



An Australian Government Initiative



Quantifying the tradeoff between tree and crop productivity on farms

**A report for the RIRDC/Land & Water Australia/FWPRDC
Joint Venture Agroforestry Program**

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Foreword

The Agricultural Production Systems Simulator (APSIM) is a computer model which simulates cropping systems, to help in farm decision-making. This project added to APSIM the capability to simulate complex agroforestry systems, and used this to assess the productivity and risk of investment in commercial agroforestry on grain farms in Australia's medium to low rainfall regions. The project also measured tree-crop competition to provide input data for the model, as there were few data available.

This report details the capability of the APSIM modelling framework to simulate two-dimensional agroforestry systems; that is, systems which simulate many points in a crop or tree area and the interaction between adjacent crops. This new APSIM capability was used in preliminary economic assessments of the feasibility of planting tree windbreaks at selected sites in Australia. These and other simulations were also used interactively with landholders to allow them to assess agroforestry options for their own farms.

This project has helped create a tool that can be readily applied in other locations and landholder circumstances. It is hoped that this exciting capability will be made available to landholders interested in agroforestry investment options. The report will help researchers and extension to assess the productivity and risk of investment in commercial agroforestry in Australia's medium to low rainfall regions.

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This report is an addition to RIRDC's diverse range of over 1700 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

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Authors' Disclaimer

This report has been prepared to demonstrate the new capabilities of APSIM to address agroforestry systems. While care has been taken in preparation of this report and its encompassing analyses, no responsibility will be taken by the authors for omissions or inaccuracies, or for the use of any information by any other party. It is recommended that those interested in the reported systems analyses undertake their own investigations on which commercial decisions may be based.

Abbreviations

A30	Area at basal height (30cm)
ABH	Area at breast height
APSIM	Agricultural Production Systems Simulator
APSRU	Agricultural Production Systems Research Unit
BD	Bulk Density (g/mm^3)
BJFG	Brigalow Jimbour Floodplains Group
DUL	Soil water content at the drained upper limit ($\text{mm}^3 \text{ mm}^{-3}$)
DBH	Diameter at breast height
GM	Gross Margin
MCA	Michael Castor and Associates
NPV	Net Present Value (\$/ha)
PAR	Photosynthetically Active Radiation
PAW	Plant available water content of soils (mm)
QFRI	Queensland Forestry Research Institute (now QDPI&F Horticulture and Forestry Science)
WIFAD	What IF Analysis & Discussion session

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Executive Summary

What the report is about

The Agricultural Production Systems Simulator (APSIM) is a computer modelling tool which simulates agricultural cropping systems, to help in farm management and assessment of risk. In this report, APSIM is used to quantify the trade-off between tree belts and crop productivity on farms in the medium to low rainfall areas of Australia. The analyses are based on windbreaks and mallee belts and their interaction with crops at the paddock scale. The report also details the emergent capability within the APSIM framework to simulate two-dimensional agroforestry systems; that is, systems which can simulate many points in a crop or tree area and the interaction between adjacent crops.

Who the report is targeted at?

This report is targeted at researchers and agribusiness advisory services with an interest in quantitatively assessing the viability of integrated agroforestry and crop production enterprises. The modelling tool APSIM can also be used to discuss outputs and agroforestry scenarios with landholders.

Background

The long-term benefits of retaining or planting trees on farms to rehabilitate land and protect the soil from erosion or salinity problems have to be traded off against the impact of tree competition on commercial crops, especially in the medium to low rainfall regions of Australia. The incentive to plant trees will be higher where tree competition can be offset by economic returns gained from farm forestry products and by the beneficial impacts of tree windbreaks on crop yields and resource sustainability.

APSIM has a well-established capability to simulate cropping systems. It also has process-level modules for tree, crop, soil and atmospheric components and this provides considerable flexibility for specifying interactions between the tree and crop components of an agroforestry system. While several components of APSIM's capability for simulating agroforestry systems have been previously tested e.g. for tree growth, tree water balance and windbreak impacts, this project was the first to compile and test APSIM's capability to simulate an integrated agroforestry system. It should be noted, however, that a significant limitation to achieving this objective has been the lack of comprehensive measured data on tree-crop interactions in agroforestry systems in Australia.

Aims/Objectives

The two main objectives of this project were to:

- develop the capability within APSIM to simulate an integrated tree-annual crop agroforestry system, and
- apply the model to assess the productivity and risk of commercial agroforestry investments on grain farms in the medium to low rainfall regions of Australia.

An additional objective was to use the new capability to design and implement activities that allow individual landholders to explore the viability of agroforestry investments for their own farms.

Methods used

Data on tree-crop interactions for several sites in southeast Queensland were collected and APSIM was configured to simulate a conceptual multi-point agroforestry system consisting of a tree belt along the border of a crop field.

Simulations were conducted for four tree-crop systems around Australia, and the predictions were tested against measured data from the sites. The detailed APSIM-Forest module was used to dynamically calculate effects on a neighbouring crop, on a daily basis – such effects included both windbreak and tree competition impacts (soil, water and nutrients). Case studies for a range of tree-crop systems were then assessed over the historic climate record for wood production, crop yield, profitability and deep drainage.

Following the model validation, APSIM agroforestry simulations were used in interactive discussions with a number of landholders and their advisers, to discuss the viability of paddock-scale agroforestry investments.

Results/Key Findings

The achievements of this project included:

- The specification of APSIM multi-point simulations for the conceptual agroforestry system consisting of belts of trees established along the borders of cropping paddocks. This system incorporated the simulation of the differential growth of inner and edge trees, as well as crop yield losses due to tree competition, and yield increases due to windbreak protection.
- The initial parameterisation of the module ‘APSIM-Forest’ with the APSIM computer tool, to enable the dynamic simulation of the growth of several tree species, including *Eucalyptus argophloia* (Chinchilla white gum), *Eucalyptus globulus* and *Pinus pinaster*, and the simulation of steady-state growth of *Acacia harpophylla* (brigalow). The simulation of tree growth and productivity was tested against limited datasets.
- The testing of APSIM multi-point simulations against measured data for four tree-crop systems located in Queensland and WA. Simulations performed satisfactorily against limited data, but there were significant deficiencies in the data available for model parameterisation and testing.
- Demonstration of the ready capability of APSIM to accommodate alternative agroforestry systems through a case study analysis of a hypothetical short-duration “oil mallee” system in WA. The simulated productivity of oil mallee hedges was consistent with values reported elsewhere and suggested that short-duration trees grown within agroforestry systems are at least as profitable as traditional cropping systems at some locations.

The economic scenario analysis undertaken using APSIM simulations for five sites in northeast Australia (Emerald, St George, Roma, Dalby and Moree) indicated that at the likely prices and costs forecast for timber production in 2003 (\$60/m³ and \$2025/ha), the economics of *E. argophloia* windbreaks would be unattractive at all sites. However such agroforestry systems began to equate economically with the current practice of dryland wheat production when establishment costs were significantly reduced and timber prices were increased. Under improved economic scenarios, the most favourable location for the simulated agroforestry system was Emerald in Central Queensland and the least favourable was Moree in northern NSW. For farmers to plant long rotation *E. argophloia* windbreaks on their dryland wheat paddocks, the balance between timber price and established costs would need to improve significantly, or they would have to value windbreaks in more than economic terms, e.g. for their aesthetic value or for their environmental impacts, such as in reducing drainage or soil erosion. Whole farm benefits beyond the paddock were not simulated.

Interactive discussions with landholders were held to explore their land management interests. This discussion included planting of windbreaks and retention of remnant vegetation on cropping lands. Almost all scenarios showed inferior economic performance of long rotation agroforestry systems relative to standard cropping systems at the paddock scale. However, these analyses did not account for the environmental and aesthetic benefits highly valued by these landholders, nor did they explore alternative short rotation agroforestry options which may be more viable.

Implications for relevant stakeholders

Investing in long rotation commercial agroforestry (e.g. for sawlogs) is risky, especially in the medium to low rainfall regions of Australia. The tradeoffs involved with such a changed farming system are difficult to determine and should be further researched. The ability to combine economic analyses with APSIM's simulation capabilities provides a powerful tool for evaluating various agroforestry options. This tool can be employed for simulating tree-crop interactions for a range of site, soil, climate, crop or windbreak designs.

While APSIM is available for download from www.apsim.info, its agroforestry simulation capabilities would not be readily useable without access to expert support. One future option is to increase the availability of APSIM for use by individual landholders so that they can quantitatively assess the viability of integrating agroforestry and crop production on their own farms. Current initiatives to use APSIM within established commercial advisory services (www.yieldprophet.com.au) and in public extension activities will potentially facilitate the extension of this new agroforestry capability to landholders around Australia.

Recommendations

There remain significant barriers to using APSIM as a routine advisory tool on agroforestry options for landholders. While the APSIM multi-point framework has been developed, its parameterisation and testing is troublesome given the lack of data on the growth parameters of suitable tree species and on the interactions between trees and adjacent crops. An important imperative therefore is to invest in obtaining such data and in testing APSIM against actual agroforestry systems and in a greater range of environments. It is the intention of the Agricultural Production Systems Research Unit (APSRU), a joint venture between several Queensland agencies including CSIRO, to continue the development, testing, and application of this new capability.

This model could be used in the future with new data on tree-crop interactions and environmental values, to evaluate new farm forestry and agroforestry systems at the paddock scale.

1. Introduction

1.1 Background

Salinity is one of the greatest challenges to dryland farming systems in Australia (NLWRA, 2000). As a consequence there is considerable interest in Australia for capturing the expected long-term benefits of retaining or planting trees on farms to rehabilitate land and protect the soil from erosion or salinity problems (Prinsley, 1992). However, trees compete with commercial crops both for land area and resources, especially in the medium to low rainfall regions of Australia. The incentive for landholders to plant trees will be higher where crop losses can be offset by the beneficial impacts of tree windbreaks on crop yields and resource sustainability and by the economic returns gained from farm forestry products. A significant problem in encouraging landholders to act on this incentive is that it is difficult to quantitatively assess this trade off between crop and tree productivity for different regions and cropping systems, and almost impossible for landholders to do so in the context of their own farm.

A number of recent research developments now provide the opportunity to quantify the trade off between tree and crop productivity on farms by using systems simulation in a manner relevant to commercial farming practice. Firstly, the beneficial effect of tree windbreaks has been quantified and the ability to predict such effects has been developed (Cleugh et al., 2002; Meinke et al., 2002). Secondly, the ability to predict tree productivity has progressed to a point that is now comparable to current crop simulation models (Huth et al., 2001). And thirdly, considerable evidence now exists in Australia that simulation models are regarded by farmers and consultants as viable and relevant tools in the management of commercial farming enterprises (McCown et al., 1998; Carberry et al., 2002b). Many farmers and several agribusiness firms regularly use a model to quantitatively assess alternative cropping strategies in the context of their own farm or business (Hochman et al., 2000).

There is increasing public pressure for more trees on farmlands, driven mainly by the land conservation and biodiversity benefits that accrue from planting trees; however, the cost of achieving this falls largely on the farming community. Convincing evidence to support an economic benefit to farm productivity from retaining and/or planting trees on farms would greatly enhance the incentive for increasing the farmland under trees. Thus, the primary beneficiaries of a capability to explore relevant agroforestry design options are landholders who may be better able to assess the economic benefits that they can expect from integration of agroforestry enterprises into dryland cropping systems. Other beneficiaries from enhanced landholder investment in commercial agroforestry include the Australian timber industry through increased production diversity and the broader community through improved land conservation.

This project used a computer simulation model to assess the productivity and risk of commercial agroforestry investment in grain-growing areas of low to medium rainfall northern Australia. APSIM, the Agricultural Production Systems Simulator, is nationally and internationally recognised as a highly advanced cropping system simulator. APSIM simulates the growth of crops and cropping sequences for specific locations. It contains a number of plant modules (currently 20) with additional modules for water, soil nitrogen, soil organic matter, soil phosphorous, erosion and land management. It includes the capability to interface with seasonal climate forecasts based on the state of the ENSO (El Nino Southern Oscillation) system and has recently been extended to deal with crop-weed interactions¹. This project extended the capability to deal with agroforestry systems.

¹ <http://www.apsru.gov.au/apsru/AboutUs/Capability%20statement%20V1.11.pdf>

1.2 Objectives

To enable landholders to assess the productivity and risk of commercial agroforestry investment on grain farms in Australia's medium to low rainfall regions, this project aimed to:

- i. add the capability to simulate tree-crop competition for light, water and nutrients to APSIM's existing capacity to simulate the impact of windbreaks on crop production and its emerging capacity to simulate tree productivity
- ii. quantify the potential benefits and risks of planting trees in association with cropping land, through an economic analysis of associated crop and tree yields predicted using the historical climate record at selected sites
- iii. with landholders, extension officers and researchers, use this new capability to design and implement action learning activities that allow individual landholders to explore the viability of agroforestry investments for their own farms.

1.3 Project outline

Data collection

A key realisation from this project was the almost complete lack of comprehensive datasets on tree-crop interactions in Australia. At the project's inception it was envisaged that data sources, including the windbreak experimental sites at Esperance (Sudmeyer, 2002) and other related projects, could provide sufficient agroforestry data to enable model parameterisation for such systems. This was not the case: most existing datasets were not yet available or were deficient in some aspect of their tree, crop or soil data. Several useful studies were underway or nearing completion but timeframes for availability of relevant data did not match the requirements for this project.

Accordingly, the project invested significant time and resources into collecting data on tree and crop interactions at select sites in southern Queensland. These data are reported in Chapter 2.

APSIM development and testing

APSIM has a well-established capability to simulate cropping systems in Australia. The capability to simulate tree growth and productivity was added in 2001 by incorporating the APSIM-Forest module within its library of plant models. This project reports the capability within the APSIM simulation framework to simulate two-dimensional agroforestry systems. These are systems which can simulate many points in a crop or tree area and the interaction between adjacent crops.

While the testing of APSIM's ability to simulate agroforestry systems is limited by the scarcity of measured data on tree-crop interactions, Chapter 3 does provide some evidence that APSIM can represent real agroforestry systems.

Simulation and economic analyses

In Chapter 4, APSIM is run for a range of tree-crop configurations across long term historical climate records for select medium to low rainfall regions of northeast Australia. Predicted wood production and crop yields (incorporating the aggregate effect of crop yield loss due to tree competition offset by yield increase due to windbreaks) are used in economic analyses to assess profitability and risk of alternative system configurations.

The case studies presented in Chapter 4 examine the production, drainage and economic consequences for planting *Eucalyptus argophloia* (Chinchilla white gum) as windbreaks in northeast Australia.

Action learning activities

Our experience has demonstrated that simulation can provide a powerful learning tool in assisting farm managers to explore their farming system. As part of this project, a number of pilot “What IF Analysis & Discussion” sessions (WIFADs) using APSIM were run with landholders and their advisers to enable the viability of agroforestry investments or retention of existing shadelines to be explored in the context of an individual’s own farm. These WIFAD sessions were conducted in the northern cropping region. Chapter 5 reports the results and reactions from two of these interactions.

Implications and recommendations

This project developed a capability to predict the expected outcomes from agroforestry investments on farms in the medium to low rainfall regions of Australia. Current deficiencies in the available measured data and in the testing of APSIM suggest that, for this capability to be widely used, there is a requirement to continue its development and application. Chapter 6 provides recommendations for future work in this area.

2. Data collection on tree-crop interactions

The application of the Agricultural Production Systems Simulator (APSIM) to simulating agroforestry systems was a key objective of this project. APSIM is a modelling environment that can simulate the growth of a range of crops in response to a variety of management practices, crop mixtures and rotation sequences (McCown et al., 1996). In 2001, the APSIM framework was expanded to incorporate forestry systems (Huth et al., 2001) and, while Wright et al. (1997) introduced a multi-point capability within the APSIM framework, this project represents its first real application. A detailed description on how APSIM simulates two-dimensional agroforestry systems is given in Section 3.2 of this report.

The specification and application of APSIM requires access to comprehensive data on the climate, crop, soil and management parameters relevant to the system being simulated. However, early in the project's life it was realised that available data on tree-crop interactions was a significant limitation to achieving project goals. Such scarcity of existing data restricted the ability to develop and use the APSIM simulation capability to predict outcomes for a range of agroforestry systems. This was particularly so for the southeast Queensland region where the participatory research component of this project was to be completed (see Section 5). Consequently, a series of small measurement studies was undertaken on selected farms in this region where tree-crop interactions were evident. These data were also augmented with measurements from other nearby experimental sites with planted tree species.

The next section provides a brief description of the minimum data requirements for configuring and running APSIM for both simple cropping systems and more complex agroforestry systems. This is followed by a report on data collected, as part of this project, on tree and crop interactions at selected sites in southern Queensland. These data are subsequently employed in Section 3.3 to test APSIM simulations on tree-crop interactions.

2.1 Data requirements for configuring and applying the APSIM systems model

General parameters

The APSIM modelling framework can be used to configure simple or complex descriptions of systems. Most observations on a system can be used either directly or indirectly in parameterising APSIM or in checking its performance. Table 2.1 lists the major data requirements for APSIM and attributes a priority to each (1 = high priority, 5 = low priority). These recommendations serve simply as a guideline as relative importance may change according to the nature of the simulation being undertaken.

As a brief guide, however, the unavailability of data with a priority of 1 or 2 may cause high uncertainty in parameterisation. Data with priorities of 4 or 5, while proving beneficial if available, are not required in most instances.

Table 2.1. Basic data requirements for configuring APSIM for cropping systems.

Data	Units	Comments	Priority (1-5)
<i>Weather Data</i>		Collected daily from weather stations located adjacent to the site of interest	
Maximum Temperature	°C	Can use manual max/min thermometer	1
Minimum Temperature	°C	Can use manual max/min thermometer	1
Rainfall	mm	Rain gauge should be located at site	1
Radiation	MJ/m ²	Can use data from nearby station	3
<i>Soil Water</i>		Soil measurements split into depth increments (commonly 15-30 cm) and for each soil horizon	
Bulk Density	g/mm ³	Measured or calculated from moisture data (on some soils)	3
15 bar moisture content*	mm ³ /mm ³	Measured or can be derived from observed moisture drying patterns if required	2
Drained Upper Limit*	mm ³ /mm ³	Can be derived from observed wetting/drying patterns or from soil physical measurements such as 0.1 bar if required. Ideally, a drainage experiment can be used to measure DUL	2
Saturation *	mm ³ /mm ³	Can be derived from observed wetting/drying patterns or from bulk density if required	2
Site description		Description of soil type, slope, surface conditions etc can be used to determine model parameters for runoff	3
Surface conditions		The presence of residues from a previous crop will affect the water balance	3
Initial Soil Water*	mm ³ /mm ³	Very important measurement if water is limiting. Essential for predicting growth of a single crop when the model is initialised just prior to planting	1
Time course of soil water*	mm ³ /mm ³	Observed soil moisture data is one of the most useful model verification data sources. Note - Intensive measurements through time can be used to derive the inputs above - Measurement method and calibration technique may be useful in quantifying likely magnitude of measurement error	2
Crop water extraction	mm ³ /mm ³	The lower limit of crop water extraction (CLL) is used to specify the absolute water supply of the crop during the simulation. CLL can be derived from observed moisture drying patterns	2
Depth of water extraction	mm	Maximum depths of water extraction can be used to determine water supply and estimate these extraction patterns if required	2
Water Balance Terms	mm	Measurements of individual water balance terms can be used to verify each component of the water balance being simulated - Runoff - Evaporation/Transpiration - Drainage	5 5 5

Data	Units	Comments	Priority (1-5)
<i>Soil Nitrogen</i>		Soil measurements split into depth increments (15-30 cm) and for each soil horizon	
Organic Carbon	%	Note that measurement method needs to be known in order to determine applicability to the model	3
Total Nitrogen	%	Beneficial for specifying nitrogen content of soil organic matter pools can be estimated	4
pH		Mainly important in cases of extreme pH conditions. Measurement technique (pH in water or CaCl ₂) must be noted	5
Initial NO ₃ **	ppm	Important in cases where N is known to be limiting, especially when initialising just prior to planting	2
Initial NH ₄ **	ppm	Only important in cases where nitrogen is known to be limiting and nitrification is inhibited	5
Soil History		The history of site management (with crop yields and grain nitrogen if available) can be used to determine the relative size of soil organic matter pools and overall soil fertility in cases where data are unavailable	3
Time course of soil nitrogen	ppm	N content of the soil after crops assists verification of N supply of the soil. N content of the soil after fallows assist in verification of soil fertility parameterisation and model	3
<i>Crop Management</i>			
Sowing Information		APSIM requires sowing date, species and cultivar. It can also make use of sowing density (preferably plants rather than seeding rate), row spacing and sowing depth	1
Fertiliser Rates		Application dates and amounts of active constituents – N as NO ₃ , NH ₄ or Urea	1
Harvesting		Dates of harvesting are mostly required for multiple season experiments	3
Phenological Observations		Dates of major growth stages such as flowering and maturity are VERY beneficial. Observations for other stages may also prove useful. These are, however, not essential	3
Growth Observations		Measurements of growth and dates of observation are required for verification of the model. The model can be used to compare • weight of individual plant parts • total weight • grain yields (moisture content must be specified) • leaf area • Nitrogen uptake • grain Nitrogen	5 2 1 3 3 4
Other crop management		Dates and information regarding management such as spraying	3
Crop Observations		Dates and information regarding growth of the crop or effects of disease or pests	3

* All volumetric measurements must make note of bulk density used in their calculation

** Sample handling procedures should be noted as they can cause errors in both NO₃ and NH₄.

Additional data requirements for simulating agroforestry systems

The simulation of tree growth and the tree-crop interactions evident in agroforestry systems requires access to data beyond those required for simpler cropping systems. Table 2.2 lists a suggested minimum data set necessary for configuring and testing APSIM in agroforestry systems, again with priority attributes.

Table 2.2. Suggested data required to specify APSIM for agroforestry systems.

Data	Units	Comments	Priority (1-5)
<i>Weather Data</i>		Collected daily	
Vapour Pressure	Pa	Measured, although techniques exist for calculation or infilling from nearby sites	3
Wind run & direction	km/d	Needs to be measured if simulation of windbreak impacts required	2
Pan Evaporation	mm	Measured, although can be calculated from other climate parameters	4
<i>Soil data</i>		APSIM can be specified to use Richards' Equation for simulation of water movement as an alternative approach (especially if dealing with water tables) but it requires additional data	
Soil Hydraulic Conductivity		Measured saturated conductivity, Ks and some observation of field capacity or description of measured K vs ψ (or θ) (i.e. conductivity content vs soil potential)	3
Soil Moisture Characteristic		Description of measured θ vs ψ (i.e. volumetric water content vs soil potential) with information of the measurement technique employed	3
Water table		Depth and salinity of water table	3
<i>Tree data</i>		Needs to be characterised for inner trees and edge trees in order to quantify likely resource use from nearby cropping land	
Wood		Measured branch mass, bark mass, stem wood mass	2
Foliage		Measured live foliage mass, senesced foliage mass, leaf area index, canopy cover, litter fall, leaf fall, bark fall, branch fall	3
Roots		Structural root mass (large roots and tap root or stump), fine to coarse root mass, turnover of fine roots. Observations of extent of rooting into cropping land	4 3
Stand Characteristics		Measured height (used by the model for calculation of aerodynamic resistance to vapour flow and can be used to infer extent of tree roots into cropping land) and population (from effects of management and self-thinning)	1
N content		Tree N content for each biomass pool	4
Optical porosity	%	Can be used to infer the level of shelter provided by the windbreak	4

Data	Units	Comments	Priority (1-5)
<i>Tree Management</i>			
Planting Information		Measured establishment date, species, established population, row configuration, fertiliser application	1
Thinning & pruning		Dates and description of events (including root pruning)	2
Understorey management		Description of understorey composition, growth and management	3
<i>Competition zone</i>		Required to quantify tree-crop interactions in the competition zone (0-3 tree heights from edge of trees)	
Soil water & nutrient		A transect of sampling points at different tree heights perpendicular to the edge of trees for soil water content and N status	2
Crop growth		A transect of sampling points at different tree heights perpendicular to the edge of trees for crop biomass & yield	2
<i>Sheltered zone</i>			
Crop growth		A transect of sampling points at different tree heights (4 – 40) perpendicular to the edge of trees for crop biomass & yield. Effects of crop wind damage should be noted	4
Wind		Total daily wind run for points along a similar transect can be used in specifying the extent of the shelter provided by the trees	5

2.2 Data collection in southeast Queensland

The winter of 2000 in southeast Queensland consisted of extremely dry conditions with clear competition observed between field crops and planted tree belts (mostly Chinchilla white gums, *Eucalyptus argophloia*) or remnant vegetation (brigalow-belah, *Acacia harpophylla*-*Casuarina cristata*) (Figure 2.1). Accordingly, this project took advantage of this opportunity to collect quantitative data on both the extent of the competition zone and the impacts of nearby trees on crop yields. The main purpose of these observations was to gain insight into tree-crop competition in a low/medium rainfall region. Some of the observed data were used to configure and test APSIM for relevant agroforestry systems on farms involved in the participatory research initiatives (Section 5).

Initially, observations and measurements were taken on crop and tree characteristics at twelve sites (Table 2.3). Two of these sites were subsequently selected for more detailed investigation:

- The property “Coorangy”, southwest of Moonie, owned by Geoff and Mary Woods. Most paddocks had remnant brigalow-belah shadelines on their boundaries. This site had previously been measured for impacts of windbreaks by George-Jaeggli et al. (1998).
- The property “Prospect” at Warra, owned by Jeff Bidstrup. A number of paddocks had been planted to *E. argophloia* in 1996 and 1998 in both a north-south and east-west configuration.

At each site, digital photography was used as an efficient means of field sampling, to record site conditions and to calculate tree heights. Digital video was used to assess sites for cover and basal area estimates. The competition zones between trees and various winter and summer crops were measured and photographed. Soils were sampled and characterised for water holding capacity, plant available water and physical composition. At distances measured in tree heights from the edge trees, transects of both crop and soil were sampled for crop biomass and grain yield, and for soil water. Within the tree belts, transects for canopy cover, light transmission, dominant species, diameter at breast height (DBH) and basal diameters were measured. Both edge-affected and “steady state” inner trees within tree belts of varying widths were sampled.



Figure 2.1: Photo showing the impact of remnant Brigalow-Belah on an adjacent crop in the year 2000.

Table 2.3. Description of sites where tree-crop interactions were observed in southeast Queensland.

Site	Latitude	Longitude	Tree species	Growth	Planted /age	Crop
Oakey	27° 30' 5"S	151° 42' 58"E	eucalypt	Planted	< 8 years	Barley
Jondaryan	27° 31' 30"S	151° 31' 23"E	<i>E. argophloia</i>	Planted	< 15 years	Fallow cotton
Jondaryan	27° 25' 55"S	151° 30' 24"E	eucalypts	Planted		Fallow
Chinchilla	26° 52' 32"S	150° 50' 12"E	brigalow	Regrowth		Wheat
Warra	26° 53' 51"S	150° 53' 04"E	<i>E. argophloia</i>	Planted	1996 1998	Wheat, cotton
Warra *Site 2	26° 53.80"S	150° 54.045"E	brigalow-belah	Remnant	Cleared 1940/50	Wheat, cotton
Warra	26° 53' 51"S	150° 53' 04"E	brigalow	Regrowth		Barley
Jimbour	26° 55' 53"S	151° 24' 37"E	eucalypt, <i>Casuarina</i>	Planted & Regrowth		Wheat
Dalby	27° 09' 14"S	151° 23' 13"E	eucalypt	Regrowth		Wheat
Dalby	27° 09' 14"S	151° 23' 13"E	eucalypt	Planted	1996 1998	Wheat
Oakey	27° 15' 51"S	151° 45' 8"E	<i>E. argophloia</i>	Planted	1999	Barley
Kingsthorpe	27° 23' 37"S	151° 46' 22"E	eucalypts	Remnant		Wheat
Moonie *Site 1	28° 08.710"E	149° 52.297"S	brigalow-belah	Remnant	Cleared 1940/50	Wheat, chickpea, fallow
Moonie	28° 08.710"E	149° 52.297"S	eucalypts	Planted		Fallow
Braemar *Site 4	27° 11.294S	150° 47.233E	<i>E. argophloia</i> <i>E. sideroxylon</i>	Planted	1971	Pasture
Tara *Site 5	27° 10.143S	149° 59.697E	<i>E. argophloia</i> <i>C. maculata</i>	Planted	1971, 1981, 1884, 1990, 1998, 2000	Native pasture
Gatton	27° 32.515'S	152° 20.108'E	eucalypt, <i>Casuarina</i>	Planted		Maize

Remnant brigalow-belah shadelines, Moonie, Queensland

On the property “Coorangy”, southwest of Moonie, four paddocks (“Square”, “Triangle”, “Georges” and “Avrdex Alley”) were evaluated over the 2000-2001 cropping seasons for competition effects between remnant brigalow-belah shadelines and a range of field crops (wheat, chickpea, sorghum) and fallows. Paddocks were cleared for both cropping and grazing in the early 1950s. Paddocks sampled for an assessment of windbreak impacts in 1997 (George-Jaeggli et al., 1998) were re-sampled. Soils at the site are deep, grey-brown cracking clays (grey vertosols) locally referred to as Mt. Carmel brigalow soil, with the original vegetation consisting of brigalow (*Acacia harpophylla*), belah (*Casuarina cristata*) and wilga forest (*Geijera latifolia*).

Digital photography

Photos were taken at random locations along remnant tree blocks. A 2 m PVC tube was placed at the tree line to allow calculation of height measurements from the images. Photos of the competition zone, impact on crops and understorey were also taken to aid interpretation of the measured and simulated data. Aerial video photography over field sites was used and evaluated for estimating cover, basal areas, canopy heights and extent of competition zone.

Tree belt transects

Tree blocks were measured for orientation and width. Replicated vertical observations using a mirrored vertical periscope to record branch intercepts were taken at 1 m intervals across a measured transect. A line source PAR meter was used to estimate light transmission at recorded distances along the above transects. PAR readings were taken in open sun at the start and end of each transect to minimise effect of cloud conditions on individual readings. Relative differences were calculated and compared to canopy intercept observations. Random measurements of both vertical interception and light transmission were also taken within a tree block.

Four replicate edge strips of 100 m² were measured for dominant species, DBH and basal diameter (30 cm above ground) and stem areas at both breast and basal height were calculated (Table 2.4). Smaller understorey was disregarded in these observations. A site within a larger tree block was selected as an example of “steady state” growth and marked into two 10 x 20 m and one 15 x 20 m areas. Vertical canopy interception at 1 m intervals were measured on a number of transects across these areas. Dominant species, DBH and basal diameter were also recorded and stem areas calculated. Soil samples were also taken to determine organic carbon, and electrical conductivity beneath the brigalow treeline. Relationships between tree height, diameter at breast height (DBH) and diameter at base (30 cm) for brigalow edge trees are presented in Figure 2.2. These data were used to parameterise APSIM for steady-state brigalow growth in subsequent simulations (Section 3.3).

Soil characterisation and transects

The local soil was characterised (“Square paddock”, 28° 10.627’S 149° 53.597’E) to determine drained upper limit (field capacity), crop lower limit and wet bulk density (BD) using standard sampling methodology (Dalglish and Foale, 1998). Soil chemical analyses to determine soil nitrogen, organic carbon, pH, electrical conductivity, chloride and exchangeable cations were also made (Figure 2.3). Exchangeable sodium percentages were calculated to help interpret whether water extraction by crop roots at depth was limited by subsoil salinity.

Soil samples in 2000 were taken to 1.5 m depth (30 cm increments) along transects at measured distances from a north to south treeline in both a winter fallow (“Georges”, 5 m, 10 m and open field) and wheat crop (“Square”, 1 m, 5 m, 10 m, 20 m, 30 m, 40 m, 120 m and 170 m). Samples were again taken in 2001 along the same transects to determine plant water use over the cropping season and fallow efficiency of the summer fallow (Figure 2.4).

Table 2.4: Transect results for cover and area at breast height (ABH, 130cm) and area at basal height (A30, 30cm).

Measurement	“Triangle” paddock Centre (steady state)	“Square” paddock Edge effect
Cover estimates from canopy intercepts	0.55	0.491
Cover estimates from PAR measurements		0.55
Total stem area live (m ² /ha), Brigalow	ABH: 6.16 A30 : 7.07	ABH: 17.38 A30 : 20.56
Total stem area live (m ² /ha), Casuarina	ABH: 9.38 A30 : 11.77	ABH: 14.17 A30 : 17.98
Total stem area dead (m ² /ha), Brigalow	ABH: 3.06 A30 : 3.43	ABH: 2.05 A30 : 2.38
Total stem area dead (m ² /ha), Casuarina	ABH: 0.25 A30 : 0.25	ABH: 0.45 A30 : 0.75

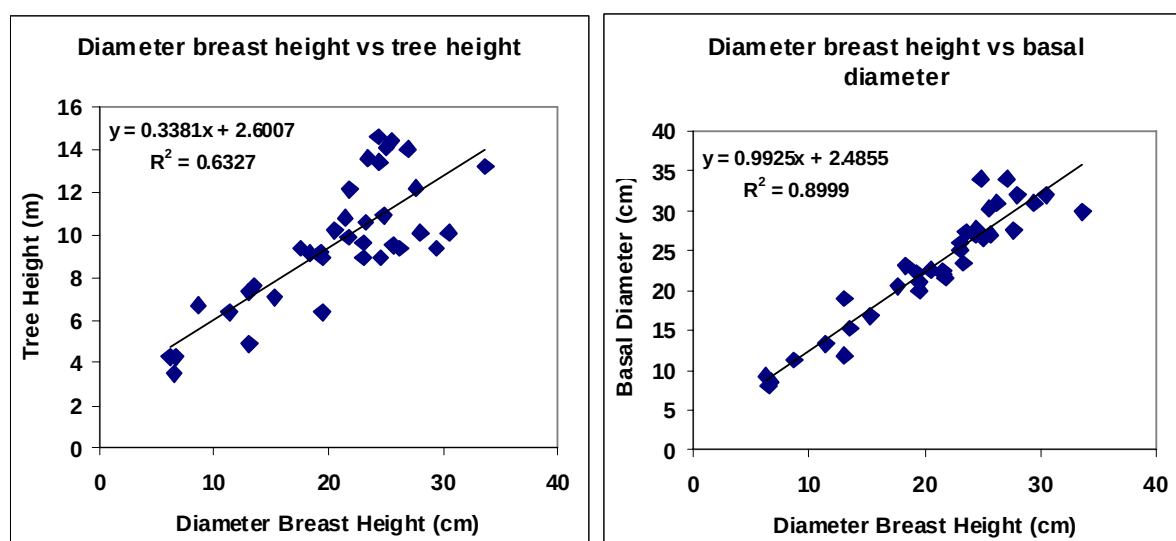


Figure 2.2: Tree height, diameter at breast height (DBH) and diameter at base (30 cm) relationships for brigalow edge trees, “Coorangy”.

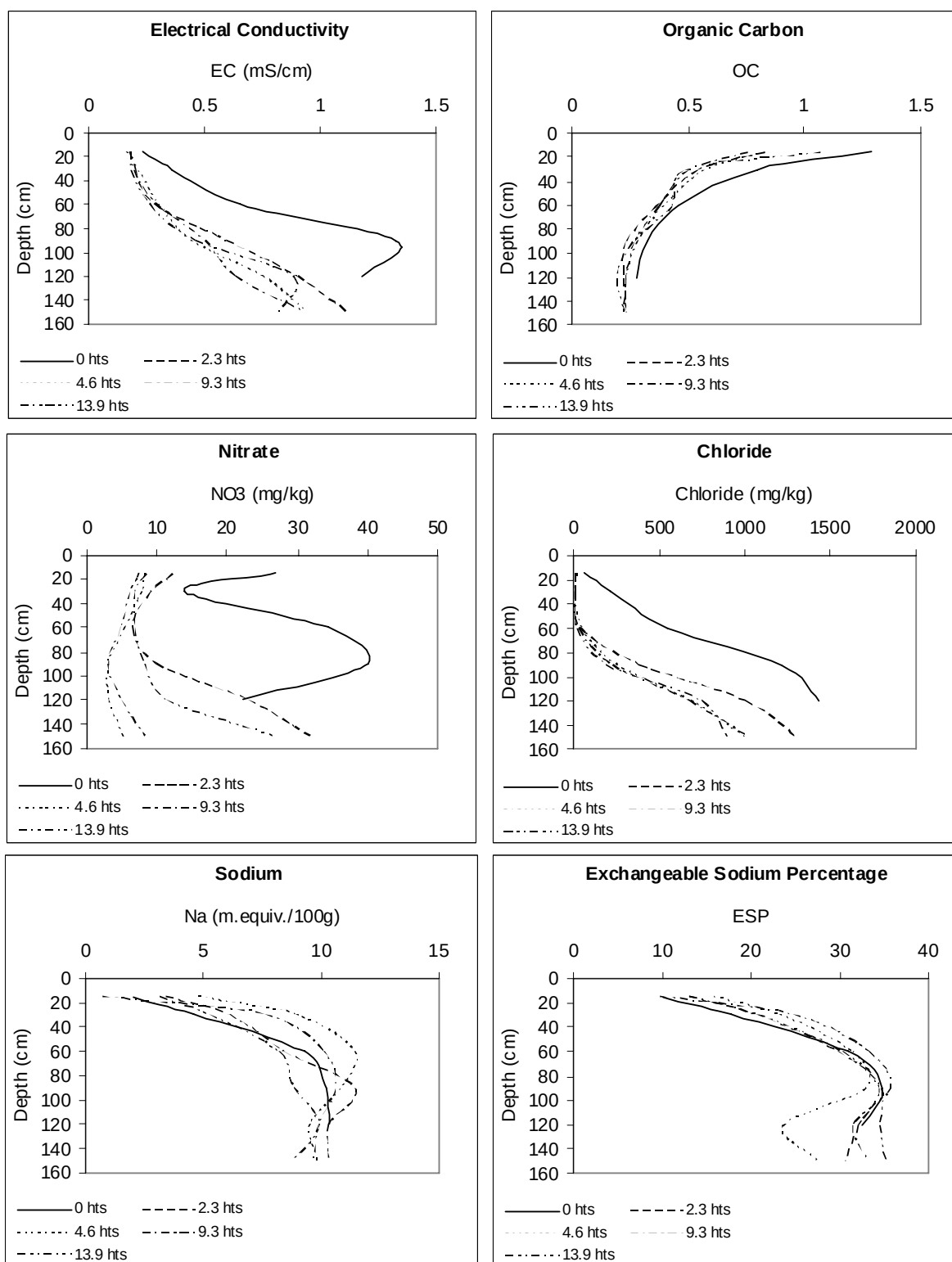


Figure 2.3: Chemical analysis results along transects measured in tree heights for a grey vertosol, “Coorangy”.

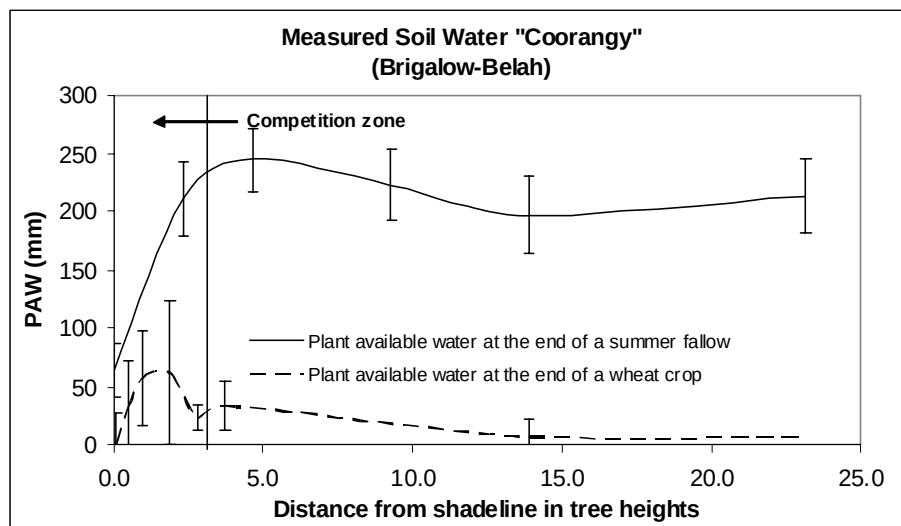


Figure 2.4: Transects of measured plant available soil water (PAW) to 1.5m depth at the start and end of a summer fallow at “Coorangy”. Lines are smooth curves joining observed data points with error bars ($\pm$ sd).

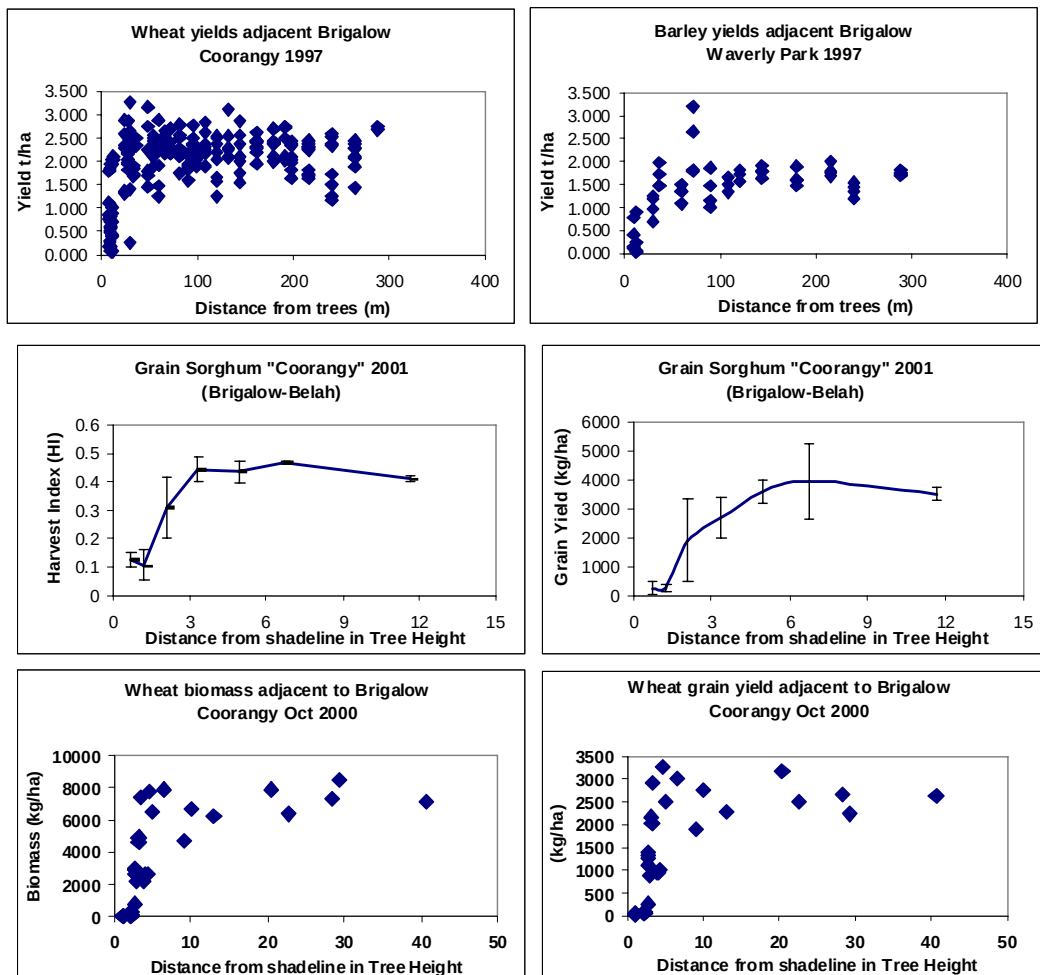


Figure 2.5: Transects of grain yield, biomass and harvest index for different crops grown adjacent to brigalow shadelines. Crops included wheat at “Coorangy” and nearby “Waverley Park” in 1997, wheat at “Coorangy” in 2000, and wheat and sorghum at “Coorangy” in 2001.

Crop transects

Crop samples were taken for grain yield, biomass and grain nitrogen across transects perpendicular to the treeline of interest (Figure 2.5). Visual assessment of the extent of competition zone was used to select the initial sampling distance. Wheat grain and biomass samples were taken at maturity for measured distances out to a point that equated to an open field sample, where no windbreak effect would be expected (180 m). Sorghum yield and biomass samples were similarly taken at anthesis and maturity.

Tree/crop competition zone

A measuring wheel was used to record distances of the visually affected area between the trees and crops. Due to the exceptionally dry season the impact of competition for soil moisture on crop growth was clearly evident. A good relationship was observed that indicated the width of the zone with zero yield equalled 1.7 times the height of the adjacent trees (Figure 2.6). While this zero yield zone does not indicate the full extent of the competitive zone, the resulting simple linear relationship suggests that a simple functional relationship may exist between tree height and root extent throughout the entire period of tree growth and development.

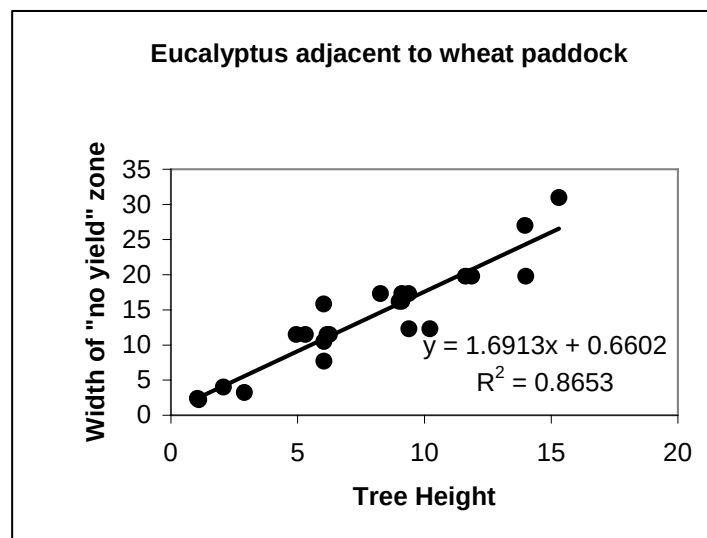


Figure 2.6: The relationship between the width of the visually-determined zone with zero yield (in tree heights) versus tree height for winter crops at 23 sites on the eastern Darling Downs in 2000.

Planted *E. argophloia* windbreaks, Warra, Queensland

The Warra site was planted to *E. argophloia* in 1996 and 1998 in north-south and east-west configurations respectively. A north-south windbreak, to the west of a number of cropping strips, was selected for measurement. The trees were planted in four rows at approximately 5 m spacings – the second and fourth rows were offset by 2.5 m. Root ripping (50 cm depth) was carried out at 2.5 m from the trees but too late in the season to modify the competition effects of the trees. The site also contains remnant brigalow-belah windbreaks (cropping paddocks cleared in the late 1950s) at the eastern end of the cropping strips and offered an opportunity to evaluate both planted eucalypts and brigalow remnants at one site. The 2000 wheat strip and tree blocks were sampled – procedures were consistent with those described previously. A transect for soil moisture was taken in the adjacent fallow strip (fallowed from wheat in 1999 and planted to cotton in Oct 2000).

Soil characterisation and transects

The site had previously been characterised for organic carbon, bulk density and plant available water contents (Dalglish and Foale, 1998). Transects (1 m, 10 m, 20 m, 50 m, 125 m) were taken in both the wheat strip (eastern and western ends) and the fallow strip (wheat 1999) for soil moisture to 1.8 m depth. Nitrogen, pH, electrical conductivity, chloride and exchangeable cations to a depth of 2.1 m were also sampled (data not presented). Soil cores at 2.5 m inside both eucalypt and brigalow blocks were taken to 2.1 m depth. Samples were collected at the end of a cotton crop and summer fallow to determine plant water use over the cropping season and fallow efficiency of the summer fallow (Figure 2.7).

Crop transects

Yield and biomass of the dryland cotton crop grown in the 2000-2001 season were sampled at transects from the windbreaks (data not presented). These data showed strong competition effects of the trees on cotton productivity and contributed to our understanding of the tree-competition zone. However, no further use was made of the crop yield data in the context of this report due to the deficiencies of the cotton module in APSIM in simulating the impacts of windbreaks.

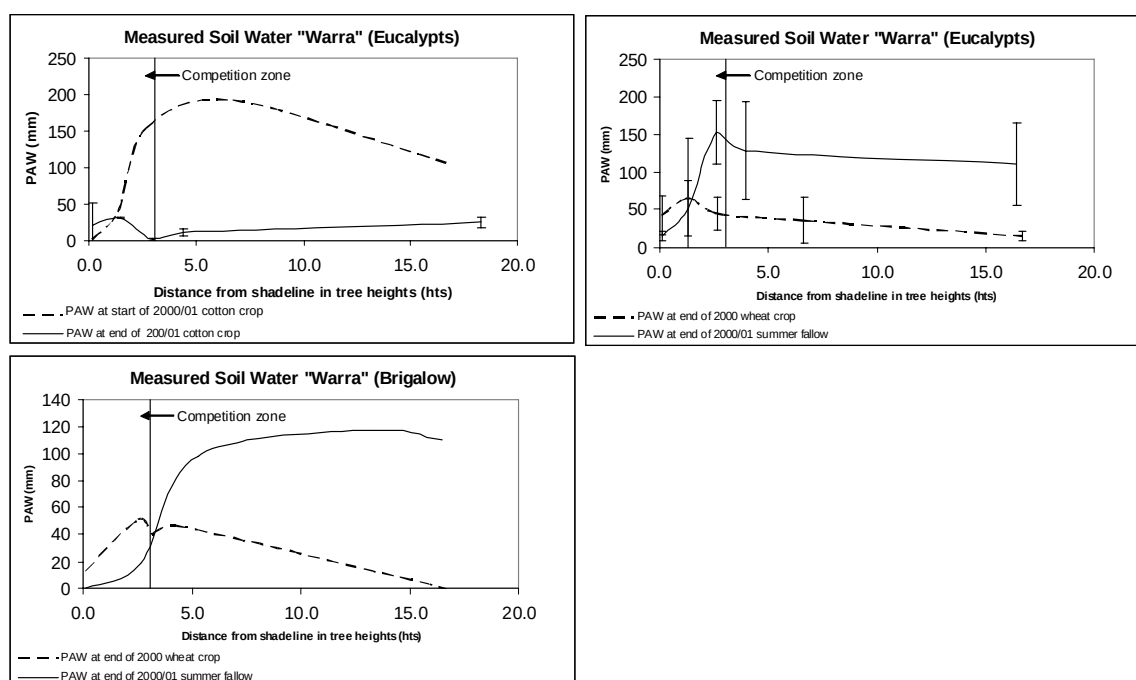


Figure 2.7: Transects from eucalypt and brigalow windbreaks of measured plant available soil water to 1.5m depth (PAW) at the start and end of the 2000-2001 cotton crop and of the 2000- 2001 summer fallow.

Other observation sites, Southern Queensland

A range of other field sites in southern Queensland with both eucalypts (*E. argophloia*, *Corymbia citriodora*, *E. sideroxylon*) and brigalow (*Acacia harpophylla*) at various ages and densities was also investigated, photographed and any zone of competition visually assessed. At most, DBH, basal diameter and height were recorded, with leaf samples taken for specific leaf weight. These data were used in helping to parameterise APSIM for relevant species.

Queensland Forestry arboretum at Braemar.

A number of eucalypt species were planted at the Braemar arboretum (27° 11.301'S 150° 47.412'E) by Queensland Forestry from around 1971, including *E. argophloia* and *E. sideroxylon*. The stands consisted of three rows by eight trees at 30 years of age. They were photographed and measured for DBH, basal diameter (30 cm) and diameter at 2 m and 4 m height in order to estimate wood volumes.

Ourigilla, Tara, Qld

A number of eucalypt species were planted at Ourigilla (27° 10.14'S, 149° 59.68'E) by the Lethbridge family from the early seventies. Species including *E. argophloia*, *C. citriodora* and *E. sideroxylon* were established and in 2001 were aged 30 years. Further plantings of *E. argophloia* were also undertaken at the site, such that a chronosequence existed on site for ages 30, 20, 17, 11, 3 and 1 years. The data collected on DBH and height for different tree ages (Figure 2.8) provided a valuable source of information for developing a simulation capability for *E. argophloia*.

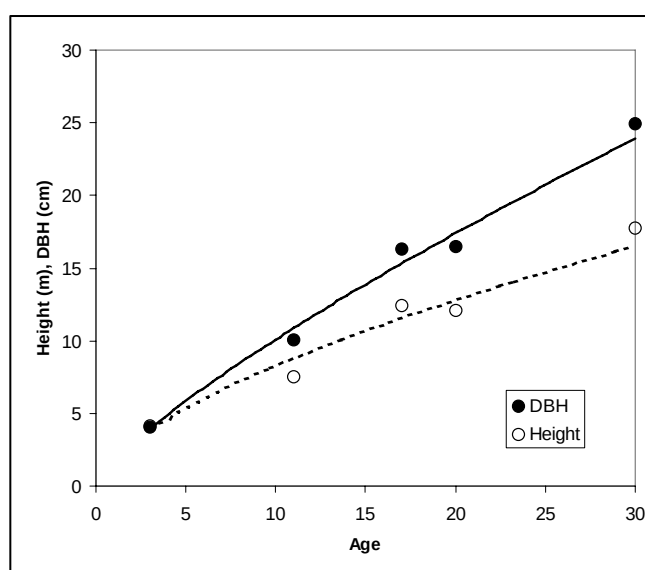


Figure 2.8: Comparison of DBH, tree height and age of *E. argophloia*, Ourigilla.

3. Simulation of agroforestry systems using APSIM

A general characteristic of most agroforestry systems is the heterogeneity introduced by combining crops or pastures with a tree component. Conceptually, it may be possible to describe an agroforestry system as a series of discrete crop-based or tree-based components with flows of mass or energy between each component dependent upon the states of the components. A simulation model based upon this concept would be required to not only simulate the dynamic processes within each component, but also to dynamically describe the interactions between components.

The few existing agroforestry models are based upon the abstraction of a system into discrete areas with defined interactions. The WaNulCAS model (Van Noordwijk and Lusiana, 1999), for example, uses a series of soil zones to calculate subsurface competition between trees and crops at different distances from the trees in question. In a similar manner, the SBELTS model (Qi et al., 2001) simulates crop production at a range of discrete points down-wind of a windbreak in order to calculate a spatially integrated yield response to wind protection. In both cases, the abstraction of the system into functional units allows the application of existing simulation methodologies to be followed by simple integration to investigate overall system behaviour.

One possible constraint to such an approach is the ability to bring together simulation capability from the differing disciplines into one integrated framework (Jones et al., 2001). The Agricultural Production Systems Simulator (APSIM) (McCown et al., 1996) has been specifically designed to facilitate cross-disciplinary simulation-based research. A component-based design allows individual models to interconnect via a common communications engine. Over twenty individual crop and pasture modules are available within APSIM for use in simulating diverse farming systems. These crop modules communicate with existing modules to simulate soil processes such as carbon, nitrogen and phosphorous cycling, surface residue dynamics, water and solute fluxes, soil temperature, and soil acidity. A forest production modelling capability was added to APSIM in 2001 (Huth et al., 2001). APSIM has been used to investigate competition for light and soil resources of intercropped plant species (Carberry et al., 1996) and also to investigate sheltering effects using traditional single point simulation methods (Carberry et al., 2002a). An updated description of the APSIM model is provided by Keating et al. (2002).

The modules within APSIM are essentially one-dimensional, point-based models, which represent the behaviour of the system at some single point in space, or alternatively one discrete homogeneous area. Developments on the inter-module communications protocol employed by APSIM (Wright et al., 1997) now allow the application of APSIM to systems that contain a two-dimensional, spatial component. The new protocol allows multiple groups of point-based models with communication of data between them within a single simulation. Thus an agroforestry system can be represented by a series of functional units with clearly defined data flows between them. How APSIM achieves this outcome is described in the following sections.

3.1 A conceptual agroforestry system

An agroforestry system of interest to landholders and policy researchers in the medium to low rainfall zones of Australia is the introduction of tree windbreaks or tree belts into dryland cropping systems. Such agroforestry systems usually consist of belts of trees planted along the borders of crop fields. The shelter provided by these trees is thought to provide multiple benefits (Cleugh et al., 2002). These include protecting the crops from wind damage or pesticide drift, increased yield through reduced water demand within the sheltered zone, shelter from wind and sun for livestock, and control of losses due to overland flow of runoff. This system can be conceptualised in two dimensions (Figure 3.1).

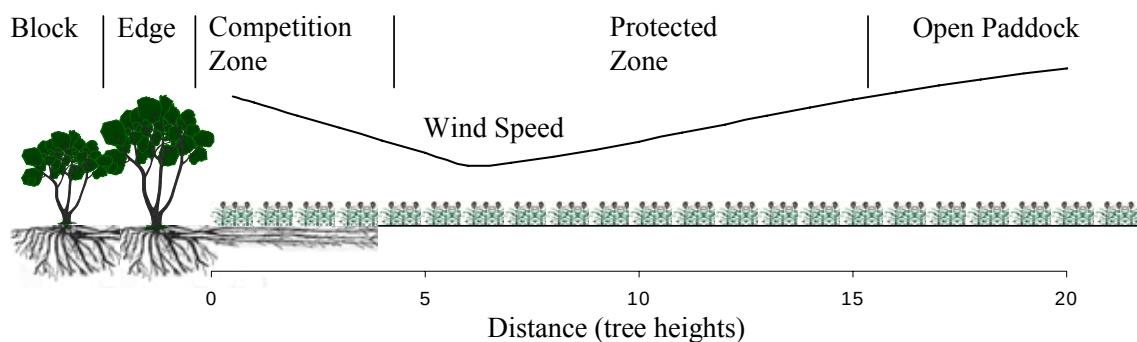


Figure 3.1: Diagram of the agroforestry system under consideration. A normalised wind speed curve is included to demonstrate likely reductions in wind speed in the protected zone behind a windbreak positioned perpendicular to prevailing winds.

Windbreaks often consist of several rows of trees along the side of a field facing the prevailing winds. This belt of trees can be divided into two functional components (Albertsen et al., 2000). The roots of trees on the edge of the tree belt have access to water and nutrients within the cleared field and, as a result, the productivity of these trees is often greater than that of the trees in the inner rows. An analysis of this system would need to take this difference into account and so the two functional components of the analysis need to be the inner block and the outer edge zones.

Nuberg (1998), Bird (1998) and Cleugh (1998) have described the ways in which trees may impact upon a neighbouring field in temperate agricultural systems. These authors suggest that in some situations the net effect of these impacts may only result in very subtle effects on crop productivity. In the low to medium rainfall areas of Australia the availability of water is likely to exert greater influence on crop productivity than variations in light or temperature arising from the presence of the trees. As a result, the conceptualisation of this system will deal with only three tree-crop interactions: competition for stored soil moisture and soil nitrogen and changes in crop evaporative demand due to alterations in wind speed.

The resources trees use from within the field can lead to lower crop production within the tree-crop competition zone. The extent of the yield reduction will depend on many factors, but these can basically be summed up as differences between sink and source strength for soil resources. As the trees grow their root systems within the field will extend; however, this may not necessarily lead to lower crop yields. The demand for resources may increase as the trees mature but a more extensive root zone provides a larger resource base from which to meet the demand. The ultimate effect on the crop will depend on the supply of the resource in question. In the case of water, the competition between crop and tree will have a greater effect in a dry season than during a wet season. As a result, the interplay between crop and tree will vary with tree size and recent climatic history.

A belt of trees oriented to act as a windbreak will affect the crop for a significant distance down-wind. Reduction in wind speed can lead to alterations in the crop's microclimate that results in enhanced growth. The extent and magnitude of this effect will vary with season, crop and type of windbreak (Cleugh, 1998). Tree height is the major determinant of the level of shelter at any given point down-wind from the windbreak. In this conceptual agroforestry system, the height of the trees growing on the edge of the tree belt can be used to determine the spatial variation in wind speed for each point in space. The final zone of the system is that portion of the field that is not influenced by the windbreak. In essence, this zone represents the open field situation. The location of this open field zone has to be positioned far enough away from the windbreak to be unaffected by wind speed.

3.2 APSIM multi-point simulation

APSIM configuration

APSIM version 2.1 was configured to simulate the conceptual agroforestry system represented in Figure 3.1. To do so, APSIM was set up to consist of a main driving system with an array of discrete points (subsystems) that represent a two-dimensional view of the system (Figure 3.2). The two dimensions being simultaneously simulated are (i) the horizontal flows of wind and translocation of water and nitrogen within tree roots between adjacent points, represented in Figure 3.2 by an inner tree block, an edge tree area and points 1 to N of crop area, and (ii) the vertical flows at each point of water, nitrogen and carbon between plants and the soil to depth.

To achieve multi-point simulation, each subsystem point contains APSIM modules for the simulation of the particular plant and soil processes at that point in space. All subsystems require their own instance² of the key soil modules responsible for simulation of soil water balance (module APSIM-SoilWat), soil nitrogen dynamics (APSIM-SoilN) and surface residue breakdown (APSIM-Residue). The two subsystems representing the inner and outer edge of the tree belt each contain an instance of the APSIM-Forest module to simulate tree growth. Likewise, each point within the cropping area contains an instance of APSIM module for the crop being simulated. All subsystems incorporate APSIM modules responsible for point-specific farmer management logic (APSIM-Manager module) and for reporting output data specific for each point (APSIM-Report module).

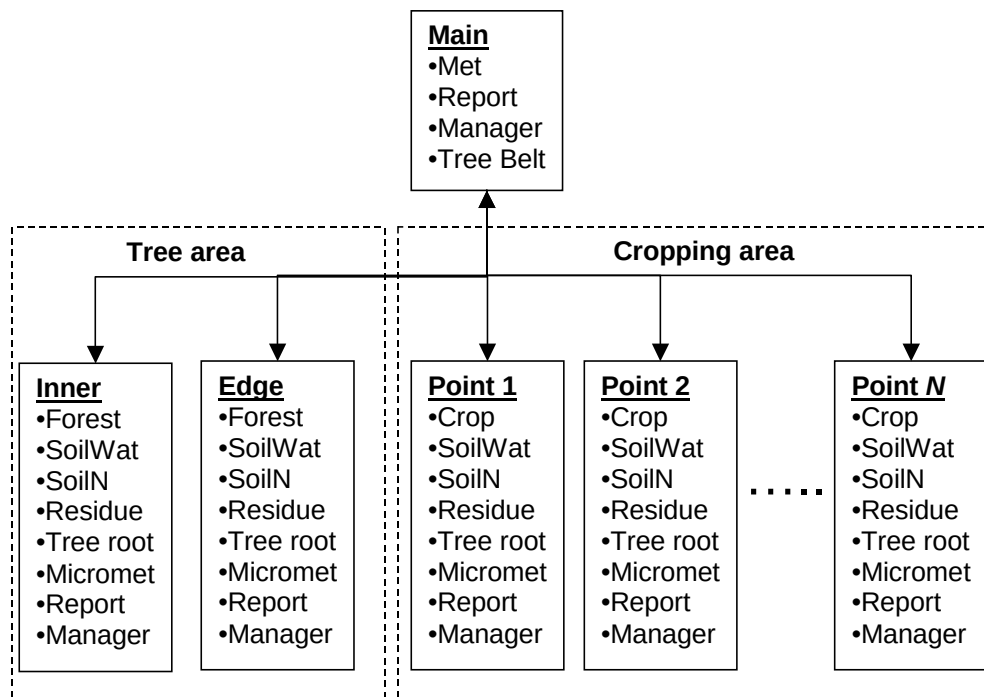


Figure 3.2: Diagram of model configuration showing different instances of APSIM and the APSIM Modules used within each instance.

All subsystems also include an instance of the APSIM-Micromet module, which is responsible for calculating a potential transpiration demand term for each plant component for that point in the system using the Penman-Monteith equation. Within the cropping area, this potential transpiration term at each subsystem point is affected by daily wind speed as influenced by the adjacent tree windbreak. The relative reductions in wind speed at different distances downwind from the tree belt are based on

² An “instance” is a term used in object-oriented software programming to represent the same software code being used multiple times (instances) without having to reproduce the code for each new circumstance.

the relationship proposed by Cleugh (2002) and employed by Carberry et al. (2002a). Given the complex advective conditions down-wind from a windbreak, empirical equations relating wind speed to aerodynamic conductance for water vapour (Cleugh, unpublished data) are used to capture the resulting behaviour of turbulent flow. Actual water use by the crop at each subsystem point is calculated in each instance of the APSIM crop module as the balance of potential transpiration demand, calculated by APSIM-Micromet, and soil water supply as determined in the instance of the APSIM-SoilWat module for that particular subsystem point.

The APSIM-Micromet module is also responsible for determining potential transpiration demand for the two tree subsystems. However, in the edge tree subsystem, soil water supply could be sourced from multiple subsystem points, both within the tree and cropping areas. The number of subsystem points that contributes to satisfy the tree transpiration demand would also change over time as the trees grow and their root system expand further into the cropping area. Within each subsystem point, a tree root module (represented by the APSIM-Root module) extracts soil water in response to tree transpiration demand, calculated by APSIM-Micromet, and to soil water supply as determined by the APSIM-SoilWat module.

The main driving system contains modules with universal functionality to be communicated to all subsystems – e.g. the supply of daily weather data (APSIM-Met module) the reporting of system status (APSIM-Report module), and overall management logic for the agroforestry system (APSIM-Manager module). The main driving system also contains a tree belt module responsible for specifying the interactions between the points in space and time due to the presence of the tree belt. These interactions include uptake of soil water by the trees and local micrometeorological variations due to shelter from the trees (mainly altered wind speed). In most of the following simulations, seventeen discrete points were included in the analyses, of which the fifteen points within the cropping area have been specified to lie within 500 m of the specified tree belt. The simple rules for partitioning tree transpiration demand between subsystem points were based upon the soil water supply at each point and the assumption of a decrease in tree rooting intensity across its root zone proportional to the square of the distance from the tree.

Parameterisation of APSIM for *Eucalyptus argophloia*

Eucalyptus argophloia (Chinchilla white gum) is commonly planted in medium to low rainfall regions of northeast Australia. However, little information exists for expected long-term production of this species for these areas³. Even less information exists for important growth characteristics required for parameterising APSIM. Estimates of expected yields and wood properties were obtained from the data sources detailed in Chapter 2 and from local forestry professionals (P. Voller, personal communication 2003). Where possible, model parameters were set to reflect those measured (and expected) for a eucalypt species that has evolved in medium to low rainfall environments. Remaining parameters were adjusted until growth predictions matched these data and experts' opinions. Consequently, an APSIM-Forest module was specified for development and growth of *E. argophloia*, although its simulations need further testing.

Determination of the width of the competition zone

The main determinant of the competitive effect of trees on a neighbouring paddocks will be the width of the tree-rooting zone within the paddock. The width of the competition zone is a required parameter for APSIM simulations. Accordingly, the series of field observations undertaken in Sections 2.1 and 2.2 were used to quantify the extent of tree roots on the clay soils of the Darling Downs, Queensland. These were then compared to observations made by Ellis et al. (2001) to determine if any general behaviour could be identified. Tree height was found to be a major factor in the extent of the competition zone. Figure 3.3 shows the combined data from Ellis et al. (2001) and those observations made from the Darling Downs.

³ Some Queensland Forestry Research Institute trials established in 2000 will provide future growth by site data (see Lee et al., 2005).

A simple relationship between tree height and width of the competition zone accounted for just over 70% of the variation in the results – i.e. the competition zone extends to approximately three times the height of the adjacent trees. This simple “rule of thumb” has been used to dynamically specify the width of the competition zone in all subsequent simulations.

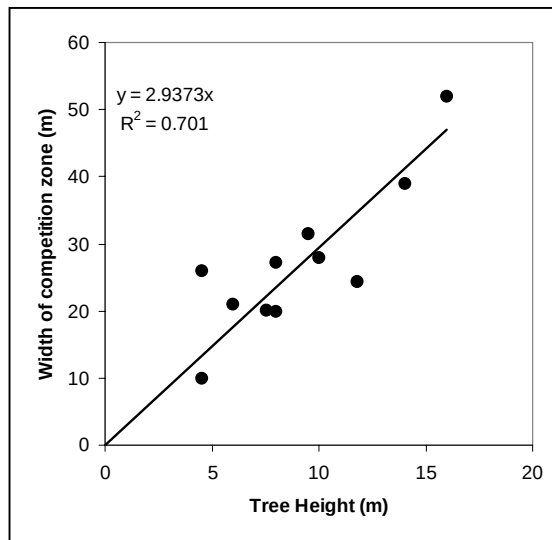


Figure 3.3: Relationship between width of the competition zone and adjacent tree height.

Determination of extent of the “edge effect”

Trees on the edge of a tree belt can access water and nutrients from the neighbouring cropland and, as a result, show higher growth rates than trees inside the tree belt (the so-called “edge effect”). The level of this enhanced growth can indicate the amount of extra resources gained from the cropland.

Measurements taken of *E. argophloia* from the Warra site described in Section 2.2 were taken to help verify simulations made for these sites. Figure 3.4 shows total standing stem wood volume for the four edge rows of two windbreaks at this site. The results indicated that even after only three or four years of growth the edge trees were already two or more times the size of inner trees. Most of the enhanced growth appeared in the outermost row of trees. Information gained from these observations was used to specify the model for these and other sites.

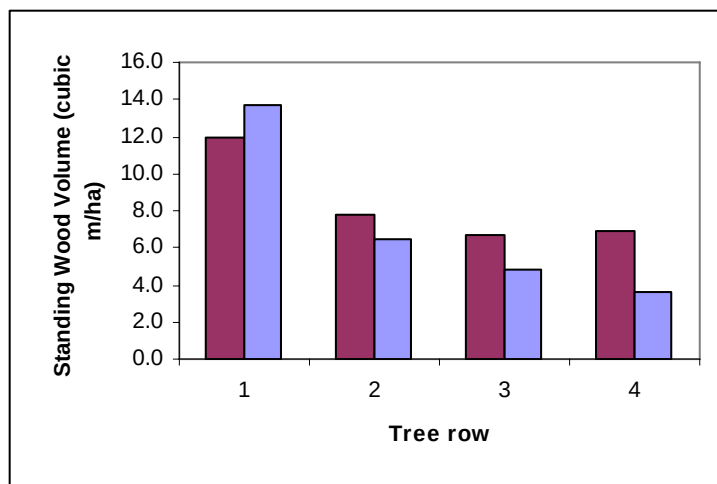


Figure 3.4: Total standing wood volume for the four edge rows (1 = closest to cleared field, 4 = fourth row in from field) of two windbreaks (denoted by different shades of grey) on the property “Prospect” at Warra, Qld.

3.3 Testing APSIM simulations

The APSIM v2.1 multi-paddock simulation capability, configured for the simulation of the agroforestry system represented in Figure 3.1, was used to simulate a number of actual tree-crop interactions at sites around Australia. Consequently, APSIM simulations of tree-crop interactions were tested against measured data from these sites. Testing sites included:

- commercial crops grown adjacent to *Pinus pinaster* windbreaks at the Howick site, Esperance, WA – described by Sudmeyer (2002)
- commercial crops grown adjacent to *Eucalyptus globulus* windbreaks at Esperance, WA – these data are being collected by Dr Rob Sudmeyer (WA Department of Agriculture)
- commercial crops grown adjacent to remnant Brigalow-Belah shadelines on the property “Coorangy”, southwest of Moonie, Qld – described in Section 2.2 above
- commercial crops grown adjacent planted *Eucalyptus argophloia* on the property “Prospect” at Warra, Qld – described in Section 2.2 above.

There were few datasets available for testing the simulation of agroforestry systems. This is due to the very few sites where measurements have been collected on the complete agroforestry system, including measurements of tree and crop productivity, and soil water and nutrient availability over time. Clearly, the research work of Dr Rob Sudmeyer and colleagues is the best available source of relevant datasets, although these data were just becoming available as this project was completed. Consequently, the results reported in the following sections do not fulfil the requirements for an adequate validation of APSIM’s multi-point simulation capability. The following results do, however, provide some evidence that APSIM can represent real agroforestry systems. Further testing is required and will be undertaken when relevant data become available.

***Pinus pinaster* windbreak at Howick site, Esperance, WA**

Sudmeyer (2002) and Sudmeyer et al. (2002) describe the crop and environmental consequences of a series of *Pinus pinaster* windbreaks planted on the paddock boundaries of commercial dryland crops at the Howick site near Esperance, WA. Data from this site were collated and analysed in order to test APSIM’s agroforestry simulation capability.

Using neutron probe data collected over the 1995 to 1997 cropping season, soil input files were constructed and benchmarked against measured crop growth. Single-point simulations of open field lupin (1994), canola (1995), barley (1996) and lupin (1997) were undertaken (data not presented). Open paddock simulations assumed no influence from local windbreaks and no effects from pests or

disease. Single-point simulations using APSIM-Forest of tree growth, height, wood volume and soil water use by the trees were also compared with measured data from the site during the period 1994 to 2000 (data not presented).

Multi-point simulations were constructed to investigate competition between windbreak trees and field crops at the site. The dynamic simulation of wind reduction behind the growing windbreak was simulated (data not presented). Daily changes in wind speed and direction were not considered in the simulations. Simulations consisted of an inner and outer edge of trees and 15 points along a transect at 90 degrees to the windbreak (Figures 3.5, 3.6).

When the tree-crop competition zone was simulated with competition for water alone, the results did not match the observed competition effect adjacent to the trees (data not presented). The simulation of water use in the 2-3 tree height competition zone by the trees and crop indicated a possible nutrient issue. In fact, Sudmeyer et al. (2002) reported that crop growth had responded to root pruning and fertiliser application at the site, indicating that competition for soil nutrients could also be a factor in the competition effects. Multi-point simulation with reduced soil nitrate out to 3 tree heights compared favourably with measured data (Figure 3.6). The extent of competition in the one tree height zone could not be totally simulated and is possibly due to shading or the impact of the trees on early crop establishment.

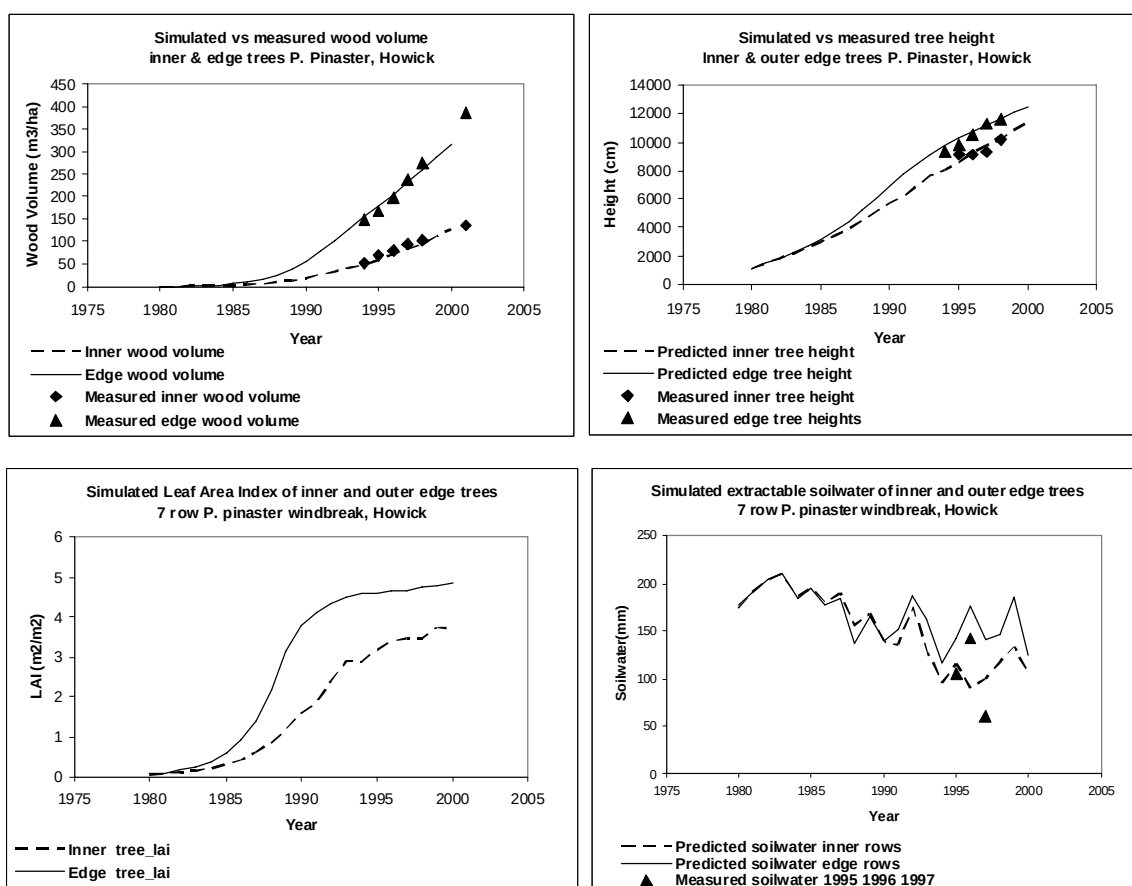


Figure 3.5: Multi-point simulations of growth and water use of both inner and outer edge rows of a 7-row *P. pinaster* windbreak, at Howick over the period 1980-2000.

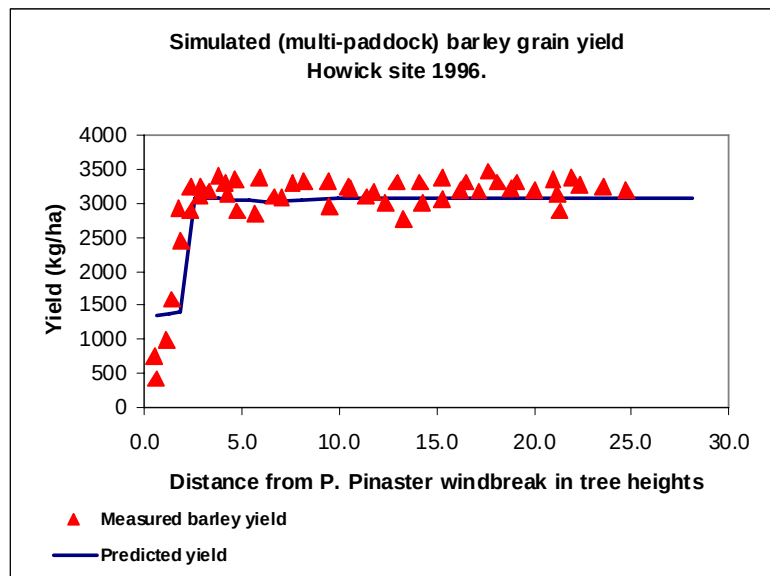


Figure 3.6: Multi-point simulations of barley yield grown adjacent to a 7-row *P. pinaster* windbreak, at Howick in 1996.

***Eucalyptus globulus* windbreak at Esperance, WA**

The growth of belts of *E. globulus* and the related impacts on neighbouring agricultural land have been investigated in Western Australia where both trees and crops growing on a deep sand were monitored near Esperance (Sudmeyer and Flugge, 2005). Some of these results were used in a comparison with a representative simulation of the experimental site. The simulation was constructed to resemble the key aspects of the site as part of an initial attempt at a modelling analysis of the experiment. The fertilised and unthinned (560 trees/ha) treatment was used for this comparison.

Multi-point APSIM was configured using tree measurements from 1999 to initialise the APSIM-Forest module. Soil properties were set to be representative of a deep sandy soil for that region. A water table is present below the plantation at a depth of approximately 4 m. This depth was assumed as the maximum rooting depth for the trees. Tree roots were assumed to only extend twice the height of the tree into the paddock, as observed by Sudmeyer (2002).

Although the agricultural crop varied with season at the experimental site, a winter wheat crop was sown each year in this simplified comparison. The wheat crops received 20 kg N/ha as DAP at sowing with a further 35 kg N/ha as Urea added on month later. Weather data from Esperance Downs Research Station for the period from 1999 to 2001 was used.

The model simulations were able to capture the difference in observed growth rates between the inner and edge trees (Figure 3.7). In the model, uptake of extra water and nitrogen from the neighbouring cropping land resulted in the edge trees obtaining the observed higher growth rates (additional photosynthesis from increased available light at the shelterbelt edge was not considered). These edge trees obtained roughly one third of their water from the agricultural area, and were able to use a greater proportion of the rainfall falling on the forested area than the more nutrient-limited inner trees.



Figure 3.7. Observed (symbols) and predicted (lines) growth in stem volume for *Eucalyptus globulus* grown in a windbreak at Esperance.

Growth of both trees and crops at this site was likely to be severely limited by the low nutrient status of the deep sand. In fact, the low productivity of the site led to its withdrawal from agricultural production by the land owner (Sudmeyer, personal communication). Model predictions of grain yield for the site were above those measured in 1999 (Figure 3.8). This may be due to underestimates of nutrient leaching in the model, or the presence of nutrient constraints other than nitrogen in the field.

The low water requirement of the nutrient-starved crop led to almost no impact on yield due to competition for water. Figure 3.8 shows simulation results for crops with and without competition for nitrogen by the trees. Competition for water is present in both cases. Simulation results suggest that competition for nutrients, rather than water, may be more important on such impoverished soils. The simulated transects of drainage and uptake of water and nitrogen shown in Figure 3.9 further demonstrate this point. In a season when large amounts of excess water were simulated to leach below the crop, the uptake of nitrogen by the trees was equivalent to nearly 80% of the applied fertiliser rate. This competition for nutrients would certainly be of great influence.

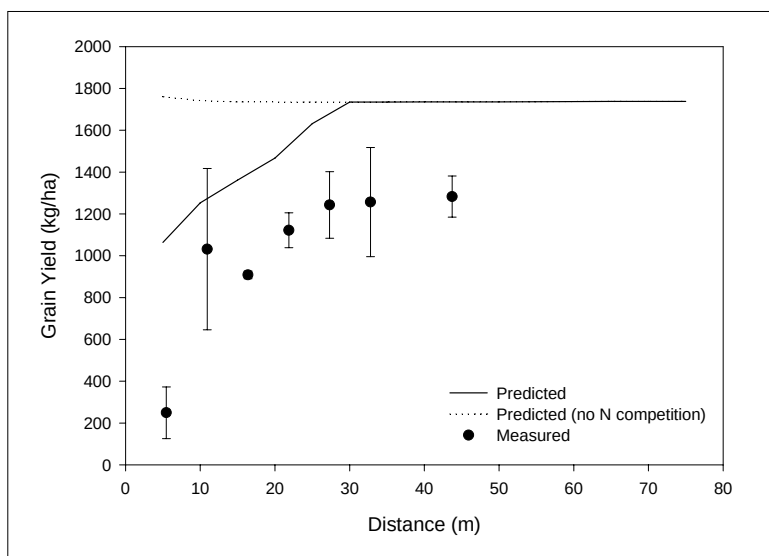


Figure 3.8. Transect of observed (symbols) and predicted (line) grain yield for a wheat crop grown next to *Eucalyptus globulus* at Esperance in 1999.

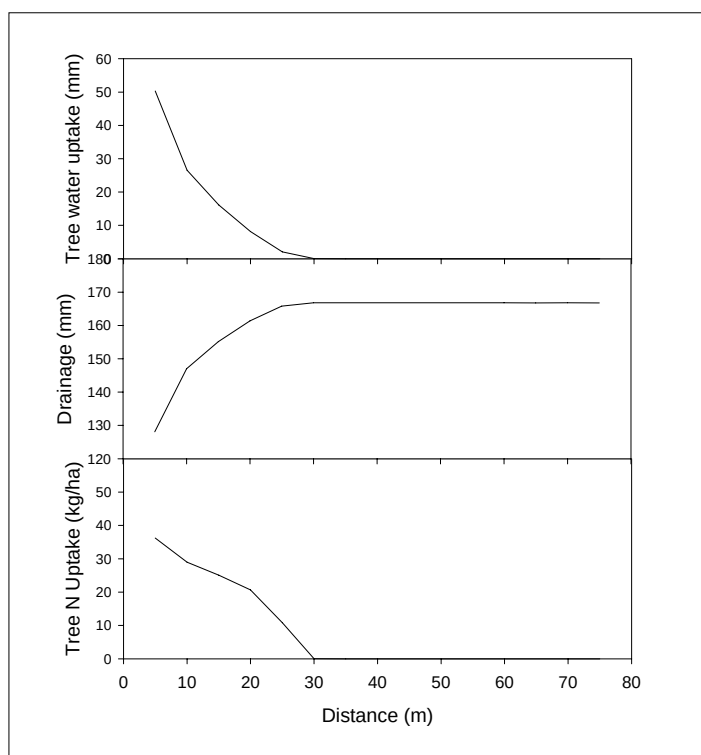


Figure 3.9. Predicted transects of drainage and uptake of water and nitrogen by trees for 1999.

Remnant brigalow-belah shadelines near Moonie, Queensland

APSIM simulations were constructed using soil characterisation data, crop growth measurements and soil water use collected from commercial crops grown adjacent to remnant brigalow-belah shadelines on the property “Coorangy”, south-west of Moonie, Qld – these data are presented in Section 2.1.

Multi-paddock simulations were constructed to investigate the tree/crop competition zone measured at the site. These simulations used APSIM-Forest which was parameterised to simulate a steady-state brigalow (*Acacia harpophylla*) windbreak. Windbreak effects were also considered – these assumed protection from all sides of the paddock and daily changes in wind speed and direction were not considered (as data were unavailable). Simulations consisted of an inner and outer edge of trees and 15 points along a transect at 90 degrees to the windbreak.

Transect simulations of wheat yield in 2000 were compared with measured data in Figure 3.10. The observed competition zone at one tree height was not simulated because other factors apart from in-season competition for soil moisture influenced wheat yields. Poor or total lack of germination in these years was the likely explanation and this phenomenon needs to be investigated further. Soil water measurements taken at the end of this 2000 wheat crop and after the summer fallow in 2001 were simulated reasonably well in Figure 3.11. These measured and simulated results for soil water suggest that low fallow water storage adjacent to trees is a major reason for low crop yields, in addition to direct competition for in-season rainfall by trees and crops.

Figure 3.11 demonstrated that the transect simulation of the summer fallow compared favourably with observed data. Using chloride profile data collected from beneath the brigalow windbreak and out in the open field, a solute leaching simulation was investigated using the APSIM-Solute module. Assuming chloride levels beneath the brigalow windbreak were in steady-state (accounting for additional chloride from rainfall), a simulation from 1946 to 2000 using conventional tillage surface management compared favourably with measured open field profiles in 2000 (Figure 3.12). This simulation indicated that the simulation of drainage by APSIM for wheat cropping systems was in the same order of magnitude as suggested by the leaching of chlorides over the 50-year cropping history at this site. Further research work is continuing on testing APSIM’s ability to simulate deep drainage.

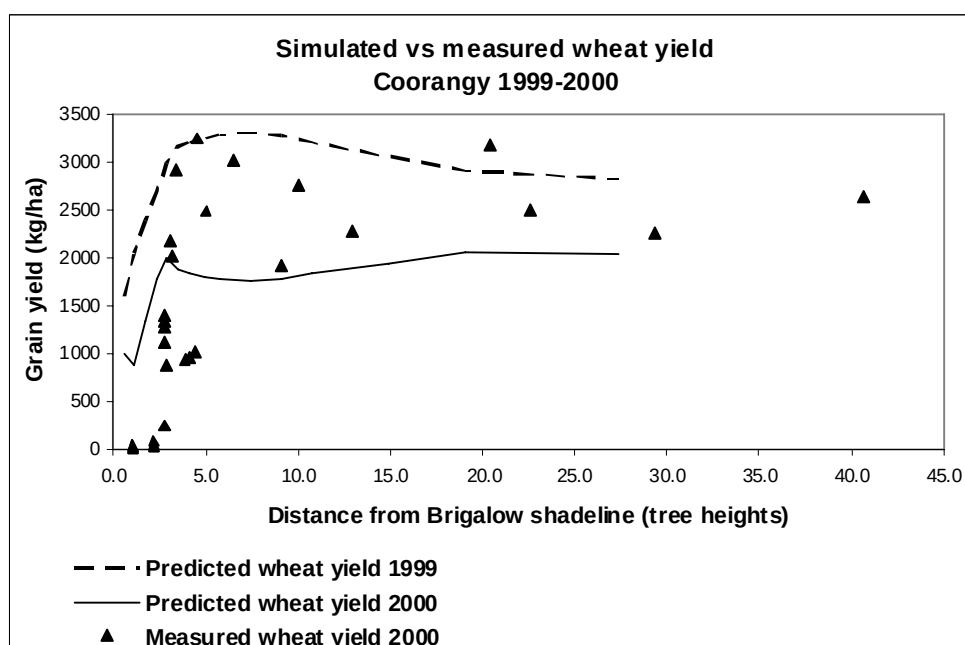


Figure 3.10: Simulated (multi-paddock) wheat grain yield 1999 & 2000 seasons. Observed points are for year 2000 only.

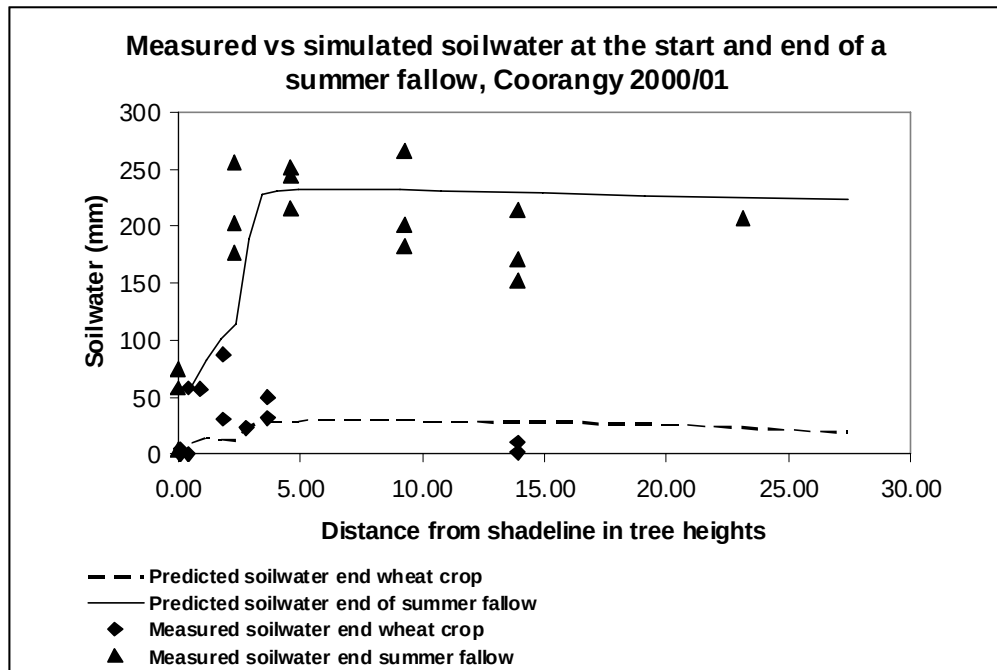


Figure 3.11. Measured (symbols) and multi-paddock simulations (lines) for the soil water transect in the competition zone behind brigalow-belah shadelines at Coorangy, Qld during the 1999-2000 fallow periods.

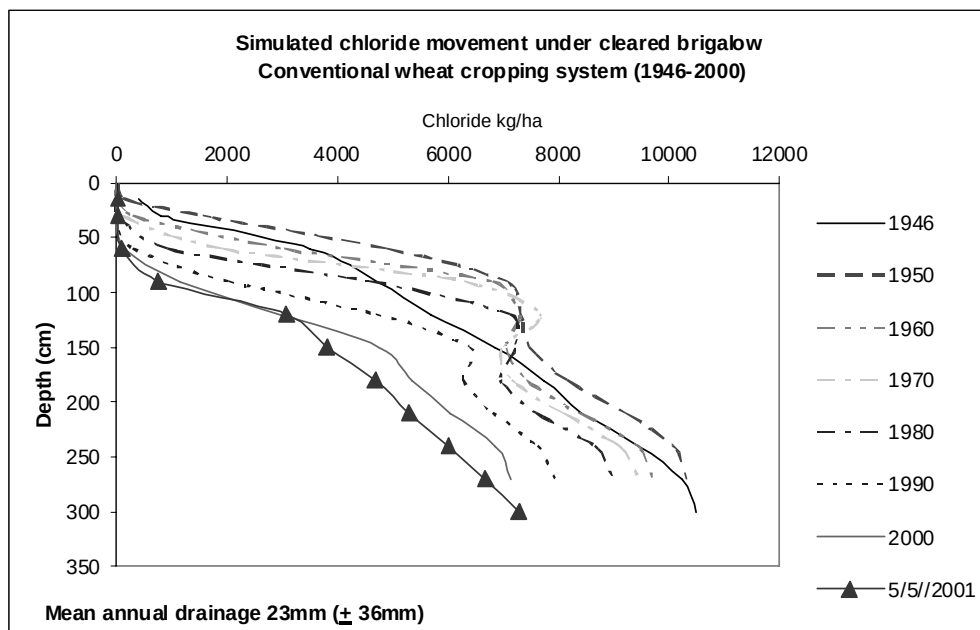


Figure 3.12: Simulated solute movement post-clearing of brigalow-belah vegetation from 1946 using a continuous wheat conventional tillage system. Initial starting conditions were based on samples of steady-state chloride levels below brigalow-belah shadelines measured in 2000-2001.

***Eucalyptus argophloia* windbreaks at Warra, Queensland**

Multi-point APSIM simulations were constructed using soil characterisation data, crop growth and soil water measurements collected from the Warra site over the 1999 and 2000 seasons (see Section 2.2). Unfortunately, for several reasons, much of the measured data collected at this site were not suitable for testing simulations. Nevertheless, APSIM simulations of *E. argophloia* windbreaks were constructed and the competition between the edge trees and the 2000 wheat crops was estimated by the model (Figure 3.13).

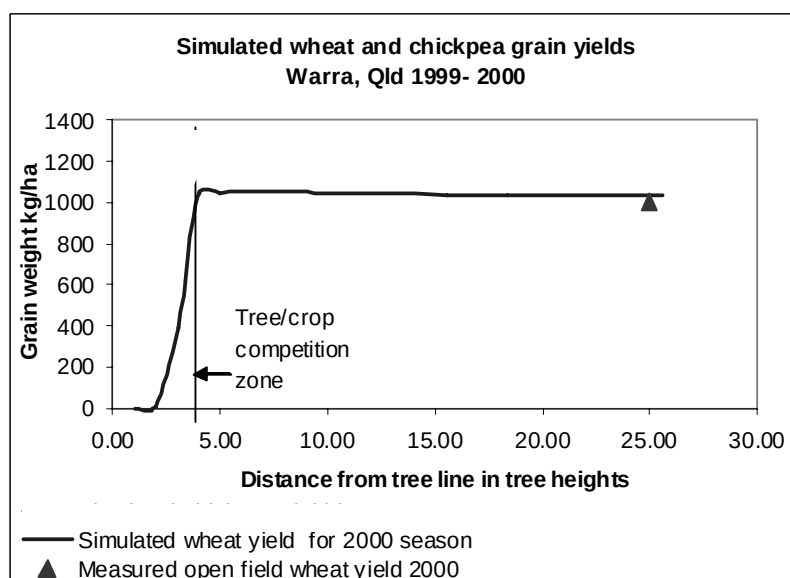


Figure 3.13. Simulated (multi-point) transect for wheat grain yield for the 2000 seasons at Warra. The only measured datum point was for open field wheat yield.

4. Systems analysis of agroforestry options

APSIM can now simulate tree-crop interactions. This enables scenarios to be run for a range of tree-crop configurations over the historical climate record for selected regions of Australia (for a range of agroforestry options). Wood production and crop yields (incorporating the aggregate effect on crop yield of loss due to tree competition, offset by yield increases due to windbreak effects) can now be simulated. These simulations can be used in economic analyses to assess profitability and risk of alternative system configurations. APSIM's ability to simulate associated issues, such as deep drainage and water table height, permits the environmental impacts of trees to be addressed concomitantly with the economic analyses. This comprehensive systems analysis capability for agroforestry systems is a key achievement of this project.

A range of system configurations can be addressed with this innovation within the APSIM framework, however the agroforestry simulations presented in this report are largely based on the conceptual and software configurations for APSIM shown in Figures 3.1 and 3.2 respectively. Such agroforestry systems consist of belts of trees planted along the borders of crop fields.

A simple economic analysis framework is used, with APSIM-simulated data, to quantify the potential benefits and risks of planting trees. The framework provides a paddock-scale economic analysis to compare the performance of an agroforestry system over a defined period (e.g. 30 years) with an 'open field' paddock of a benchmark crop over the same period of time. Net Present Value (NPV) and annual net cash flow are the selected economic performance indicators used to evaluate the agroforestry investment case studies. The use of simulated data based on long-term climate records represents an important development in Australian agroforestry economic analysis frameworks by (i) allowing for the assessment of economic risk attributable to climate variability and (ii) providing benchmarks for comparisons of with/without scenarios.

4.1 Economic analysis framework

In the section that follows, the economic analysis framework used is based on the key criteria of net present value (NPV) of an agroforestry investment and annual net cash flow over the life of the investment. These standard economic analysis criteria have been widely used in other economic analysis tools for agroforestry investment e.g. Agroforestry Calculator, Australian Farm Forestry Financial Model, Imagine (see www.rirdc.gov.au/programs/aft.html).

Economic calculations are based on the crop and tree yields simulated by APSIM. Additional physical and financial parameters characterising the agroforestry system also need to be specified, including the size and configuration of the area planted to trees, crop area lost to tree planting, commodity prices and associated operating costs, duration of investment period, discount rate, and other fixed and variable production costs. In subsequent analyses, investments are assessed without inflation.

Net present value

Net present value is based on a discounted cash flow budget. NPV permits assessment of the total net benefit of an agroforestry investment over the entire investment period. The NPV calculation sums the discounted, additional costs and benefits involved in planting trees compared to the 'do nothing' design for each year of the investment period. For an investor, an investment is acceptable when, subject to budget constraints, the NPV is positive. The NPV of an agroforestry investment over n years can be calculated, where B_t and C_t are the benefits and costs in year t , and r is the discount rate:

$$NPV = \sum_{t=0}^n \frac{(B_t - C_t)}{(1+r)^t}$$

Discounting is a calculation that converts future cash flows into present-day values, allowing a sum of money received today to be compared with a sum of money received in the future. This process captures an investor's time-preference for money, i.e. a dollar received today is worth more than a dollar received at some time in the future. Discounting means deducting from an investment's expected earnings the amount that the investment funds could earn in the most profitable alternative use (also known as the opportunity cost). An appropriate discount rate could be the current market interest rate available for a low volatility investment for a similar amount of funds and for a similar period. If the NPV of the investment after discounting is positive then this investment is better than the alternative earnings.

NPV can be also presented on an equivalent annual basis using an annuity calculation, where C is the annual cash flow (annuity), r is the discount rate and t is the number of years:

$$NPV = C \left(\frac{1}{r} - \frac{1}{r(1+r)^t} \right)$$

Annual net cash flow

NPV is an appropriate measure to summarise economic feasibility over the entire duration of an investment. However, it does not provide information about year-to-year income variability within the investment period. For example, an investment with a positive NPV could be rejected if cash flow variability is considered too high. The basic annual net cash flow calculation for each agroforestry option and its related benchmark is determined as cash income from crop and tree production less cash variable and cash overhead costs for each year of the investment. In subsequent analyses, the capital costs of establishing trees are assumed incurred in the first year of the investment period. Annual net cash flows are not adjusted for tax deductions and payments, personal drawings or repayments on borrowed capital.

Economic spreadsheet

The economic analyses in this report were undertaken using a custom-built MS Excel™ spreadsheet that calculated the Net Present Value (NPV) of a tree-based system compared to an open field 'status quo', supported by net cash flow analysis. In such calculations, APSIM was run for a specified tree-crop configuration over a long-term climate record for the selected location. Predicted wood production and crop yields were used in such economic analyses to assess profitability and risk of alternative system configurations. Specification of an agroforestry system was undertaken using the input worksheet depicted in Figure 4.1.

BIOPHYSICAL CHARACTERISTICS

defined cells

1. Areas

a) Whole paddock dimensions

Length (m)	500
Width (m)	1000
Area (m ²)	500000
Area (ha)	50

b) Tree zone (inner)

Length (m)	15
Width (m)	1000
Area (m ²)	15000
Area (ha)	1.5

Tree zone (edge)

Length (m)	5
Width (m)	1000
Area (m ²)	5000
Area (ha)	0.5

c) Wheat

Length (m)	480
Width (m)	1000
Area (m ²)	480000
Area (ha)	48

2. Tree management

Spacing (meters apart)	5
Trees/km	200
Length of tree row (km)	1
Trees/row	200
Distance between row (m)	5
Number rows	4
Total km of trees (km)	4
Total no of trees	800
Harvest age (years)	30
Hours/spray	1
Total area of trees (ha)	2

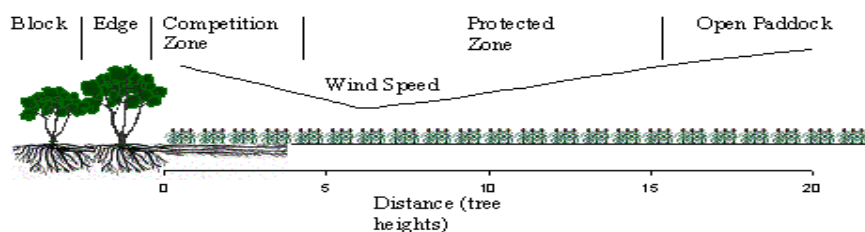


Figure 4.1: The parameters available in specifying the depicted agroforestry system.

4.2 Chinchilla white gum planted at Dalby, Queensland

System description

A case study is simulated for Dalby, Qld (27°S, 153°E) where a belt of Chinchilla white gums (*Eucalyptus argophloia*) is assumed planted on the edge of a 25 ha paddock measuring 500 m x 500 m, in which a winter crop of chickpea (*Cicer arietinum* L.) is grown each year between 1955 and 1984. The simulation was run continuously over this period and continuous chickpea, while not realistic due to disease constraints, is used to represent a simple baseline cropping enterprise. Each chickpea crop was planted based on a sowing criterion of receiving 25 mm rainfall over a five-day period between 1 May and 25 July using the cultivar Amethyst sown at 30,000 plants/ha.

The windbreak consisted of one hectare on the edge of the paddock planted with *E. argophloia* at 5 x 5 m spacing resulting in 400 trees planted in 4 rows. The trees were assumed sown at the beginning of this simulation in 1955 and they reached a height of approximately 25 m by the end of the simulation in 1984. The extent of the tree-crop competition zone was assumed to be equal to three times the height of the trees for *E. argophloia* (see Section 3.3). This “rule of thumb” was used in the model to specify expansion of the tree root system into the neighbouring cropping land. Both edge and inner trees have access to deeper soil resources in soil directly below them. The edge zone was set to consist of only one row of trees as indicated by surveys of existing windbreaks within this region.

This case study was used to report the agroforestry simulation capability of APSIM in an invited journal paper submitted by Huth et al. (2002).

Simulation results

APSIM was configured to simulate the growth of a hypothetical belt of trees positioned adjacent to annual crops of chickpea. Figure 4.2 presents the simulated growth of the belt of trees over the 30-year period. The differing rates of wood production from trees positioned inside the belt compared to those on the belt's edge are the result of the increased water supply to the edge trees in this low rainfall environment. Trees on the belt's edge are able to capture resources from the adjacent cropland. This analysis clearly demonstrates the need for separating the tree area into the two functional zones of inner and edge trees. Also noticeable is the relatively constant annual growth rate of edge trees in this highly variable environment – annual rainfall for Dalby between 1955 and 1984 ranged from 380 mm to 1031 mm. Whereas total annual rainfall could explain over 50% of the variation in simulated annual increment in stem wood volume for the trees inside the tree belt, the correlation was much lower for the edge trees (where rainfall accounted for only 11% of the variation). The trees growing on the side of the tree belt were able to use water from the cropping land during extended dry periods to maintain relatively higher growth rates.

Figure 4.3 shows how wind speed (as a fraction of open field wind speed) across the transect is affected by the age and height of the simulated trees. As the trees grow, the extent of the sheltered zone within the field increases such that, by the age of ten years, there is a sheltered zone of several hundred metres. The impact of this sheltering on subsequent crop yield is indicated in Figure 4.4b. While the level of yield enhancement due to a windbreak effect is quite small, the spatial extent of this increased production may result in a significant overall response to the shelter.

The increased yields due to shelter will be offset by the yield depression due to competition for soil resources. Figure 4.4b also shows various levels of yield depression as a result of the state of the soil, climate and tree belt. In this environment, storage of rainfall during the summer fallows is important for supplementing rainfall during the cropping season. Much of the competitive nature of the tree-crop interface can be found in the reduced soil water storage near the trees at sowing time (Figure 4.4a). The prevailing climate and tree size led to a wide range of competitive levels simulated throughout the life of the tree belt.

The long-term benefits of planting trees on farms to protect the environment from downstream salinity impacts are evident in Figure 4.5. Reduction in water drainage below the crop root zone is not limited

to the area under the trees but extends across the entire tree root zone within the field (assumed to be 3H). As a result, total simulated drainage loss across the field has been reduced by 7.5% by reforestation of just 4% of the area.

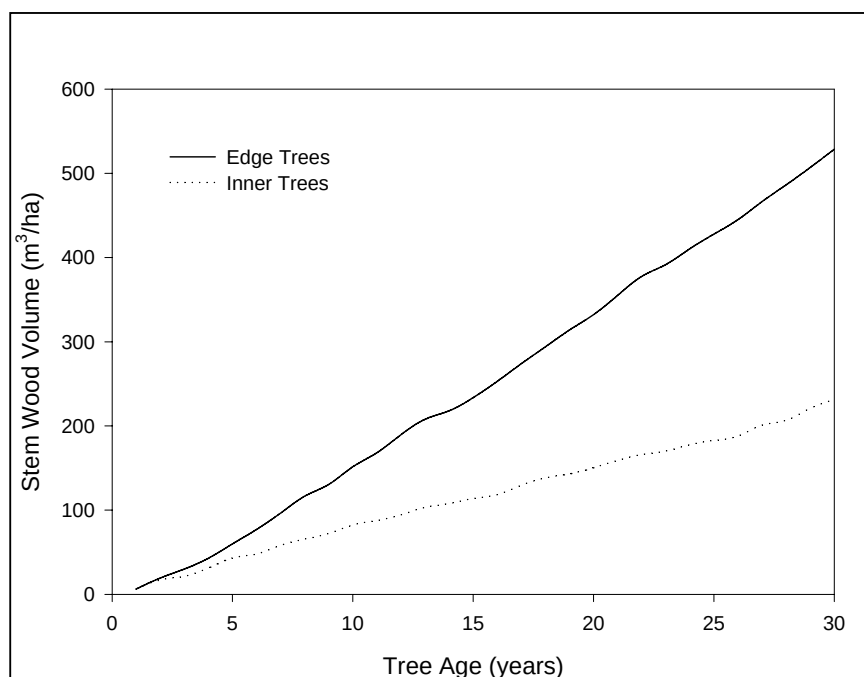


Figure 4.2: Simulated standing wood volume (over bark) of tree stems for the inner and edge trees during the 30-year simulation period.

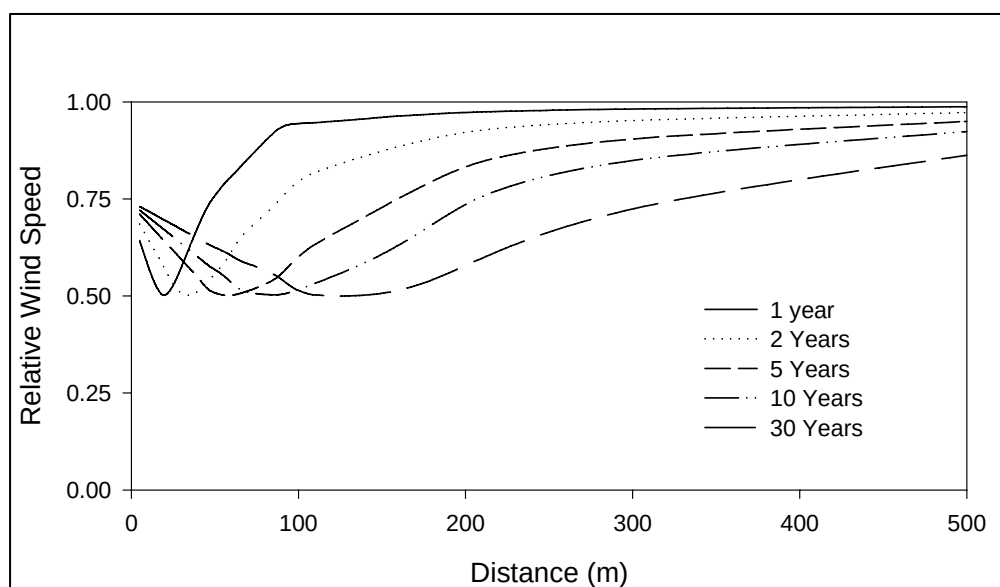


Figure 4.3: Simulated wind speed (relative to open field) for up to a distance of 500 m downwind from the windbreak. Data are shown for various ages of trees up to 30 years.

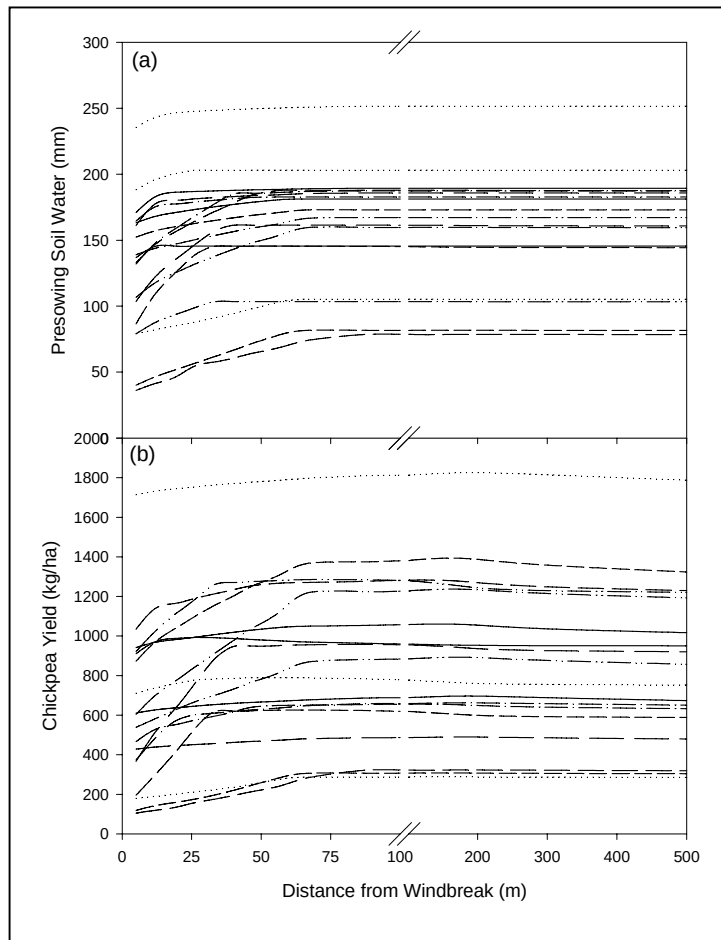


Figure 4.4: (a) Pre-sowing extractable soil water and (b) chickpea yield for up to 500 m down wind from a windbreak. Each line represents a different season within the 30-year simulation period. Note the break and scale change in the X-axis.

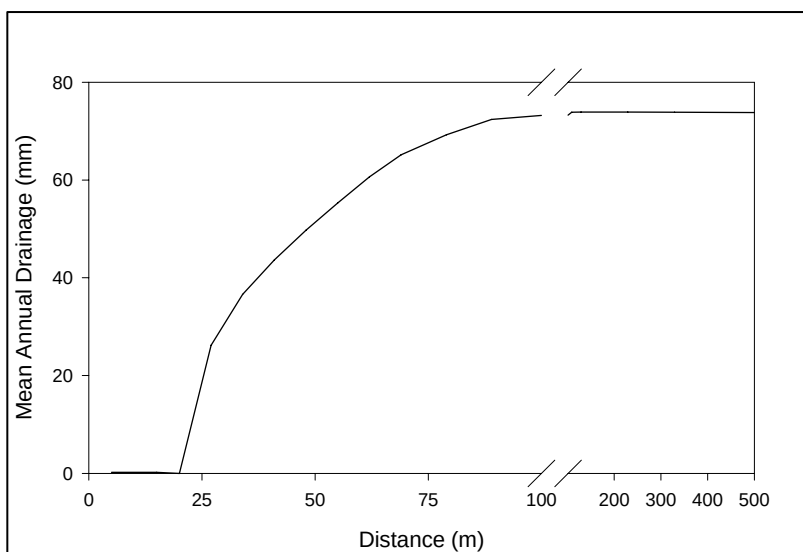


Figure 4.5: Mean annual drainage below 2.7 m for a 500 m transect from the edge of the paddock. The tree belt is 20 m wide. Note the break and scale change in the X-axis.

Economic analysis

The economic analysis assumed a 25 ha paddock measuring 500 m x 500 m. The benchmark scenario was 25 ha of chickpeas. The agroforestry system assumed that 1 ha on the edge of the paddock was planted with *E. argophloia* at 5 m x 5 m spacing resulting in 400 trees planted in four rows (one edge and three inner rows) – the remaining 24 ha were planted with chickpea. The following price/cost assumptions were used:

- Chickpea: price = \$420/t; variable costs = \$220/ha
- *E. argophloia*: price = \$60/m³ (sawlogs sold at stump). The variable costs comprised \$1350/ha in the establishment year (site preparation, trees, planting, pre-plant weed control, immediate post-plant weed control), \$675/ha in the second year (post-plant spraying, first pruning/thin) and \$500/ha pruning costs in years 5, 10 and 15. In addition, \$20/ha was added in years 3-30 for fire control.
- A discount rate of 6% was applied to a 30-year investment
- Real prices for year 2002 were used with no adjustment for inflation.

The net present values for the agroforestry system and open field benchmark for the 30-year period are summarised in Table 4.1. To highlight the effect of discounting on the performance of each investment, the same summed net cash flows without discounting are also presented. Sensitivity testing is performed for three establishment costs (\$900, \$1350 and \$2000/ha). Because the discounting process erodes the value of future cash flows, the establishment costs, which are incurred at the start of the investment period, could be expected to have the most significant impact on the NPV and on the time taken for the paddock to generate positive cumulative net cash flows, also known as the payback period.

While simply totalling the net cash flows of the two systems indicates that agroforestry generates at least \$11,000 of extra net income, the corresponding NPVs indicate that the annual cropping option is the marginally better performing system in this instance. This occurs because the discounting process erodes the value of income generated from trees at the end of the investment period. The large lag period between the time of capital outlay and return from the investment is a critically important issue for farmers to consider. Over the 30-year period, the differences in establishment costs did not appear to have a major impact on NPV. However, the short-term effects on cash flow are more significant.

Table 4.1. Net Present Values (NPV) for the agroforestry system, the open field benchmark and the difference (agroforestry NPV - benchmark NPV) for three establishment costs over a 30-year period.

Establishment cost (\$/ha)	Discounted returns			Equivalent, non-discounted returns		
	NPV (\$) Agro-forestry	NPV (\$) Benchmark	Difference (\$)	NPV (\$) Agro-forestry	NPV (\$) Benchmark	Difference (\$)
900	31,835	32,354	- 519	73,312	61,135	12,177
1350	31,385	32,354	- 969	72,862	61,135	11,727
2000	30,735	32,354	- 1619	72,212	61,135	11,077

Annual and cumulative net cash flows are presented in Figure 4.6. For both systems, annual net cash flows display year-to-year volatility. Cumulative cash flows for the agroforestry system do not catch up to the benchmark system until the final year of the investment period when the trees are sold. The annual difference between the cash flows for years 1-29 is shown in Figure 4.6c. The final year cash flow difference of \$18,321 is omitted from this graph to allow the axis to be restricted to a range of net incomes permitting closer examination of the variations. For the assumed prices and costs, there are only three years where cash flows for the agroforestry system are higher than for the benchmark. In years when tree management expenses are not incurred, the difference in cash flows between the two systems is usually small. However, differences in favour of the benchmark system of up to \$430 did occur.

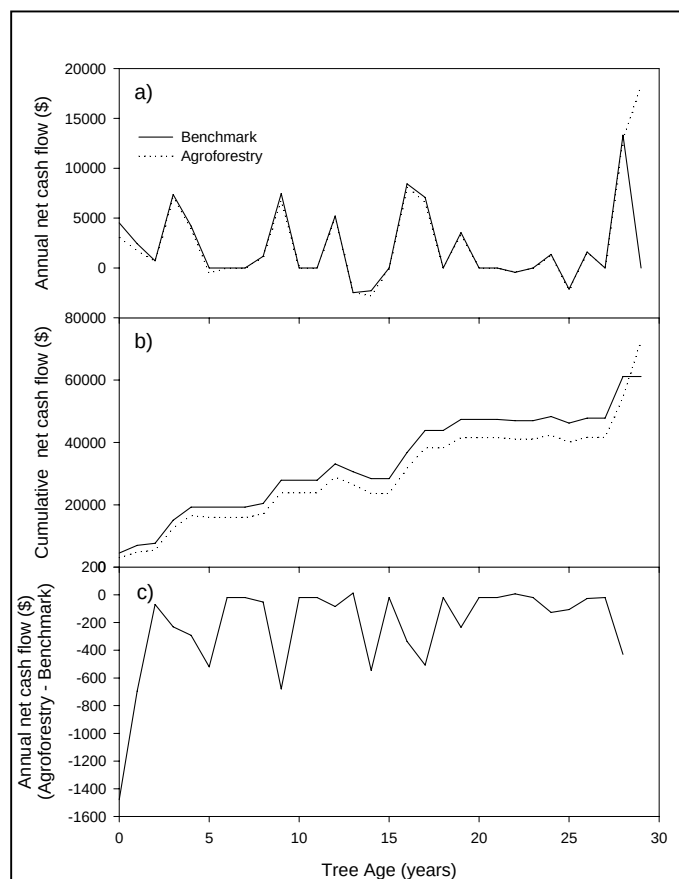


Figure 4.6. Net cash flow for a 30-year tree belt growing cycle: (a) annual cash flow for benchmark system (solid line) and agroforestry system (broken line); (b) cumulative cash flow; and (c) difference in annual cash flow between benchmark and agroforestry systems for years 1 to 29 of the investment.

4.3 Economic assessment of planted Chinchilla white gum in northeast Australia

The case study presented in Section 4.2 can be used as the basis of an assessment of the economic consequences for planting timber trees as windbreaks at selected locations in northeast Australia. *E. argophloia* is widely proposed and currently planted in medium to low rainfall regions in this climatic zone. However, little information exists on the expected long-term production of this species for these areas. Nor is there much information on the economic consequence of planting trees as windbreaks adjacent to commercial cropping paddocks.

The objective of the following analyses is to undertake a preliminary assessment of the economic benefits and costs of planting *E. argophloia* as windbreaks on paddocks with a continuous wheat cropping system as the standard benchmark system.

System description

As with the system described in Section 4.2, the following analyses assess *E. argophloia* windbreaks for five sites (Table 4.2) in northeast Australia. The windbreak system consisted of a belt of white gums planted on the edge of a 50 ha paddock (measuring 1000 m x 500 m), with a winter crop of wheat grown each year between 1955 and 1984. The simulations were run continuously over this

period at each site. The wheat crops were planted at each site each year based on a sowing criterion of receiving 20 mm rainfall over a seven-day period between 20 April and 9 July using the wheat cultivar Hartog sown at 100 plants/m². A typical grey vertosol soil was used at all sites – the soil could potentially hold approximately 200 mm of plant available water to the maximum wheat rooting depth of 1.5 m.

The windbreaks on one edge of the paddock consisted of 1 kilometre planted with *E. argophloia* at 5 m x 5 m spacing resulting in 800 trees planted in 4 rows (i.e. 2 ha of trees). The trees were sown at the beginning of this simulation in 1955 and thinned at five and 10 years of age. Each thinning resulted in the removal of one third of remaining trees, representing one quarter of the standing stem volume.

The extent of the tree-crop competition zone was assumed to equal three times the height of the trees and the edge zone was assumed to consist of only one row of trees.

Table 4.2. Sites used in the simulation of *E. argophloia* windbreaks.

Site Information			Climatic Summary 1955-1984		
			Mean Annual Rainfall	Median Annual Rainfall	Mean Annual Temperature
Site Name	Latitude	Longitude	Mm	Mm	°C
Emerald	23.5 °S	148.2 °E	668	580	22.3
Dalby	27.0 °S	153.0 °E	650	599	18.3
Roma	26.6 °S	148.8 °E	630	550	20.5
Moree	29.5 °S	149.9 °E	609	621	19.1
St George	28.0 °S	148.6 °E	548	533	20.6

Simulation results

Tree Growth

Predictions of tree growth at final harvest are summarised in Table 4.3. Caution should be used in interpreting these results given the low level of knowledge of *E. argophloia*, but several properties of these simulations indicate the differing characteristics of agroforestry systems across climatic gradients. Production of the inner trees declined with the mean annual rainfall of the sites. This clearly indicates the dependency of forest production upon rainfall in the low to medium rainfall zone. This same trend, however, was not observed in the growth of the edge trees. The simulation specifications for each site are identical apart from the weather data used. Climate can affect the level of resource use via several mechanisms, including:

- Affecting the competitive ability of the wheat crop – differences in seasonal rainfall patterns can influence whether the crop or tree is best placed to use rainfall. Radiation and temperature levels can influence the yield potential of the crop with flow-on effects on soil water demand. Similarly, areas with higher evaporative potential will result in crops competing more aggressively for soil water resources, which might impact on the amounts of extra water available to edge trees.
- Affecting the growth potential of the tree crop – if trees are grown outside their niche environment they may not be able to achieve the levels of increased growth first expected by the level of enhanced water resource. The law of the minimum may come into play. For example, a tree grown in a cold environment may be water limited within the woodlot. The edge trees, having access to extra water resources may be limited more by temperature. As a result, the relative growth of the edge trees would no longer directly indicate that level of enhanced water supply.

- Affecting the levels of resource losses - loss mechanisms such as deep drainage and surface soil water evaporation remove water that would otherwise be available for plants. Winter-dominant rainfall patterns can lead to drainage losses higher than experienced in areas of summer-dominant rainfall patterns. In the fallow field next to trees, the level of losses will affect the amount of fallow rainfall stored and available for consequent use by the trees. In the same way, the variation in stubble dynamics due to difference in wheat yields may influence the surface water balance loss terms such as evaporation and runoff.

The range of mechanisms described above is likely to be responsible for the variation in level of enhanced simulated growth of the edge trees described in Figure 4.7. Here the relative growth rate of the edge trees to the inner trees (the “edge effect”) varied significantly between the sites. Analysis of the key meteorological statistics for each site could find no single factor to describe the range of simulated responses and so the behaviour is likely to be the result of several complex processes.

Table 4.3. Predicted total standing stem volume (over bark) and mean annual increment at final harvest for the five simulation sites.

Site Name	Stem Volume at Age 30 years m ³ /ha		Mean Annual Increment m ³ /ha/yr	
	Inner	Edge	Inner	Edge
Emerald	187	432	6.3	14.4
Dalby	157	435	5.2	14.5
Roma	140	311	4.7	10.4
Moree	130	237	4.3	7.9
St George	120	295	4.0	9.8

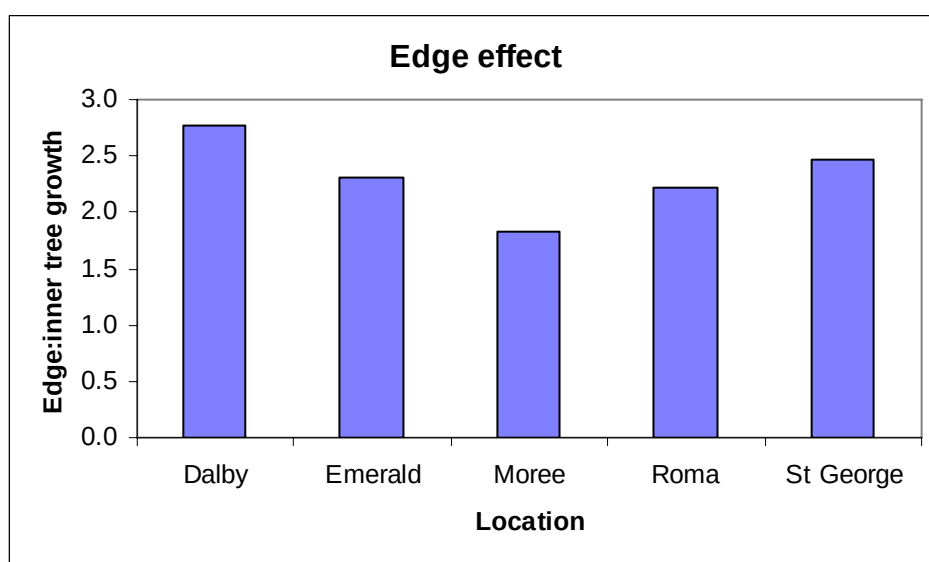


Figure 4.7. The simulated “edge effect” (growth of edge trees relative to inner trees) for five sites in northeastern Australia.

Crop Growth

Planting opportunities for wheat crops were observed in at least 25 years of the simulation period. The average yield transect for these seasons is shown in Figure 4.8. Only slight long-term yield enhancements in the protected zone were simulated at each site – increases in average yield in the sheltered zone ranged from 3.6% at St George down to 2.4% at Moree. St George also showed the

greatest level of average yield depression next to the trees (0.93 t/ha). Emerald showed the lowest level of average yield depression next to the trees (0.64 t/ha).

Deep drainage

The impact of trees on deep drainage can be seen across the entire tree root zone which extends up to 75 m from the edge trees by year 30 (Figure 4.9). Drainage declines closer to the trees because of the simulated higher demand for soil water resources and the longer period of root residency. These simulated transects of drainage closely resembled those determined in other studies (Ellis et al., 1999; Ellis et al., 2001).

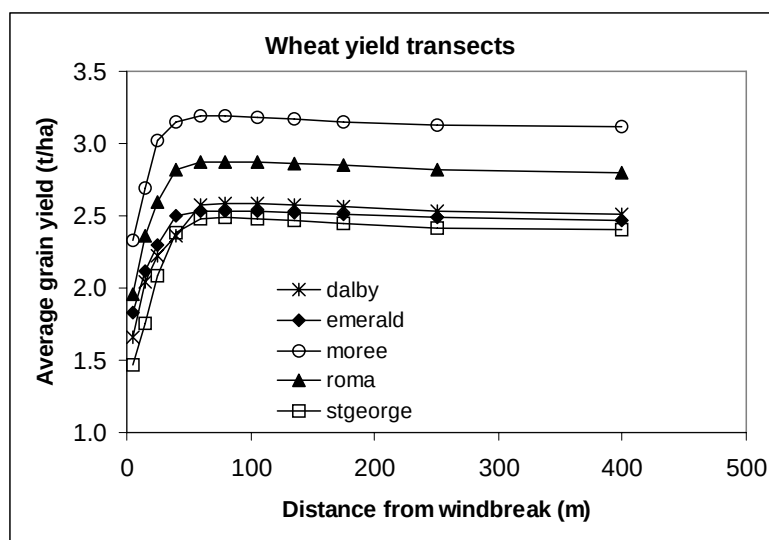


Figure 4.8. Transects of average simulated wheat yields (t/ha) for five sites in eastern Australia.

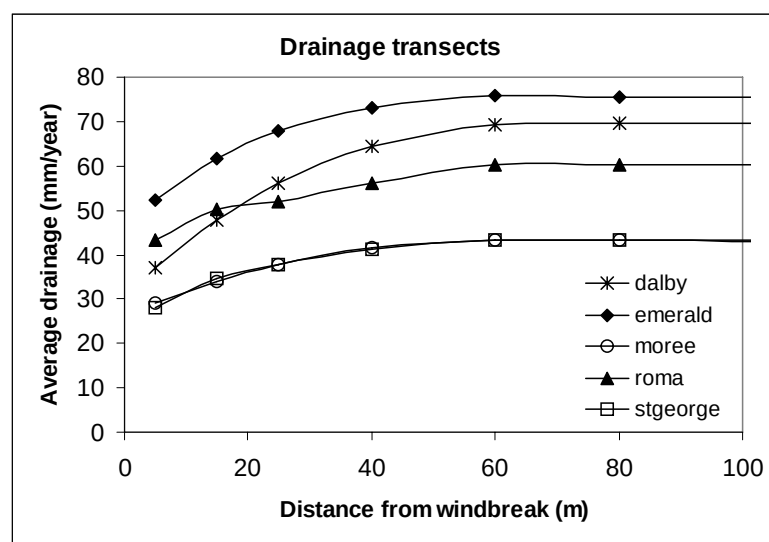


Figure 4.9. Long-term average annual deep drainage (mm) for five sites in eastern Australia.

Economic assessment

Prices and costs

The economic analysis assumed, in this case, a 50 ha paddock, measuring 1000 m x 500 m. In these analyses, the benchmark scenario was 50 ha of wheat. The agroforestry system assumed that 1 kilometre on the edge of the paddock at each site was planted with *E. argophloia* (2 ha) at 5 m x 5 m

spacing resulting in 800 trees planted in four rows (one edge and three inner rows) – the remaining 48 ha were planted with wheat. The following price/cost assumptions were used:

- Wheat: price = \$170/t; variable costs = \$200/ha
- *E. argophloia*: price = \$60/m³ (sawlogs sold at stump). The variable costs comprised \$1350/ha in the establishment year (site preparation, trees, planting, pre-plant weed control, immediate post-plant weed control), \$675/ha in the second year (post-plant spraying, first pruning/thin) and \$500/ha pruning costs in years 5, 10 and 15. In addition, \$20/ha was added in years 3-30 for fire control.
- Millable timber was assumed to be 90% of simulated tree biomass (Paul Ryan, personal communication)
- A discount rate of 6% was applied to a 30-year investment
- Real prices for year 2002 were used with no adjustment for inflation.

In order to evaluate scenarios that permitted the planting of trees to be at an advantage, tree prices and costs were altered as follows:

- *E. argophloia*: price = \$100/m³; variable costs comprised \$350/ha in the establishment year (assuming that site preparation, tree seedlings and planting costs were subsidised or costs greatly reduced by economies of scale or technology improvements) and \$300/ha in the second year (no post-plant spraying, and subsidised pruning/thinning); other costs remained unchanged.

Using the above economic data and simulations for each site, the NPV of the benchmark wheat system was subtracted from the NPV of the proposed agroforestry system to determine the difference in discounted returns for planted *E. argophloia* windbreaks – this difference was expressed on an annual basis (by calculating an annuity on a per kilometre of planted trees per year of investment (\$/km/year)). The difference in equivalent non-discounted returns and in unmanaged windbreaks was also calculated. Unmanaged windbreaks were assumed not to be thinned nor pruned, thus saving on these costs but foregoing the sale of timber in year 30.

Finally, assuming the lower establishment costs of \$650/ha over the first two years, the price of timber was calculated for each site whereby the discounted return from the agroforestry system at least equalled that for the standard wheat cropping system. This timber price provides an index of the likely success of the proposed agroforestry system at each site.

Results

Assuming a timber price of \$60/m³ and variable costs of \$2025/ha over the first two years, the differences in discounted and non-discounted returns (\$/km/year) of *E. argophloia* windbreaks relative to the sole wheat benchmark are presented in Table 4.4. Under these economic assumptions, the planted *E. argophloia* windbreaks were not profitable at any site – losses ranged from -\$225/km/year at Emerald to -\$699/km/year at Moree. If the trees are not managed by thinning and pruning and thus the timber not sold in year 30, the losses are significantly higher at all sites. Only if future costs and returns are not discounted (essentially a discount rate of 0%) does the agroforestry system become profitable relative to a standard wheat cropping system and then only at Emerald, Dalby and Roma.

With a higher timber price of \$100/m³ and lower variable costs of \$650/ha, the difference in discounted and non-discounted returns (\$/km/year) are presented in Table 4.5. At these prices and costs, Emerald and Dalby returned discounted profits of \$113 and \$22/km/year respectively. Discounted returns at the remaining sites were negative, with Moree still losing -\$449/km/year even with a better price:cost ratio. Conversely, non-discounted returns were attractively positive at all sites and unmanaged trees were universally unprofitable.

Table 4.4. The difference in discounted and non-discounted returns (\$/km/year) of either managed or unmanaged *E. argophloia* windbreaks relative to the benchmark of without windbreaks. Returns assumed a timber price of \$60/m³ and variable costs of \$1350/ha in year one and \$675/ha in year two.

Site	Non-discounted returns (\$/km/year)		Discounted returns (\$/km/year)	
	Managed	Not managed	Managed	Not managed
Emerald	406	-488	-225	-585
Dalby	227	-931	-295	-761
Roma	24	-1054	-392	-826
Moree	-152	-716	-699	-926
St George	-11	-1029	-498	-908

Table 4.5. The difference in discounted and non-discounted returns (\$/km/year) of either managed or unmanaged *E. argophloia* windbreaks relative to the benchmark of without windbreaks. Returns assumed a timber price of \$100/m³ and variable costs of \$350/ha in year one and \$300/ha in year two.

Site	Non-discounted returns (\$/km/year)		Discounted returns (\$/km/year)	
	Managed	Not managed	Managed	Not managed
Emerald	1049	-443	113	-487
Dalby	818	-885	22	-663
Roma	509	-1008	-117	-727
Moree	271	-670	-449	-828
St George	428	-984	-242	-810

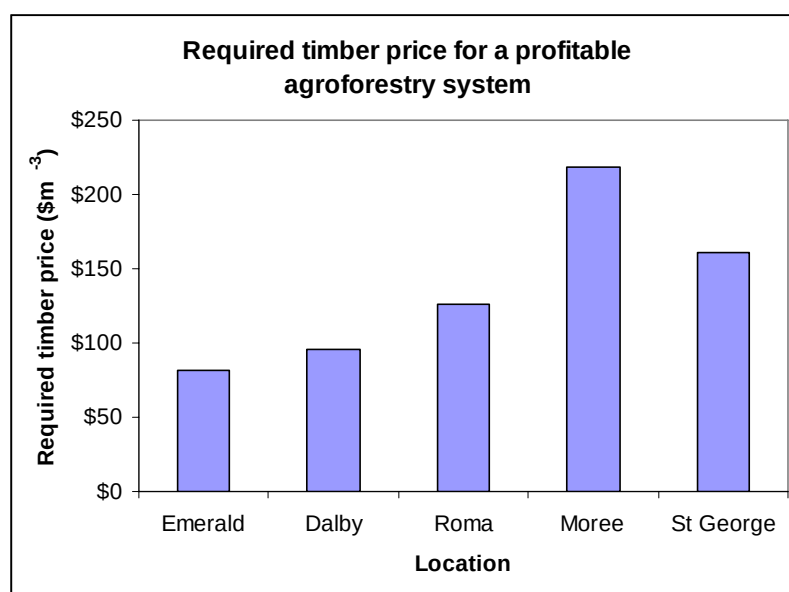


Figure 4.10. The price of timber required at each site whereby the discounted return from the agroforestry system equalled that for the standard wheat cropping system.

Figure 4.10 shows the estimated price for timber required at each site to allow the discounted return from the agroforestry system to at least equal that for the standard wheat cropping system at each site. The most favourable location for the simulated agroforestry system was Emerald in Central Queensland and the least favourable was Moree in northern NSW. These results appear to be directly correlated to the relative growth performance of the trees and wheat. At Emerald, the simulated growth of trees was the fastest (Table 4.3) and the average simulated wheat yields were amongst the lowest (Figure 4.8). The good growth of trees at Emerald could therefore offset the relatively small loss of wheat yield from tree competition. Conversely, tree growth at Moree was slow and wheat yields were high, which necessitated high timber prices to offset the relatively large reduction in wheat production due to tree competition. Whether a crop rotation of winter and summer crops would influence these results remains to be tested.

Conclusions

This scenario analysis has explored the paddock-scale economic profitability of establishing *E. argophloia* windbreaks at five sites in northeast Australia using the APSIM systems model. Caution should be used in interpreting these results given the minimal level of experience in simulating *E. argophloia*. However, several properties of these simulations indicate the differing characteristics of agroforestry systems across climatic gradients. At the prices and costs forecast for timber production (\$60/m³ and \$2025/ha), the economics of *E. argophloia* windbreaks appear unattractive at all sites under the production scenarios simulated by APSIM. Such agroforestry systems only begin to compete with the current practice of dryland wheat production if establishment costs can be significantly reduced (via subsidies or reduced cost establishment) or if prices for timber rise. For farmers to plant *E. argophloia* windbreaks on their dryland wheat paddocks would require them to value such windbreaks in more than economic terms, e.g. for their aesthetic value or for their environmental impacts such as in reducing drainage (Figure 4.9).

4.4 Assessment of a hypothetical oil mallee system in Western Australia

In low and medium rainfall regions of Australia, the economic returns from long-rotation tree crops established within agroforestry systems are often low or negative – this result was well demonstrated in the case study described in Section 4.3. With an end-product realised far into the future, many landholders see little economic incentive to plant long-rotation timber trees. In contrast, short-duration tree crops (2-5 years production) may be viewed far more favourably within agroforestry systems if their economic performance can match that for dryland cropping systems in low and medium rainfall regions of Australia.

In Western Australia, oil mallee eucalypt trees are being actively trialled as a prospective “tree crop” for the low-rainfall regions (Enecon, 2001). The advantages of oil mallee trees are their adaptation to low rainfall environments, their suitability for integration as hedges within wheat systems, and their commercial potential within short-rotation harvest systems. Oil mallee produces marketable eucalypt oil, as well as charcoal and activated carbon products from its wood (Enecon, 2001). More information on oil mallees is available at www.oilmallee.com.au.

While this project committed no resources to addressing oil mallees, the following analysis of a hypothetical “oil mallee” system is attempted in order to demonstrate the ready capability of APSIM to accommodate new systems. It also brings attention to the economic performance of short-duration tree crops relative to that for the longer-duration agroforestry systems on which this project and others have concentrated (see Section 4.3). It should be noted, however, that the following simulated and economic results are for a hypothetical “oil mallee” system and have not been tested against actual data.

System description

The following analyses assess oil mallee hedges at three sites in Western Australia – Esperance (mean annual rainfall of 500 mm), Narrogin (498 mm) and Merredin (320 mm). Figure 4.11 shows the average monthly rainfall for these three sites.

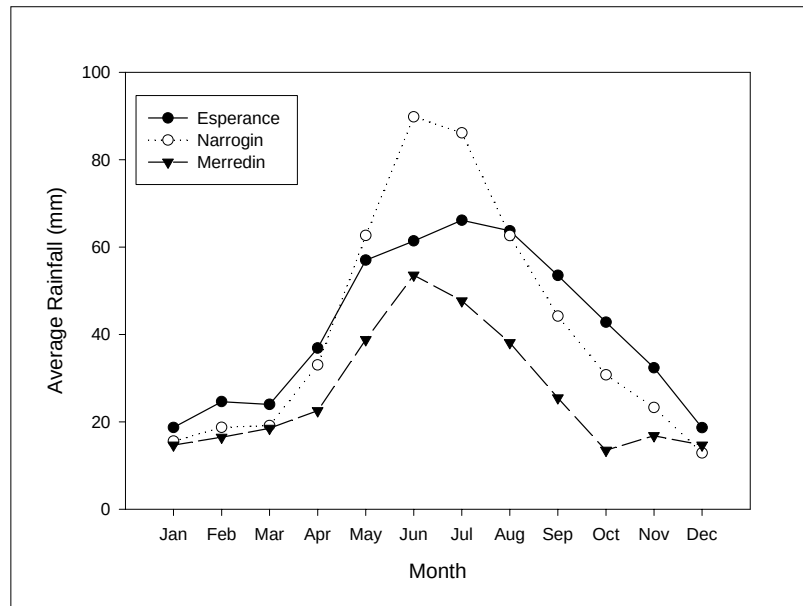


Figure 4.11. Average monthly rainfall for the three case study sites in Western Australia.

APSIM was configured for an oil mallee agroforestry system as recommended on the www.oilmallee.com.au web site. Briefly, a multiple tree belt system was set up that consisted of a belt of oil mallees planted on the edge of successive 10 ha blocks (measuring 1000 m x 100 m), with a winter crop of wheat grown in between belts each year. Each belt consisted of two oil mallee hedges, containing two rows of trees. The centres of the hedges were assumed 4 m apart and the rows within hedges 2 m apart. Allowing for some canopy extension into the paddock would result in an overall belt width of 10 m. The trees within each row were assumed planted at a 1.5 m spacing, which equated to 2666 trees/ha within the area planted to trees. This configuration provided a revegetation cover of 10%.

Growth parameters specified in APSIM-Forest for the oil mallee trees were assumed to reflect those for other drought-tolerant eucalypts – simulations were checked against the reported average productivity of oil mallees in this region. Partitioning of assimilate into leaves and stems was set so that foliage mass represented approximately one third of above-ground biomass at the time of harvest.

The simulations assumed a duplex soil profile, with a 60 cm loamy sand A horizon overlying a clay B horizon. Roots from the wheat crop could extend only 30 cm into the B horizon. Oil mallee roots could extend vertically to the notional bottom of the soil profile at 3 m. In addition, the tree root systems were assumed to extend 16 m into the neighbouring cropping land. These lateral roots could fully explore the sandy A horizon, but could only extend 30 cm into the clay subsoil (Rob Sudmeyer, personal communication).

Simulations were run continuously for the climate data at each site between 1971 and 2000 (30 years). Wheat was assumed sown during the months of May and June upon a sowing rain of 20 mm received within a 7-day window. An initial fertiliser addition of 20 kg N ha⁻¹ was followed by a further 20 kg N ha⁻¹ application in mid July.

No establishment phase for oil mallees was simulated. Rather, the oil mallees were assumed already established and a short-rotation (2-3 years) coppice system was simulated. In this system the trees were harvested in early September on a 2-year harvest cycle. At Merredin tree growth was set to extend to a third year if tree fresh weight was simulated to be less than 11 kg per tree in poor seasons.

Simulation results

The simulated tree productivity from a hypothetical “oil mallee” system at three sites in WA is presented in Figure 4.12. The simulated above-ground tree biomass ranged from 20,000 to 30,000 kg ha⁻¹ dry weight across the three sites. With 2666 trees per hectare and an assumed biomass moisture content of 40%, the fresh weight of individual trees was simulated to range from 13-19 kg per tree. This result is consistent with the recommended harvestable size of 15 kg per tree for a two year coppicing system (Enecon, 2001). The simulated fresh weight of trees average 16.8 kg/tree at Esperance, 16.1 kg/tree at Narrogin and 15.2 kg/tree at Merredin. There was only one postponed tree harvest at Merredin over this 30-year period.

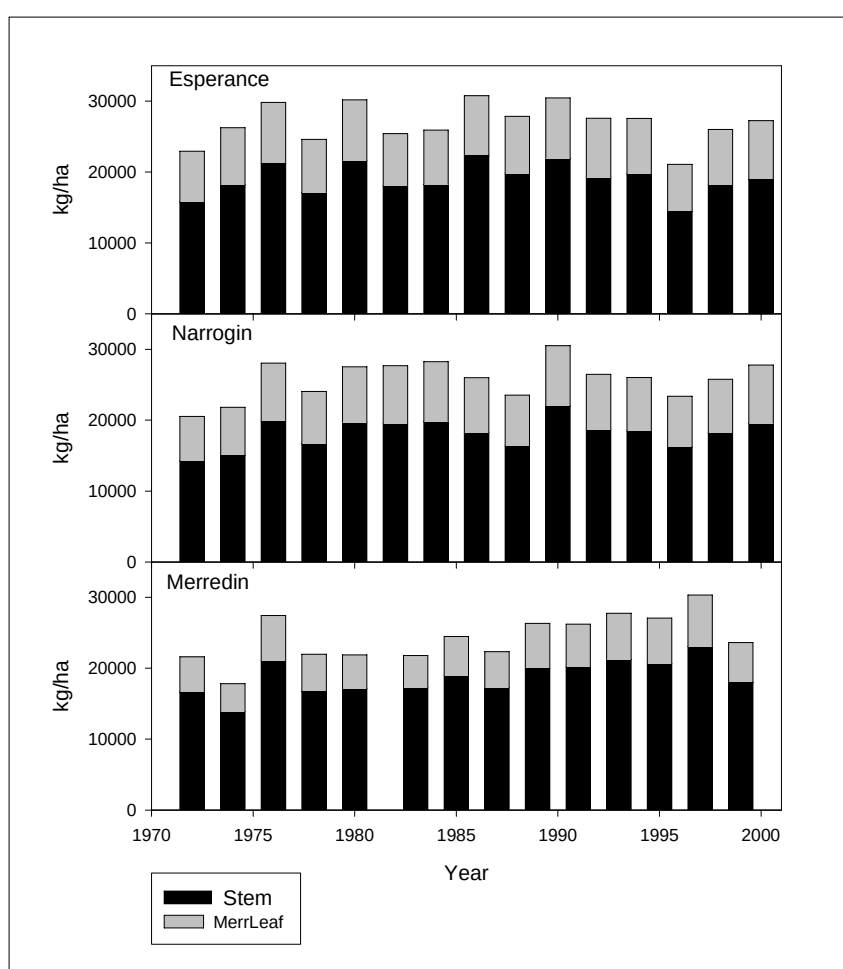


Figure 4.12. Simulated stem and leaf biomass (kg ha⁻¹ dry weight) harvested from hypothetical “oil mallee” trees grown at three sites in WA. Results represent pooled growth from the simulated inner and edge trees.

Simulated transects of wheat yield at Esperance are presented for each of the 30 years in Figure 4.13. The simulated open-field yields averaged 2.9 t ha⁻¹, but yields were highly variable across seasons. The competition zone with tree roots was assumed to extend for 16 m into the crop and there was significant competition for water and nitrogen in this zone in all years – the average simulated yield

reduction was 65% at 2 m from the tree belt and it was still 46% at 10 m from the belt. A similar outcome was simulated for Narrogin – the simulated open-field yield averaged 2.9 t ha^{-1} , with average reductions of 60% and 39% at 2 m and 10 m respectively from the tree belt. At Merredin, average open-field yields were lower (1.8 t ha^{-1}) and the impact of tree competition was slightly less – 63% and 18% reductions at 2 m and 10 m respectively from the tree belt.

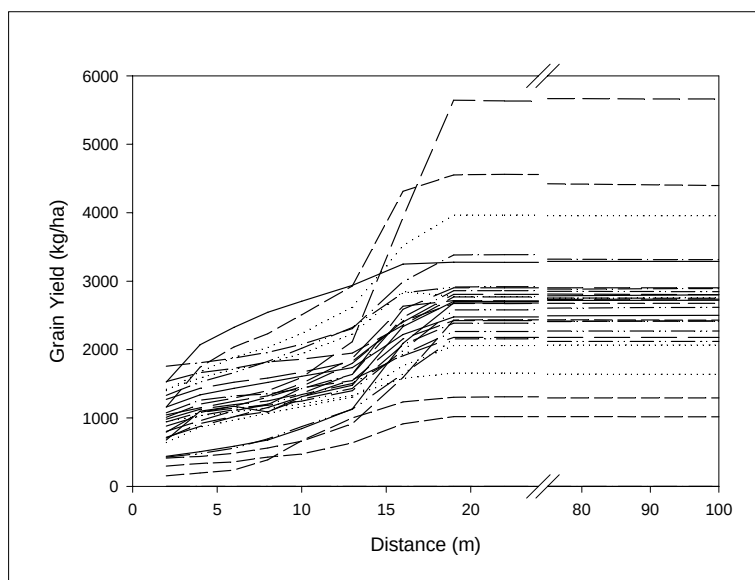


Figure 4.13. Simulated transects of annual grain yield for wheat crops grown adjacent to oil mallee hedges at Esperance (1971-2000). Tree roots were assumed to extend to 16m. Note the break and scale change in the X-axis.

A simple economic analysis can be undertaken using the simulated wheat and oil mallee yields. This analysis assumed an on-farm price of $\$15 \text{ t}^{-1}$ for oil mallee biomass (net of harvest costs and costs of transport to the processing plant) and an annual maintenance cost of $\$20 \text{ ha}^{-1}$ of trees (Herbert (2000)). Wheat prices were assumed at $\$170 \text{ t}^{-1}$ with variable costs of $\$200 \text{ ha}^{-1}$. As no establishment phase was simulated for oil mallee trees, the following comparisons are strictly on average annual gross margins calculated for a standard continuous wheat system versus an established agroforestry system consisting of continuous wheat grown between belts of 10 m wide oil mallee hedges. To explore the impact of belt spacing, the economic performance of the agroforestry system was undertaken for belts that were assumed to be either 200 m, 100 m or 50 m apart, representing 5%, 10% and 20% revegetation cover respectively.

The average gross margins for the four systems—the baseline of sole wheat and the three agroforestry systems—are presented for the three sites in Figure 4.14. At Esperance and Narrogin, the baseline of continuous wheat was clearly simulated to return the highest average gross margin and returns decreased as the oil mallee belts came closer together. For oil mallee to compete with wheat under the assumptions used in this study, its price would have to increase to over $\$40 \text{ t}^{-1}$ and this still does not account for establishment costs. In contrast, the highest average gross margin at Merredin was simulated for the agroforestry system with oil mallee hedges situated 100 m apart. The price of oil mallee would have to fall below $\$8 \text{ t}^{-1}$ for this system to become comparatively unprofitable.

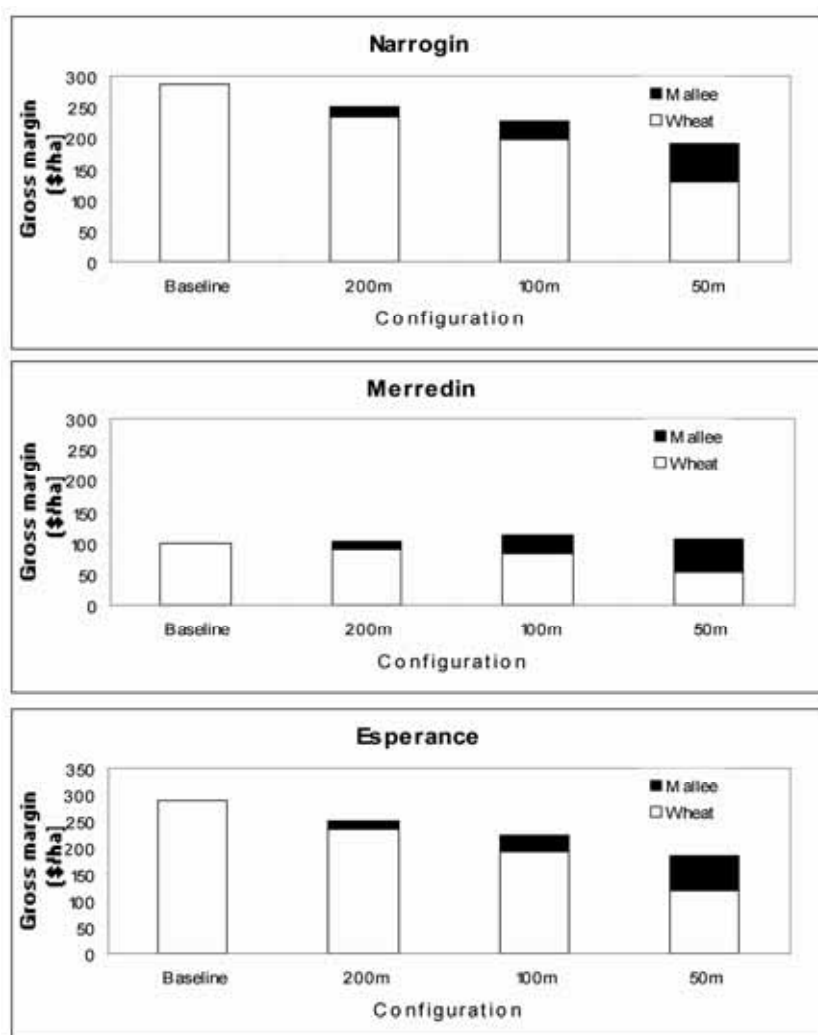


Figure 4.14. Average gross margins at three sites simulated for the baseline of sole wheat and the agroforestry systems with belts spaced 200 m, 100 m and 50 m apart. The contribution of either wheat or oil mallee to \$ ha⁻¹ returns is indicated.

Conclusions

In viewing this case study, one must remember that the simulated productivity of the proposed agroforestry system is based on a hypothetical system for which few parameters were known for configuring APSIM. While the simulated productivity of the oil mallee trees was consistent with reported values, the simulated competitive impacts of oil mallee hedges on adjacent wheat crops are unconfirmed. Likewise, the baseline simulation of wheat gross margins is substantially higher than the \$50-\$80 ha⁻¹ year⁻¹ opportunity costs of land used in other studies (Herbert, 2000; Enecon, 2001). For these reasons, the results presented here should not be taken as representing the projected performance of oil mallee hedges in WA.

The purpose of this simple case study was to demonstrate the ready capability of APSIM to accommodate new agroforestry systems. APSIM can dynamically simulate the productivity of trees and crops as well as the impacts of tree-crop interactions for new sites and scenarios. For example, tree-crop competition is a key determinant of the economic performance of agroforestry systems and one that has not been explicitly addressed in some economic analyses (e.g. Herbert, 2000). APSIM's capability to dynamically quantify the competitive impacts from agroforestry hedges can add new knowledge to the assessment of such systems. This hypothetical case study has well demonstrated this capability.

5. Simulation of agroforestry systems with farmers and advisers

Recent APSRU experience has demonstrated that simulation is a powerful learning tool in assisting farm managers to explore their farming system (Carberry et al., 2002b). As part of this project, a number of pilot “What IF Analysis & Discussion” sessions (WIFADs) using APSIM were planned for groups of landholders to enable the viability of agroforestry investments or retention of existing shadelines to be explored in the context of individual’s own farms. These WIFAD sessions were to be conducted principally in the northern cropping region.

The scarcity of good datasets on tree-crop interactions for northern Australia necessitated the project to invest significant resources and time into collecting new data from planted windbreaks and remnant shadelines in southeast Queensland – see Chapter 2 above. This unexpected effort led to significant delays in establishing the capability within APSIM for simulation of relevant agroforestry systems for the northern cropping region. Consequently, the original plan for at least six pilot WIFADs with farmers and their advisers was not fully completed. Five discussion sessions using APSIM agroforestry simulations were undertaken with nine landholders and their advisers and several research and extension officers working in the region.

The sessions that were conducted included interactions with:

- Nevin Olm, Jeff Bidstrup and Wade Bidstrup, farmers at Warra, Qld, each of whom have planted *E. argophloia* windbreaks on their three farms. Nevin also coordinates the Brigalow-Jimbour Floodplain Landcare Group. Their reasons for planting trees included an intention to harvest wood, to stop spray drift, to screen farm operations from adjacent roadways, and aesthetic and biodiversity values. The meeting was held at Nevin Olm’s office in February 2002.
- Michael Castor, Paul Castor, Paul Gardoyle, agronomic consultants with Michael Castor & Associates (MCA) at Goondiwindi, Qld, who have a number of clients with tree remnants on their properties. The meeting was held at MCA offices in February 2002.
- Geoff and Mary Woods and their son David, farmers at Billa Billa, Qld who have maintained over 90 km of remnant Brigalow-Belah windbreaks on their property. Although aware that the trees were impacting on their wheat crops, they liked having trees on the property and valued their biodiversity and wildlife corridor benefits. The meeting was held on their property “Coorangy” in March 2002.
- Jeff Esdaile, agricultural consultant, Tamworth, NSW and former farm manager of Livingston Farm, Moree, NSW, who has expressed an interest in the planting of *E. argophloia* windbreaks on Livingston Farm. The meeting was held in Toowoomba in April 2002.
- Peter Voller, Chris Chilcott, Warwick McGrath, Lili Peach and John Grey (all with the Queensland Department Natural Resources and Mines), and John Rolfe and Geoff Cockfield who are both economists with the University of Southern Queensland, Toowoomba. Each of these research and extension officers is currently exploring different forms of agroforestry systems in Queensland. Discussions centred on the quantification of the economic consequences of establishing or maintaining trees on farm as assessed by this project. This meeting was held in Brisbane in May 2002.

The following sections provide brief reports on these interactions.

5.1 Remnant shadelines at Moonie, Queensland

As reported elsewhere in this report, the property “Coorangy”, located south-west of Moonie, is owned by Geoff and Mary Woods, and with their son David they run a mix of enterprises encompassing dryland cropping and grazing cattle on their 3600 ha. Most paddocks on the property have remnant brigalow-belah shadelines on their boundaries.

When asked about the impact of these trees on their crops, Geoff responded that the trees were likely costing them “*a heap*”. However, David stated that the trees had the benefit of preserving moisture in the protected zone – he referred to the report of George-Jaeggli et al. (1998) who had measured the yield impacts of their shadelines during the 1997 season.

Geoff and Mary Woods stated emphatically that they valued the remnant vegetation on their property for its contribution to biodiversity and wildlife corridors. They acknowledged that the trees probably “*don’t do us much good from a business point of view*”. They believed that their positive attitude to trees was influenced by their relatively comfortable financial situation as they could afford to accept the loss in cropping area and the competition from the trees.

In preparation for this meeting, multi-point APSIM was set up and run for the system of remnant brigalow-belah shadelines as found on “Coorangy”. These simulations used APSIM-Forest that was parameterised to simulate steady-state brigalow trees as described in Section 3.3. The simulations assumed a 35 ha square paddock consisting of 2.1 ha of trees along a 1 km paddock edge and 32.9 ha of adjacent dryland wheat. Wheat was simulated every year with wheat gross margins calculated using a price of \$170/t and variable costs of \$200/ha. Simulations were run for all years between 1950 and 2001 (52 seasons).

Figure 5.1 shows the simulated gross margin (GM, \$/km) difference between the current system on the property, of wheat crops grown adjacent to remnant shadelines, and the alternative of wheat crops grown in paddocks without shadelines. In 46 out of 52 seasons (88.5%), the presence of remnant trees resulted in gross margin losses – the average GM loss was -\$1692 per km of trees.

Assuming only a third of the property is cropped each year (1200ha), an average paddock size of 200 ha and trees along all four boundaries of each paddock, the calculated length of the tree-crop interface each year is 33.9 km. This length of interface would result in an annual average loss for the whole property of -\$52,552 per year. In other words, leaving native trees on the boundaries of their wheat paddocks was likely to be costing the Woods family over \$50,000 per year in lost wheat income.

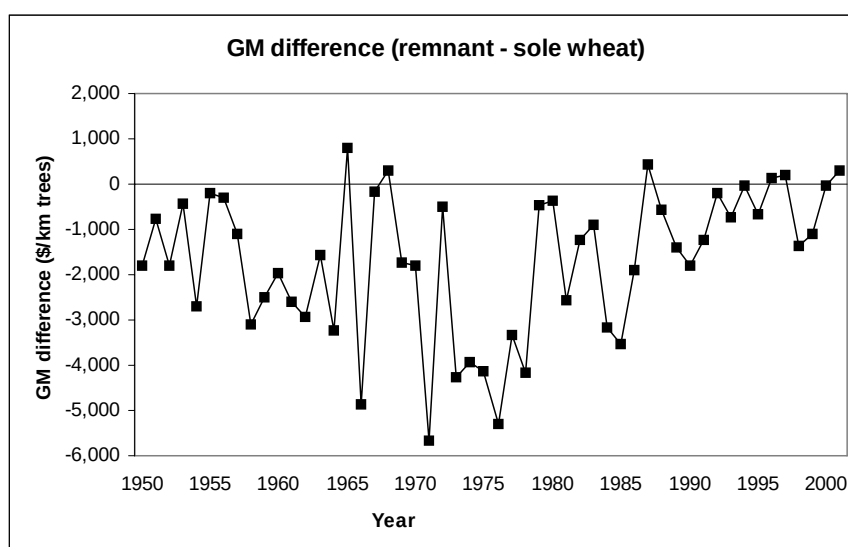


Figure 5.1. Simulated gross margin (GM, \$/km) difference between wheat crops grown adjacent to remnant shadelines versus crops grown in paddocks without shadelines.

The impact of trees on crop yields and gross margins can be reduced by deep ripping along the edge of the remnant vegetation to prune tree roots. This situation was simulated by removing tree roots from the surface 30 cm of the multi-point APSIM simulations. Figure 5.2 shows the change in gross margin between root-pruned and unpruned simulations. The average benefit from root pruning was \$144 per km trees per year. By pruning 34 km of shadelines per year, these simulations suggest a benefit of almost \$4900 per year, although the costs of pruning have not been deducted.

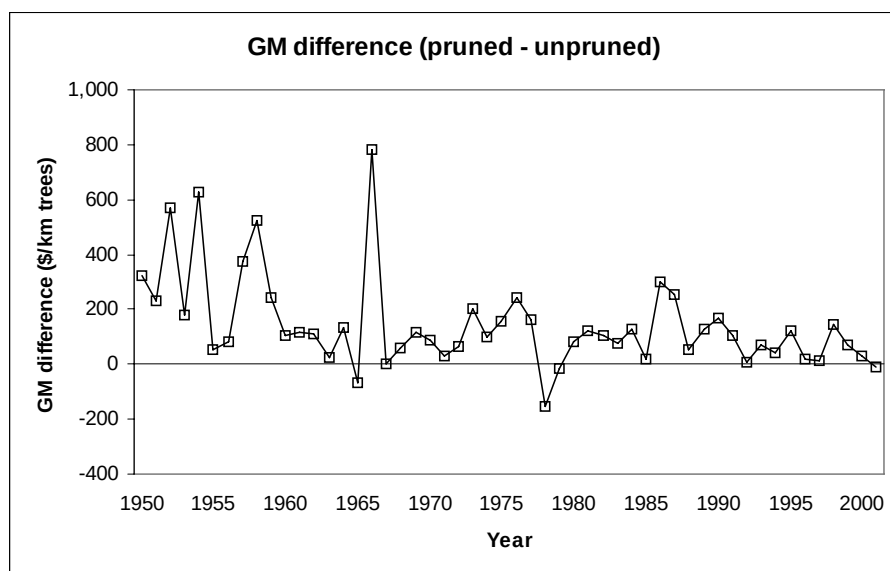


Figure 5.2. Simulated gross margin (GM, \$/km) difference for wheat crops grown adjacent to remnant shadelines that have been root pruned versus unpruned.

The reaction of Geoff and Mary Woods to the presented simulation results was to confirm their desire to keep the remnant vegetation on their property. They were not worried by the estimated cost of keeping native vegetation on their farm.

Geoff Woods was most impressed by the simulated value for root pruning as he had been previously unconvinced about its value. The simulations suggested that root pruning may be well worth doing, although an understanding of effectiveness of repeated root pruning would need to be gained in order to judge the longer term feasibility of such a management scenario.

Both Geoff and Mary were impressed with the simulation capability of APSIM. They suggested that its agroforestry capability would be most useful in allowing landholders without remnant vegetation to assess the consequences of planting trees on their farms.

While pleased and interested in the simulation session, at its end, Geoff commented “*It wasn’t all good news ... maybe it wasn’t so good to know how much the trees were costing!*”.

5.2 Chinchilla white gums planted at Warra, Qld

The property “Prospect” at Warra, owned by Jeff Bidstrup and his son Wade, has also been represented in other sections of this report. The property has a number of paddocks planted with windbreaks consisting of *E. argophloia*. To date, a total of 7.7 km of trees were planted in 1996 and 1998 in both north-south and east-west configurations. The property produces dryland cotton, wheat and sorghum crops.

Jeff and Wade Bidstrup cited the benefits of planting trees as assistance in stopping spray drift, in screening farm operations from highway traffic, their aesthetic appeal, and possible future economic returns. They acknowledged observed yield losses in the competition zone next to the planted trees but

they planted these windbreaks to gain experience. The establishment of the trees was done on advice from forestry experts but Jeff thought that maybe fewer rows and lower densities might have been better. He volunteered that issues such as planting configurations could be explored using APSIM – Jeff has had prior experience with APSIM simulations in his dryland cropping management.

The *E. argophloia* - wheat system simulated in Section 4.3 for Dalby approximately represents the agroforestry system currently practised on “Prospect”. To recap, the simulations were for a 50 ha square paddock consisting of 2 ha of trees planted along a 1 km paddock edge and 48 ha of adjacent dryland wheat. The trees were assumed planted in 1955 and harvested in 1984. Wheat was grown every year with wheat gross margins calculated using a price of \$170/t and variable costs of \$200/ha. Establishment and maintenance of the trees averaged \$90/year over the 30 years and, in year 30, the trees were assumed sold at stump for a price of \$60/m³. These establishment costs were provided by Nevin Olm and are lower than those used in Section 4.3 due to available subsidies for tree planting.

Figure 5.3 indicates that the cumulative cash flow from the agroforestry system is always less than for the wheat system until the final year when the trees are harvested and there is significant cash return from the agroforestry system. Over the 30 years, the agroforestry system returned an average added benefit of \$460 km⁻¹ trees year⁻¹ over the continuous wheat system. However, if a 6% discount rate was applied to the returns from these two systems, the agroforestry system would have resulted in an average loss of \$-103 km⁻¹ trees year⁻¹. If the agroforestry system was not managed to produce quality timber products (eg. thinned and pruned) then it would have resulted in an average loss of \$-585 km⁻¹ trees year⁻¹ (non-discounted) and \$-296 km⁻¹ trees year⁻¹ if discounted.

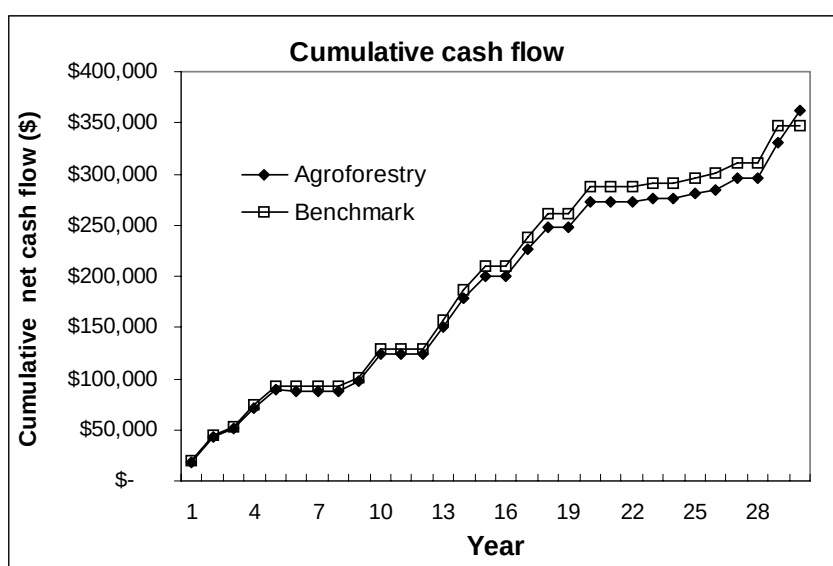


Figure 5.3. The cumulative cash flow from 50ha of an agroforestry system and a benchmark wheat system.

For Jeff and Wade Bidstrup, these analyses suggested that their 7.7 km of *E. argophloia* windbreaks, if managed, equated to a non-discounted return of \$3545 year⁻¹ or a discounted loss of -\$795 year⁻¹. Jeff expressed surprise at the discounted loss, as he had hoped that “*we might have made more dollars from the trees*”. Nonetheless he reaffirmed his previously stated view that the trees were planted for multiple reasons and were not solely considered in monetary terms.

During the discussions, the deep drainage simulations for the agroforestry system (Figure 4.9) were also presented. These simulations created considerable debate with some scepticism of the drainage numbers under the wheat crop expressed by the attending growers. This debate clearly defined the role of using models such as APSIM to explore multiple facets of agricultural systems.

All attendees expressed interest in the simulation session. Nevin Olm subsequently published the results of the simulations in the newsletter for the Brigalow Jimbour Floodplains Group (No. 29, April 2002).

5.3 Conclusions

All discussion sessions were very successful with participants most interested in simulated results related to their own or their clients' circumstances. In response to viewing simulations, a number of new analyses were requested of the simulation and economic models, including requests to alter price and cost scenarios and to add the impacts of root pruning. No participant questioned the veracity of the simulation outputs as they were willing to believe APSIM, given the total absence of alternative "real" data on either the 30-year productivity of *E. argophloia* or the impacts of trees on crop performance.

Participant reaction to the results was mixed. The predicted loss from a managed *E. argophloia* windbreak system at a 6% discount rate was regarded as disappointing. Participants were keen to alter price and cost figures for the trees in order to find the situations for when such a system would become profitable. However, the predicted cost of their planted trees was not of great concern and was traded-off against the other benefits of trees (biodiversity, spray drift protection).

Likewise, Geoff and Mary Woods confessed to realising their remnant brigalow-belah strips were costing "a heap" but they were willing to wear this cost. While the predicted cost per year for keeping the remnant vegetation surprised them for being so large, they remained committed to maintaining such remnants.

The two analyses reported above were closely specified to the situations of the interested landholders. These same analyses can be readily repeated for other locations and for the circumstances of other landholders. The intention is to make this capability available to landholders interested in agroforestry options.

6. Implications and recommendations

The achievements of this project included:

- The specification of APSIM multi-point simulations for the conceptual agroforestry system consisting of belts of trees established along the borders of cropping paddocks. This system incorporated the simulation of the differential growth of inner and edge trees, as well as crop yield losses due to tree competition, and yield increases due to windbreak protection.
- The initial parameterisation of APSIM-Forest to enable the dynamic simulation of the growth of several tree species, including *Eucalyptus argophloia* (Chinchilla white gum), *Eucalyptus globulus* and *Pinus pinaster*, and the simulation of steady-state growth of brigalow (*Acacia harpophylla*). The simulation of tree growth and productivity was tested against limited datasets.
- The testing of APSIM multi-point simulations against measured data for four tree-crop systems located in Queensland and WA. Simulations performed satisfactorily against limited data, but there were significant deficiencies in the data available for model parameterisation and testing.
- Demonstration of the ready capability of APSIM to accommodate alternative agroforestry systems through a case study analysis of a hypothetical short-duration “oil mallee” system in WA. The simulated productivity of oil mallee hedges was consistent with values reported elsewhere and suggested that short-duration trees grown within agroforestry systems are at least as profitable as traditional cropping systems at some locations.

The research undertaken by this project resulted in a new capability to assess the viability of agroforestry options in the medium to low rainfall regions of Australia. A number of tools currently exist to help evaluate agroforestry investments (e.g. the Agroforestry Calculator, see www.rirdc.gov.au/reports/AFT/99-154.pdf; the Farm Forestry Toolbox, see Warner 2007). APSIM can dynamically simulate the growth of crops, trees and their main interactions in response to the climate, soil and management options applicable at any selected location in Australia. APSIM’s capability thus permits the economic and biophysical consequences of either planting trees or retaining native vegetation to be assessed quantitatively and realistically.

A new tool, if unused by decision-makers, provides no real benefit. The pilot discussion sessions using APSIM with landholders and their advisers indicated a strong interest in using APSIM to explore management options for agroforestry systems on their own farms. While these initial sessions were few, there remains considerable interest in further discussions with landholders. However, how this new capability can potentially be made available to many more landholders around Australia remains an issue. Access to APSIM is currently offered as an on-line subscriber system for wheat and barley crops nationally via the www.yieldprophet.com.au web interface. Whether agroforestry systems can be included in such systems requires market research to determine likely demand.

The economic scenario analysis undertaken using APSIM simulations for five sites in northeast Australia (Emerald, St George, Roma, Dalby and Moree) indicated that at the prices and costs forecast in 2002 for timber production (\$60/m³ and \$2025/ha), the economics of *E. argophloia* windbreaks would be unattractive at all sites. The simulations found that while simply totalling the net cash flows of the two systems indicates that agroforestry generates at least \$11,000 of extra net income, the corresponding NPVs indicate that the annual cropping option is the marginally better performing system in this instance. This occurs because the discounting process erodes the value of income generated from trees at the end of the investment period. The large lag period between the time of capital outlay and return from the investment is a critically important issue for farmers to consider. Over the 30-year period, the differences in establishment costs did not appear to have a major impact on NPV. However, the short-term effects on cash flow are more significant.

However such agroforestry systems began to equate economically with the current practice of dryland wheat production when establishment costs were significantly reduced and timber prices were increased. Under improved economic scenarios, the most favourable location for the simulated agroforestry system was Emerald in Central Queensland and the least favourable was Moree in northern NSW. For farmers to plant long rotation *E. argophloia* windbreaks on their dryland wheat paddocks, the balance between timber price and established costs would need to improve significantly, or they would have to value windbreaks in more than economic terms, e.g. for their aesthetic value or for their environmental impacts, such as in reducing drainage or soil erosion. Whole farm benefits beyond the paddock were not simulated.

There remain significant barriers to using APSIM as a routine advisory tool on agroforestry options for landholders. While the APSIM multi-point framework has been developed, its parameterisation and testing is troublesome given the scarcity of data on the growth parameters of suitable tree species and on the interactions between trees and adjacent crops. An important imperative therefore is to invest in obtaining such data and in testing APSIM against actual agroforestry systems and in a greater range of environments. It is the intention of the Agricultural Production Systems Research Unit (APSRU)⁴, a joint venture between several Queensland agencies including CSIRO, to continue the development, testing, and application of this new capability.

This model could be used in the future with new data on tree-crop interactions and environmental values including carbon, to evaluate new farm forestry and agroforestry systems at the paddock scale.

⁴ The Agricultural Production Systems Research Unit (APSRU) is an unincorporated joint venture between: Queensland Department of Primary Industries and Fisheries, CSIRO Sustainable Ecosystems, Queensland Department of Natural Resources and Water, CSIRO Land and Water, and the University of Queensland.

7. References

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