Tradeoffs in Dryland Agroforesty: Birds vs Dollars

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Keywords: *Model, Competition, Habitat Complexity Score, Species Richness, APSIM*

EXTENDED ABSTRACT

There are numerous reasons why landholders are looking at revegetating parts of their farms. There is also a range of ways in which these efforts can be configured and managed. The degree to which each design will achieve various social, biodiversity, natural resource or economic goals is not always understood. Woodlots can be different sizes and shapes and the trees can be managed differently in order to meet specific needs. In addition to this, trees can impact on the surrounding farm enterprise and these costs or benefits need to be managed. This study demonstrates a new way to quantify both the biodiversity benefits and economic costs of small agroforestry woodlots.

Perhaps the largest cost of woodlots to landholders is the lost production of high value agricultural products. This lost production extends outside the boundary of the woodlot as edge trees compete with neighbouring cropland for water and nutrients. This competition zone has been found to extend up to three times the height of the trees into surrounding farmland and so thin strips of trees can affect areas much larger than their internal area. As a result, landholders need to consider woodlot shape when fitting woodlots within an existing farm.

The biodiversity benefit of a woodlot is determined by the size and structural complexity or habitat value of the particular agroforestry enterprise. These benefits can be offset by increased costs associated with displacing larger areas of agricultural production, often with marginal return to the landholder. Similarly, the benefits of altered woodlot structural complexity, via the incorporation of grass or shrub components is not well understood but is likely to result in decreased productivity of the woodlot itself.

In this paper we describe a case study that seeks to tease out the tradeoffs involved for agroforestry in dry land farming systems on the Darling Downs in Queensland, Australia. The designs of various agroforestry enterprises are evaluated in terms of the net effect on production and habitat value for woodland birds. Models of different scales and levels of complexity are used to explore tradeoffs between biodiversity benefits and economic costs.

Key insights into ways in which trees and crops could be managed include:

1. Manipulation of the structure of low-quality habitat as found in agroforestry systems can result in trading off one habitat structural element for another with very small net effects. For example, competition for water by an added grass layer results in a smaller tree canopy.
2. Economic costs of such a planting are best minimised by structuring the woodlot to shorten the rotation length. This has a minor effect on long term habitat value.
3. Production losses can be minimised by ensuring a minimum woodlot width of 50m or placing the woodlot against roadways or remnant forest.
4. Agronomic changes to surrounding agricultural land may be able to reduce the production footprint of an agroforestry planting.
5. Further analysis is required to compare the relative value of block plantings with very short-rotation low value habitat such as strips of trees.

1. INTRODUCTION

A large amount of effort is being put into revegetating much of Australia's agricultural land to restore hydrological balance and biodiversity values. The challenge will be to attain these goals whilst minimising tradeoffs with the agricultural production that underpins the livelihoods of those living in these areas. Whilst much has been done to understand the benefits or costs of agroforestry at a landscape or woodlot level, little has been done to study the way such an undertaking might fit into an existing farm, and how it might be designed to manage the perceived economic, ecological and natural resource tradeoffs.

In this paper, we study the effect of various key agroforestry woodlot attributes on such tradeoffs and suggest a range of management options to maximise the benefits of agroforestry whilst minimising negative impacts. To do this, some simple relationships are developed from available data to describe the agricultural production losses and biodiversity gains associated with agroforestry. These are then used to study a range of agroforestry scenarios developed from simulations of a case study site using a detailed point-based model. The impacts and recommended management of various agroforestry designs are then described from these results.

2. ACCOUNTING FOR PRODUCTION LOSSES

In order to quantify tradeoffs, insight into the production losses resulting from establishment of a woodlot is required. Previous studies have shown that tree-crop competition can lead to significant crop production losses (Sudmeyer et al 2002, Huth et al 2002). A field study was undertaken to quantify these for northern cropping systems and to develop a simple model for studying tradeoffs and management strategies.

2.1 Method

Monitoring of tree growth, crop production, tree-crop competition, deep drainage and associated salt leaching has been undertaken at a farm near the township of Warra, Qld (26.93°S, 150.93°E) where a belt of four rows of *Eucalyptus argophloia* at approximately 5 x 5 m spacing has been planted along the edge of fields used for the production of wheat, cotton and chickpeas. At the commencement of the study the trees were approximately seven years old with a height of 10 m which increased to about 12 m over the next two years (data not shown). This site has been previously studied for the impacts of these trees on commercial cropping and deep drainage (Huth et al. 2002). The soils of the area have been characterised as self-mulching grey vertosols (Harris et al. 1999)

Transects of crop yield were measured for wheat in the winters of 2004 and 2005 and for cotton during the summer of 2004/5. Measurements were taken at regular intervals out to a distance of 50 m from the edge of the trees in order to quantify the production losses in the tree-crop competition zone. Whilst complex models have been used in the past to quantify the yield and hydrological responses across the tree-crop interface (e.g. Huth et al 2002) a simple approach is used here which basically describes the loss as an effective width of production. For example, a 50% loss in production across a 50m transect is equal to a 25 m total loss of production. This approach is similar to that employed by Albertsen et al (2000).

2.2 Results

Crop yield transects for 2004 and 2005 are shown in Figure 1. Extreme competition from the trees resulted in total crop failure at distances of 10 to 22 m from the trees. Yields were depressed for distances of 30 to 40 m from the trees with a higher level of spatial variability than observed in the open paddock away from the trees. These data support the notion that the competition zone extends to roughly three times the height of the trees into the neighbouring field (Huth et al 2002, Sudmeyer et al 2002).

The equivalent production loss distances for the three crops shown in fig 1 are approximately 28 m (wheat 2004), 22.5 m (cotton 2004/5) and 14 m

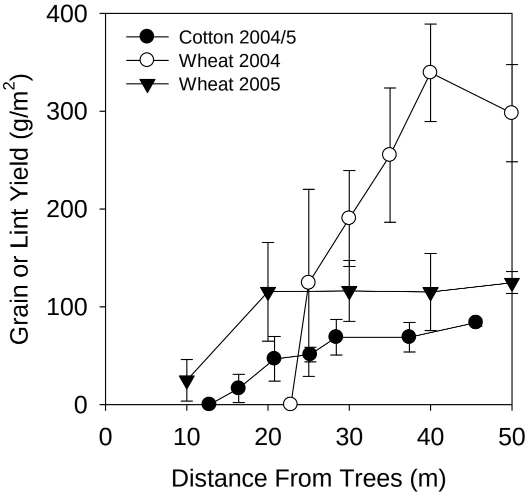

Figure 1. Yield of wheat and cotton crops during 2004 and 2005 at various distances from a *Eucalyptus argophloia* windbreak. Error bars indicate standard deviation from the mean.

(wheat 2005). Albertsen et al (2000) found much lower values for (<10m) *Eucalyptus globulus* tree belts in Western Australia, most probably due to the different climatic conditions and the improved competitive capability of those pasture systems. These authors also noted that the loss width increased with tree age. Such an obvious trend was also observed in Northern cropping systems (Huth et al 2002). For the sake of the simplification in the tradeoff calculations to follow, we will assume that the measured production loss width within the tree-crop competition zone is representative of an average value for the lifespan of a woodlot incorporating both the age of the trees and the cropping system in question. The effect of this simplification will be revisited in the later analyses.

3. ACCOUNTING FOR BIODIVERSITY VALUE

To analyse tradeoffs between ecological and production values one must also have some idea on how to calculate a biodiversity benefit. This is not easily done as biodiversity is a multidimensional attribute of the environment. To simplify these analyses we will constrain the analysis to a sub-set of values that may be important to the land manager considering agroforestry for its assumed biodiversity benefits. Of course, we are also constrained by the availability of data with which one can build a relationship for comparing scenarios. For these reasons, we have chosen a simple habitat quality score as a general model of biodiversity benefit for a given agroforestry enterprise type. To enable a comparison of scenarios of woodlot size, structure and shape, data for woodland bird species richness has been used to develop a new model based upon simple ecological principles. Woodland birds have been chosen for the case study because data are readily available and because they represent a range of vegetation dependant species highly valued by landholders.

3.1 Method

The distribution and abundance of woodland birds within a landscape depends upon variables such as the size and structural diversity of each patch. Tree, shrub, litter layer, log/rock and ground herbage cover has been shown to strongly influence the diversity of bird species in an area (Wiens 1989). The Habitat Complexity Score (HCS) developed by Catling and Burt (1995) is one such system for integrating a variety of structural elements into one index of habitat quality. Freudenberger (2001) modified this approach to study habitat requirements for a wide range of woodland bird species (Table 1). This system will yield an index between 0 and 18 where a value of 0-6 might represent woodland with poor structure, 7-12 grassy or shrubby woodland and a value of greater than 12 describes structurally complex woodland. In the analyses to follow, this model will be used to calculate an overall habitat quality score.

Table 1. Elements of the habitat complexity score used by Freudenberger (2001).

	Score			
Component	0	1	2	3
	Canopy Layer Cover (%)			
Tree Canopy	0-10	10-20	20-50	>50
Tall Shrub (2-4m)	0-10	10-20	20-50	>50
Short Shrub (0.5-2m)	0-10	10-20	20-50	>50
	Ground Layer			
Herbage	0-10	10-40	40-70	>70
Logs/Rocks	0-10	10-40	40-70	>70
Litter	0-10	10-40	40-70	>70

Freuedenberger (2001) recorded the woodland bird species present in a range of vegetation patches and showed that species richness responded clearly to patch size and quality, as described by a HCS. These data have been used here to develop a model of woodland bird species richness for a given patch based upon these two attributes. This simple model consists of a suite of species-area curves for habitat patches of a given HCS. The model is given in equation 1. Symbols are described in Table 2.

$$S = S_{\max}.\frac{HCS}{HCS_{opt}}.\min(1, \kappa A^{P}) \qquad (1)$$

Most of the model parameters have an obvious meaning and representative values could be easily suggested. For example, Smax represents the total number of species found in very large, high quality sites and so a value of 45 was taken from Freudenberger (2001). The same author found that species richness varied over the entire range of measured patch HCS and so the maximum observed value of 15 has been used here. The value of κ represents the fraction of the maximum number of bird species that would be present in a high quality patch of 1 hectare. The value of P determines the size of a patch at which S can reach Smax (i.e. Aopt). In this study, data was available and so we have instead fitted κ and P to the data of Freudenberger (2001). Only species classified as requiring a woody habitat have been included in the analysis.

Table 2. Definition of symbols used in the woodland bird species richness model.

Symbol	Description.
A	Area of vegetation, ha.
A_{opt}	Optimum vegetation area, ha.
κ	Constant term for species-area curve.
P	Power term for species-area curve.
HCS	Habitat complexity score.
HCS_{opt}	Optimal habitat complexity score.
S	Number of woodland bird species
S_{max}	Number of woodland bird species found in large area optimal habitat.

3.2 Results

The applicability of the given functional form is demonstrated in Figure 2. The observed data have been grouped according to site quality (i.e. HCS) into low (0-5), medium (5-10) and high (10-15) value sites to show the interaction between patch size and quality on bird species richness. Optimal values for κ and P were 0.399 and 0.142 respectively. These result in a value of approximately 640 ha. Predicted species area curves are shown for the average HCS for the sites in each quality range. The overall ability of the model to describe species richness across all the sites is shown in Figure 3. The model was able to account for 80% of the variation in species richness with a mean absolute error of 3.7. This error is likely due to inherent problems of determining species occurrence in each patch in the field as well as basic model error. One major source of error is likely due to the discrete index system of the HCS. According to the model, for large, high quality patches each HCS unit will result in 3 extra bird species. The field study recorded HCS components with a resolution of 0.5 HCS units. Such granularity is likely to cause significant noise in the predictions. On the whole, though, the model appears to capture the major drivers of bird species richness in habitat patches within agricultural landscapes.

4. ANALYSIS OF TRADEOFFS

To evaluate the options for managing tradeoffs in various agroforestry systems, a range of woodlot types were first simulated using the forest and pasture modelling capability within the Agricultural Production Systems Simulator (APSIM) (Keating et al, 2003). Simulations were conducted using soil properties and climate data (SILO Database, www.bom.gov.au/silo) for the experimental site at Warra, Qld.

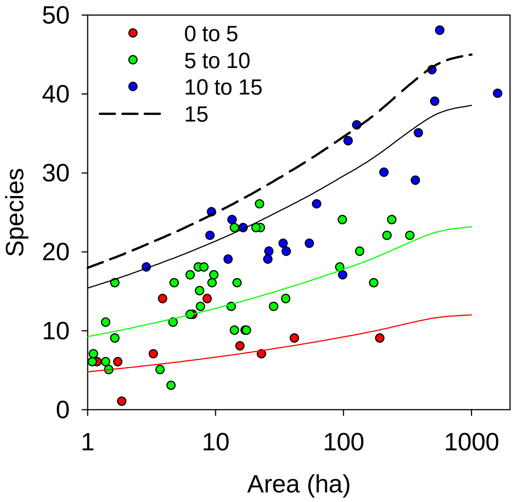

Figure 2. Observed (symbols) and predicted (lines) number of woodland birds for areas of different sizes. Observed data are grouped into according to site habitat complexity score. The predicted upper limit of woodland bird species richness is shown for comparison (dashed line).

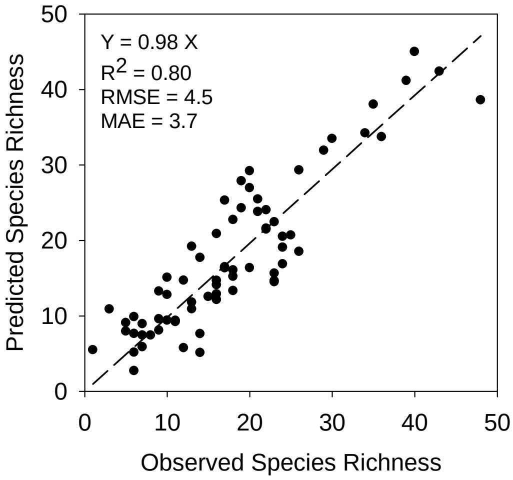

Figure 3 Predicted versus observed species richness of woodland birds. Summary statistics shown include the equation of the line of best fit through the origin (shown using dashed line), correlation coefficient, root mean square error and mean absolute error.

Four scenarios were simulated for woodlots of *E. argophloia*.

- T – Trees Only. Planted at 400 trees per hectare.
- TG – Trees + Grass. Planted at 200 trees per hectare. A pasture of *Panicum coloratum var. makarikariense* was sown beneath the trees however no grazing was simulated.

- TGS – Trees + Grass + Shrub. Planted with 200 trees per hectare and 200 shrubs per hectare as an understorey. To capture the effect of an Acacia understorey, nitrogen stress was removed from the shrubs to account for fixation.
- TE – Tree Edge. Trees on the edge of the woodlot have access to resources from the neighbouring agricultural land. Extra water and nitrogen was supplied to this simulation until growth rates matched those seen in the field.

Simulation results were used to create time courses of tree, shrub, grass and litter layer cover dynamics which were then used to calculate average annual HCS values for each scenario (Figure 4). These simulation results now provide estimates of woodlot production and habitat value. These can be used to evaluate each woodlot configuration for these two sets of values against various criteria.

If we assume that the trees in base scenario (T) are of harvestable size at age 40, we can use the results to determine a time to harvest for the other scenarios by comparing growth rates. The TG and TGS woodlots experience competition from the different understoreys and so production rates are lower; however stocking rates have been halved to concentrate this growth into fewer trees, thus reducing the time to harvest. Time to harvest varied greatly across scenarios from 53 years for TGS to only 15 years for the very productive trees in TE which had access to extra soil resources. This time to harvest has a large impact on the economic performance of the woodlot. Firstly, there is the cost of lost agricultural production for each year. In table 3 these costs have been expressed as a future value of an annuity where the annual payment is described in terms of 1 ha of production. Secondly, there is the cost of establishing the woodlot which we similarly describe on an area basis and assume the same value for each scenario. In these scenarios, revenue from the trees is assumed to be received only at time of harvest. Table 3 shows just how heavily time to harvest influences the total future value of lost production or establishment costs. Lower production rates for the TGS scenario delayed harvest such that the value of lost production at harvest was significantly higher than the other scenarios. Conversely, high growth rates of edge trees (TE) result in early harvest and compounding of production losses is minimised. The ratio of these costs to the timber volume at harvest indicates the relative value of the timber required to recoup costs incurred by the agroforestry enterprise in terms of years of agricultural production. The shorter rotation length for the TG scenario almost exactly offsets

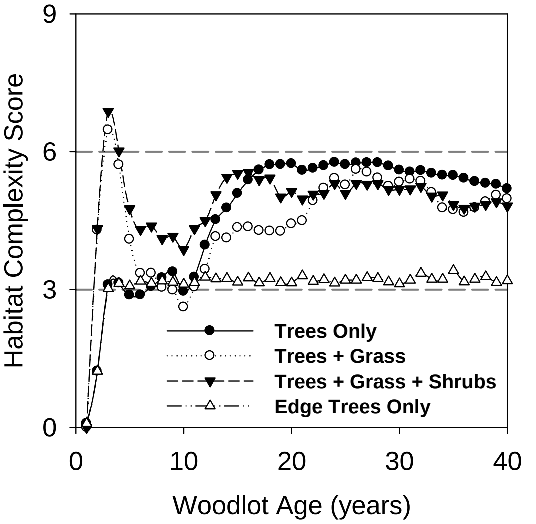

Figure 4. Habitat complexity score over time for four simulated woodlots.

Table 3. Outcomes from analysis of Tree Only (T), Trees+Grass (TG), Trees+Grass+Shrub(TGS) and Tree Edge (TE) scenarios.

	Scenario			
	T	TG	TGS	TE
Wood Volume (m^3/ha)	300	150	150	300
Time to Harvest (y)	40	29	53	15
Tree Growth Rate (m^3/ha/y)	7.6	5.3	2.8	20.6
Future Value of Lost Production (ha.y)*	155	74	349	23
Future Value of Initial Costs (ha.y)*	10.3	5.4	21.9	2.4
Break even value of timber for lost production (y/m^3)	.52	.49	2.3	.07
Break even value of timber for Initial costs (y/m^3)	.03	.03	.14	.01
Mean HCS	4.7	4.3	4.9	2.8
QAHY (y)	12.5	8.3	17.2	2.8
Mean Bird Species Richness**	7.0	6.4	7.3	4.3

* Assuming interest rate of 6%

** Assuming 5 ha woodlot

the lower timber volume obtained due to the lower stocking rate resulting in a similar timber value required to break even. The long rotation length of TGS would require a much higher timber value to recoup costs whereas the short rotation length for trees accessing agricultural land (TE) means that the value of the timber needs to only be a small fraction of that required for the basic woodlot (T).

Various measures of the biodiversity value of each scenario are included in table 3. The average HCS for the period from planting to harvest for each scenario did not differ greatly apart from that for TE. In such a rainfall-limited environment, moving cover from the tree layer to either shrub or grass layers simply changed the makeup of the HCS component scores but not the overall HCS value itself. This is not surprising given the similarity in scoring approach for each layer and the notion that such an environment will only maintain a given amount of leaf cover. The time trend in HCS differed between scenarios. High scores were received for grassy treatments early in the simulations until canopy closure, thereafter scores for litter layers increased resulting in staged increases in HCS. The TE scenario recorded consistently lower values as no understorey was said to exist due to extensive tree cover and the litter layer retained incomplete cover as high nutrient levels increased turnover rates. If we assume a 5 ha woodlot, we can convert these HCS values into a predicted average woodland bird species richness value. The low number of birds for each scenario helps us put the range of HCS values into some sort of perspective.

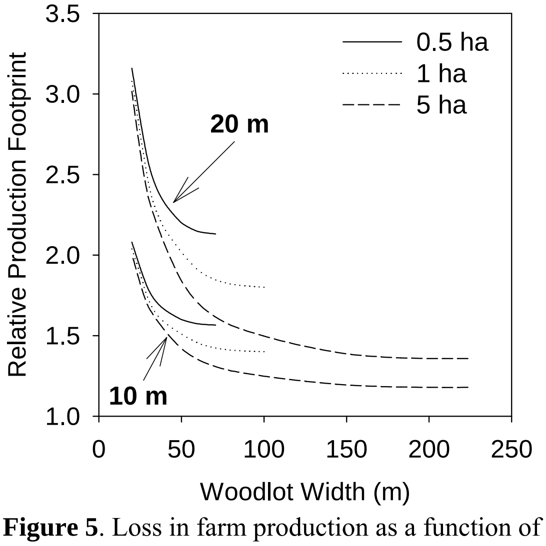

Figure 5. Loss in farm production as a function of woodlot width for situations where either 10 or 20 m of production is lost around the perimeter of the woodlot. The relative production footprint is calculated as the ratio of effective area of lost production to the area of the woodlot.

Whilst the overall effect on mean HCS was slight, incorporating the effect of rotation length brings a different story. The field of medicine has used the idea of Quality Adjusted Life Years (QALY) to measure the effect of medical interventions on both longevity and life quality. An analogy here would be a Quality Adjusted Habitat Year (QAHY) where we accumulate each year of habitat provided discounted by the quality of habitat in that year. Quality was calculated as the ratio between HCS and $\mathrm{HCS}_{\mathrm{max}}$ for each year. The total QAHY value for each scenario in Table 3 shows a large difference between the short duration – low quality habitat and long duration – high value habitat scenarios.

Considerations thus far have centred on the costs or benefits centred on the type or structure of a unit of area under agroforestry. We now turn to considering the effect of size and shape of woodlots on production-biodiversity tradeoffs. Equation 1 tells us that there will be a diminishing return in increased woodland bird species richness with increasing woodlot size. Given the risks associated with the above-mentioned production losses a landholder may choose to take this into account when determining the area to plant to trees. A 1 ha woodlot with a HCS of 5 is predicted to provide 6 woodland bird species. This only increases to 7.5 or 8.3 species as area is increased to 5 or 10 ha suggesting that farmers seeking to entice birds back onto their farms need only consider planting small areas when one considers the return on the investment required. Whilst species abundance is likely to respond to increase patch size it is not considered here.

Finally we consider the shape of the woodlot. Field studies at Warra indicated that a significant cost was also associated with losses in agricultural production in the crop competition zone surrounding a woodlot. This is quite noticeable for long, thin windbreak plantings. If we assume an average production loss distance of 20m as suggested earlier, we can calculate a relative production footprint for any rectangular woodlot of a given size. Figure 5 shows the area of production lost per unit area of woodlot for the assumed loss distance of 20 m. A 20 m windbreak has a production footprint of 3 as the overall loss of agricultural production includes the width of the windbreak plus the loss of production in the competition zone either side of the windbreak. The shape of the plots of relative production footprint suggests that a simple rule of thumb exists for minimising the tree-crop competition. The value of the footprint drops sharply as the woodlot width is increased from 20 m to about 50 m and then remains fairly flat. The same pattern is seen for woodlots of various sizes. This suggests that up to half of the losses can be reduced by increasing windbreak width from 20 to 50 m. Figure 5 also shows the footprint obtained if the production loss width is reduced to 10 m. This could be done in various ways. Firstly, and most simply, but positioning the tree belt along a roadway, remnant or non-productive area. This will reduce the competition zone to one side of the woodlot. Alternatively, this could be done by changing the management of the neighbouring agricultural area. For example, Albertsen et al (2000) measured lower production loss widths for pastures. The experimental study at Warra found a lower loss width for an opportunistically planted wheat crop in 2005. Sowing of the crop soon after rainfall provided less time for the trees to extract stored soil moisture before the crop could access it resulting in a loss width much more like those seen for pasture.

5. CONCLUSIONS

The analysis of field data for production losses within tree-crop competition zones, and bird species responses to habitat size and quality has provided some very simple models which can be used to evaluate various agroforestry scenarios. For the case of farmers looking to diversify their land so as to re-establish some bird species within their farms, a few basic rules have emerged for managing the tradeoffs with such systems.

1. Manipulation of the structure of low-quality habitat as found in agroforestry systems can result in trading off one habitat structural element for another with very small net effects. For example, competition for water by an added grass layer results in a smaller tree canopy.
2. Economic costs of such a planting are best minimised by structuring the woodlot to shorten the rotation length. This has a minor effect on long term habitat value.
3. Production losses can be minimised by ensuring a minimum woodlot width of 50m or placing the woodlot against roadways or remnant forest.
4. Agronomic changes to surrounding agricultural land may be able to reduce the production footprint of an agroforestry planting.
5. Further analysis is required to compare the relative value of block plantings with very short-rotation low value habitat such as strips of trees.

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