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Phase Farming with Trees

A report for the RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program

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August 2000
RIRDC Publication No. 00/48
RIRDC Project No. CAL-3A

ISBN 0 642 5807 8
ISSN 1440-6845

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Published in August 2000
Printed on environmentally friendly paper by Canprint

Foreword

Salinity is a major problem in Australia. It affects not only agricultural land but also remnant natural ecosystems in agricultural landscapes, water resources and rural infrastructure.

Tree planting can be a solution to salinity. However, for a range of reasons trees are not always planted particularly in areas with low rainfall.

The scoping study reported here tests phase cropping with trees, an innovative approach which integrates short rotations (3-5 years) of trees with agricultural activities to control salinity and conserve soil. If successful, from both the biophysical and economic viewpoints, it may provide a management option that will increase the sustainability of the dryland farming systems of southern Australia.

This project was funded by three R&D Corporations — RIRDC, LWRRDC and FWPRDC which are funded principally by the Federal Government. The project is an addition to RIRDC's diverse range of over 450 research publications and forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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Peter Core
Managing Director
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Acknowledgements

We thank John McGrath and John Bartle (CALM) for enthusiastic discussions and helpful comments on the manuscript.

Abbreviations

PFT	Phase farming with trees

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Executive Summary

A scoping study was undertaken to determine the economic and biophysical feasibility of a proposal to research a system of phase farming with trees (PFT) in medium to low (300-600 mm) rainfall areas of southern Australia. This system is designed to use trees grown in very short term rotations (3-5 years) to rapidly de-water farming catchments, at risk of salinity, by depleting unsaturated stored soil water and reducing recharge while producing utilizable products. If feasible, the system will utilize a resource that is currently contributing to environmental problems while building more sustainable agricultural systems. Potential benefits include decreased salinization, improved farm cash flows, improved soil structure and acting as a disease and weed break.

Trees are recognised as an effective means of containing dryland salinity, which threatens over 11.8 Mha of productive land in Australia. Uncertainties about appropriate species, their placement and long lags until commercial return may inhibit farm tree planting. A method that offers certainty of de-watering target areas and producing a commercial product in a very short period, may encourage tree planting.

In the PFT system trees would be used as temporary elements in rotations with annual cropping. They would be planted at densities sufficient to use both the annual rainfall and water that has accumulated in soils during the cropping phase. Plantings would be in wide strips, blocks or whole paddocks depending on crop rotation and land-holder preference. The trees would be harvested when the accumulated water has been evaporated, probably within 3-5 years after planting. The harvested trees would be sold as feed-stocks for industry or used for bio-energy to contribute to farm income. Annual cropping would then resume.

If successful this system will allow the rapid expansion of tree planting in low rainfall areas across southern Australia, with:

- the rapid restoration of catchment water balances,
- the utilization of a resource (stored soil water) which is currently contributing to environmental problems,
- the production of wood fibre and non-wood products,
- an impact on Australia’s net carbon dioxide emissions by providing both a carbon sink in the vegetation and a feedstock for bio-electricity, and
- the development of more sustainable agricultural systems through the reduction in salinization, providing a disease and weed break and “biological ploughing” of sub-soils.

The PFT system has no direct counterpart in forestry, with short rotation systems invariably involving permanent plantings that are coppiced at regular intervals; our proposal in more akin to phase cropping with perennial agricultural plants such as lucerne (*Medicago sativa*). Similarly, the system could involve practices normally avoided in lower rainfall forestry such as high planting densities and substantial inputs of fertilizer. These would be used as a means of promoting early growth and water use. Although we have not made an explicit comparison with lucerne the major advantages of phase cropping with trees are likely to be a greater depth of rooting, and the maintenance of a larger canopy which will enhance both evapotranspiration and rainfall interception.

Biophysical analysis

In the absence of appropriate growth and hydrological data the WAVES model was used to examine the bio-physical feasibility of the system in both Western Australia (Merredin, mean rainfall 320 mm, potential evapotranspiration 1800 mm) and the Murray Darling Basin (Walpeup, Victoria (340 mm, 1750 mm) and Hillston, NSW (581 mm, 1750mm)). The WAVES model was run using real rainfall data for each location.

Several scenarios were examined, with these suggesting broad differences in likely response to the PFT system. The modelling suggests that the premise of the PFT system (*viz*. depletion of sub-soil moisture reserves under trees and subsequent recharge under agriculture) is realistic. Moreover, the outputs suggest different tree planting strategies according to differences in soil and hydrological conditions:

1) *20 m deep sandy soils.*
   Here PFT depleted soil water storage and stopped the recharge under agriculture (100 mm/year) within 2-3 years of planting. The high recharge rates resumed 3 years into the next agricultural phase. PFT is not suitable for such soils with the best strategy being permanent blocks of trees.

2) *Soils with 1 m of sand overlying 2 m of clay, with and without a fresh water table and with a saline water table.*
   Here recharge rates returned to a maximum within 1-5 years of clearing the trees. It is likely that soil salinity will accumulate under the trees grown over a saline water-table, with this requiring leaching before another rotation is possible. Again permanent plantations or salt tolerant perennials are recommended in these situations.

3) *Soils with a clayey surface horizon.*
   Here the rates of recharge are very low (1 mm/year) and trees may only be required at very long rotation intervals (~decades).

4) *Soils with 1 m of sand overlying 9 m of clay.*
   Here PFT depleted soil water storage and stopped recharge under agriculture within 3-4 years of planting. In contrast to the other sites, recharge did not commence under the agricultural phase for 10 years, before reaching a peak of 67 mm/year at 17 years. It may be possible to get zero recharge with a system with 5 years of trees and 10 years of crop.

The last situation corresponds to broad areas of southern Australia, and Western Australia in particular, where the regolith may be up to 30 m deep. The key question is whether this depth of soil is exploitable by tree roots; limited data in higher rainfall zones suggests tree roots have grown to at least 9 m depth within 6 years of planting *Eucalyptus globulus*. The effect of sub-soil conditions on the depth of rooting in drier areas is not known and needs to be resolved.

In the one case examined in this work, salt leached out of the soil profile much slower than it built up, and transiently the leaching caused substantial increases in soil water salinity. *The presence of salt complicates the question of a sustainable and economically viable system so greatly that more detailed work is required to find any general patterns*. The concept of a critical groundwater depth may be useful in this context.

Effects on soil fertility

A literature review of the likely affects of the PFT system on soil fertility suggests that several positive outcomes may accrue from the tree phase:

- enhancement of the activity of soil organisms involved in the cycling of nutrients
- provision of deep root channels for subsequent crops allowing deeper penetration, and utilization of the sub-soil
- provision of a disease break by reducing plant pathogens
- production of more recalcitrant forms of organic carbon
- a reduction of soil erosion

The tree phase may also allow the management of herbicide resistant agricultural weeds, an issue of particular importance in Australian dryland farming sytems.

The most likely deleterious effects will come from the production of surface debris following tree harvesting. Although smaller debris may contribute to the soil reserves of recalcitrant organic carbon, the larger debris may interfere with agricultural practice. Breakdown products of this material may be toxic to plants. Some potential PFT products, such as bioenergy, may result in the total removal of tree material and debris will not be an issue. Any nutrient depletion associated with the tree phase is considered manageable. An issue that needs practical resolution is the removal of stumps on harvest.

Economic analysis

The likely yields of the PFT system were examined using a tree crop (*Eucalyptus globulus*). We used this species as a current market exists for wood fibre; other species may be more suitable and more profitable.

A gross margin analysis using the whole farm economic model MIDAS, indicated that the PFT system was not profitable over a 30 year time in the 300 or 400 mm rainfall zones, when compared to agriculture. For phase farming with trees to equal the returns of agriculture, the on-farm price of tree products would have to rise to $160/t and $115/t in the 300 mm and 400 mm rainfall zones respectively. This is equivalent to 14 t/ha and 20 t/ha for the two zones at the end of six years, with only limited transport of the products.

We suggest that the profitability of the system can be improved by reducing establishment costs through direct seeding and increasing returns by obtaining multiple, specialized products from harvested trees (e.g. cineole, tannins, wood fibre or bio-energy.) Similarly, more valuable tree products may be identified and developed for the lower rainfall areas as the result of current R&D projects.

The economic analysis did not bring into account the likely land conservation benefits of the PFT system such as reducing the loss of land to salinity and the reduction in off-site impacts such as the loss of natural flora, wildlife habitat, water resource quality and rural infrastructure. We suggest that if market based assessments are to be made of technical solutions to natural resource problems a framework should be used that brings the value of the natural resource base and other off-site effects to account. Developing such a framework is a priority for research.

In the meantime the PFT system may provide a means of rapidly restoring the water balance of catchments where biodiversity or rural infrastructure (e.g. rural townships) is at immediate risk and a direct subsidy is paid to overcome the problem.

Despite its current marginal economic status, we suggest that the PFT system provides a feasible technical solution to reducing the rate of salinization associated with agriculture in drier areas. Moreover, prospects for adoption are enhanced compared to other options, as the system will allow the continuation of current farming practices.

Research needs

This scoping study has indicated several areas where research needs to be undertaken, most of which are focused on resolving whether the basic premise of our proposal—water removal to depths of 10 m over wide areas of low rainfall—is achievable in 3-5 years using trees.

- The hydrological modelling presented here suggests that with readily penetrable soils PFT can achieve the desired aims of stopping additional recharge and depleting water in unsaturated stores. However, the root penetrability of soils in the target zone is unknown and may in fact be deeper than the 10 m assumed in scenario 4. Understanding the interaction between the roots of potential PFT species, sub–soil properties and watertables is thus crucial.
- Actual growth rates over the first 3–5 years (i.e. the likely length of a PFT rotation) need to be determined for different species and related to variations in climatic and soil/hydrological conditions. This determination should include above/below ground productivity and identify the harvest index for stems, bark, leaves and other identifiable products.

- Determine whether growth, and water use, can be enhanced through management inputs (fertilizers, stocking) to shorten the PTF phase.
- Optimize the rotation length of the tree and crop components for different sites
- Comparison of water-use, leaf area, rooting depth and system costs of PFT with phase-farming with lucerne or tagasaste.
- Low impact and cheap silvicultural systems need to be developed. Harvesters for oil mallees already being developed are likely to be easily modified for PFT harvesting. However, direct seeding needs to be developed into a reliable system. In particular, the species that give good establishment and their planting requirements (e.g. depth, soil moisture and temperature regimes and weed control) need to be identified.
- Comparative performance of small trees established by direct seeding or from nursery seedlings planted into sites of differing preparation intensity needs to be determined.

Given that the development of a suitable harvest strategy is vital for the success of the project, it would be beneficial to:

- quantify the changes in abundance of specific species of soil organisms in response to the transition from agriculture to agroforestry,
- quantify the impact of a number of harvest strategies (i.e. retain or burn plantation residues or remove stumps with heavy machinery) on the activity and abundance of species of soil organisms,
- manipulate nitrogen pools in soil to promote the degradation of substances with a high C:N ratio,
- assess the impact of nitrogen applications on the lignin metabolism of white and brown rot fungi.

In order to meet conditions for adoption of a tree phase, a research project should also:

- demonstrate a need, or preferably respond to an expressed need, for the innovation in terms of the objectives of individual farmers; and
- demonstrate, preferably in on-farm situations, that the innovation can make an observable difference in the ability of individual farmers to meet their objectives.

In conclusion, we suggest that phase farming with trees presents a major opportunity of producing a sustainable agricultural system for dryland areas of southern Australia. It requires research to field-validate the modelled outputs in this report, optimize the system for different site conditions and demonstrate its potential to landholders.

1. Introduction

Richard Harper, Stuart Crombie and Tom Hatton

1.1 Dryland salinity

Rising groundwaters and resultant salinity threaten agricultural land, conservation reserves and water resources across southern Australia. This problem has been induced by the widespread removal of deep-rooted native vegetation for farming, and replacement with shallow-rooted annual plants. The reduced water-use has resulted in rising water tables that mobilise salt stored in the regolith. Saline groundwaters enter plant root zones, or discharge on the ground surface (Bettenay *et al.* 1964; State Salinity Strategy 1996; Hatton and Nulsen in press).

In Western Australia 1.8 Mha is currently salinized, with 6.1 Mha likely to be affected in the future; respective Australia-wide estimates are 2.5 and >11.8 Mha (Ferdowsian *et al.* 1996; State Salinity Strategy 1996). Effects of salinity include the destruction of farmland, conservation reserves, infrastructure and water resources, with the capital value of the agricultural land in Western Australia alone being ~$1.4 billion (State Salinity Strategy 1996). Pearce (1999), citing LWRRDC data, suggests that the annual costs of salinity in Australia are around $380m, without accounting for the loss of vegetation and wildlife.

1.2 Trees as a solution to salinity

Williams (1999) suggests that land use systems capable of reducing salinization *and* providing an adequate income are not currently available for large areas of Australia’s agricultural zone. We know that salinity control can be obtained by controlling groundwater recharge and that trees can achieve this (Schofield 1990; Hatton and Nulsen in press). Not only are trees relatively cheap to establish and maintain compared to drains or diversion systems, but they have the potential to produce saleable products such as timber, pulp or fuel-wood with the benefit of diversifying farm incomes (Shea and Bartle 1988; Bartle and Shea 1989; Bartle 1991). With the scale of the salinity problem, the area of land that needs to be revegetated is ~3 million ha in Western Australia alone, assuming that 30% of the land needs to be planted to control salinity (State Salinity Strategy 1996). Trees also provide a solution to other forms of land degradation prevalent in this region, such as wind erosion (Carter 1995).

A market based solution to salinity has been developed in Western Australia, based on the establishment of Tasmanian blue-gums (*Eucalyptus globulus*) on farmland in the higher rainfall (>600 mm) areas (Shea and Hewett 1997). Under this model investors seek profit by planting *Eucalyptus globulus* to produce high quality wood pulp. While growing, the trees use stored soil water, preventing secondary salinity developing. 120 000 ha of trees have been planted in the last 10 years, with a mean rate of establishment of 26 000 ha/year over the last three years (Love *et al.* 1999). Similar strategies to overcome salinity in the lower rainfall (<600 mm) areas of Western Australia involve the encouragement of investment in maritime pine (*Pinus pinaster*) in the 400-600 mm rainfall zone and oil mallees (*Eucalyptus* spp) for cineole production in the <400 mm rainfall zone (State Salinity Strategy 1996).

1.3 Limitations to tree adoption

Given the scale and increase in salinity, rapid deployment of trees is required to restore the hydrological balance over large areas and minimise the areas affected. Whereas there has been widespread adoption of trees in higher rainfall areas, adoption of trees in lower rainfall areas has been limited for several reasons. Apart from the generally low initial rates of adoption of new farm technology (Marsh *et al.* 1996b), we speculate that reasons include:

(a) *Uncertainties about returns*

In some situations acceptance of trees has been restricted because of uncertainties about the costs and returns of farm-forestry relative to the short term returns from agriculture (Hamilton and Bathgate 1996; Malajczuk *et al.* 1996). This particularly applies in the lower rainfall areas where tree growth is slower.

(b) *Uncertainties about where to plant trees.*
There is also considerable uncertainty about where trees should be planted for greatest hydrological effect (Schofield 1990; Ruprecht and Schofield 1991; Taylor *et al.* 1996). Rates of groundwater recharge vary across landscapes and present landscape hydrological models require detailed knowledge of soil properties (Sivapalan *et al.* 1996; Taylor *et al.* 1996; Vertessy *et al.* 1996). In practice, defining and locating the type and location of macro-structures such as dykes, palaeo-channels and basement rock, which affect local hydrology (Clarke *et al.* 1997), are likely to remain beyond the financial and technical resources of most landholders.

(c) *Limitations on the effectiveness of trees.*
Similarly, in some landscapes groundwater movement is slow, and only localised draw–down around trees may occur (Stirzaker and Lefroy 1997; George *et al.* 1999). Thus, trees in alley farming systems may have limited ability to use water beyond their own root zones (Passioura and Ridley 1998).

(d) *Conflicts with agricultural activities.*
The effective de-watering of landscapes may require trees to be planted over large areas, which will impede the use of farm machinery and compete with water with crops.

1.4 Phase Farming with Trees (PFT) as a potential solution to salinity

We propose an innovative planting system which would use plantings (as wide strips, blocks or whole paddocks) of medium-high rainfall commercial species in lower rainfall areas, in ultra-short rotations (3-6 years) to quickly de-water the local area while producing biomass. We have termed this Phase Farming with Trees (PFT).

Despite poor long-term survival of these species, it is expected that prior to death they will exhaust stored un-saturated soil moisture that has accumulated under annual crops and pasture since clearing. Depleting the water will help restore catchment hydrological balances. Instead of relying on water to move (slowly) through the landscape to strategically (and uncertainly) placed trees, strips will be rotated across the landscape at relatively short intervals, using presently un-utilised water. Optimum tree placement, such as dispersing trees across the landscape and ensuing conflicts with farming practice will not be an issue. Traditional farming systems can be maintained in the areas not planted to trees.

1.5 Aims of this study

The aims of this scoping study are to determine:

- the biophysical constraints to the system and whether PFT will contribute to restoring catchment water balances (Ch.4, Hatton and Dawes),
- the benefits to soil sustainability of introducing a short rotation tree crop (Ch. 5; Abbott and House),
- the economic feasibility of the proposed system taking into account both the production components and the increased sustainability of farming systems (Ch. 6, Challen),
- any gaps in knowledge that need to be resolved if the system is to be promoted (Ch. 7, Harper *et al.*)

2. Phase Farming with Trees (PFT)

Stuart Crombie and Richard Harper

2.1 Outline

Our proposal for phase farming with trees (PFT) is broadly similar to phase farming using perennial pasture plants such as lucerne (*Medicago sativa*) described by Passioura and Ridley (1998). The critical differences are that tree roots will have the ability to penetrate to depths of several metres more than those of lucerne and maintain a leaf canopy with potentially higher rates of evapotranspiration and interception of rainfall. By appropriate species selection, the PFT tree phase may be used to produce a mixture of wood fibre, grazing fodder or other products.

De-watering soil profiles to depths of several metres will provide soil water storage for years with abnormally high winter rainfall, or with summer rainfall, when annual plants are not growing. Experience suggests that significant depletion of stored water to 4 m depth can be achieved after two years with very dense plantings (Eastham *et al.* 1990). Similarly, depletion to wilting point has occurred to 9 m under 6 year old *Eucalyptus globulus* grown on deep regolith in WA (Harper & Crombie, unpub.)

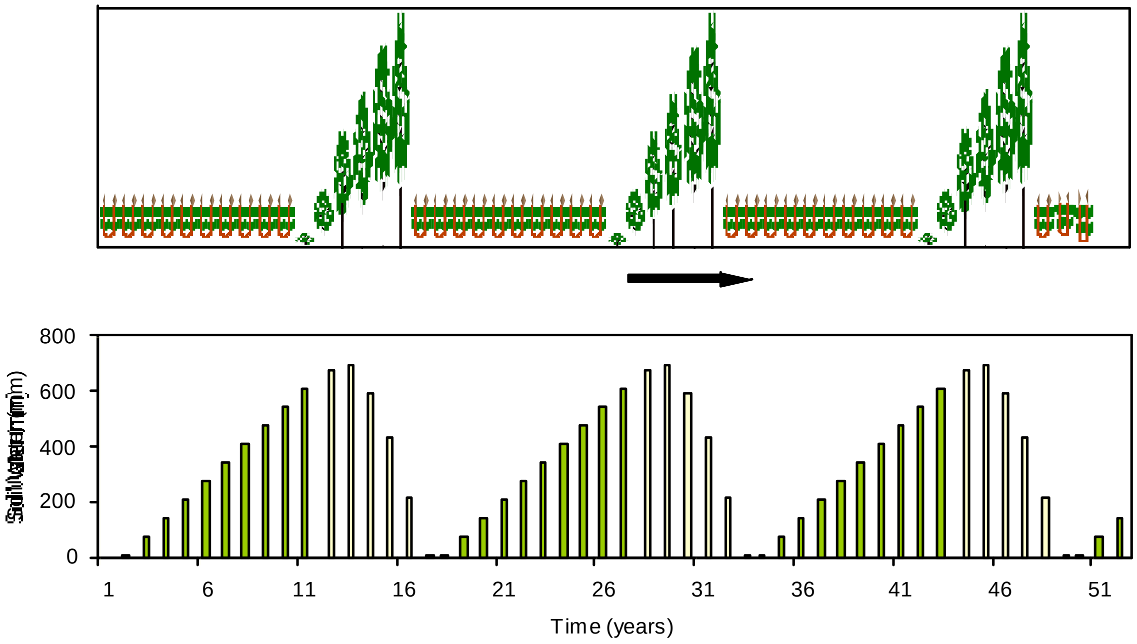

Fig. 1 Conceptual diagram showing phase farming with trees with its associated cycle of soil water storage (mm)

Progressive planting of short rotations offers the possibility of de-watering the whole of a property on a schedule which can be fitted in with other farm land uses such as cropping and pasture leys. There may be little requirement for mapping of soil or hydrologic properties, apart from removing areas with gross limitations to tree growth and survival (e.g. Harper *et al.* 1998). Because trees can be removed at almost any age to provide a marketable product, in the form of wood chips, fuel-wood or other products, rotation length can be varied to suit local circumstances. Such an approach has more in common with European biomass plantings (Christersson 1986; Zohar 1989) than with traditional forestry. Rapid development of high leaf areas to support maximum growth rates and consequent transpiration (Beadle *et al.* 1995) is essential to deplete soil water as quickly as possible.

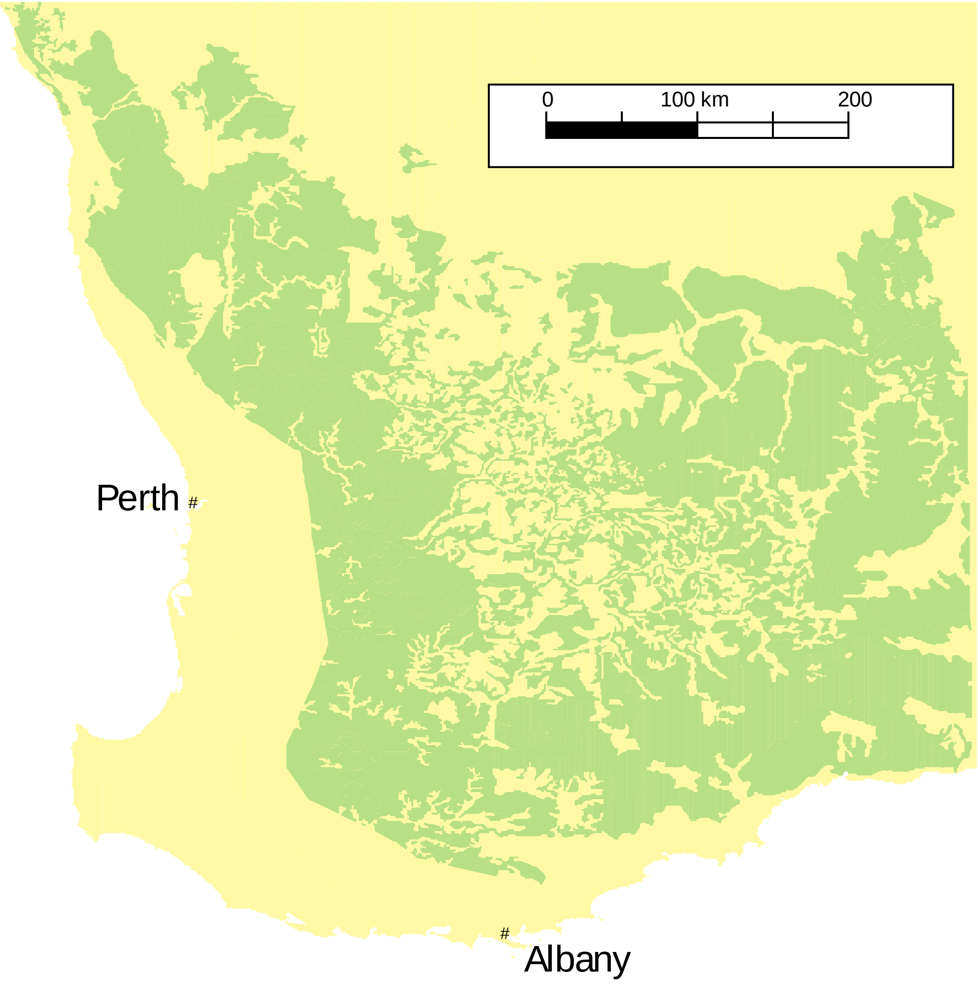

Fig. 2 Areas in south-western Australia, with <600 mm annual rainfall, where Phase Farming with Trees may be a suitable land treatment for the control of salinity (dark stippled).

The novelty of the PFT system is the short period for which trees are in place. Under the PFT system trees will occupy land only for the time necessary to transpire the water which has accumulated during the preceding cropping phase. The trees will then be harvested and the land returned to cropping (Fig. 1). Drought-related mortality and growth losses, which are considered a hazard in normal long-rotation plantations, will not be a problem as this will indicate that the trees have successfully performed their de-watering task.

PFT plantations thus differ from normal plantations in the length of the rotation, the frequency of planting and harvest operations, the age and size of product produced and perhaps the parts of the tree used. Moreover, a major emphasis is placed on returning the plantation site to annual agriculture rather than to another tree rotation.

2.2 Target area

The target area for this study is the dry temperate (“wheat-sheep”) zone of southern Australia where the greatest area is at risk from salinity. The target area in Western Australia is west of a line from Geraldton in the north to Esperance in the south and in eastern Australia the Eyre and Yorke Peninsulas and the southern Murray Darling Basin. The climate is Mediterranean with the bulk of the annual rainfall of 300 and 600 mm falling in the cooler months of June to August. The summers are warm and dry. Annual pan evaporation is between 1000 and 2400 mm and is inversely related to rainfall (Bureau of Meteorology 1989).

The areas where this system may be suitable in south-western Australia, are indicated in Fig. 2. This analysis (Geoff Hodgson, CSIRO Land and Water, pers. comm.) was based on the Bureau of Rural Sciences' digital version of the Atlas of Australian soils (Northcote *et al*. 1967). (http://www.brs.gov.au/data/datasets). Mapping units were assessed using the limitations of (a) annual rainfall between 250 and 600 mm/yr, (b) no deep sands and (c) no "hostile" soils. "Hostile" soils were considered to be those that had (a) high salinity and (b) profiles >2 overlying basement rock or hardpans. Each unit was classified as suitable or not suitable and coded accordingly. It should be noted that the units used in the Atlas of Australian Soils classification are very broad and a high degree of variability within these categories is expected.

2.3 Existing systems using perennial plants

2.3.1 Short rotation coppice systems

Although forestry systems with very short rotations between harvests have been previously proposed, they have relied on permanent plantings that are regularly coppiced. These include, for example, the “silage sycamore” system proposed in the southern USA using *Platanus occidentalis.* Here very high density stands were harvested with a silage harvester at 1-3 year intervals (Dutrow 1971; Steinbeck *et al.* 1972) with the aim of rapid wood fibre production.

Short rotation coppice systems have also been advocated in other bio-energy systems (Wright and Hughes 1993; Kemp n.d.). An example is given by Kroll and Downing (1995) who describe bio-energy plantings of poplar (*Populus* spp) and willow (*Salix* spp) in peat-land. In each example the stands are coppiced and the land is not returned to agriculture.

2.3.2 Phase farming

Alternating crops with perennial pastures such as lucerne (*Medicago sativa*) in dryland farming systems (“phase farming”), has been advocated by Passioura and Ridley (1998) as a highly promising system for controlling recharge. Benefits come from both the out of season water use and the deep roots which utilize previously unused water. The dried out soil profile will also provide storage for out of season rainfall.

The benefits from lucerne phase farming depend on its successful growth but this is not assured across a wide range of soils and environments. We have suggested in §2.1 that the roots of Australian tree species may have a competitive advantage over lucerne in being able to exploit root-inhospitable sub-soils and thus grow deeper. Similarly, a tree canopy will have a greater leaf area than grazed lucerne, and thus greater water use, while the tree canopies will have greater rainfall interception.

2.3.3 Alley farming

In southern Australia, alley farming is most widely practised using belts of tagasaste (*Chamaecytisus proliferus*) to provide stock fodder while simultaneously controlling groundwater (Stirzaker and Lefroy 1997). It is estimated that the total area of alleys is ~11 000 ha (Stirzaker and Lefroy 1997).

Alley farming using forestry species for more traditional wood and pulp products is also conducted to a limited extent (Moore and Bird 1997). Cropping sometimes continues in the alleys between the belts. Management inputs in alley farms can be substantial, as belts of fodder shrubs need to be pruned to keep foliage in reach of stock, or to maintain form of potential saw-logs. Alley farming brings normal farming into much closer proximity to trees than is envisaged with PFT. Consequently, problems of competition between trees and inter-alley crops will be greater than between large blocks of PFT trees and large areas of crops. Also, alleys are fixed features in paddocks whereas PFT plantings are temporary.

2.4 Silviculture of PFT

2.4.1 Site preparation and establishment

We envisage that site preparation for PFT will be minimal both to contain costs at establishment and to make the return to cropping easier. In standard plantation practice bare-rooted or containerized plants are produced at a nursery and planted into a weed-free planting mound erected over a deep-rip line. The planting density is adjusted to match the capacity of the site to support the trees. This method maximizes tree establishment and productivity but is relatively expensive. Flattening of planting mounds after harvesting of the trees to return a site to cropping is likely to be expensive.

Options to contain costs are to:

- direct seed to avoid costs of raising plants in the nursery and subsequent hand or machine planting (e.g. a *Eucalyptus globulus* seed costs about $0.003 but a planted seedling costs approximately $0.50). It may be possible to use agricultural air-seeding drills to keep establishment costs down and to improve establishment success by placing seed accurately at optimal depths and spacing. It should be stressed that direct seeding technology is not proven in WA conditions (Pigott *et al.* 1994),
- plant into a seedbed similar to that for an annual crop (i.e. suppress weeds with herbicides and possibly cultivation but without mounding or deep ripping),
- minimize fertilizer inputs as nitrogen and phosphorus accumulated during previous cropping phases are likely to be adequate for initial tree growth (McGrath, unpub.), particularly in lower rainfall environments. It may be possible to use N-fixing tree species to supplement residual N stores.

Water repellency is widespread in the agricultural soils of Western Australia (Harper *et al.* in press) and is usually considered a problem. It may, however, be used to advantage in tree establishment in drier areas by enhancing run-off into the trees from adjacent agricultural areas (Hillel and Berliner 1974).

2.4.2 Stand management

Species, stand density and nutrient inputs can be varied to enhance water use. The system envisages using high planting densities and high residual nutrient levels for rapid development of large leaf areas. The desired outcome is achieving the greatest biomass production and water consumption rates several years earlier than with standard plantation practice.

High densities in PFT plantings will enhance the hydraulic efficiency and economics of PFT systems through:

- *Rapid early leaf production.*
  As increases in leaf area are followed linearly by increases in transpiration (Beadle *et al.* 1995; Hatton *et al.* 1998) and growth (Nambiar and Booth 1991; Beadle *et al.* 1995; Ribeiro *et al.* 1997) high planting densities will shorten the time required to de-water a site without reducing biomass production. Early canopy closure will also reduce weed competition to the benefit of the trees.
- *An increase in above and below ground competition.*
  Greater below ground competition stimulates root growth and water extraction from deeper in soil profiles (Eastham and Rose 1990). Competition also increases the relative allocation of photosynthates to harvestable above ground parts compared to roots (Eastham and Rose 1990; Nambiar 1990).
- *An increase in height growth and restriction of diameter growth.*
  The smaller stumps left at the end of the PFT rotation are likely to be easier to remove than the larger stumps left from fewer but larger trees, thus reducing the costs of returning land to agriculture.

Comparisons of water use by different species show that leaf area and canopy cover are the main determinants of plantation water use and growth (Hookey *et al.* 1987; Specht and Specht 1989; Barrett *et al.* 1996). Experience with *Eucalyptus globulus* and *Pinus radiata* in WA is that early growth is rapid even in low rainfall areas. This early growth is supported by soil water accumulated during a preceding pasture or crop phase. Mortality can occur when the plantation has depleted this reserve of water and is dependent on annual rainfall alone. As the proposed plantings are designed to draw on soil water storage in excess of rainfall from an early age and to be removed when this water is exhausted, virtually any available tree species with the potential to develop a deep root system and reasonable leaf areas can be used. Salt tolerance may also be considered on sites where salinization is already occurring (Sun and Dickinson 1997).

The time taken to deplete soil moisture will depend on the amounts of water held in soil, the rate at which trees can access and transpire this water and the continuing rates of soil water recharge from annual rainfall or in-flows from nearby areas. Hatton and Dawes (§4) model these aspects. The utilization of soil water will obviously depend on the tree roots being able to penetrate sub-soils. Harvest of PFT plantings would occur soon after soil moisture is exhausted.

2.4.3 Harvesting

Harvest options will depend on the product to be produced. Standard tree harvesters and forwarder combinations are very expensive when applied to large numbers of small stems. Single stem harvesting does however produce a relatively large product that can be used for oriented strand-board or other reconstituted wood product as well as pulp or biomass fuel.

Biomass harvesters that reduce either whole plants or stems into chips on-site may be cheaper than standard harvesting techniques. Harvester set-up can be optimized to produce chip to the highest value specification for different product lines. Post-harvest sorting of wood, leaves and bark into streams for pulp chip, biomass, cineole distillation and tannin extraction could also increase product value.

Slash left after harvesting an PFT plantation is likely to interfere with farm machinery and will increase nitrogen requirements for successive cropping due to increased carbon/nitrogen ratios (see §5). The alternative of carrying slash off-site or burning of all leaves and bark on-site may not be desirable because of the amount of nutrients that would be removed (Noble and Randall 1998). Total removal will most likely occur with bio-energy plantings. Managing the twin problems of nutrient removal in leafy material and difficulties in cropping in woody slash will have to be developed. Options may include:

- using chemical defoliants, or a lethal water deficit prior to harvest, to separate nutrient-rich leaf material which is retained on-site from the harvested, relatively nutrient poor woody material. Such harvested material would also be partly dried increasing its value as fuel and reducing its weight for transport.
- Chopping and spreading the slash material at the time of harvest.

Low cost methods of removing or working around or over stumps left after harvest need to be developed. As larger stumps require larger, and more expensive, machinery for their removal reducing stump size by using higher density plantings may be desirable. Alternatively, stumps could be lifted from the ground at harvest and included in the saleable product.

2.5 Effect on soil quality

The PFT system may have a positive effect on the quality of soil due to reduced disturbance, reduced use of chemicals, reduced vehicle trafficking, increased root growth at depth and improved physical soil structural conditions (Doran and Alexander 1977; Noble and Randall 1998). As the PFT system entails a break from cultivation and farming practices further benefits may accrue from:

- a disease and weed break (this may for example allow the management of weeds which have developed resistance to herbicides in cropping systems),
- "biological ploughing" of the soil with improved soil physical properties,
- enhanced soil biological processes.

Abbott and House (§5) review many of these issues. Sustainable management of ecosystems, as desired for agriculture and agroforestry, requires practices that enhance soil biological processes which promote nutrient cycling, maximise the efficient use of fertilisers and facilitate the interdependence of plants and symbiotic soil organisms.

2.6 Costs and returns

Using existing commercial species such as *Pinus pinaster* and *Eucalyptus globulus*, from higher rainfall areas, will allow the products from the system to be inserted into existing fibre markets. Similarly, the system may be suitable for a range of alternative scenarios including new products (cineoles, tannins) and bio-energy production. Some potential products from the system are described in §3 and Challen (§6) undertakes a detailed economic analysis.

The short time between planting and harvest will contain management costs as pruning or thinning are not required and reduced interest charges will accrue over the life of the rotation. The PFT system has the potential to be applied opportunistically, as finances allow or to areas where remediation is required immediately. Farmers may prefer a system in which trees effectively de-water the landscape while (a) only comprising a temporary element on the farm, with a relatively short lapse between planting and harvest of the product and (b) with minimal disruption to the use of large farm machinery.

The direct costs and cash returns will be associated with planting and harvesting trees, returning land to annual cropping and foregone income of annual cropping. A full cost accounting for PFT phase cropping would also include:

- the additional benefits to sustainable agriculture of preventing salinization, improvements to soil structure (Noble and Randall 1998),
- maintaining soil biological fertility (discussed by Abbott and House (§5) and,
- acting as a break crop to reduce populations of pathogens and herbicide resistant weeds reduction in weeds and soil-borne pathogens.

3. Potential products

Stuart Crombie and Richard Harper

3.1 Background

The economic viability of conventional low rainfall agroforestry has recently been reviewed, with a range of potential species and products considered by the Joint Venture Agroforestry Program. This considered options such as sawn timber, wood/panel products, specialty timbers, biomass for electricity, fodder and eucalyptus oil. The best prospects using conventional rotations were fodder, eucalyptus oil and biomass for electricity.

This suggests that the range of species suitable for the PFT system, with its much shorter rotation length, will be limited. Major requirements of species that can be planted in low rainfall areas in a PFT system include:

- production of commodities that require broad scale plantings, thus removing from contention species with products that fit into niche markets,
- can produce economic products within 3-5 years,
- can be sold into existing markets.

This limits the number of potential species that are currently suitable for PFT.

3.2 Product characteristics

Widespread adoption of PFT will produce large amounts of biomass from small trees. However, only relatively small volumes of product will be available from each area of PFT planting because of rainfall limitations on productivity and the young age at which stands are harvested. Options for increasing harvest yields by lengthening the crop rotation are limited because of the risk of drought losses once stored soil water has been exhausted

The trees will contain larger fractions of bark and leaf and relatively less stem material than standard forestry products. Also, the plantations will be a distant from existing markets such as export ports for chipwood or board-making plants in major cities. Commercial utilization of PFT trees will therefore require either a high value product (to justify transport) or a close market for a large volumes of lower value product.

It may be possible to separate high and low value products from the harvest stream to optimise returns. For example, a PFT stand could be chipped in–field and sorted to produce a leaf fraction which could be distilled for high value cineole, bark for tannins and wood chip for pulp. Residues from cineole distillation and tannin extraction and un-utilized twigs could be consumed locally to produce bio-energy.

Some existing farm forestry systems have advanced to the commercial deployment stage in southern Australia. These include *Eucalyptus globulus* based pulpwood plantations, *Pinus pinaster* for lumber and reconstituted wood products, oil mallees for cineole production (Shea and Hewett 1997) and tagasaste (*Chamaecytisus proliferus*) for stock fodder. Other commercial, tree-based options in the research phase include *Acacia mearnsii* for tannin (Barbour in review), *Eucalyptus camaldulensis* and its hybrids for dryland or saline soil pulpwood and sandalwood (*Santalum spicatum*). A project has recently commenced in Western Australia that will investigate the potential of a range of tree species for the low rainfall areas in terms of environmental suitability and likely product demand (J. Bartle, pers. comm.)

3.3 Existing markets

3.3.1 Short rotation pulp

The major difference of the PFT system over competing agroforestry systems will be its short rotation length. PFT is likely to develop around rotations of about 5 years which allow trees to be used as an agricultural “break crop” after which annual cropping can resume. This compares with 30 to 60 year rotations before final harvest for Maritime Pine (*Pinus pinaster*) or other standard plantation species, or permanently emplaced oil-mallee belts harvested at 2 yearly intervals (J. Bartle, pers. comm.)

As described earlier, Tasmanian blue-gums (*Eucalyptus globulus*) are now widely planted in southern Australia because of their capacity to produce high quality pulp and their rapid early growth. These plantings are normally restricted to areas with >600 mm annual rainfall. Pulp rotations are typically 10-12 years with target productivities of around 20 m^3/ha/year. Growth rates increase rapidly as leaf area increases with age. Under favourable conditions yields can be very high. For example, a high density, heavily fertilized, *Eucalyptus globulus* stand at Morwell in Victoria achieved a biomass of 8.6 t/ha at two years old and 30.3 t/ha at four years (Cromer *et al.* 1975).

Productivity of *Eucalyptus globulus* in the PFT target zone, however, will be substantially lower than these values. This is a consequence both of the drier conditions and of harvesting at around the time of maximum leaf area (and hence growth rates) so that average annual growth is less than that of a plantation grown on after reaching maximum leaf area. High vapour pressure deficits will reduce growth rates even when soil moisture is not limiting (Myers *et al.* 1996). Reductions in WUE (water use efficiency, the amount of wood produced per unit of water transpired) associated with the long period of high vapour pressure deficit in the WA wheatbelt during summer (Leuning 1995; Lindroth and Cienciala 1996) also suggest that tree productivities will likely to be lower than would be expected based on the relationships of growth to available water developed under milder conditions. Moreover, highly productive stands which develop large leaf areas during suitable conditions in winter and autumn will be at risk of severe drought stress during the rainless summer (Honeysett *et al.* 1996) unless they have very effective control of leaf water loss and rapidly developing root systems.

Growth trials of *Eucalyptus globulus* at lower rainfall sites in Western Australia confirm these expectations, with average stand volumes in various studies summarized in Table 1.

Table 1 Measured total wood volumes of *Eucalyptus globulus* (m^3/ha) in medium rainfall zones in Western Australia

Location	Rainfall (mm/year)	Volume (m^3/ha)	Age (years)	Study
Darkan	590	54	6	Hingston *et al.* (1995)
Esperance - block	450-650	7-60	5	Harper *et al.* (1996)
Esperance belts	550-600	60	6	Harper *et al.* (1996)
Frankland	550	50	6	Crombie (unpub.)

Other species such as *Eucalyptus camaldulensis* and *Acacia mearnsii* may have better survival than *Eucalyptus globulus* in the lower rainfall zones. Productivity is still likely to be limited by rainfall while markets for the wood chip product are distant and undeveloped compared to *Eucalyptus globulus*.

3.3.2 Wood fibre

Reconstituted wood products such as paper, fibre board, oriented strand board (OSB) and Scrimber® could potentially use wood from the small stems of PFT plantings. Efficient production of these materials requires precise optimization of processes for each feedstock. To justify the cost of such optimization large volumes of similar material would need to be available (implying widespread adoption of the PFT system with a narrow range of species). Profitability of such products is very sensitive to transport costs. Given the dispersed nature of PFT plantings, their distance from markets and uncertainty of species selection it is unlikely that a PFT industry feeding into a reconstituted wood product market would be profitable in the near term. A PFT system based on *Eucalyptus globulus* chip may be able to supply material to the existing chip market in higher rainfall areas. The juvenility of the wood from PFT would, however, be likely to cause a discount in chip price.

Despite its relatively modest yields in these lower rainfall environments, we consider *Eucalyptus globulus* as the strongest contender for inclusion in the PFT system because of the established infrastructure for its propagation, rapid early growth and known silvicultural requirements. Key changes to standard management compared to higher rainfall areas would be reductions in the effort at establishment, shortened rotation length and probably changes to harvesting by in-field chipping of the smaller trees. High transport costs of taking pulp chips to ports could be avoided by using the product locally, probably for bio-energy.

3.3.3 Oil mallee

A eucalyptus oil industry, using alley plantings of high yielding mallees, is being developed in WA (Shea and Hewett 1997). The trees are first harvested at about 4 years and every two years subsequently (J. Bartle, pers. comm.) Rapid early growth may be achievable (Table 2).

Provisional estimates of cineole production are for 1,500 tonnes in 2000, rising to 12,000 tonnes by 2010 (Collins 1998). Cineole is a high value product (farm–gate price of $1,000-$5,000/t) so that long transport distances will not affect profitability. As cineole is only about 1.5% of the harvested mass (all above ground parts are harvested) production of cineole will also produce 100,000 to 800,000 tonnes of woody residues (wood, twigs and leaves) in 2000 and 2010, respectively. These residues would be suitable for a biomass based renewable energy system.

The potential exists for PFT and the oil mallee industry to share infrastructure assets and some markets (bio-energy plants and potential reconstituted wood product streams).

Table 2 Above-ground biomass (dry weight adjusted to an equivalent hectare basis (t/ha)) of *Eucalyptus* trees planted for cineole production (Bartle and McCarthy pers comm.) Trees were planted at 2 m intervals along two rows 2.4 m apart in a paddock used for annual cropping near Kalannie, Western Australia (annual rainfall 350 mm).

Plant part	*Eucalyptus plennissima*			*E. loxophleba subsp. lissophloia*	
	Age (years)				
	4	5	6	4	5
			(t/ha)		
Whole plant	14	26	29	16	15
Stem	4	10	16	9	9
Twigs	4	6	5	2	2

3.3.4 Bioenergy

PFT material would be suitable for bioenergy generation. A possible scenario is that bioenergy plants in the 0.5-5 MW range situated near the larger population centres in the target zone could be supplied from relatively close PFT plantings. Such a scheme is being investigated by ENECON at Esperance, WA (J. Bartle, pers. comm.) in a JVAP funded project.

Although returning a low price (about $10/t dry weight) bioenergy has several advantages for PFT. These include:

- the mechanical properties of the material are relatively unimportant. Consequently, species range is increased to allow greater matching of species and site. Also, mixing of biomass from multiple species will not reduce prices to the same extent as when supplying the reconstituted wood market.
- the whole plant (stems, twigs and leaves) can be used. This increases returns to growers and whole tree harvesting eliminates trash problems from leaves and twigs stripped from stems on site.
- markets (the bioenergy plants) are closer to the farms where the trees are grown than are existing export ports or wood fibre manufacturing plants

3.3.5 Silvopastoral Phase Tree Crop

An adaptation of PFT may be the use of use of fodder trees such as tagasaste (*Chamaecytisus proliferus*) or *Leucaena leucocephela* to supplement stock grazing. Unless pruned heavily or coppiced fodder tree crowns tend to rise above the grazing reach of stock. This is accompanied by an increase in the wood fraction of the above ground parts.

A PFT system using fodder trees has the potential therefore to be managed to provide either fodder or wood fibre or a sequence of each. Tagasaste is invariably planted on deep sandy soils (Wiley *et al.* 1994). More importantly, however, as will be seen in the Chapter 4 the PFT system is not suitable for such soils.

4. Biophysical Simulation and Interpretation of Phase Farming with Trees

Tom Hatton and Warwick Dawes

4.1 Introduction

The feasibility of phase farming with trees has two distinct aspects: economic attractiveness and biophysical performance. In this chapter, we evaluate the parameters that might control the effectiveness of a hypothetical phased tree/crop system, particularly in terms of groundwater recharge control and tree biomass production.

To make the above assessment, we have few or no observations on real systems in the geographic regions for which we might desire such a land use. Most observations on plantation performance are for sites receiving more than 600 mm of annual rainfall, while data on tree performance and water use in drier country are for silvicultural systems other than plantations. Thus, we appeal to a numerical ecohydrological model (WAVES (Zhang and Dawes 1998), incorporating carbon and allometric algorithms from 3-PG) which we have some confidence captures the essential behaviour and processes under consideration. This approach provides the added advantages of investigating the sensitivity of the system's performance under a variety of soil and climatic conditions as well as for periods of simulation that greatly exceed the normal length of experimental observation.

The results of these simulations are detailed in Appendix 1, as are relevant citations; this chapter distils the essential features of the analyses.

4.2 The modelled systems

4.2.1 The generic approach

For each of the modelled scenarios, the biophysical system was conceived of as a one-dimensional hydrological system involving interactions between plant growth, the surface energy balance, the soil water balance, and the salt balance. A full description of the model is available through references in the Appendix, but the salient features for these applications are:

- Two distinct phases are modelled: trees grown from very small seedlings and a winter wheat crop/summer pasture system. The realism of the cropping phase is intentionally compromised in that we recognised the typical rotations of grains, pulses and fallow, but have instead taken a conservative approach to the representation of the water balance in the non-tree phase. That is, we have employed a cropping land cover pattern that should yield the minimum recharge for that phase.

- The crop/pasture physiological parameterisations are based on extensive testing at two of the modelled sites, and we are confident in their calibrations.

- The tree physiological parameterisation is based on data from a site growing blue gums in Victoria under dry conditions; we are less confident in the absolute values of wood production in our simulations, but have much greater confidence in the water balance results. Implicit in these simulations is the generic quality of tree growth among the species potentially involved in this system.

- For each simulation, the initial soil water (and where applicable, salinity) profile was established through a thirty year simulation under the cropping phase only.

- Given the above initial condition, tree growth and self-thinning was simulated for thirty years, followed by a thirty year phase with the crop system. Interpretation of the soil water (and salinity) profiles developed over these cycles suggests (a) the length of the soil water mining period for the tree phase (with the associated amount of wood production) and (b) the length of the soil water replenishment period for the crop phase.
- No chemical or physical constraints to rooting were simulated that would limit the innate biological potential of the plants.
- No impacts of external risks such as pests, disease or fire have been considered.

4.2.2 Sites and conditions simulated in the study

The phased tree/crop system was assessed in the above manner for key sites across southern Australia, reflecting a variety of climatic, soil and groundwater conditions. The hypothetical sites are within the 300-600 mm rainfall zone in southern Australia, but with varying seasonal distributions of rainfall and local soils. The specific combinations of site, soil and water table are detailed by Dawes (Appendix 1), but can be summarised as follows:

Merredin

This town of Merredin is at 31°35´S 118°14´E, approximately 250 km east of Perth, Western Australia. The climate is Mediterranean in nature, with 70% of the 320 mm annual rainfall falling in the six months from April to September. The average potential evapotranspiration is nearly 1800 mm/yr. The soil depth and texture is varied at this site, to include deep sand, a duplex of sand or light clay over heavy clay to various depths, and a duplex with a shallow water table. Three different soil profiles, with and without fresh and saline water tables, were modelled with the Merredin climate record. These were:

- a uniform 20 m deep sand allowed to drain,
- 1 m of sand over 9 m of clay allowed to drain,
- 1 m of sand over 2 m of clay allowed to drain,
- 1 m of sand over clay with a fresh water table at 2 m,
- 1 m of sand over clay with a saline water table (27 dS/m, approximately half the salinity of sea water) at 2 m,
- 0.5 m of light clay over 2.5 m of heavy clay allowed to drain.

Hillston

The town of Hillston is at 33°30´S 145°33´E, approximately 550 km west of Sydney, New South Wales, on the Lachlan River. The climate is semi-arid with mean annual rainfall of 370 mm coming roughly uniformly through the year, with a subtle increase in the third quarter of the year. *[Note: The climate data used for this study is from 1964 to 1993, and the annual average rainfall over this period is 581 mm]* The average potential evapotranspiration is 1750 mm/yr. The soil modelled at this site is a calcareous red earth with a duplex structure, with a sandy clay A-horizon 0.5 m deep over a clay B-horizon 3.0 m thick.

Walpeup

This site is at the Mallee Research Station near the town of Walpeup, located at 35°09´S 141°59´E, approximately 450 km north-west of Melbourne, Victoria. The climate of the area is semi-arid, receiving 340 mm of annual rainfall of which 65% falls between May and November. The average potential evapotranspiration is 1750 mm/yr. The soil is a solonized brown soil, duplex in nature, with a sandy clay loam A-horizon 0.15 m deep over a heavy clay B-horizon 3.35 m thick. To compare and contrast with cases for Merredin, this site was also modelled with a sandy A-horizon 0.5 m deep.

4.3 Results from the biophysical modelling

4.3.1 Merredin, Western Australia

4.3.1.1 Uniform 20 m deep sand

- Under long-term cropping, an average of 100 mm/year of recharge results
- A large recharge event occurs roughly every 3 years under cropping
- Groundwater recharge is effectively halted by trees after 2-3 years of growth
- Tree LAI and productivity come into equilibrium with contemporary rainfall within 2-3 years
- Rooting extends over the entire soil column by the end of the simulation, with 80% in the top meter but also an area of concentration at 3-5 m
- Tree biomass is 59.7 t/ha after 30 years (MAI = 2.0 t/ha).
- Within 4 years of tree harvest, recharge under cropping is back to pre-tree levels.

Control of recharge by annual or shallow-rooted plants would be unlikely, while trees require around 3 years to control recharge. A phased tree system in this environment would have a very short cropping period, approximately 4 years per rotation.

4.3.1.2. 1 m of sand over 9 m of clay

- Under long-term cropping, an average of 67 mm/year of recharge results.
- Recharge rates are only slowly responsive to rainfall variation under cropping; an episodic event may occur every 15 years or so and at only about double the long-term average rate.
- Trees effectively halt groundwater recharge after 3 years of growth.
- Tree LAI and productivity come into equilibrium with contemporary rainfall within 3 years.
- Rooting extends over the entire soil column by the end of the simulation, with 99% in the top meter.
- Tree biomass is 53.4 t/ha after 30 years (MAI = 1.8 t/ha).
- Recharge at 10 m begins after 10 years under cropping and is back to pre-tree levels after 17 years.

Tree growth performance in this environment is relatively poor but the large clay resource creates effective drought protection and growth is quite constant. In this environment, a rotation length of 10 years for cropping and 5 years for trees would minimise recharge and take advantage of the most productive period of tree growth.

4.3.1.3 1 m of sand over 2 m of clay

- Under long-term cropping, an average of 62 mm/year of recharge results.
- Recharge rates are more variable than the above case under cropping.
- Trees effectively halt groundwater recharge after 1-2 years of growth.
- Tree LAI and productivity come into equilibrium with contemporary rainfall within 3 years.

- Tree biomass is 122.7 t/ha after 30 years (MAI = 4.1 t/ha).
- Recharge begins after 1 year under cropping and is back to pre-tree levels after 5 years.

Annual plants cannot control annual recharge of around 50 mm/year, and while trees were simulated to grow well here, they keep the soil profile dangerously dry and may suffer from droughts. This scenario requires short cropping rotations of 4 to 5 years if recharge is to be minimised, while trees may be grown for 5 to 10 years if the short-term climate is favourable.

4.3.1.4 1 m of sand over clay with a fresh water table at 2 m

- Under long-term cropping, an average of 34 mm/year of recharge results; no uptake from groundwater system is achieved.
- Trees effectively halt groundwater recharge after 1-2 years of growth, after which water is taken up in large amounts (up to 300 mm per year) from the watertable, which drops by about 0.4 m per year.
- Tree LAI and productivity come into equilibrium with contemporary rainfall and the watertable after about 10 years.
- Tree biomass is 160.5 t/ha after 30 years (MAI = 5.4 t/ha).
- The watertable is back to pre-tree levels after only 1 year under cropping.

The simulated good connection between local and regional water levels meant that the profile refilled within 2 years following the removal of trees. Developing rotation strategies in these systems is likely to be difficult. With less well connected groundwater systems, local rises would be expected under cropping and possibly decline in production due to high water tables, while with trees, local draw-down could be more substantial and both extraction and tree growth may decline as a result. The length of tree rotation recommended is 10 years, while the cropping rotation length will depend on climatic factors that would affect local groundwater rise, *i.e.* the crop rotation should stop when local water levels start to rise and impact on production.

4.3.1.5 1 m of sand over clay with a saline water table (27 dS/m, approximately half the salinity of sea water) at 2 m

- Under long-term cropping, an average of 34 mm/year of recharge results; no uptake from groundwater system is achieved and thus there is only minor accumulation of salt in the soil profile.
- Trees effectively halt groundwater recharge after 1-2 years of growth, after which water is initially taken up in large amounts from the watertable, which drops by about 1.0 m over the first 5 years.
- Tree LAI and productivity over the first 5 years is as vigorous as in the above case with a fresh watertable. At this stage salt built up in the profile begins to limit tree growth, and by year 12 has come back into equilibrium with contemporary rainfall with a 0.5 mm per year downward leakage.
- The salt bulge formed under the trees affects the subsequent crops and as a consequence recharge under cropping increases to 43 mm per year. This salt bulge comes back into equilibrium with the watertable after about 30 years of cropping at a level similar to that formed under the trees after 5 years in the first rotation, with the consequence that the next rotation of trees will not enjoy the same initial growth benefits.
- Tree biomass is 66.6 t/ha after 30 years (MAI = 2.2 t/ha) in the first rotation.

This scenario is probably widespread in Western Australia, where local groundwater is saline; half the salinity of sea water was used. Cropping in a salt free profile mirrored Case 4, while cropping in a salty profile had yields reduced by 5-25% and leakage to the water table increased by 25%. The tree rotation that filled the profile with salt coming from the water table suffered significant decline between 5 and 10 years after establishment, and grew on rainfall alone thereafter. Leaching of salt under cropping took many years to reduce the salt in the profile to conditions suitable for planting trees again. Without an effective drainage strategy incorporating a leaching fraction under trees, tree plantations over shallow saline groundwater are unlikely to have a sustainable long term role. Cropping over saline groundwater does not cause rapid salt build up, but because the system is leaky, it may promote widespread groundwater rise.

4.3.1.6 0.5 m of light clay over 2.5 m of heavy clay

- Under long-term cropping, an average of 65 mm/year of runoff and about 1 mm recharge result.
- Runoff substantially reduces crop performance.
- Trees effectively halt groundwater recharge after 1 years of growth.
- Tree LAI and productivity come into equilibrium with contemporary rainfall within 2 years, and are affected by the reduced infiltration and runoff losses.
- Tree biomass is 38.7 t/ha after 30 years (MAI = 1.3 t/ha).
- Recharge begins after 2 years under cropping and is back to pre-tree levels after 12 years, although soil water profiles are back to pre-tree levels after only 8 years.

Using a more common scenario of a clayey A-horizon, some substantial changes in the water balance were modelled. A significant amount of runoff is generated and yield and recharge are reduced due to less infiltrating water. Recharge below cropping systems is low at around 1 mm/year, although up to 20% of this total may occur in a single month. This environment is a candidate for episodic events that can produce significantly higher amounts of recharge than average annual values. Recharge also resumes relatively quickly after tree removal, although stored water lags this result. Tree growth performance is quite poor and the modelled leaf area plateaus very quickly. Crop rotations could be as long as 10 years given the low average recharge, while the length of tree growing will depend only on the size of individual stems and the target product.

4.3.2 Hillston, New South Wales

4.3.2.1 0.5 m of sandy clay over 3.5 m of clay

- Under long-term cropping, an average of 2.4 mm recharge and 58mm of runoff per year result.
- Tighter clay than at the Merredin site leads to a relatively small, constant rate of recharge
- Trees effectively halt groundwater recharge after 2-3 years of growth.
- Tree LAI and productivity come into equilibrium with contemporary rainfall within 5 years.
- Tree biomass is 49.5 t/ha after 30 years (MAI = 1.6 t/ha).
- Recharge begins after 13 years under cropping and is back to pre-tree levels after 20 years.

This scenario is dominated by low permeability soils and highly variable annual rainfall totals. The slow clayey soils means that recharge is at a low rate and subdued relative to rainfall variation even under cropping. This variation however also negatively impacts on production of both crops and trees. Modelled peak crop leaf area varied from more than 4.0 to less than 0.5, while tree leaf area grew strongly for 6 years then steadily declined afterwards. Equal rotation lengths of between 5 and 10 years appears appropriate with caution noted on the possibility of crop or plantation failure due to extreme rainfall variability.

4.3.3 Walpeup, Victoria

4.3.3.1 0.15 m of silty clay loam over 3.5 m of clay

- Under long-term cropping, an average of 0.55 mm recharge and 7.3 mm of runoff per year result.
- Tighter clay than at the Merredin site leads to a relatively small, constant rate of recharge
- Trees effectively halt groundwater recharge after 2-3 years of growth.
- Tree LAI and productivity come into equilibrium with contemporary rainfall within 3-4 years.
- Tree biomass is 46.0 t/ha after 30 years (MAI = 1.5 t/ha).
- Recharge does not begin within 30 years, and appears to require a sustained episode of higher rainfall to begin.

Recharge and runoff are small due to low permeability soils and a less variable climate than Hillston. Crop leaf area is also lower than Hillston but more consistent, while tree growth is slightly better and with less annual and inter-annual variation. Recharge does not appear to be a major factor with this scenario, thus rotation lengths would be determined by economic factors, *e.g.* commodity prices, rather than biophysical ones.

4.3.3.2 0.5 m of sand over 3.5 m of clay

- Under long-term cropping, an average of 14 mm recharge per year results, with large annual variations.
- Trees effectively halt groundwater recharge after 1-2 years of growth.
- Tree LAI and productivity come into equilibrium with contemporary rainfall within 3-4 years.
- Tree biomass is 84.8 t/ha after 30 years (MAI = 2.8 t/ha).
- Recharge begin after 13 years under cropping.

This scenario imposes a sandy A-horizon 0.5 m deep on the underlying Walpeup clay. Infiltration is promoted, and so is recharge under cropping systems. A “baseflow” of recharge is maintained and there is definite response to sustained above average rainfall. Both storage and recharge take more than 10 years to recover to pre-tree conditions with the second cropping rotation. Crop growth is strong and consistent, and tree growth is better than for Case 1 although only responding to increased annual rainfall after 10 years. In this environment, equal rotations of 10 years for cropping and trees appears to be appropriate

4.4 Discussion

1) *It appears that the rooting depth available to trees plays a large role in their development and health*. The larger the root zone becomes, the smaller is the annual variation, but the higher the general level of water stress and therefore lower total growth. This is a result of the tree perceiving water over the entire root zone, and if only the top 10% has water in it, *e.g.* 1 m out of 10 m, then the soil environment appears hostile and the plant acts conservatively. As the root zone becomes smaller, the annual variation increases, because when the plant is entirely at the mercy of rainfall it can only react to that.

2) *All the vegetation responds better when the maximum amount of rainfall actually infiltrates and is available.* A more conductive surface soil horizon with moderate water holding capacity can capture most rainfall events, making water available to surface roots. This water will likely wet up lower horizons acting as a store when rain is less plentiful. The shallower the biological root zone of the plant however, the less recharge control can be exerted.

3) The presence of a fresh water table kept below the surface by regional potentials will act as a water source and promote growth of trees and crops. Trees may lower water levels locally and have an effect in the area dependent on hydraulic conductivity and plantation size. If groundwater is saline, concentration of salt in the surface soil by trees can have immediate and long-term consequences for plant growth potential.

4) Trees generally peak in leaf area after 2 to 5 years, and then equilibrate with rainfall and other conditions after 5 to 10 years. A sequence of above average rainfall years promoted growth, but did not alter the long-term apparent equilibrium leaf area. Wood production varied from an MAI of 1.5 to 5.0 t/ha and averaged 2.5 t/ha over all the cases considered. These values are based on a largely untested calibration and should be considered relative and indicative.

5) *Recharge control by trees appears to be rapid once established.* With a large enough root zone, combined with a slow subsoil devoid of preferred pathways, trees can control recharge from most events. The cropping rotations do not readily control recharge in winter dominant climates. To provide a crop-tree rotation system that performs to a certain recharge threshold, it is ultimately only the crop system that requires extensive examination. For example, in Merredin Case 2 the crop-grass system leaks at a rate of 60 mm/year, but takes 10 years to initiate recharge after trees. It is possible therefore to get nearly zero recharge with a crop-grass rotation of 10 years or less and trees for 5 years, after which their growth was greatly slowed.

6) Post-tree recharge below crop-grass systems recovers to pre-tree conditions in proportion to the pre-tree recharge rates under crops. The more leakage that occurs, the faster pre-tree conditions are established, and the slower recharge rates were, the longer it takes to recover the initial state. This point must be recognised when designing systems for arbitrary recharge or growth targets. There is a compounding problem that depending on the soil retention properties and soil depth, in some cases the amount of stored water must be high to allow recharge to occur, while in other cases moisture is more efficiently transported through the matrix and can appear as recharge quickly.

7) Fresh groundwater is an invaluable resource to promote and maintain high growth rates in both crop-grass and tree rotations. However, shallow water levels do suffer from substantial leakage from crop-grass systems which if widespread may cause a slow rise in regional levels. Trees will use fresh groundwater to supplement rainfall to grow at a rate where temperature, radiation, and vapour pressure become controlling factors; these may vary from site to site. Local lowering of water levels is achievable with trees, the depth and extent of effect outside plantations is dictated by local conditions.

8) In the one case examined in this work, salt leached out of the soil profile much slower than it built up, and transiently the leaching caused substantial increases in soil water salinity. *The presence of salt complicates the question of a sustainable and economically viable system so greatly that more detailed work is required to find any general patterns.* The concept of a critical groundwater depth may be useful in this context.

5. Potential Impact of Phase Farming With Trees on Soil Biological Fertility

Lynette Abbott and Clarissa House

The effects of trees on soil physical and chemical properties have been recently reviewed for the Joint Venture Agroforestry Program (Noble and Randall 1998), thus this review will concentrate on soil biological effects.

5.1 Overview

Soil organisms can contribute to the sustainability of land rotated between agriculture and agroforestry, on whatever length of rotation is chosen. This is because the organisms in soil are of key importance in nutrient cycling and uptake of nutrients by plants and in soil aggregation. Soil management practices therefore need to be selected to ensure that the benefits of these important processes are allowed to accrue. The physical characteristics of the soil have a great impact on the habitat of organisms. Changes in soil physical conditions will alter the relative abundance of organisms and the activities of different groups.

Decomposition of woody plant matter is carried out by a succession of organisms in soil. The rate of breakdown of organic matter depends on the chemical characteristics of the plant matter and the suitability of the soil conditions for the growth of fungi and bacteria that have the ability to degrade it. Generally this is a slow process. Slow decomposition of deep roots would be beneficial by providing root channels for agricultural plants to penetrate deeper into the soil profile. Larger components of surface debris from trees would need to be removed before returning to agriculture because the long degradation time of larger organic latter would interfere with agricultural practices such as cultivation. Smaller debris from trees could be beneficial in the long-term by restoring reserves of recalcitrant soil organic matter that have been gradually lost throughout the years of agricultural land use.

Disturbance has a major impact on soil biological fertility. It is difficult to quantify the exact effects of the different types of disturbance associated with rotation of agriculture and agroforestry on soil organisms. Different organisms are altered by different soil conditions. The major processes of soil organic matter breakdown will continue under most soil conditions. The rates of breakdown will be greater where there is more physical disturbance, as occurs during the agricultural phase of the rotation. Therefore, it is expected that phases of agroforestry will reduce the rate of loss of soil organic matter, and provide inputs of organic matter that are more likely to be retained. These effects will maintain a higher level of soil organic matter and contribute to the sustainability of land use. Disturbances of the soil environment also occur with fertilizer and pesticide application and use of heavy machinery but it is not possible to predict the effects of these activities on individual groups of organisms. Major biological processes are usually not changed greatly by these practices although individual organisms may be seriously affected. Therefore, although many of the major biological processes in soil are unaffected, some key organisms may be. Organisms affected may include beneficial mycorrhizal fungi. However, major disturbance, such as a change in rotation, can lead to reductions in plant pathogens due to the introduction of a disease break.

Agricultural ecosystems are generally characterised by high levels of disturbance that lead to loss of organic matter, loss of soil incrementally by erosion, and decline in soil structural characteristics. Increases in disease incidence usually occur in parallel with these changes due to the presence of monocultures. These processes, in addition to the application of high levels of phosphate fertilizer, create soil conditions that favour nutrient breakdown and loss at inappropriate times in terms of plant utilisation, and reduce the opportunity of soil organisms to contribute effectively to the efficient use of fertilizers. Rotation with agroforestry provides an opportunity to break the cycle of degradation associated with many current agricultural practices, interrupt the disease cycle of detrimental plant pathogens, restore organic matter levels, and increase the potential for deep root penetration by agricultural plants due to the creation of channels by roots and associated activities of soil organisms at depth in the profile.

In conclusion, the integration of tree planting into farming systems has the potential to improve soil conditions that will lead to more sustainable long-term land use. Management of residues after tree harvesting will need to be studied further to identify practices that will minimise immobilisation of nitrogen and interfere with agricultural machinery use. Overall, the benefits of rotation between agriculture and agroforestry are expected to:

1. improve the physical and biological state of soil,
2. reduce erosion,
3. increase depth of the soil profile useful for agricultural plant species,
4. enhance the quality of soil organic matter in the recalcitrant fractions that are important for long term productivity of any land use,
5. provide a disease break for root disease of agricultural plants.

5.2 Introduction to soil biology

Plants are dependent on soil as a medium in which to form roots and extract nutrients and water. The sustainability of plant communities is strongly dependent on the fertility of soil, which is a function of its physical, chemical and biological properties. The biological components of soil which can influence its fertility include plants, microorganisms (especially bacteria and fungi) and animals (microfauna, mesofauna and macrofauna). Plants influence soil structure and create a dynamic environment for soil organisms. Exploration of soil by roots improves the porosity and aggregation of soil (Coleman and Crossley 1996). Uptake of nutrients, consumption or release of oxygen, alteration of soil pH and exudation of carbon compounds by roots, provide a variety of habitats and substrates for soil organisms.

The abundance and diversity of microorganisms and animals in soil is largely dependent on the distribution and type of organic matter and soil moisture. Many organisms, including soil fauna, are involved in the degradation of litter in soil (Scheu 1993). Bacteria occur within soil aggregates or around patches of organic matter. Fungal hyphae explore many small microhabitats and form a network within the soil. The mesofauna inhabit air-filled pore spaces, whereas macrofauna have the ability to create their own spaces through their burrowing activities (Coleman and Crossley 1996).

Soil organisms drive the cycling of nutrients and degradation of complex molecules in soil. Soil fauna initiate the decomposition process by mechanically fragmenting and redistributing plant material through the soil strata, increasing its surface area for colonisation by microorganisms. A succession of microorganisms colonise the organic substrates. Fungi and bacteria use soluble components of the substrates and initiate decomposition of more complex organic molecules by excreting “digestive” enzymes onto the surface of the substrate and then absorb the dissolved breakdown products through their cell wall. During the decomposition of organic matter, some bacteria and fungi produce long chained carbon molecules (polysaccharides) that can assist in the aggregation of soil. These compounds adhere to the soil particles and so bind them together. Fungal hyphae are also important aggregating agents as they link or enmesh soil particles (Degens 1997).

The breakdown of organic matter is fuelled by energy that is released when the chemical bonds that hold organic molecules together are broken. During this process, the carbon released is used by microorganisms to construct structural molecules such as proteins. At the same time, elements that are held within organic compounds are converted to inorganic forms (Coleman and Crossley 1996). If the quantity of elements in the organic material is in excess of the microorganisms’ requirements, these may enter the surrounding soil and become available for plant uptake, resulting in net mineralization.

Alternatively, if a microorganism has a large requirement for an element or the supply of elements is limited; they are absorbed from the soil solution through the cell wall leading to net immobilisation.

A number of species of bacteria and fungi are able to increase plant access to elements such as nitrogen and phosphorus. For example, ammonifying microorganisms liberate ammonia during the decomposition of plant and animal residues. Ammonia may then be converted to nitrate by nitrifying bacteria (Paul and Clark 1996). Several species of fungi form specialised associations with roots. Arbuscular mycorrhizal fungi are instrumental in facilitating plant uptake of phosphorus in deficient soils. They do this by forming a network of hyphae around the root which increases the volume of soil that is explored (Smith and Read 1997). Similarly, ectomycorrhizal fungi play an important role in the phosphorus and nitrogen nutrition of plants.

Not all bacteria-fungi-plant associations are beneficial. Some microbial species cause diseases of cultivated plants or animals and others produce toxic by-products that inhibit the activity of other soil microorganisms. In undisturbed ecosystems, the interactions between soil organisms prevent major outbreaks of disease. The suppressive characteristics of soil usually become less apparent with high levels of disturbance and with the introduction of plant monocultures (Andrade *et al.* 1994; Wiseman *et al.* 1996).

As the biological, physical and chemical components of soil are interdependent; an activity that alters the state of soil is likely to lead to changes in the suitability of soil for plant growth and productivity. The objective of this review is to investigate the potential impact of phase farming with trees on the biological component of soil fertility to assist with the development of a sustainable agroforestry system for Western Australia that benefits soil fertility and provides hydrological benefits and timber contributions across the agricultural landscape.

5.3 Decomposition of woody plant organic matter

The nutrients within plant residues are returned to soil by decomposer organisms. Primary colonisers of plant litter metabolise easily degradable carbohydrates. Once this resource has been exhausted, the degradation of recalcitrant compounds begins (Colpaert and Van Tichelen 1996). White and brown rot fungi are the principle agents of wood decomposition (Boddy and Watkinson 1995). Brown and white rotters decay simple carbon compounds, hemicelluloses and celluloses. White rotters are also capable of causing extensive lignin degradation (Boddy and Watkinson 1995). As lignin comprises up to 15-30% of woody cells of gymnosperms and angiosperms its degradation is a significant step in an ecosystems carbon cycle (Gold and Alic 1993).

A succession of fungal species occurs during the different stages of wood decomposition (Niemela *et al.* 1995). Either white or brown rot fungi may serve as primary species, although white rotters are more common (Niemela *et al.* 1995). Primary colonisers initiate decay by ramifying living or recently died tree trunks with their hyphae. Mycelia that are located in the cell lumina secrete lignolytic, cellulolytic and/or hemicellulolytic enzymes that act synergistically to cause the progressive thinning of the fiber walls (Daniel *et al.* 1989; Dosoretz *et al.* 1991). By changing the properties of wood, primary rotters facilitate the entrance of successor fungi. Some successors act as mycoparasites, such as certain fungi of the hypocreales, which utilise the basidiocarps of their predecessors. Others simply utilise primary fungi exudates, or take advantage of the chemically and structurally altered wood (Holmer *et al.* 1997).

Fungal growth and the activity of wood decay enzymes are strongly dependent on wood moisture, and temperature (Zak *et al.* 1995). Optimal conditions for growth are temperatures between 15°C and 25°C and soil moisture greater than 30% (Boddy *et al.* 1989). The growth of various species of white rot fungi is enhanced in the presence of nitrogen supplements, but the activity of lignolytic enzymes is inhibited (Kirk *et al.* 1978; Boyle 1998). Carbohydrate supplements do not appear to affect the growth or lignolytic activity of white rot fungi although, conflicting evidence is presented in the literature (Kirk *et al.* 1978; Dosoretz *et al.* 1991).

5.4 Effect of soil disturbance on soil biological processes.

All ecosystems are subjected to a variety of disturbances that range in type, magnitude and frequency. Land that is managed for commercial purposes may be cultivated annually, treated with herbicides and pesticides, supplemented with inorganic fertilizer and compacted by the traffic of livestock and farm machinery. These activities tend to have little measurable effect on the total biomass of soil organisms but the effect on individuals is difficult to predict because many cannot be isolated or identified. In the following section examples are used to illustrate the impact of agricultural and plantation management practices on soil biota and soil processes that are mediated by these organisms.

5.4.1 Disturbance that is associated with plantation and agricultural land management

Cultivation has a direct physical impact on soil organisms. Organisms are re-distributed through the soil profile and some are physically damaged. For example, the viability of fungi such as *R. solani* and arbuscular mycorrhizal fungi is reduced because tillage breaks up hyphae and so restricts their ability to function. Secondary effects of cultivation include an increase in the mineralization of organic matter as soil organisms are activated by the transient increase in availability of organic matter and oxygen within cultivated soil.

Fertilizer application increases total microbial biomass in soil. This occurs as the addition of fertilizers improves plant productivity, which leads to higher inputs of organic matter into soil. However, chemical fertilizers modify soil chemical properties, making conditions suitable for some but not all soil organisms. Thus, there are changes in the relative abundance and activity of soil organisms in response to fertilizer addition that are not indicated by gross measures of soil biomass. For example, addition of phosphorus fertilizer may increase the abundance of heterotrophic fungi in the soil. In contrast, the abundance of beneficial mycorrhizal fungi may decrease depending on the quantity of phosphorus. Of specific importance to the management of land during the transition from agroforestry to agriculture is the impact of nitrogen based fertilizers on the metabolism of lignin degrading fungi (Boyle 1998). Whilst these fertilizers provide elements that promote the growth of hyphae, high applications may inhibit the decomposition of lignified plant residues (Kaal *et al.* 1995).

In agroforestry or agricultural systems, pesticides may be applied to decrease the abundance of plants and organisms that reduce the vigour of a commercial product. The direct effect of pesticides on soil organisms depends on the type and specificity of the chemical, the susceptibility of target species and the rate of application. Due to the interdependence of plants and soil organisms, there are also flow-on effects of pesticide application. This is illustrated by the reduction in densities of total fungi and funigivorous nematodes that resulted from the application of fungicide to shortgrass prairie (McGonigle 1995).

Much damage can be done to the soil itself by the movement of machinery over the site (Hilton 1987). During the cultivation of agricultural land or the extraction of logs from plantations, the traffic of vehicles compacts soil. This reduces its bulk density and decreases aeration and water infiltration. These physical changes decrease the suitability of soil for the activity of many organisms and consequently decrease the possibility of soil animals contributing to nutrient cycling.

Agriculture increases the risk of outbreaks of disease as pathogens have unique opportunities to spread within the homogenous environment that is created by crop monoculture. Crop rotation is one of the most successful practices for avoiding plant disease. If botanically unrelated crops are included in rotations, pathogens in soil may be depleted of resources if they are unable to invade the roots of the succeeding crop. In this way, plantations of trees that are rotated across the landscape have potential to reduce the pathogen load in soil.

The different types of organic matter that are contributed by plant species in rotation also have a significant effect on soil organisms. The chemical structure of plant litter determines the rate of breakdown by soil organisms and thereby influences the dynamics of the community of organisms in soil. For example, the wax coated leaves and lignified bark of Eucalyptus species are likely to be more recalcitrant to decomposition than the nitrogen rich residues of legume crops and will require a different suite of organisms to catalyse their decay.

5.4.2 Disturbance that is unique to the management of plantations

The removal of vegetation during tree harvest is a major disturbance, since trees provide a habitat and substrate for numerous organisms. During harvest, whole trees are cut down at the base of the trunk. The branches are then removed and the logs are transported from the site. Post-harvest there is the option to retain or burn plantation residues. The type and quantity of organic matter that is retained on site and the environmental conditions of the microhabitat will have a selective effect upon the kinds of soil communities that develop.

At forest sites on Vancouver Island B.C. Canada, the decomposition of cellulose was found to be five times greater at cut than uncut sites. This suggests that microbial activity is increased by the influx of organic matter. The magnitude of this increase will depend on the harvest strategy. In a Scots pine *Pinus sylvestris* L. stand, where whole tree harvest (WTH) and residue retention treatments were compared, WTH generally resulted in lower abundance of several soil fauna groups (Bengtsson *et al.* 1997). Thus logging techniques that conserve plantation residues at the site may promote the growth of soil organisms and would conserve a valuable nutrient reserve (Hilton 1987). This is essential if the activities of soil organisms are to be exploited to degrade tree stumps and roots post logging.

To facilitate the transition from plantation to agricultural land use, heavy machinery could be used to dig up stumps, which could subsequently be stacked and burnt. An objection to burning is that there will be a loss of nutrients due to the leaching of soluble ash constituents (Attiwill 1994). In agricultural systems that depend on inputs of inorganic fertilizer, the loss of nutrients is a minor concern. However, the loss of organic matter may have a negative impact on site productivity due to the decline in abundance of beneficial soil organisms. Beneficial soil organisms are important for determining the functioning of agroecosystems (Wardle *et al.* 1999).

Given the range of organisms in soil and their tolerance of a variety of different soil conditions, it is unlikely that the diversity of organisms in soil will be reduced greatly by disturbance associated with agriculture and agroforestry. However, a major determinant of the functioning of heterotrophic organisms is the availability of organic matter. Thus, the change in the type and quantity of organic matter that would be associated with the transition from agriculture to agroforestry systems will have a significant impact on the majority of soil organisms.

5.5 Dynamics of biological cycling of nutrients

A suite of heterotrophic organisms carries out the decomposition of organic matter. Carbon and energy moves from initial organic substrates to primary decomposers, either bacteria or fungi and then to higher tropic levels. The interaction between predators and prey in the detrital food web have a significant impact on the cycles of the major nutrients; nitrogen, phosphorus and sulfur (Coleman and Crossley 1996).

The activities of fauna are especially important for nutrient cycling mechanisms. In experiments where fauna population size was controlled, the presence of abundant fauna enhanced nutrient return by 20 - 25% (Coleman and Crossley 1996). Fauna contribute to the pool of nutrients in soil through their interaction with microflora. For example a 2.5 fold increase in nitrate concentration in litter resulted from the passage of 6% of litter through collembolan guts (McGonigle 1995). All living biomass in soil contribute to the cycling of nutrients when they die. Although carbon and nutrients present in organisms represent only a small proportion of that which is present in soil the elements within them are rapidly mineralised when the organisms dies.

The distribution and activity of organisms present in soil is influenced by microclimate factors such as temperature, moisture and gaseous regimes (Griffith and Boddy 1991). Some organisms tolerate a wide range of temperature and moisture levels, whereas others tolerate a narrower range. The growth of many wood-inhabiting fungi, particularly basidiomycetes is inhibited by water potential below - 5 MPa and temperatures above 25 °C and below 5 °C. High water potential can also inhibit growth, as the diffusion of oxygen in water saturated wood is reduced. Thus, during summer and winter months the rate of decay of crop or plantation residues is likely to decline. Nutrient cycling under plantations may be buffered from seasonal moisture and temperature extremes as vegetation cover controls the temperature and desiccation of substrates (Castillo and Demoulin 1997).

Organic materials differ in the relative proportion of carbon to nitrogen in their cellular structures. It is this ratio of carbon to nitrogen that controls the release or immobilisation of nitrogen from decomposing substrates (Edmonds and Eglitis 1989). Organic matter with a high C:N degrades slowly as insufficient nitrogen relative to carbon is available for the growth of microorganisms. The turnover of organic matter with a high nitrogen content is rapid as organisms which catalyse decomposition are supplied with adequate amounts of nitrogen for growth.

Breakdown rates in agricultural systems tend to be more rapid than in forested systems as crop residues have fewer recalcitrant components (Coleman and Crossley 1996). However, the quantity of organic matter that is cycled in agricultural systems is small as most is lost through the export of crop produce. The practice of burning aboveground residues to increase the ease of cultivation also leads to a loss of organic matter.

The dynamics of organic matter cycling under plantations are presumed to be comparable to those under forest, thus reference is made to forest systems. Woody trash contains a high proportion of cellulose and lignin and a lower proportion of nitrogen. Consequently, the breakdown of organic materials may occur over a number of years and lead to temporary immobilisation of nutrients. Therefore, during the transition from plantation to agriculture, large and sudden inputs of organic matter need to be carefully managed to maintain the productivity of soil for the growth of commercial agricultural crops. The addition of suitable levels of nitrogen should ensure that pools of nitrogen in soil are sufficient to avoid immobilisation of nitrogen.

5.6 Impact of soil physical properties on soil organisms

Soil with a good structure has aggregated particles of different sizes. Roots and soil organisms in combination with organic matter contribute to both strong and weak forces that aggregate soil particles. Macrofauna make significant contributions to the macro-structure of soil through bioturbation and the movement of soil material. For example, the nesting activity of ants at Yathong reserve, N.S.W. significantly increased the water penetrability of soil (Eldridge 1993). Microorganisms play an important role in the formation of stable aggregates. Some fungi and bacteria produce polysaccharides that adhere to the surface of soil particles and bind them. Other soil binding agents are the hyphae of fungi and roots of plants (Degens 1997). Roots and hyphae form links between particles and hold them in temporary aggregates. Fungi that are likely to exert the greatest influence on soil aggregation are those that colonise fresh organic matter and fungi that form mycorrhizal associations with roots.

Land that has been managed intensively for agriculture is susceptible to erosion. In part this may be due to practices which negatively impact upon soil aggregating processes. For example tillage breaks up the soil surface and may cause aggregates to become unstable. Indirect effects of tillage include changes in soil conditions, that are more suitable for the growth of bacteria than fungi (Coleman and Crossley 1996). As the scale at which bacteria function in aggregating soil is small, it is predicted that the stability of aggregates in agricultural soil would be less than in soil where fungi are abundant, such as in association with woody perennial species. Seasonal changes reduce plant growth for much of the year in mediterranean environments. Thus, the aggregating action of plant roots and soil organisms is negligible for extended periods.

The integration of trees into agricultural systems may ameliorate the degradation of agricultural land. The abundance of fungi and fungivores is greater in soils with a litter layer than in those without

(Coleman and Crossley 1996). Thus the development of a cool, moist litter layer beneath plantations should increase the abundance of litter decomposers and their predators. As described previously the activity of these organisms promotes the formation of aggregates. The majority of soil biomass (~70%) is associated with the small fraction of soil that is influenced by plant roots (Coleman and Crossley 1996). Therefore, the deep roots of tree species should enhance soil aggregation through the binding action of the roots themselves and their influence on soil biota at greater depth in the soil profile than would occur under agricultural systems.

5.7 The potential impact of major changes in land use, such as rotation between agriculture and agroforestry, on soil biological processes

Agricultural ecosystems are characterised by high levels of disturbance, low levels of plant species diversity and low levels of input of organic matter. The impact of disturbance such as cultivation, herbicide application or pesticide use is difficult to predict as the habitat of soil organisms is changed in several different ways following every management practice. Modification of the state of soil to improve the productivity of commercial plant species may cause soils to become less suitable for the growth of some endemic plants and soil microorganisms.

To prepare soil for the cultivation of tree species for PFT, the site may be deep ripped and treated with herbicides and other pesticides to reduce the abundance of weedy plant species and insect pests. The impact of these activities on soil biological diversity and activity is difficult to quantify. Generally, application of herbicides influences some but not all groups of soil organisms. However, the impact on soil biological processes such as mineralization of organic matter is usually not affected because a wide variety of organisms are present with similar functions.

During the early stages of plantation establishment, uptake of nutrients from the topsoil is rapid as the canopy and root system of the young trees develop (Bargali *et al.* 1993). Nutrient levels may be replenished by the addition of inorganic fertilizers and/or the cycling of nutrients from leaf and other debris. As the plantation matures the accumulation of plant organic matter is predicted to support a greater total biomass than conventionally managed agricultural land. Within the soil, the structure of soil flora and fauna communities will be significantly affected by the presence of different types of living and dead organic matter. For example, deep rooted vegetation may create conditions that promote the growth of ectomycorrhizal fungi (providing they are introduced or already present) and reduce the abundance of agricultural pathogens. Furthermore, as intricate links occur between organisms in soil, a change in the abundance of one species will affect the relative abundance of others.

Within 3 - 5 years of establishment of the plantation, trees will be logged for wood chips. Depending on the harvest strategy, a quantity of wood and leaf debri will remain at the completion of this process. The time required for the decomposition of this debri is dependent on variables such as its chemical characteristics and it can be described mathematically by an exponential decay model (Colpaert and Van Tichelen 1996). To enable the rapid return to previous agricultural practices, it may be preferable to remove most of the debri from the site. In the long-term, the retention of some woody material is perceived to be advantageous as soil organic matter enables the development of communities of soil organisms that have a beneficial effect on soil stabilising processes and nutrient cycling. On the other hand, there is evidence that some soil organisms that colonise the debri of native plants can be detrimental to important agricultural microorganisms such as rhizobia (Holland and Parker 1966). A benefit derived from the input of diverse and recalcitrant native plant organic matter may be to promote activity of a high diversity of soil organisms. The extent to which they may contribute to the suppression of pathogenic organisms through predator prey interactions is not known. The quantity of debri retained that is optimal, from an economic and environmental perspective, may be determined with the aid of a computer simulation model.

5.8 Conclusion and recommendations for further research

The integration of tree plantations into farming systems has the potential to improve the biological fertility of soil. The development of a litter layer under plantations and the input of organic material following logging is predicted to increase the abundance and activity of a diverse community of soil organisms. Benefits derived from practices that encourage the activities of soil organisms include the natural suppression of pathogens and an increase in soil aggregating processes and nutrient cycling. However, there is some potential for problems to arise from toxic substances produced by soil organisms during decomposition of woody debri. In the long term, the existence of robust communities of soil organisms may increase the sustainability of agriculture by decreasing the dependence on inorganic fertilizers and pesticides. The input of native plant organic matter into the soil, that is more recalcitrant than organic matter from agricultural plants, may lead to an enhancement of the component of organic matter in the soil that is important for long-term soil stability. A preliminary estimate of a benefit of soil biological activity to production is $5 per ha in wheat/lupin rotations in WA (J. Bayne pers. comm.). Corresponding estimates from expected increases in soil physical and biological fertility caused by agroforestry have not been made.

The main factor that will decide the success or failure of the transition from agriculture to agroforestry and back to agriculture is predicted to be the speed at which plantation sites can be utilised for agriculture following tree harvest. The key determinant of the time required for the transition from plantation to agricultural land use will be the harvest strategy and the recalcitrance of woody debri to decomposition. An optimal harvest strategy would be one that is economically viable and creates conditions that promote the activity of soil organisms.

Given that the development of a suitable harvest strategy is vital for the success of the project, it would be beneficial to:

- quantify the changes in abundance of specific species of soil organisms in response to the transition from agriculture to agroforestry,
- quantify the impact of a number of harvest strategies (i.e. retain or burn plantation residues or remove stumps with heavy machinery) on the activity and abundance of species of soil organisms,
- manipulate nitrogen pools in soil to promote the degradation of substances with a high C:N ratio,
- assess the impact of nitrogen applications on the lignin metabolism of white and brown rot fungi.

Potentially, this knowledge will provide options for selecting practices that manipulate soil organisms to mediate the rapid decay of plantation residues. Alternative methods of maintaining the nutrition of agroforests may also be investigated to reduce the cost of plantation management. For example, trees may be inoculated with ectomycorrhizal fungi to increase the efficiency with which they extract phosphorus from soil or leguminous perennials may be sown between the alleyways to reduce inputs of nitrogen fertilizers. The long-term beneficial effect of plantations on soil biological and physical characteristics should be considered as well as short-term disadvantages associated with removal of stumps and other debris.

6. Economic Feasibility

Ray Challen

6.1 Introduction

This chapter examines economic issues of a phase farming with trees. The two issues examined are:

1. the financial feasibility of a potential phase-farming rotation and relative profitability with a conventional cropping system
2. the adoption of a phase farming system as a technological innovation for broadacre agriculture.

Conclusions are drawn in respect of prospective financial feasibility and adoption, and directions for more detailed research in both these areas are outlined.

6.2 Financial analysis

6.2.1 Preamble

A financial analysis was undertaken to compare the profitability of two different agricultural systems:

1. a “standard” agricultural cropping rotation;
2. a phase-farming system comprising a similar cropping programme, but with a tree phase incorporated

A thirty year period was chosen for the analysis which allowed two phases of trees, each lasting six years. Financial returns were calculated as a cumulative cash flow (based on gross margins) and net present values.

6.2.2 Assumptions

6.2.2.1 Geographical setting

The financial analysis were undertaken for three hypothetical locations corresponding nominally to farm settings in the wheatbelt of Western Australia, with 300, 400 and 600 mm of annual rainfall, respectively.

The soils at all three locations were assumed to be well drained duplex soils, corresponding to that characterized in §4.3.1.2. Soils of this type are amenable to direct drilling of seed which is potentially a cheap, effective method for establishing trees. Direct drilling of seed with minimal ground preparation is unlikely to be viable on heavier soils.

6.2.2.2 Standard agricultural practice

The standard farming system used to establish a financial benchmark was a lupin-wheat rotation. In the wheatbelt it is common for wheat to be grown in two successive years followed by a break crop such as lupins. This type of rotation can be represented by L,W,W where L and W denote lupins and wheat, respectively.

Continuous cropping is less common in higher rainfall areas (>600mm), although the downturn in wool prices has prompted a shift towards more frequent cropping in these areas.

The crop yields used by the analysis are indicated in Table 3. These are typical of the production achieved by the top 30% of farmers in Western Australia[1]. Yields have been adjusted to take into account interactions between each phase of the rotation. For example, lupins boost the yield of a subsequent wheat crop by fixing nitrogen and reducing disease.

The prices for agricultural products used by the analysis are shown in Table 4. The gross prices indicated in Table 2 are Free-on-Board "world prices" for the commodities. Farm gate prices are net of transport costs, marketing charges, and industry levies. These estimates are based on a medium term outlook, and are the same as those used in a whole farm model developed by Agriculture WA and known as MIDAS (Model of an Interactive Dryland Agricultural System Morrison 1986). Current commodity prices are approximately $20 to $25/t higher than those depicted in Table 4.

Table 3 Yields of agricultural crops in Western Australia

	Rainfall (mm)		
Enterprise	300	400	600
Wheat yield after lupins (t/ha)	1.8	2.4	2.6
Wheat yield after wheat (t/ha)	1.6	2.2	2.4
Lupins yield after wheat (t/ha)	0.8	1.2	1.4

Table 4 Agricultural product prices (1999 expectations)

Product	**Gross price**	**Farm gate price**
Wheat (ASW 10%)	$175/t	$135/t
Lupins	$185/t	$150/t

Gross margins for each stage of the agricultural rotation were calculated using the prices and production assumptions listed in Tables 3 and 4, and are indicated in Table 5. A gross margin is equivalent to the farmer's gross income from an activity net of variable costs such as fertiliser, weed control, and harvesting costs. It excludes overheads, interest, and capital depreciation. The costs associated with cropping and sheep enterprises were based on those contained in the 1998 Farm Budget Guide published by Agriculture WA.

Table 5 Gross margins of agricultural cropping activities

	Rainfall (mm)		
Enterprise	300	400	600
Wheat after lupins ($/ha)	138	207	234
Wheat after wheat ($/ha)	111	180	207
Lupins after wheat ($/ha)	5	46	68

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[1] pers comm, Agriculture Western Australia.

6.2.2.3 Phase-farming practice

For the phase farming system, it was assumed that a phase of blue-gums (*E. globulus*) was inserted into the standard farming rotation. Specifically, the rotation can be described as six years of tress followed by nine years of L,W,W. This rotation was repeated twice over the thirty year planning horizon. The assumptions associated with this farming system are summarised below.

6.2.2.3.1 Tree establishment and maintenance costs

Two alternative methods for establishing trees were considered: direct seeding and planting nursery tubestock into well prepared ground. Direct seeding is much cheaper than planting seedlings, but it has not been proven in the field. Also, there may be a one year delay in growth for trees established from seed. However, for the purposes of this analysis, trees established under both methods were assumed to grow at the same rate.

Direct seeding of trees was assumed to cost $175/ha, based on a farmer carrying out all cultivation and seeding operations (ploughing and airseeding) using on-farm machinery. Costs include weed and insect control in the first and second year of establishment, but does not include fertiliser. It was assumed that adequate nutrient levels would persist from previous cropping phases.

A second analysis was conducted to examine the effect of higher establishment costs on the economic viability of phase-farming. This analysis assumed that trees were established from nursery grown tubestock at a total cost of $870/ha. This cost estimate is based on contract rates for preparing the ground (ploughing) and planting the seedlings. As before, allowance was made for adequate weed and insect control in the first and second years of establishment but no fertiliser was applied.

There was assumed to be no ongoing maintenance costs of the trees apart from weed and insect control in the second year of the phase. There was also assumed to be no fire insurance of the trees.

6.2.2.3.2 Tree harvest costs

Tree harvesting was assumed to be undertaken using a “buncher/forwarder” producing a stem-log product. The logs are then chipped for pulping. This activity was assumed to be carried out by a contractor at a cost of $16/t of product. This cost is $6/t more expensive than an alternative harvesting method (a mallee chipper), but produces a superior product. Harvesting by a mallee chipper was not considered in the analysis as the estimated harvesting cost was equal to the envisaged product price (both $10/t), and hence would not have been a viable option.

6.2.2.3.3 Land restoration costs

After harvesting of trees, the land surface would have to be restored to remove trash and stumps and allow access to machinery for crop cultivation. Restoration was assumed to be undertaken by cultivation with a disc plough to break up stumps and roots, followed by raking and burning of trash. This was assumed to be carried out by a contractor at a cost of $70/ha, based on contract rates published in the 1998 Farm Budget Guide (Agriculture WA).

6.2.2.3.4 Yields

Assumed yields for the blue-gums harvested after six years are indicated in Table 6. These yields relate to tree stems that are suitable for pulping. Yields for the agricultural crops were assumed to be the same as those in Table 3. This may not be entirely realistic because the yield of lupins grown immediately after trees may be reduced by low soil fertility or delayed seeding. Whilst there is no research evidence of this, it is inevitable that blue-gums would lower phosphorous levels because no fertiliser is applied during their growth. To accommodate these concerns, the analysis included an extra $20/ha input of phosphorus fertiliser in the first year of cropping after the tree phase.

Over the length of the planning horizon, the phase-farming system may indeed improve crop yields relative to those that would otherwise have been obtained under a standard continuous-cropping regime. For instance, including a tree phase in the rotation may prevent the onset of herbicide resistance and/or salinity. Rather than speculate on the size and exact nature of these potential benefits, this analysis examined the amount by which crop yields would need to fall under conventional agriculture to equal the economic returns generated by the phase-farming system.

Table 6 Yields of trees harvested after six years, as used in the economic analysis

Rainfall (mm)	Yield (t/ha)
300	5
400	10
600	25

6.2.2.3.5 Prices for tree product

The feller/buncher harvesting method produces tree stems suitable for production of good quality pulpable wood chip. This product is assumed to attract a price of $35/m^3, which is equivalent to $75/tonne (based on a basic density of 0.44 t/m^3). The price net of harvesting costs is $59/t.

This price applies to product delivered to the processing plant. In order to attain a farm gate price, transport costs of $2/t were also subtracted. This transport cost assumes that the farm is located 20km from a processing plant and a cartage rate of $0.10/t.

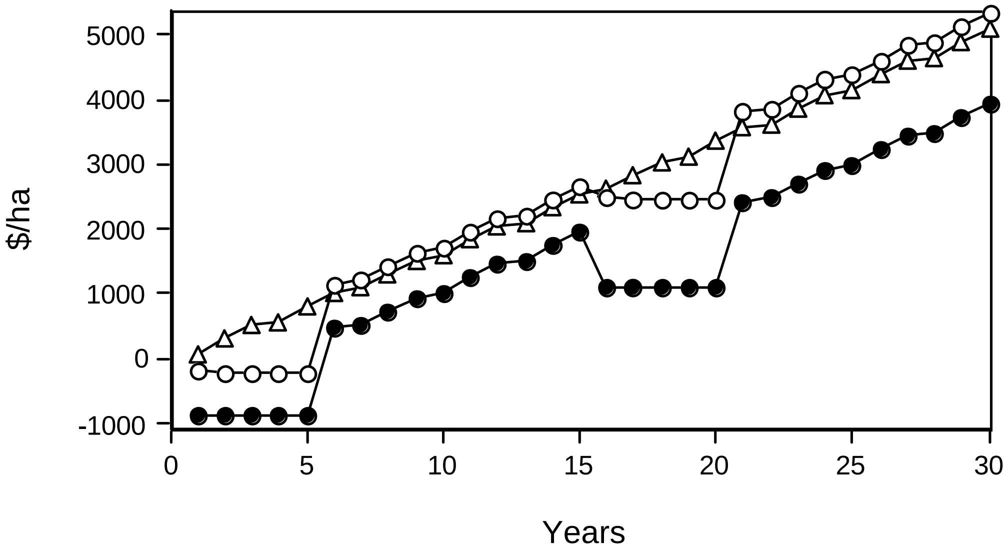

Fig. 3 Cumulative cash flow (nominal values) for an agricultural rotation and two phase farming rotations in a 600 mm rainfall zone. Direct seed (O), tubestock (●), standard agriculture (Δ).

6.2.3 Results

Results from the analysis are presented in two ways. Firstly, cumulative nominal cash flows over a thirty year period are indicated for each rotation (by rainfall zone) in Figures 3, 4, and 5. Secondly, the nominal cash flows were converted to net present values and annuities to allow comparison of rotations without complications caused by differing distributions of costs and benefits over time. The net present values and annuities are indicated in Table 7.

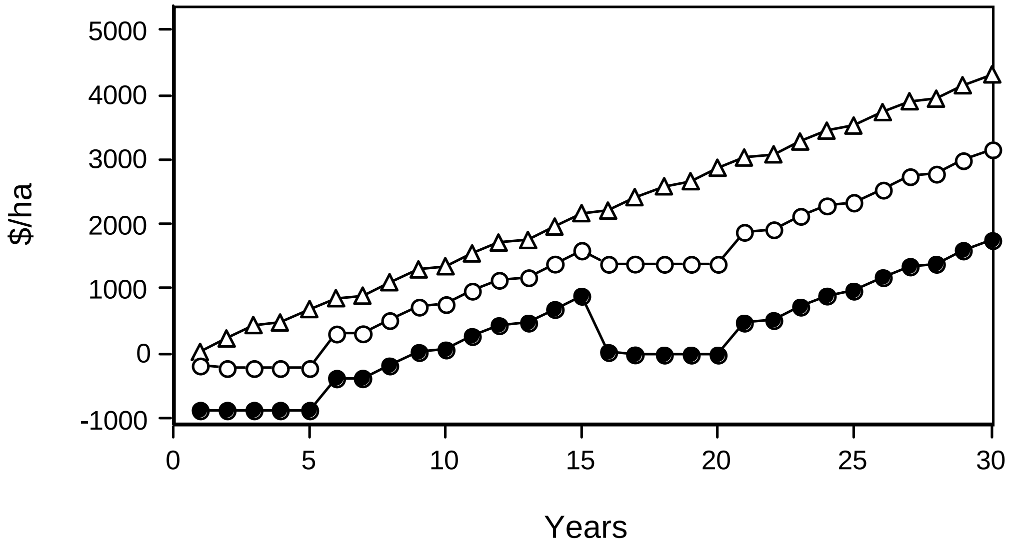

Fig. 4 Cumulative cash flow (nominal values) for an agricultural rotation and two phase farming rotations in a 400 mm rainfall zone. Direct seed (O), tubestock (●), standard agriculture (Δ).

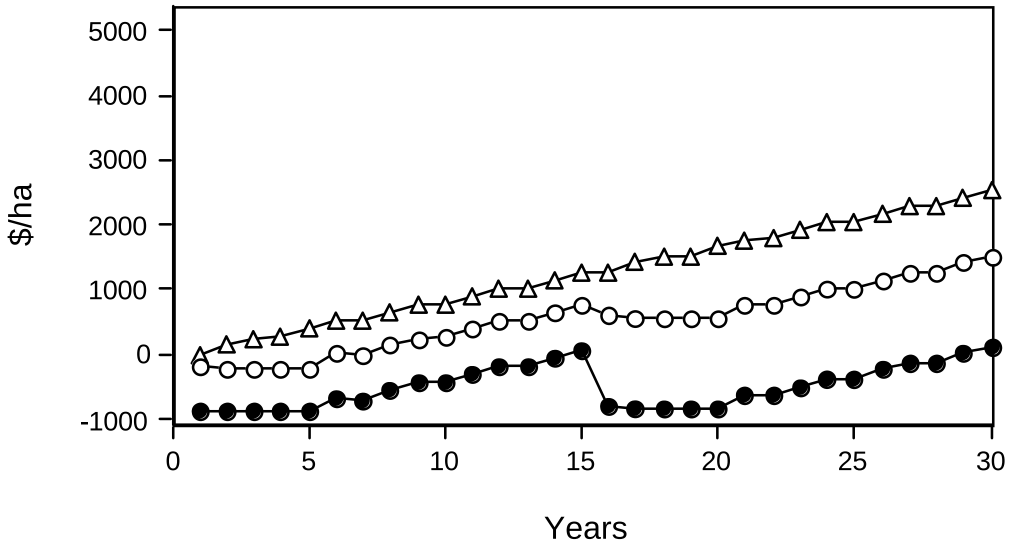

Fig. 5 Cumulative cash flow (nominal values) for an agricultural rotation and two phase farming rotations in a 300 mm rainfall zone. Direct seed (O), tubestock (●), standard agriculture (Δ).

Principal results are summarised as follows.

- In the 600 mm rainfall zone, phase-farming was found to be economically competitive with "standard agriculture", provided trees were established via direct seeding. The annuity from phase-farming was calculated to be $84/ha/yr, which is comparable to returns from continuous cropping, estimated to be $80/ha/yr. If trees are established from seedlings, the profitability of phase-farming drops to $62/ha/yr which is well below that of the standard lupin wheat rotation.
- In the 300 and 400 mm rainfall zones, phase-farming is not competitive with continuous cropping, regardless of the method used to establish trees. In the best case scenario, where trees are established using the low cost method of direct-seeding, the annual returns from phase-farming are

40% to 26% below those generated by standard agriculture in the 400 and 300 mm rainfall zones respectively.

- The poor profitability of phase-farming in the 300-400 mm rainfall zones is being driven by the low yields assumed for trees in these zones. In the 600 mm rainfall zone, phase-farming is competitive with “standard agriculture” because the analysis assumes a large (150%) increase in tree yield when moving from the 400 to 600 mm rainfall zone. By comparison, crop yields are assumed to be less responsive to rainfall and increase by less than 20%.
- In summary, if phase-farming with short rotation blue-gums is to even approach the profitability of continuous cropping in the low rainfall zones of Western Australia it will be necessary to minimise the cost of establishing trees. The establishment of trees by direct drilling, or a similar inexpensive method, will be required.

Table 7 Economic performance of a standard agricultural rotation and two phase farming rotations as measured by net present values ($/ha) and annuity returns ($/ha/yr) over a thirty year period

	Rainfall (mm)		
	300	400	600
Standard agricultural rotation			
NPV	617	1052	1237
Annuity	40	68	80
Phase-farming (direct seeded)			
NPV	370	770	1296
Annuity	24	50	84
Phase-farming (tubestock)			
NPV	33	432	958
Annuity	2	28	62

Note: Calculations are based on a 5% annual discount rate

For the low and medium rainfall zones, sensitivity analyses were conducted to determine increases in on-farm prices for tree products or the product yields of trees that would be necessary to increase the returns from the phase farming rotation to levels comparable with the standard agricultural rotation. Results are indicated in Table 8.

Table 8 Yields and prices for tree products necessary for comparative profitability of PFT with the assumed conventional agricultural rotation

	Rainfall (mm)	
	300	**400**
Tree Yields	20 t/ha	14 t/ha
On-Farm Tree Product Prices*	$160/t	$115/t

* Prices are net of harvesting and transportation costs, totalling $18/t.

While the results presented above suggest that phase-farming with short rotation blue-gums in the 300-400 mm rainfall zone is not economically viable relative to the standard lupin-wheat rotation, there are some concerns about the long term sustainability of continuous cropping. Rising ground water tables and the emergence of herbicide resistance are probably the two greatest threats to the sustainability of cropping rotations currently practiced in the wheatbelt. Phase-farming may prove to be more attractive than continuous cropping in the long term because trees have the capacity to slow the rise in the groundwater table, improve the physical and biological properties of the soil, and help prevent the onset of herbicide resistance.

This financial analysis has excluded these potential "indirect" benefits attributable to phase-farming. Rather than attempt to incorporate these benefits explicitly in the model, a simple break-even analysis was conducted to quantify the amount by which yields would need to fall under continuous cropping (due to salinity, for example) in order to equalise the economic returns from phase farming and standard agriculture. This analysis found that crop yields would need to fall by 17 or 15% to equalise the returns from phase farming (with low cost tree establishment) and standard agriculture, for the 300 and 400 mm rainfall zones respectively.

This result provides an indication as to the size of "indirect benefits" required to make continuous cropping competitive with phase-farming. That is, in the 300 and 400 mm rainfall zones, phase farming may need to produce "yield protection" benefits for grain crops in the order of 15 to 20% to lift the benefits of phase farming to levels similar to standard agriculture. This result should, however, be treated with caution. The break-even analysis assumes that yield reductions are constant over the entire planning horizon and commence in the first year of the analysis. In reality, productivity will probably be affected gradually and not become severe until some time in the future. A more thorough economic investigation of phase-farming should recognise the dynamics of this process.

6.3 Issues of adoption

6.3.1 Preamble

The fundamental challenge in developing and promoting a new farming system is to have it adopted and maintained by farmers (Pannell in press). Farmers will generally not change their farming practices unless they perceive there are clear benefits to them from doing so. Developing this perception, and hence of achieving widespread adoption, is potentially difficult if new practices are of only marginally greater profitability than existing practices and are complex and/or radically different from current farming practice. This is the case with a phase-farming system and both research and extension of such an innovation need to recognise the potential difficulties of adoption. The following section of the report briefly outlines issues of adoption of an agricultural innovation that are important in such circumstances.

6.3.2 Factors influencing adoption of an agricultural innovation

There is a wealth of empirical evidence on the factors that influence farmers' adoption of innovations (Feder *et al.* 1985; Lindner 1987; Feder and Umali 1993; Rogers 1995; Marsh *et al.* 1996a; Abadi Ghadim and Pannell 1998; Frost 1998; Pannell in press), and it includes some very clear-cut messages. Factors influencing adoption of innovations are described below.

6.3.2.1 Ability to learn

Adoption theory in agriculture essentially sees the adopt/reject decision as a "risky choice" problem. The decision to adopt a new innovation is risky because the farmer is unsure whether he or she will be better or worse off by adopting. The likelihood of making a correct, or incorrect, decision clearly depends on the decision maker's knowledge of the relevant parameters: the more that is known about the innovation, the less likely it is that an incorrect decision will be made. Adoption is essentially a process of collecting information, revising opinions/attitudes and reassessing decisions, that is, a dynamic learning process.

There is strong evidence that, the world over, most farmers are "risk-averse" (Binswanger 1980; Bond and Wonder 1980; Antle 1987; Bardsley and Harris 1987; Myers 1989; Pluske and Fraser 1996). This is evident from the observation that they will not leap into large-scale adoption of a new innovation. Rather, they generally use small-scale trials to gain knowledge and confidence in their perceptions about the performance of the innovation. Pannell (1996) asserts that on-farm trialing is perhaps the most important factor in determining final adoption or disadoption, and that if small scale trials are not possible or not enlightening for some reason, the chances of widespread adoption are greatly diminished.

If for some reason it is difficult to learn about the effectiveness and benefits of an innovation, such as through trialing, then the adoption decision is made more difficult for the farmer. The complex changes to farming systems designed to achieve more sustainable farm management practices tend to fall into this category. Often they involve benefits that are difficult to assess and/or which occur over a long time period. The changes are often not compatible with previously introduced ideas, or beliefs and values already held. Such innovations are not able to be quickly assessed and implemented by farmers.

The importance of on-farm trials is also reinforced by a growing recognition within the extension discipline that extension which is cognisant of the principles of adult learning (Knowles 1990) and experiential learning (Kolb 1986) enhances the learning process.

Enabling farmers to learn about the effectiveness and the benefits of the proposed innovation is crucial in facilitating the adoption process. Farmers' on-farm trials are an important way in which they assess the merit of new innovations/systems.

6.3.2.2 Relative profitability or advantage

Factors that influence farmers' adoption of innovations can be divided into those that directly affect the objective profitability of an innovation and those which influence the attitudes and perception of the potential adopters about the profitability (or desirability) of the innovation. The weight of empirical evidence is that farmers' adoption behaviour in most cases is explained well by how much more profitable the innovation will be for any particular farmer, compared to their current practice. Generally, farmers will adopt innovations that are more profitable than their current practice. The more profitable the innovation compared to current practice, the more rapidly it will be adopted.

The quality and quantity of farm resources (land, financial, and human) affects the "true" relative profitability of the innovation to the individual. "True" relative profitability (or advantage) is also affected by other characteristics of the innovation itself; such as the scale at which the innovation is applicable, or how compatible it is with needs. Viewed like this, it is evident that environmental considerations may fit directly as an element of profit, or may be a conflicting objective to be traded off against profitability.

6.3.2.3 Perceptions

The "true" profitability of an innovation is only relevant in the context of farmers' awareness of the innovation and their perception about the relative profitability/advantage of the innovation. Farmers will only change their farming practices if they perceive that it is in their "best interest" to do so, and they perceive that change is possible for them.

Perceptions are influenced by a wide range of factors including:

- demographic factors such as age, ethnicity, gender, wealth, experience, education, family size, health, family size and composition, psychological make-up, etc.;
- the actions of leading farmers;
- peer pressure from farmers and/or communities;

- extension activities; and
- attitude to risk.

The complexity of these factors means that, in practice, adoption decisions vary for a multitude of valid reasons. Lindner (1987) concluded that there was strong empirical evidence that farmers in general are rational, meaning that if they are not adopting an innovation it is because they don't believe it is in their own best interest. Apparent irrationality can be explained by ignorance (of the true value of the innovation), misconception by others about the decision maker's objectives, and/or inappropriately designed technology.

Extension theory also recognises that people will not change, even if they perceive it is in their "best interest" to do so, if they cannot see how they can change. That is, along with the capacity to change, there must be clear "actionable first steps".

6.3.3 Adoption of a tree phase farming system

The single most significant issue affecting adoption of a phase farming system with a tree phase would be profitability relative to conventional farming and other phase farming alternatives, for example systems with lucerne phases. However, regardless of relative profitability, barriers to adoption would exist for a phase farming system. Reasons for this relate to the factors described above, and are as follows.

- The incentive for farmers to "trial" the innovation is low due to:
    - the extended time period of a single "rotation";
    - a trial may not indicate environmental benefits without being undertaken over a large area;
    - trialing would require a substantial investment in practical knowledge and new agronomic techniques, or risking substantial losses from a failed trial establishment; and
    - opportunity costs associated with removing land from conventional farming for a lengthy period are high; and
    - the trialing decision is expensive to reverse if unsuccessful due to the need to restore the land before resuming crop or pasture production.
- Trialing may in any case be of limited value as a learning process for farmers because many benefits, such as effects on groundwater tables, are not readily measurable and subject to "masking" by such factors as weather variation, insect attack and disease.
- Because of the limited usefulness of trialing as a learning process, farmers would be heavily reliant on information sources external to their own experience. Learning and adoption would therefore depend upon successful extension activities by the promoter of the technology.
- Environmental benefits may be highly spatially variable depending upon hydrogeological characteristics of the landscape, and this variation may not be readily predictable.

Although there are potential barriers to adoption, there are also features of phase-farming systems that could assist adoption. These are as follows.

- The phase farming system is essentially a "cropping" technology that in many respects is not radically different from a farming system based on annual cropping, and does not involve a (currently low profitability) livestock component.
- There is a already a general perception amongst broadacre grain farmers that phase farming may be a beneficial technology to combat agronomic problems such as herbicide resistance.

- There already exists active groups of farmers (Landcare and catchment groups) concerned with issues of land degradation caused by rising water tables who are actively seeking innovative methods to combat this problem.

6.4 Recommendations for further research

The financial analysis described above indicated that while in some circumstances phase farming may be close to standard agricultural systems in terms of profitability, the advantage is most likely to be marginal or dependent upon indirect benefits that are not readily apparent in cash flows.

Research into phase farming with trees must in the first instance seek to develop a phase farming rotation or system that is demonstrably more profitable (or more desirable for reasons other than profitability) than current agricultural practice. Further economic research should focus on both a more detailed examination of the various assumptions and parameters utilised in this initial investigation, as well as examining in more detail the implications for the entire biophysical and management systems of farms. At a minimum this would require modelling of whole-farm cash flows. More detailed knowledge would be gained from incorporation of phase farming element into a range of farm-systems models that are currently used for both economic and agronomic purposes.

Profitability is not, however, sufficient in itself to ensure adoption. The following requirements must also be met:

- provision of individual farmers with information to enable them to assess whether the rotation is in fact more profitable (or more desirable) than current practice;
- overcoming uncertainty about the profitability (or desirability) of the rotation;
- determining how the innovative rotation can best be incorporated into the existing farming system; and
- overcoming initial technical problems associated with the establishment, maintenance and harvesting of the tree rotation.

In order to meet conditions for adoption of a tree phase, a research project should:

- demonstrate a need, or preferably respond to an expressed need, for the innovation in terms of the objectives of individual farmers; and
- demonstrate, preferably in on-farm situations, that the innovation can make an observable difference in the ability of individual farmers to meet their objectives.

To achieve this it will be necessary (but not necessarily sufficient) to incorporate the following objectives into any research project.

Establish an understanding of farmers' needs and concerns.

A project should involve extensive consultation with farmers in the beginning stages of the project so that a clear understanding can be gained of farmers' perceptions of their needs. This understanding should then guide the information that needs to be obtained from the research project, and the messages that will be delivered to raise awareness that the system is potentially relevant.

This consultation should continue throughout the project. It may, for example, be possible to work closely (i.e. achieve the active participation) of a number of catchment groups. This should enable the project to assess and address issues of concern to farmers. For example, farming systems based on trees or shrubs are usually characterised by high up-front costs, and benefits that occur some time in the future. Farmers' levels of concern about this, and other possible issues, need to be assessed and addressed during any research project.

Address issues related to learning about the benefits of the system.

A research project should generate information that is useful to farmers in assessing the desirability of the innovation and in generating valid perceptions of the innovation. Observability of the research is critical in this regard. Trials should be located in areas that are as representative of, and as close as possible to, the different areas in which the rotation may be applicable. Regular field days should be an integral part of any project.

The project should endeavour to establish a clear framework for compiling and communicating information that will enable farmers to assess the benefits of the rotation as quickly as possible. Cause and effect relationships need to be linked as closely as possible, as uncertainty about the effects of an innovation, such as the environmental benefits of a tree phase, is an inherent problem. A clear framework will allow farmers to assess the innovation benefits in their individual situations. Information should be put in context of farmers' already identified needs and concerns.

Address issues related to maintenance of the rotation.

Data and information on possible problems with the innovation should be made available and discussed with farmers. Problems associated with the establishment and maintenance of the rotation, and its incorporation within existing farming systems, should be pursued with active farmer involvement. Farmers often fail to establish a first try of a new system successfully, and the reasons for any such failure should be readily identifiable.

Address issues related to the profitability of the rotation

If the relative profitability of the rotation is questionable then all ways of addressing this problem during a research project should be pursued. This would include addressing the problem associated with the up-front costs and delayed benefits of the rotation and investigating possible institutional changes that will make the rotation more profitable.

7. Discussion and Conclusions

Richard Harper, Tom Hatton and Stuart Crombie

7.1 Preamble

Specific discussion and recommendations for future work are contained in the chapters on biophysical simulation (Ch. 4), potential impact on soil biological fertility (Ch. 5) and economic feasibility (Ch. 6). In this Chapter we will discuss the overall ramifications of our analysis and make some general recommendations. At the outset we must re-emphasise that much of our analysis has proceeded with a lack of real data and the assumptions of a host of factors such as growth rates and depth of rooting of trees may or may not be reflected under real conditions.

Despite this, the biophysical analysis suggests that in areas with deep, root penetratable regolith, phase farming with trees is quite likely to reduce recharge under dryland agriculture and provide storage for out-of-growing season rainfall while allowing the continuation of dryland farming. It must therefore be considered a strong candidate technique for overcoming salinity problems and ensuring the sustainability of dryland farming systems. To reiterate from §1.1, these systems are under severe threat from salinization, over broad areas and there is a strong imperative for action. Hydrological benefits are likely to be further enhanced by improved soil conditions that will lead to more sustainable long-term land use (§5.1).

PFT is marginally suitable or not suitable for other hydrological situations, such as deep sandy soils or soils with 1 m of sand overlying clay, which are freely drained or are connected to either fresh or saline water tables. In each of these situations, although recharge is controlled under the trees, recharge rapidly (1-5 years) returns to the pre-tree situation on their removal and reversion to agriculture. In §7.5 we will describe how these differences in hydrological response to PFT may be used in a whole-farm context

A major problem for adoption, however, is clear from the economic analysis (§6.2.3) where the system is not profitable in 300-400 mm rainfall regions if considered in terms of gross-margins. Where does this leave us in terms of progressing the PFT concept?

In this section we will argue that there are compelling reasons to proceed with the PFT concept, despite its current marginal profitability. These include:

- the potential to improve the profitability of the PFT system,
- the need to bring the value of land conservation to account,
- more speculatively, the possibility of future changes in the farming operating and legislative framework.

We contend that it is essential that feasible technical solutions are ready for implementation and that PFT is a strong contender in that category.

7.2 Modifying the profitability of PFT

The economic analysis suggests that although the system is currently unprofitable that profitability may be within reach. In the 300 and 400 mm rainfall zones we have assumed yields of 5 t/ha and 10 t/ha, respectively, after 6 years (Table 6). The analysis by Challen (Table 8) also suggests that the system would be profitable in its own right with total wood yields after 6 years of 14 t/ha (~25 m^3/ha) and 20 t/ha (~36 m^3/ha) at 300 mm and 400 mm annual rainfall, respectively. We believe that such yields and stand alone profitability are within reach, albeit with an assumption of 20 km transport to a processing plant.

Options to increase profitability by decreasing the costs of growing and harvesting the trees appear limited given that with direct seeding costs are comparable to normal crop establishment and harvesting is also a low-cost operation. The best option for profitability is to increase yields, or the value of the products obtained. We have intentionally used a product with a moderate return (*Eucalyptus globulus* for pulp-wood), as a ready market for this material already exists. Other, more valuable species may be developed in the future as a result of current investigations for commercial low-rainfall zone forestry species. It may be possible to obtain multiple products from a particular species – for example, oil from the leaves, tannin from the bark and biomass for energy production from the stems.

7.3 Bringing land and nature conservation values to account

A real problem confronting the economic analysis has been the difficulty in bringing to account both the value of the land that can be saved from destruction by overcoming salinity, and other off-site benefits such as the retention of natural flora, wildlife habitat, water resource quality and rural infrastructure. As Challen describes in §6.2.3. salinity and the emergence of herbicide resistance are the two major threats to the sustainability of continuous cropping. The need to overcome these problems may provide landholder's an incentive to subsidise the PFT system, perhaps considering it as a capital improvement of the land, or a vital component of cropping systems.

Economic modelling of the potential profitability outcomes over more than one PFT/cropping cycle needs to be improved. Values of soil improvement from the tree phase (i.e. increased soil organic matter, improved soil biota, cation cycling) are unlikely to be available for several years. Accordingly, economic models will need to use "best bet" values in sensitivity analyses. The simple analysis in this report needs to be improved to include a greater range of product growth rates and values, distances to markets and soil conservation benefits. The model should also include estimates for values for different land types from those at little risk such as deep, well drained sands, through slow draining duplex profiles recharging locally to high risk discharge zones.

We suggest that if market based assessments are made of technical solutions to natural resource problems a framework should be used that brings the value of the natural resource base to account. Developing such a framework appears to be a priority for research.

7.4 Future changes in the operating environment

The economic analysis applies to the current operating environment. Future changes in the operating or legislative frameworks are speculative but could include:

- the emergence of new industries such as bio-energy or the identification of high value timber products which can be obtained from very young material,
- changes in legislation which make low rainfall farm forestry more profitable. For example bio-energy plantings in Minnesota increased after a legislative requirement that a proportion of electricity be generated from renewable sources (Kroll and Downing 1995; Kemp n.d.),
- government subsidies for salinity control, with favour tree plantings,
- carbon credits which are highly prospective source of income for more traditional farm forestry (Shea 1998),
- external pressure on operating practices such that access of farm products to particular markets depends on meeting sustainability criteria such as outlined under the ISO 14000 series (Baker and McKiel 1997),

- changes in the regulatory framework, where it may be mandated that farming systems operate sustainably.

7.5 Better targeting of PFT

Profitability will also be improved by using different strategies according to a site's soil and hydrological conditions. A major outcome of the biophysical analysis is the large differences in response to the PFT system with different site conditions. In §4.3 it can be seen that the time for recharge to return to pre-tree conditions, after a tree phase, varies with different soil/hydrological situations. It is feasible that these different situations can be mapped and the PFT treatment applied to specific sites only, or the length of rotation modified. This outcome differs from our expectation in §2.1, where we suggested that little site characterization would be required.

7.5.1 Areas suitable for PFT

Phase farming with trees appears to be most suitable for areas with a deep regolith (1m sand + 9 m of clay), that is penetratable by tree roots. Here watertable recharge recommenced at 10 years after tree harvest and took 17 years to re-establish peak rates of around 67 mm/year. Thus, it may be possible to get zero recharge for a system with 5 years of trees and 10 years of crop. Much of south-western Australia is covered with such a deep regolith (Churchward and Gunn 1983).

In lower rainfall areas, however, tree roots may not be able to penetrate the full depth of the soil due to barriers to roots such as high concentrations of salt, water tables, extremes of pH or the presence of hardpans. Determining the likely exploitation of these sub-soils by roots is a priority for research for any form of tree establishment in these areas.

7.5.2 Areas unsuitable for PFT

Recharge from a deep sandy soil at Merredin returned 100 mm/year, equal to that under crops before trees were planted, within 3 years of removing the trees. Such sites are also often highly wind erodible (Harper *et al.* in review) and poorly productive to agriculture. Accordingly, we suggest that these areas are unsuitable for PFT and trees should be established in these areas on a permanent basis. Passioura and Ridley (1998) also suggest that similar sites be withdrawn from conventional agriculture.

Similar rapid increases in recharge after tree removal also occur on the sites with 1 m of sand overlying 2 m of clay without a water table (5 years) and with a fresh water table (1 year). This is consistent with Raper's (1997) contention that the effectiveness of agroforestry plantings on such sites depended on the connection between local and regional water systems. Again we suggest permanent tree or other perennial plantings on these sites.

The modelling for sites with a saline water table at 2 m suggested the accumulation of salt in the soil profile, and a long period for leaching to adequately remove enough salt to allow another rotation. Stolte *et al.* (1997) suggested a similar outcome for trees overlying a saline water table near Narrogin, Western Australia.

Other areas, not considered in the biophysical analysis, are unsuitable for trees due to soil limitations that inhibit root penetration such as very shallow depths to basement rock or high salt concentrations (Harper *et al.* 1998).

7.5.3 Areas where PFT will be required at lengthy intervals

We suggest that in those areas of the landscape with very low rates of recharge (<1 mm/year) such as the clayey soils at Merredin and Walpeup, that trees will only be required at lengthy intervals, of many decades.

7.6 What we don't know

This study was a simulation using best possible data. The fact remains however that early tree performance in terms of growth, rooting and recharge control is poorly understood in the <600 mm rainfall zone.

This scoping study has indicated several areas where research needs to be undertaken, most of which are focused on resolving whether the basic premise of our proposal—water removal to depths of 10 m over wide areas of low rainfall—is achievable in 3-5 years using trees.

- The hydrological modelling presented here suggests that with readily penetrable soils PFT can achieve the desired aims of stopping additional recharge and depleting water in unsaturated stores. However, the root penetrability of soils in the target zone is unknown. Understanding the interaction between the roots of potential PFT species, sub–soil properties and watertables is thus crucial.
- Actual growth rates over the first 3–5 years (i.e. the likely length of a PFT rotation) need to be determined for different species and related to variations in climatic and soil/hydrological conditions. This determination should include above/below ground productivity and identify the harvest index for stems, bark, leaves and other identifiable products.
- Determine whether growth, and water use, can be enhanced through management inputs (fertilizers, stocking) to shorten the PTF phase.
- Optimize the rotation length of the tree and crop components for different sites
- Comparison of water-use, leaf area, rooting depth and system costs of PFT with phase-farming with lucerne or tagasaste.
- Low impact and cheap silvicultural systems need to be developed. Harvesters for oil mallees already being developed are likely to be easily modified for PFT harvesting. However, direct seeding needs to be developed into a reliable system. In particular, the species that give good establishment and their planting requirements (e.g. depth, soil moisture and temperature regimes and weed control) need to be identified.
- Comparative performance of small trees established by direct seeding or from nursery seedling planted into sites of differing preparation intensity needs to be determined

As described earlier potential tree based enterprises for the lower rainfall zone, are being considered in a recently commissioned project.

7.7 Conclusion

Despite the PFT systems' current marginal productivity we suggest that it is a promising candidate for the development of sustainable agricultural systems in the <600mm zone across southern Australia. We are optimistic that applied research can increase the profitability and identify the situations to which it is most suited.

Considerable progress in establishment techniques, product definition and economic modelling could be made in 3-4 years. Some data on likely productivities from existing plantings of various species to 5 years of age could be obtained from existing plantings in the same time.

8. Appendices

8.1 Appendix 1. Scoping Study: Biophysical Modelling

(Full report available from our website www.rirdc.gov.au/reports/Index.htm#Agroforestry_Farm)

Appendix One Phase Farming With Trees:

Biophysical Modelling

A report for the RIRDC/LWRRDC/FWPRDC
Joint Venture Agroforestry Program

by Warrick R. Dawes

Executive Summary

Phase Farming with Trees (PFT) is a system that integrates tree growing rotations directly into current cropping sequence systems. A variety of climate and soil type combinations were examined for the performance of long term PFTin terms of wood production and recharge control.

A large available root zone contributes to stability in long term leaf area of trees while compromising the growth potential. It also maximizes recharge control by all vegetation types. Shallow root zones promote growth but are not drought tolerant and suffer greatly with very variable annual rainfall.

Groundwater as a water resource greatly enhances growth of trees, and crops and grass if it is shallow enough. Trees will use up this extra water only to the point where water availability is not restricting growth. Local lowering of water levels is achievable using vegetation with deep roots and perennial activity. Inefficient or shallow rooted vegetation will allow recharge to local groundwater that may have deleterious local and offsite impacts.

Saline groundwater will restrict growth of vegetation with roots deep enough to access and concentrate the water. Leaching appears to be much slower than accumulation, so systems with access to saline groundwater must be managed more carefully than other systems.

8.2 Appendix 2: Example Cashflow Budgets

This appendix contains cashflow budgets for phase-farming and the benchmark “standard agricultural rotation”. The examples provided are specific for the 400 mm rainfall zone.

Standard Agricultural Rotation

L,W,W rotation (continuous cropping)

Input parameters

			Rainfall Zone	
Agriculture Phase		Low	Medium	High
Crop gross margins				
Lupins after trees	$/ha	**-15**	**26**	**48**
Wheat after lupins	$/ha	**138**	**207**	**234**
Wheat after wheat	$/ha	**111**	**180**	**207**
Lupins after wheat	$/ha	**5**	**46**	**68**
Grazing gross margin				
1st yr out of crop	$/ha	**12**	**20**	**50**
subsequent years	$/ha	**20**	**50**	**76**
Trees Phase				
Yr 1 estab. costs	$/ha	**175**	**175**	**175**
Yr 2 weed control	$/ha	**20**	**20**	**20**
Rehab costs for following crop	$/ha	**70**	**70**	**70**
Yield	t/ha	**5**	**10**	**25**
Price net of tsp't & hvst costs	$/t	**57**	**57**	**57**
Gross revenue	$/ha	285	570	1425
Discount Rate (all zones)	**5%**			

Cashflow Budget

Rainfall Zone: **medium**

NPV ($/ha): **1052**

		CROPPING	GRAZING	Net annual	Cumulative	
Year	ENTERPRISE	Gross marg.	Gross marg.	cashflow	cashflow	NPV ($/ha)
1	Lupins	46	0	46	46	46
2	Wheat	207	0	207	253	241
3	Wheat	180	0	180	433	393
4	Lupins	46	0	46	479	414
5	Wheat	207	0	207	686	564
6	Wheat	180	0	180	866	679
7	Lupins	46	0	46	912	681
8	Wheat	207	0	207	1119	795
9	Wheat	180	0	180	1299	879
10	Lupins	46	0	46	1345	867
11	Wheat	207	0	207	1552	953
12	Wheat	180	0	180	1732	1013
13	Lupins	46	0	46	1778	990
14	Wheat	207	0	207	1985	1053
15	Wheat	180	0	180	2165	1093
16	Lupins	46	0	46	2211	1064
17	Wheat	207	0	207	2418	1108
18	Wheat	180	0	180	2598	1133
19	Lupins	46	0	46	2644	1099
20	Wheat	207	0	207	2851	1128
21	Wheat	180	0	180	3031	1142
22	Lupins	46	0	46	3077	1104
23	Wheat	207	0	207	3284	1123
24	Wheat	180	0	180	3464	1128
25	Lupins	46	0	46	3510	1088
26	Wheat	207	0	207	3717	1098
27	Wheat	180	0	180	3897	1096
28	Lupins	46	0	46	3943	1056
29	Wheat	207	0	207	4150	1059
30	Wheat	180	0	180	4330	1052

Direct Seed Bluegum Rotation

(6 yrs of Trees followed by 9 yrs of LWW) repeated 2x

Input parameters

		Rainfall Zone		
Agriculture Phase		Low	Medium	High
Crop gross margins				
Lupins after trees	$/ha	**-15**	**26**	**48**
Wheat after lupins	$/ha	**138**	**207**	**234**
Wheat after wheat	$/ha	**111**	**180**	**207**
Lupins after wheat	$/ha	**5**	**46**	**68**
Grazing gross margin				
1st yr out of crop	$/ha	**12**	**20**	**50**
subsequent years	$/ha	**20**	**50**	**76**
Trees Phase				
Yr 1 estab. costs	$/ha	**175**	**175**	**175**
Yr 2 weed control	$/ha	**20**	**20**	**20**
Rehab costs for following crop	$/ha	**70**	**70**	**70**
Yield	t/ha	**5**	**10**	**25**
Price net of tsp't & hvst costs	$/t	**57**	**57**	**57**
Gross revenue	$/ha	285	570	1425
Discount Rate (all zones)	**5%**			

Cashflow Budget

Rainfall Zone: **medium**

NPV ($/ha): **770**

		TREES		CROPPING	GRAZING	Net annual	Cumulative	
Year	ENTERPRISE	Costs	Sales	Gross marg.	Gross marg.	Cashflow	cashflow	NPV ($/ha)
1	Trees	175	0	0	0	-175	-175	-175
2	Trees	20	0	0	0	-20	-195	-186
3	Trees	0	0	0	0	0	-195	-177
4	Trees	0	0	0	0	0	-195	-168
5	Trees	0	0	0	0	0	-195	-160
6	Trees	70	570	0	0	500	305	239
7	Lupins	0	0	26	0	26	331	247
8	Wheat	0	0	207	0	207	538	382
9	Wheat	0	0	180	0	180	718	486
10	Lupins	0	0	46	0	46	764	492
11	Wheat	0	0	207	0	207	971	596
12	Wheat	0	0	180	0	180	1151	673
13	Lupins	0	0	46	0	46	1197	667
14	Wheat	0	0	207	0	207	1404	745
15	Wheat	0	0	180	0	180	1584	800
16	Trees	175	0	0	0	-175	1409	678
17	Trees	20	0	0	0	-20	1389	636
18	Trees	0	0	0	0	0	1389	606
19	Trees	0	0	0	0	0	1389	577
20	Trees	0	0	0	0	0	1389	550
21	Trees	70	570	0	0	500	1889	712
22	Lupins	0	0	26	0	26	1915	687
23	Wheat	0	0	207	0	207	2122	725
24	Wheat	0	0	180	0	180	2302	749
25	Lupins	0	0	46	0	46	2348	728
26	Wheat	0	0	207	0	207	2555	754
27	Wheat	0	0	180	0	180	2735	769
28	Lupins	0	0	46	0	46	2781	745
29	Wheat	0	0	207	0	207	2988	762
30	Wheat	0	0	180	0	180	3168	770

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