to be considered at two levels; a biological one, in terms of total biomass production of the mixture, and an economic one, expressed as the net returns per hectare. Where the tree and crop products are of differing value per unit biomass, the economic and biological consequences may well be different. For example, a relatively high value tree product may compensate for a net decrease in crop yield in the mixture in a dry year, so that economically the mixture may break even whereas biologically there is a net dis-benefit from alley farming when compared to sole crop.

This equation emphasises the fact that the opportunity cost of the crop displaced by the trees (D) needs to be compensated by some combination of net yield benefit, the commercial value of the trees and their long term environmental benefits. Assuming the open paddock yield in Figure 11 did represent the control yield, then the value of the trees as fodder and/or their long term benefits would have to make up for a 37% decrease in harvested grain due to land taken up by the trees plus the yield decrease in the alleys, a net loss that amounted to \$58/ha. For the trees to compensate in the short term, tree fodder at the measured edible dry matter yield of 2t/ha from the 11 ha of tree belts in this paddock land would have to be worth \$105/t net, some three times the cost of equivalent feed value from alternative sources such as lupins or oats.

This study highlights several factors critical to decisions about integrating trees into cropping systems. Firstly, trees can have negative effects on crop yield through competition and microclimatic influence. To understand the nature of these interactions, measurements need to be sufficient to model the processes involved and then use historical weather data to assess the impact of a wide range of seasonal conditions. This is the approach being taken by the National Windbreaks Program, and it needs to be extended to a wider range of tree species to characterise the below and above ground influence of trees

Secondly, it is apparent from Figure 12 that the design of alley farming systems (the width of the tree belts and the width of the alleys) has a large influence on profitability through the opportunity cost of the crop displaced. This analysis suggests where alley farming systems are

most open to manipulation and where research effort could be most effective. The factors in the break even equation that we can most easily influence are D, T and Y1. That is, we can consciously set out to minimise the proportion of land occupied by trees relative to the arable area (D), to increase T by selecting for trees with high commercial value, and decrease the competitive effects of trees (Y1) by selecting for trees with deep root systems and different seasonal patterns and mechanisms of water and nutrient uptake than the alley species.

The increase in crop yield (Y2) has two distinct components; above ground benefits and below ground benefits. Above ground benefits are very much dependant on unpredictable climatic events that would induce greater heat stress, cold stress or physical damage in the open than in an alley farming situation. With below ground benefits, there is likely to be a trade off between the improved soil conditions that tree roots can produce and competition for water and nutrients. Realistically, competition will occur and is most likely in dry seasons. Having high value trees can compensate for the negative effects of trees, some of which can be influenced through plant selection, design of alley farming systems and management such as root pruning.

In summary, the important criteria for tree selection are high economic value (T) and low competition effects (Y1). Important aspects of management are design to limit the area of lost arable land (D), and possibly root pruning.

4.2 Whole farm economic modelling of alley farming

Summary

This section describes a modelling exercise that was undertaken to determine the extent to which a tagasaste alley farming system might economically drive improvements in the sustainability of agriculture in sandplain areas of south Western Australia (Lefroy *et al* 1996). The bio-economic model MIDAS was used to compare the profitability of the conventional farming system of the West Midlands sandplain region in Western Australia with three recent innovations - 1) new cultivars of the annual pasture species Serradella, 2) the forage shrub tagasaste in plantations and 3) tagasaste alley cropping. Adding serradella increased sheep numbers by 31% through increased winter feed but did not have a proportional effect on farm profit as the autumn feed bill more than doubled. Adding tagasaste in plantations resulted in a further small increase in sheep numbers but a dramatic increase in profit (77%) as it substituted for all the supplementary feed required to carry animals through the autumn drought. Alley cropping was the most profitable option, increasing sheep numbers by 76% and profit by 95%. The advantage of alley cropping over plantations of tagasaste was the more efficient production of tree fodder per unit area and the more effective use of dry pasture and crop stubbles in autumn when grazing restrictions due to wind erosion risk usually apply.

Background

Economic modelling by Mattinson and Oldham (1988) using the results of grazing experiments suggested that planting up to 10% of a sandplain farm to plantations of tagasaste could be economically justified as a substitute for the grain feeding of a self replacing ewe flock. They suggested that planting more than 10% of farm size could not be justified as tagasaste would have to compete with less expensive annual pastures and crop residues either side of the autumn period. This was later borne out in a large scale experiment (Oldham 1992). However, having only 10% of cleared land at the farm or catchment scale block planted to tagasaste may not have the desired impact on water use and have no impact on soil protection over the remaining 90 % of the farm. The question being asked in this modelling exercise was would it be as profitable to spread those trees over a larger area in the form of alley farming and achieve the ecological objectives of soil protection and higher water use.

The model used was MIDAS (Model of an Integrated Dryland Agricultural System). This is a bioeconomic model of mixed crop and livestock farming in Western Australia that uses the linear programming technique to select management strategies which maximise profit subject to resource, technical and environmental constraints (Morrison *et al.* 1986, Kingwell and Pannell 1987, Abadi Ghadim 1993, Pannell and Bathgate 1994). Given a detailed set of relationships between all crop and livestock activities provided by the user, the model will calculate the optimal mix of resources and activities that will maximise profit, including crop and pasture rotations, flock structure, stocking rate and feeding strategies. The model is strongly based on soil types and rotations, with different production specifications for each rotation on each soil type.

The model is based on a 3000 ha farm made up of 1700 ha of leached sands (S1), 1000 ha of earthy sands (S2) and 300 ha of sand over lateritic gravel (S3). Three new options were then successively introduced to the conventional model; improved serradella based annual pasture (*Ornithopus sativa* and *O. compressus*), tagasaste plantations and alley farming with tagasaste. While the serradella and tagasaste plantation options compete directly with the conventional options for land, the alley farming option is compatible with all other annual pasture and crop rotations, although if selected the arable area is automatically reduced by 8%. The

conventional options are based on current practice. The agroforestry options are based on experimental results and commercial experience (Oldham *et al.* 1991, Oldham 1993, Lefroy and Melvin 1996). As there is a great deal of uncertainty about the effect of trees on crop and pasture productivity, it was assumed in this model that the trees in the alley farming layout had no positive or negative effects on crops and pastures other than the loss of arable land. Details of the four versions of the model are set out below.

1. *Conventional*. The flock structure is a self replacing ewe flock in which all sheep were maintained in score 2 condition or better, requiring hand feeding in autumn and early winter. Wool price was set at 300 c/kg and a borrowing limit of \$200,000 imposed. Conventional rotations are sandplain lupins or continuous annual pasture on the leached sands (S1), cereal/pasture or cereal/lupin rotations on the more fertile earthy sands (S2) and cereal/pasture, cereal/field pea or continuous pasture on the sand over gravel (S3)

2. *Serradella*. Pasture production was assumed to be 50% higher than for conventional annual pasture on the deep sands (S1) and earthy sands (S2) based on large scale experimental results. The cost of establishment was assumed to be \$40/ha and this was amortised over 20 years at 12% to produce an annual cost component.

3. *Tagasaste plantations*. The layout and production of the tagasaste plantation option was based on the work of Oldham *et al.* (1991) and the commercial adoption of that research. Single rows of trees are spaced 5 m apart, giving 2000 m of row per hectare with a production of 3000 kg/ha of edible dry matter per year, or 1.5 kilograms of edible dry matter per metre of row per year. This was available for grazing in any month but for no more than five months in any one year to protect against bark stripping. The edible material was assumed to be 70% digestible and contain 18% protein, with a feed value of 10 megajoules per kilogram of dry matter. Establishment cost was \$320/ha including direct seeding, insect control, subdivisional fencing and interest on borrowing the full cost of establishment to be payed back over ten years. This was amortised over 20 years at 12% interest to produce an annual cost component. An annual maintenance cost of \$17.50/kilometre of row per year was included to cover the cost of cutting which is necessary to bring the material in the hedgerows within the browsing height of sheep.

4. *Alley farming with tagasaste*. Double rows of tagasaste separated by a 60 m wide alley giving 333 m of tagasaste hedgerow per hectare, with the trees occupying 8% of the land. Assuming the same production level per metre of row as in the plantation layout, the alley farming layout produces 480 kg/ha of edible dry matter when plantation production is 3000 kg/ha, 16% of the edible dry matter produced at plantation density. The availability of the tagasaste in alley farmed paddocks was linked to the grazing of associated pasture or stubble, being available in any month but for no more than five months in any one year as a protection against tree damage through over grazing. Establishment cost was \$52/ha, including planting, insect control, subdivisional fencing and interest on borrowing the full cost of establishment to be payed back over ten years. The cutting cost was \$17.50/kilometre of row per year.

Results

Adding the new serradella substituted directly for conventional pasture on the S1 soil type, resulting in greater winter carrying capacity with the optimal flock size increasing by 31% (Table 1). As there was no proportional increase in autumn feed supply however, the grain feeding bill increased from \$ 10,500 in the conventional model to \$38,100. The increase in farm profit was therefore relatively small at 16%. An advantage of having the serradella was that pressure was removed from the conventional annual pastures on the S3 soil type between November and April, grazing of which was held over until May (Table 2). This would help

protect both the soil structure and seed bank with implications for persistence and early winter production which are not reflected in these modelling outcomes.

Table 1. Sheep numbers, landuse, profit and % tree cover resulting from the addition of serradella, tagasaste plantations and tagasaste alley farming as options in the West Midland MIDAS model.

			Model			
			Conventional	Serradella	Tagasaste	Alley
Sheep number	dse		6,456	8,625 (up 31%)	9,027 (up 36%)	11,415 (up 73%)
Crop	ha		1,000	1,000	1,000	1,000
Profit	\$		51,331	59,635 (up 16%)	90,800 (up 77%)	102,302 (up 95%)
Feed cost	\$		10,500	38,150 (up 263%)	-	-
% Tree cover	@	2000	-	-	5	6
	@	150	-	-	-	45
			stems/ha			

When plantations of tagasaste were added as an option, the area selected to maximise profit was 5% of farm size. This option substituted directly for serradella pasture on the S1 soil type. As this feed is available outside the winter growing season, when the marginal value of each additional kilogram of feed is substantially higher than in spring (Abadi Ghadim and Morrison 1992), farm profit increased by 77%, largely through the elimination of grain feeding. Sheep numbers increased by only 5% compared to the serradella model. Feed calendars generated by the model showed that tagasaste was selected to be grazed in January, May, June and July, indicating that the period of limiting feed supply had shifted from autumn to winter. Not having to graze annual pastures from January to April would protect the seed bank and therefore improve the persistence and early winter production of those pastures

Table 2. The area selected for each rotation in the conventional, serradella , tagasaste and alley farming models (ha).

		Model			
Soil type	Landuse	Conventional	Serradella	Tagasaste	Alley
S1	conventional pasture	1258			
	sandplain lupins	442	622	628	
	sandplain lupins in alleys				164
	serradella pasture		1078	920	1181
	serradella pasture in alleys				184
	tagasaste plantation			142	171

S2	cereal/lupin cereal/lupin in alleys	1000	1000	1000	1000
S3	continuous pasture	300	300	300	300
Total		3000	3000	3000	3000

Adding alley farming as an option increased sheep numbers by 76% and profit by 95% compared to the conventional model. Much of this would be due to the greater efficiency of land use based on the assumption that closely planted double rows of tagasaste in alleys (occupying 8% of land area) would produce 16% of plantation production. With alleys, the use of tagasaste shifted from being solely on the S1 soil type to being predominantly on the more fertile earthy sands, inter cropped with cereal lupin rotation. This freed up the S1 soils for the high yielding serradella pasture. Some of this increase would also be due to more effective utilisation of annual pastures and crop residues in autumn and early winter when restrictions normally apply due to wind erosion hazard. The total area of tagasaste planted increased from 5% to 9% of arable land, reflecting its shift from a hand feeding substitute to a major feed source enabling a significant increase in carrying capacity. In terms of the ecological objectives, adding the alley farming option resulted in 45% of the farm being planted to tagasaste at 150 stems/ha and a further 6% to plantations at 2000 stems/ha.

Implications

This modelling exercise suggests there may be significant economic and ecological advantages using tagasaste in alley farming in addition to its use in plantations, depending on the validity of the following assumptions.

1) Tree yield and tree crop interactions. The assumption that closely spaced double rows in the alley layout would produce the same production per metre of row as rows 5 m apart in plantation may not be borne out in practice. Also it has been assumed that the trees have no negative or positive effect on associated crops and pastures. In reality there is likely to be some competition, especially for water in drier years, and some benefits from shelter in years with extreme weather events. This could be reflected by using yield modifiers that are based on climatic variability.

2) Tagasaste water use. It has been assumed that tagasaste in alleys, occupying about 8% of the landscape, would be effective in reducing recharge. There is no empirical evidence to support this yet, with the only work on tagasaste water use being from one plantation in the high rainfall zone.

3) Increased management. Even though the use of tagasaste eliminates hand feeding, stock numbers are significantly higher, the trees must be carefully managed and there are more decisions to be made about which source of feed to use. For instance, with the alley farming option there are at least four alternatives to annual pastures in all months except the most reliable period of the year, from August to November. While the cost of handling additional sheep and cutting the trees has been accounted for, the increased management input has not.

As MIDAS is an equilibrium model, these results do not reflect the likely negative impact that the establishment period will have on the cash flow. The value of using the MIDAS model to

analyse agroforestry systems is its ability to take into account the complex interactions in a mixed crop and livestock system. This can indicate the likely benefits of changes to a farming system at a regional scale using a generic example, but at the individual farm scale investment analysis is needed to determine the best means of achieving the optimal mix of activities within an acceptable level of short term debt.

This study also highlights the importance of high commercial value in candidate tree species for alley farming. The higher the commercial value of a species, the less critical are negative tree crop interactions, the more intensive management demands of agroforestry and the negative effect of establishment on cash flow in the early years.

Section 5. CHALLENGES FOR R&D IN AUSTRALIA

Section 4 has shown that alley farming can be driven by economic incentives alone. There were advantages in mixing trees with crops without invoking environmental issues. Tagasaste/wheat alley farming in WA may be one of the few win-win scenarios i.e. a more productive farming system that is probably more sustainable. The profitability of alley cropping depends on two factors; the value of the tree in the context of the whole farm (fodder, timber etc), and the value of crop/pasture yield forgone by displacement or by competition with trees. It is likely that more trees will be required on environmental grounds than will be planted based on farm scale economics. The challenge for R&D is to identify the most profitable trees, to plant the right proportion of the landscape in the optimal places with the least disruption to annual based farming systems. This will necessitate the ability to work through the issues from region to catchment scales. At the farm scale we need to know how to maximise the complementarity between trees and crops.

5.1 Scaling between levels of inquiry

A major challenge is to integrate information at different scales as summarised in Table 5.

Table 5. The research needs of alley farming at different scales

1. Ecosystem Comparative analysis of native and agricultural ecosystems in terms of water and nutrient cycling and energy use efficiency
2. Habitat Selection of well adapted candidate species on the basis of root architecture, phenology and commercial value
3. Catchment The hydrologic implications of introducing alley farming systems into the agricultural landscape
4. Farm The economic & social implications of integrating trees in terms of profit optimisation and investment strategies
5. Plot / Paddock Competition, relative yield analysis, resource allocation and water balance studies in mixtures of trees and crops

Ecosystem

A logical starting point is to look at water and nutrient cycling in pre-agricultural vegetation communities and see what lessons could be transferred to the agricultural setting. Precedents in this area of designing agricultural systems as mimics of native ecosystems include the work of Hart (1980), Ewell (1986), Jackson (1985), Ridpath (1985) Lefroy et al (1993) and Soule and Piper (1992).

Habitat

Regions of the world with climatic and edaphic homology to the region of interest must be systematically scoured for plants of potential economic value. There are presently only three tree species with sufficient commercial value to be economically driving the adoption of alley farming systems in WA - tagasaste, pines and Tasmanian bluegums. We need to develop

ideotypes and selection criteria eg. Huxley (1994) and van Noordwijk (1994) and Donald (1963).

Catchment

A single farmer cannot address issues occurring at the catchment scale. Alley farming design needs to be linked to catchment scale modelling to have any chance of being effective at increasing water use. Relevant modelling in progress includes that by Raper (Agriculture WA/RIRDC), Majer (WA Water Authority), Sharma and colleagues (CSIRO Water Resources WA) and Hatton and colleagues (CSIRO Water Resources SA).

Farm

The economic consequences of any change in the management of a farm business can only be assessed by examining the implications for cash flow, profit, equity and net present value on a whole enterprise basis. In order to evaluate a new management strategy, some form of optimising model and investment analysis is required (section 4).

Plot / paddock

Many of the questions about competition and complementarity in tree/crop systems can only be answered at the scale of small plot experiments. These include questions of resource allocation, particularly water, and the distinction between above and below ground competition. Questions of design (such as tree species, alley width, tree row orientation) and management (root pruning, grazing frequency and intensity and chemical susceptibility of mixtures) and how they influence relative yield totals all need to be addressed at the plot or paddock scale.

5.2 Maximising complementarity in tree crop systems

If a tree crop mixture is going to perform better than single species, the complementarity between the species must outweigh the competition between them. Complementarity can be spatial (shallow/deep root systems), temporal (seasonal/perennial growth) or functional (legume/non legume). A large amount of information is needed about tree water use patterns. Since tree planting will often be driven by the spectre of rising water tables, we need to understand interactions at the tree root/water table interface. Since alley cropping disperses trees widely over the landscape, we need to characterise the tree crop interface.

Tree root/water table interface

If trees can access the water table they will grow faster and compete less with crops. Calculations can be made as to how far apart the tree belts should be for different soil types to prevent a water table rising between the belts. A major potential problem is that when trees draw on saline water, salt will be concentrated within the root zone, and this would reduce both their growth rate and water use. Coupled water and salt transport models are needed in conjunction with well designed field experiments to test these hypotheses.

Tree/crop interface

The length of the interface is determined by the spatial arrangement of trees. In most cases the crop growth will be reduced at the interface and tree growth may be enhanced, but tree

selection will affect this. The lateral extent of the interfacial zone is determined by the horizontal distance tree roots grow from the trunk. A wide lateral rooting habit will increase the zone of tree/crop competition but reduce its intensity. The best option is a tree that has a very wide exploitation zone relative to its leaf area so that extraction rates are slow. Slow extraction must be compensated for by a deep root system and/or high water holding capacity soil, so that the storage zone can accommodate long wet periods before its eventual depletion by trees. Experiments must be set up to quantify resource allocation in the interfacial zone for a number of different trees and environments. This approach is recommended above traditional agronomic designs (spacing x tree variety x crop interactions), which assumes uniformity within plots. The performance of an alley farming system will be determined by the sum of what happens at the interfaces. Only one interface needs to be well characterised.

5.3 A check list for alley farming research

Why are we considering alley farming?

Is it primarily

- (A) to control water tables
- (B) to grow a commercial tree crop for fodder or timber
- (C) for wind erosion protection and shelter
- (D) to improve soil nutritional status through mulching
- (E) for improved nature conservation values

If it is being considered for multiple reasons, work through each in turn starting with the primary objective.

(A) *If alley farming is being considered for water use, then*

- 1 can we use lucerne or some other herbaceous perennial in rotation with annual crops?
- 2 if not, what is the minimum proportion of a catchment which must be planted to trees to manage the problem? We need to be guided by experimental data or model predictions that have been validated in the region
- 3 where should trees be located in the catchment? Simple catchment flownets will give the first approximation
- 4 how should trees be arranged in a paddock? This will depend on the tree crop interface. If it is strongly negative we must move from an alley layout towards block plantings
- 5 is there a water table? The depth and quality of a water table will override considerations in 3 and 4 above. Tree selection and arrangement should be directed toward utilising water tables where salt can be leached from the root zone

(B) *If alley farming is being considered as a way of growing a commercial tree crop, then*

1. we need to know the nature of tree/crop interactions at the interface, i.e. does the tree species have a negative or positive effect on associated crops and pastures?
2. if positive, alley farming is appropriate, go to question 3. If negative, is the value of the tree likely to compensate for reductions in crop yield? (see the break even equation in section 4 of this report) if not, then use block planting, not alley farming
3. design and layout needs to be determined on the basis of a) meeting other objectives such as water use and shelter, b) minimising shading of inter row crops, c) site conditions such as

slope and aspect, d) practical issues including pruning, harvesting, widths of agricultural machinery and grazing management

(C) *If alley farming is being considered for wind erosion protection and shelter*

1. identify the tallest, fastest growing tree species that are well adapted to your environment
2. select from 1 above species with the most positive tree/crop interface
3. plant the chosen species in rows 20 times their mature height apart orientated at ninety degrees to the most damaging winds

(D) *If alley farming is being considered to improve soil nutritional status through mulching*

trees do recycle nutrients from depth, but it is unlikely that there is any benefit in semi arid Australia in trading water for nutrients i.e. the value of water used by trees will not compensate for the nutrients they may recycle. This does not take into account the objective of tree planting to manage sub soil acidity.

(E) If alley farming is being considered for improved nature conservation values

if the opportunity cost of agricultural production foregone is not an issue, why not plant the whole paddock? If it is an issue, then use the alley farming break even equation in section 4 of this report to calculate that opportunity cost on the basis of the competitiveness of the species to be used and the proposed layout.

APPENDIX 1. People contacted during the course of the study

Name	Involvement	Location
Angus, Henry	Landholder	Meningie, SA
Bartle, John	Research	CALM WA, Perth
Bicknell, David	Extension	Agriculture WA, Narrogin
DDDavidDavid		
Bird, Rod	Research	Agriculture Victoria, Hamilton
Clarke, Rob	Research	University of Tasmania, Hobart
Clem, Bob	Research	QDPI, Brian Pastures RS, Biloela
Dalton, Greg	Research	PISA, Murray Bridge
Dodds, Ron	Extension	Greening Australia, Nhill, Victoria
Ellis, Tim	Research	University of Adelaide, Roseworthy
Gutteridge, Ross	Research	University of Qld
Haines, Phil	Research	Agriculture Victoria, Rutherglen RS
Hatton, Tom	Research	CSIRO Water Resources, Adelaide
Jenkins, David	Landholder	Bridgetown, WA
Jowett, Don	Research	Agriculture Victoria, Hamilton
Knight, Alex	Research	PISA, Murray Bridge
Lamont, Helen	Extension	PISA, Cleve
Lawes, Roger	Research	Agriculture Victoria, Walpeup
Leakey, Roger	Research	ICRAF, Nairobi, Kenya
Lemon, Jeremy	Extension	Agriculture WA, Esperance
Longbottom, Hugh	Extension	PISA, Maitland
MacFarlane, Don	Research	Agriculture WA, Albany
McDonald, Colin	Research	Agriculture WA, Albany
McGrath, Darren	Research	Agriculture Victoria, Bendigo
Melvin, Dean	Landholder	Dowerin, WA
Sherren & Craig		
Mitchell, Tom	Extension	Agriculture WA, Moora
Moore , Richard	Research	CALM WA, Busselton
Mullen, Gavin	Extension	Agriculture WA, Merredin
Nuberg, Ian	Research	University of Adelaide, Roseworthy
Oldham, Chris	Research	Agriculture WA, Perth
Ong, Chin	Research	ICRAF, Nairobi, Kenya
Peake, Bob	Extension	PISA, Keith SA
Pratt, John	Extension	Agriculture WA, Esperance
Powell, John	Research	MDBC, Canberra
	Admin.	
Raper, Paul	Research	Agriculture WA, Perth
Reid, Nick	Research	University of New England, Armidale
Smettem, Keith	Research	University of WA, Perth
Speed, Russel	Research	Agriculture WA, Geraldton
Sudmeyer, Rob	Research	Agriculture WA, Esperance
Thomas, John	Landholder	Dowerin, WA
Underdown, Mick	Research	PISA, Mt Gambier
Wallace, Ken	Research	CALM WA, Narrogin

Ward, Brett
Waugh, Gary
Wiley, Tim

Research
Research
Research

Agriculture WA, Katanning
CSIRO Forestry, Melbourne
Agriculture WA, Moora

APPENDIX 2. Annotated bibliography of Australian alley farming publications

1. Cameron, D. M., Gutteridge, R. C. and Rance, S. J. (1991) Sustaining multiple production systems.1. Forest and fodder trees in multiple use systems in the tropics. *Tropical Grassland Society of Australia* **25** (2): 165-172

Short review listing advantages and disadvantages of agroforestry

2. Chatfield, J. (1994) In Proceedings of a National Conference on Land Management for Dryland Salinity, Bendigo.

Description of revegetation strategies, including alley farming, being used for land and nature conservation in the central wheatbelt of WA

3. Cochrane, D., George, R and Bennett, D (1993) Profitable utilisation of water in farming systems. Report on RIRDC Project No COCHRA001. Start date 4/1993, end date 6/1997.

Project to asses the effectiveness of controlling water logging and salinity using trees on contour banks and valley floor alley farming (perennial pastures between commercial tree species). Geophysical survey conducted and 69 bores installed, 12 with data loggers.

4. Francis, P. (1992) Alley farming challenge for sustainable cropping. *Australian Farm Journal* 1992, 08 **2** (8): 64-69.

Description of examples of commercial alley farming in Western Australia

5. Francis, P. (1994) Bringing sustainability to the Mallee. *Australian Farm Journal* 1994, 05 **4**(3): 82-83

Profile of a contract tree planting business in Murrayville, Victoria, which is advocating farm revegetation including woodlots, windbreaks and alley farming with fodder trees and shrubs

6. Gutteridge, R. C. (1985) Alley cropping Leucaena with Kenaf (*Hibiscus cannabinus*). *Leucaena Research Reports* **6**: 1-2

Leucaena at 3 and 5 m spacings added equivalent of 110 kg/ha and 66 kg/ha N respectively as mulch. Yields of kenaf in alley cropping were less than controls with 50/kg N.

7. Gutteridge, R. C. (1988) Productivity of Gliricidia sepium in a sub-tropical environment. *Tropical Agriculture* **65** (3): 275-276.

8. Gutteridge, R. C. (1988) Alley cropping Kenaf (*Hibiscus cannabinus*) with Leucaena (*Leucaena leucocephala*) in south-eastern Queensland. *Australian Journal of Experimental Agriculture* **28** (4) 481-484.

Kenaf yields in plots mulched with Leucaena foliage were maintained at 4.7 t DM/ha while those in control and fertilised plots (50 and 100 kg N/ha) declined by 30%.

9. Gutteridge, R. C. (1988) Alley cropping. An alternative farming practice. *Agricultural Science* **1** (7): 18-21

Briefly reviews the practice of alley cropping in the tropics and advocates its adaptation to Australia to alleviate land degradation.

10. Gutteridge, R. C. (1990) Agronomic evaluation of tree and shrub species in south east Queensland. *Tropical Grassland Society of Australia* **24** (1) 29-34.

Assessment of Leucaena leucocephala, L. collinsii, L. diversifolia, L. pallida, Calliandra calothyrsus, Gliricidia sepium, Sesbania sesban, and S. grandifolia for adaptation and suitability for use in alley cropping .

11. Haines, P. J. (1993) Productive cropping systems with high water use. Report on project VICDA_251. Funded by GRDC. Start date 1994/01, end date 1996/12.

Assessing the effect of lucerne and native shrubs on soil water use and plant productivity in crop rotations in ley and alley farming systems at Rutherglen Research Station.

12. Lefroy, E. C. (1994) A tale of two alleys. Parallel evolution of agroforestry systems. *Agroforestry Today* **6**: 5-7

Description of similar alley farming systems in south western Australia and south western South Africa, both involving the cultivation of cereal/legume crop and pasture rotations between wide spaced fodder shrubs.

13. Lefroy, E. C. and Oldham, C. M. (1993) Fodder shrubs and alley farming in low rainfall zones. In Proceedings of a Workshop on Low Rainfall Agroforestry, Yanchep WA. RIRDC.

Description of the commercial use of the fodder shrubs tagasaste (Chamaecytisus proliferus), Acacia saligna and Atriplex spp. in plantation and alley farming formats in the < 450 mm rainfall zone of Western Australia

14. Lefroy E. C. and Scott, P. R. (1994) Alley farming. New vision for Western Australian agriculture. *Journal of Agriculture WA* **35**: 119-126.

Description of four alley farming systems in commercial use in WA; timberbelt, saline, sandplain and 'Mallee-alleys'. Includes measurements of productivity of a timberbelt alley farming system and discussion of the advantages and disadvantages of the others.

15. Lefroy, E. C. and Melvin, D. P. C. (1996) The influence of alley farming and intercropping on the yield of lupins. In Proceedings 8th Australian Agronomy Conference, Toowoomba, pp. 377-380

Yield of lupins in 30 m wide alleys between rows of tagasaste and acacia in 1993 were 37% less than open controls due to land occupied by the trees (24%) and the effects of competition with the trees and higher frost incidence in the alleys (13%). Inter-cropping with a summer active perennial grass had no significant effect on grain yield.

16. McCown, R. L. (1987) An agroecological approach to the management of SAT alfisols. *In Proceedings, Alfisols in the Semi Arid Tropics, ICRASAT, Pantacheru, India.* pp175-185.

Advocates research into three farming systems that are in sympathy with the limitations of climate and soil fertility in the SAT; no tillage mulch farming, legume alley farming and legume ley farming. Includes preliminary results from the assessment of a no tillage legume ley strategy in Australia which shows substantial benefits in crop and animal production and soil conditions.

17. Paterson, M. (1992) Alley farming beats salinity. *Australian Farm Journal* 1992/01 **1** (11): 93-94.

Describes an alley farming system planted in 1992 at Bibby Springs in the West Midland region of Western Australia that has been planted to control a rising water table. Rows of Eucalyptus camaldulensis and Casuarina obesa spaced 15 m apart. (A case of premature congratulation.)

18. Stirzaker, R. (1996) Lucerne/vegetable alley cropping to control leaching *In Proceedings 8th Australian Agronomy Conference, Toowoomba*, pp. 522-525

see section 3.4

19. Xu, Z. H., Saffinga, P. G., Meyers, R. J. K. and Chapman, A. L. (1992) Nitrogen fertilizer in Leucaena alley cropping. 1. Maize response to nitrogen fertiliser and the fate of fertiliser-¹⁵N. *Fertiliser Research* **33** (3) 219-227.

Description of small plot experiments evaluating the response of maize to N fertiliser and mulching with Leucaena prunings in a 4.5 m wide alley cropping system at Katherine, NT. Application of N improved maize yields and significantly increased the contribution of leucaena prunings to crop production.

20. Xu, Z. H., Myers, R. J. K., Saffinga, P. G., and Chapman, A. L. (1992) Nitrogen fertilizer in Leucaena alley cropping. 2. Residual value of nitrogen fertiliser and leucaena residues. *Fertiliser Research* **34** (1) 1-8.

Reports that of the leucaena -¹⁵N applied to maize in alleys, the maize recovered < 3%, 38-41% was found in the top 200 cm of soil, <1% leached and > 36% was lost from the soil-plant system in the first two years of a three year study. For fertiliser -¹⁵N applied to the crop, <1% was recovered by the crop, 12-13% was found in the soil, <1% leached and >36% lost.

21. Xu, Z. H., Saffinga, P. G., Meyers, R. J. K. and Chapman, A. L. (1993) Nitrogen cycling in leucaena (*Leucaena leucocephala*) alley cropping in the semi arid tropics. 1. Mineralisation of nitrogen from leucaena residues. *Plant and Soil* **148** (1) 63-72.

Further description of the experiment reported in 19, 20 and 21 above.

22. Xu, Z. H., Saffinga, P. G., Meyers, R. J. K. and Chapman, A. L. (1993) Nitrogen cycling in leucaena (*Leucaena leucocephala*) alley cropping in the semi arid tropics. 2. Response of maize growth to addition of nitrogen fertiliser and plant residues.

Further description of the experiment reported in 19, 20 and 21 above

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