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The Potential Role of Farm Forestry in the Wheat-Sheep Zone of NSW

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Abstract

The focus of this paper is the role of farm forestry in farming systems in the NSW wheat-sheep zone. The wheat-sheep zone suffers from significant land degradation problems, and the environmental and economical sustainability of many farming systems is in question. Farm forestry provides the opportunity to diversify farmer incomes, increase agricultural productivity and provide environmental solutions. It is therefore proposed that the potential role of farm forestry in the wheat-sheep zone is to provide an environmentally and economically sustainable future for farming systems, through tree planting for multiple benefits. A general model is developed for the purpose of economic analysis of agroforestry systems in the wheat-sheep zone using a bioeconomic approach.

Keywords: farm forestry, farming systems, bioeconomics

Introduction

Farm forestry, or agroforestry, is the integration of trees and schrubs in farming systems. It has been comprehensively described by many authors including Prinsley (1992), Race (1993) and Race and Curtis (1996, 1999). It includes not only tree establishment with native and exotic species but also the management of existing native forest. Farm forestry may take many forms. Common systems include alley farming where trees are intercropped with crops or pasture for grazing; shelterbelts or windbreaks for crops or livestock where trees are grown in bands along fencelines; and woodlots or small plantations where trees are grown on separate areas to cropping and pasture.

Farm forestry has the potential to diversify farmer income opportunities by the sale of wood and non-wood forest products and increase agricultural productivity and sustainability through environmental services. Market opportunities for forest products include sawlogs, poles, girders, fencing, pulpwood, fuelwood, oils, bush foods, fodder and charcoal. Environmental services include wildlife habitat, visual amenity, flood control, shelter for crops and livestock, soil erosion control, improved water quality, increased nutrient recycling and reduced dryland salinity emergence. Market opportunities may emerge for some environmental services through the implementation of carbon, salinity and biodiversity trading schemes for which there is growing interest. The potential of farm forestry to provide these benefits will vary according to the systems' design or layout, the species grown and the management undertaken.

In this paper, the role of farm forestry in farming systems in the NSW wheat-sheep zone (WSZ) is considered, and a general agroforestry model is proposed for economic analysis. The WSZ forms part of the Murray-Darling Basin, and suffers from significant land degradation problems, such as rising water tables, dryland salinity and soil erosion, which are evident in many areas and likely to deteriorate further (MDBC 1999). According to Greiner (1996), farming systems that experience rapidly advancing soil salinisation may become unviable in a short time. The environmental and economic sustainability of current farming systems in much of the WSZ is already in question (SEAC 1996). The adoption of farm forestry offers the opportunity to reverse this trend. In the paper, the WSZ is briefly described; the potential role of farm forestry is identified; the economic literature in farm forestry is reviewed; insights are drawn for the current research; and a general agroforesty model for economic analysis is presented.

NSW wheat-sheep zone

The NSW WSZ forms part of the Murray-Darling Basin, comprising the catchments of the Murray, Murrumbidgee, Lachlan, Bogan, Macquarie, Namoi and Gwydir Rivers. The WSZ covers about half the State immediately west of the Great Dividing Range and is made up of the northern, western and southern slopes and plains and parts of the central tablelands. The NSW WSZ has been described by authors including Ockwell (1990) and Malcolm et al. (1996). The details here have been drawn primarily from NATMAP (1996) and MDBC (1999).

Topography is mostly flat to undulating plains interspersed with occasional low ranges. Soils vary greatly is terms of fertility, structure and texture. Major classifications are red brown earths overlying fine grained sediments, grey to black cracking clays, yellow to red podsolics, and massive earths (Northcote 1979). An estimated 75-90 percent of the original vegetation has been cleared (Stocker 1998, Young 1999 pers. comm.). The native vegetation that remains consists of open forests and woodlands of mainly Eucalyptus and Cypress Pine, and native grasslands.

Average annual rainfall ranges from 350mm in the west to 750mm in the east, but exhibits significant variability due to drought and flood. Average monthly maximum temperatures are 34^{o} C for January and average monthly minimum temperatures are 3^{o} C for July for the middle of the zone. Temperatures over 40^{o} C are not uncommon, and temperatures below -5^{o} C have been recorded.

Farming systems are dominated by mixed broadacre grazing and cropping. Grazing is mostly sheep for wool and meat, and beef cattle. A range of crops are grown, including cereals (mostly wheat), oilseeds, grain legumes and irrigated cotton. Average return on capital for typical farming enterprises is 2-4 percent with many farmers struggling to break even. Much of the WSZ is generally described as suffering economic, environmental and social decline, due to falling commodity prices, long term low financial returns or losses, rapid technology change, population decline and land degradation (Peart 1998).

It is in this environment, that the question is posed: What is the potential role of farm forestry in farming systems?

The potential role of farm forestry

The potential role of farm forestry in the WSZ is to provide the opportunity for an environmentally and economically sustainable future for farming systems. This can be achieved through farm forestry plantings for multiple benefits.

Farm forestry in the WSZ may not reap significant timber benefits due to the poor growth and form for timber production historically achieved in this low rainfall area. (Although there is growing evidence that the potential for tree growth has been grossly underestimated (Curtis 1999 pers. comm.).) Production of forest products in general will have to contend with no existing markets reliant on farm forestry, limited access to potential markets within reasonable haulage distance and competition from State Forests and growers in higher rainfall zones. However, there is significant potential for farm forestry to provide environmental services in the WSZ, particularly given the degraded state of agricultural land. For example, it has been demonstrated at experimental sites near Wellington that densely planted Eucalyptus species can rapidly lower local water tables (Nicholson 1999 pers. comm.).

There are numerous farm forestry systems, based on design or layout, the species grown and the management undertaken, which are practiced in Australia and could be considered for the WSZ. The systems actually adopted will be determined by their technical feasibility, profitability and riskiness, as well as farmers' goals, preferences, skills and risk attitude. A discussion of specific farm forestry systems is beyond the scope of this paper.

Previous farm forestry research

The economic literature in farm forestry is reviewed to gain insights for the current research. The literature is predominantly international with only a limited number of publications based on the Australian experience. Notable exceptions are the studies by Tisdell (1985), Kirby et al. (1993), Greiner (1997, 1998) and Cacho et al. (1999). The literature is grouped in terms of particular themes.

Economic theory

The distinction between private and social benefits of farm forestry is highlighted by Tisdell (1985). Where social benefits exceed private benefits, individual producers may provide less trees than is the social optimum. In cases where producers have poor information, they may underestimate their private benefits and provide even fewer trees than is their private optimum. These types of market failure provide a rationale for government intervention to encourage trees on farms. Current and Scherr (1995) and Cacho (1999) also discuss these issues.

Several studies highlight the need for innovation in analytical approaches to agroforestry. Price (1995b) comments that most studies use discounted cash flow analysis and generally consider only financial costs and benefits, which requires no technical development and delivers no new or enlightening results. Scherr (1992) suggests that a theoretical framework for analysing agroforestry in farming systems needs to be developed, and that modelling has the potential to become a central tool in this regard. Stone et al. (1993) indicates that many studies use rudimentary models and that there is scope for innovation in both theory and technique. They demonstrate how the Faustmann model can be modified to include secondary benefits from trees.

Babu et al. (1995) and Cacho (1999) recommend dynamic models for agroforestry analysis since static and long-run equilibrium models can not capture interactions between enterprise components. Cacho (1999) uses the Hartman (1976) version of the Faustmann model which includes non-timber benefits, to estimate the optimal mix of forestry and cropping for an individual producer faced with dryland salinity emergence.

Methodology

Several computer models have been developed for agroforestry analysis. For example, Etherington and Matthews (1983) describe MULBUD which has been used to evaluate smallholder agroforestry systems in many developing countries; Thomas (1991) describes POPEYE which was developed for poplar agroforestry on the Welsh borders; Moore (1992) describes FARMTREE which was developed for financial evaluation of agroforestry systems in Victoria, Austalia; and Willis et al. (1993) describe POPMOD, an extension to POPEYE, which they use to evaluate poplar agroforestry in the United Kingdom. All these models use discounted cash flow techniques.

A bordered matrix approach has been used for a couple of studies. Wojtkowski and Cubbage (1991) developed this technique to find the optimal planting pattern and density for multi-canopied agricultural or forestry systems. It uses monocultural production functions as a base from which to estimate polycultural production levels. Wojtkowski et al. (1991) use the border matrix approach to evaluate agroforestry in Brazil. Their model comprises a biological multi-crop simulation model and a dynamic economic model. They highlight that by using a simulation approach more insight can be gained into the bioeconomics than just the optimal solution.

Linear programming is very suitable for agroforestry analysis (since it is an effective tool for solving multiple enterprise problems with resource constraints), but does not seem to have been much used. Sinden (1970) uses it to explore the benefits of integrating poplar agroforestry with dairying in NSW; Verinumbe et al. (1984) use it to analyse the potential of tree legumes in agroforestry systems in Nigeria; Betters (1988) uses it to find the optimal enterprise mix for a hypothetical system; Wojtkowski et al. (1988) use it to evaluate a hypothetical system in a tropical country; and Menz and Grist (1997) develop a linear programming formulation of a whole-farm model for a system in Southeast Asia.

Dyack et al. (1999) develop a simulation model based on benefit-cost techniques, which they use to estimate *ex ante* the threshold value of interaction effects between enterprise components necessary for agroforestry to be profitable for a landholder and desirable for society. They apply it to a black walnut agroforesty system in Canada.

Discounting

Agroforestry systems are usually long term in nature and characterised by large up-front establishment costs and production benefits that occur some time in the future. Although there is some controversy about the practice of discounting, it is used by economists to make future benefits comparable with current costs. Cacho (1999) and Pannell (1999) highlight that evaluations of agroforestry using traditional discounting generally return a much lower discounted net present value for the forestry enterprise than for the other enterprises in the system, and hence the forestry enterprise is less likely to be adopted.

The magnitude of the discount rate will influence the outcome of the discounting process. Some authors have considered this. Price (1995a) presents a simple model that shows significant advantage to agroforesty at moderate rates of discount; by comparison, pure agriculture is preferred at high rates and pure forestry at low rates. Hoekstra (1985) argues that the discount rate selected for private cost-benefit analysis of agroforestry systems needs careful consideration, particularly for subsistence farmers. Hoekstra (1985) describes the borrowing or savings rate of discount, the investment rate (or rate on equity capital) and the consumption rate. He explains that the consumption rate may be the lowest, and may best represent the discount rate of subsistence farmers.

Uncertainty and risk

Kirby et al. (1993) evaluate agroforestry under uncertainty for a South Australian case study property. They report that all previous Australian studies addressed uncertainty about future yields, prices and costs through sensitivity analysis, which often fails to adequately incorporate the probabilities that outcomes will occur, and can give misleading results. Kirby et al. (1993) demonstrate an alternative procedure to incorporate uncertainty through risk analysis using monte carlo simulation. Stochastic dominance criterion are applied to determine the preferred land use enterprise. Nelson et al. (1998) also use this kind of risk simulation for a cost-benefit analysis of alternative forms of hedgerow intercropping in the Philippines; and Tamubula and Sinden (2000) use it to compare alley cropping systems in Kenya.

Portfolio theory can also be used to analyse risk. Blandon (1985) describes portfolio theory and demonstrates it using a hypothetical analysis. A set of minimum-risk agroforestry systems is derived for which a risk efficient frontier is plotted. Systems which are not on the frontier are risk inefficient and not rationally adopted, since alternative systems exist which have higher expected benefits for the same level of risk. Lilieholm and Reeves (1991) also demonstrate portfolio theory in a hypothetical analysis using quadratic programming. Reeves and Lilieholm (1993) implement it for a case study in Costa Rica using the MOTAD method of linear risk programming.

Management

Several studies in this review consider management issues. Other such studies include the following. Akyeampong et al. (1995) evaluate tree species in intercropping systems in Burundi. They determine the most profitable tree species for a particular planting density. Menz and Grist (1996) evaluate the optimal planting density for a rubber agroforestry system on *Imperata* infested land in Indonesia. *Imperata* is a shade-intolerant weed. Menz and Grist (1996) find that at higher than optimal planting densities, the shading effect is greater but net benefits decline due to the additional labour costs associated with planting and tapping a higher number of trees per hectare. Akyeampong and Hitimana (1996) compare alley cropping with conventional no-hedge cropping on acid soils in Burundi, and the effect of fertiliser on crop yields. They find that the most profitable system combines no-hedge cropping with fertiliser. Malajczuk et al. (1996) evaluate various tree species, densities and harvesting regimes for a pine and pasture agroforestry system in Western Australia. They find that pine agroforestry can be more profitable than conventional agriculture. Tonye et al. (1997) investigate four residue management practices for a planted fallow on acid soils in Cameroon. A planted fallow is an agroforestry technique where soil improving trees or shrubs are planted in land going to fallow. They establish the most efficient practice, but note that it may not be adopted by farmers because of its high labour demand.

Salinity

Schofield (1992) discusses tree planting programs for dryland salinity control in Australia. He suggests that unless trees have high value and can be harvested, or it can be demonstrated that land will go saline, there is little incentive for individual producers to plant trees. He recommends a catchment approach to tree planting for salinity control.

Greiner (1998) presents a catchment-level analysis of dryland salinity control for the Liverpool Plains in the North West Slopes and Plains of NSW. Using a dynamic model, she finds that it is socially optimal to establish trees on the dryland plains in the catchment. In a farm-level analysis, Greiner (1997) finds that unless trees have commercial value, tree planting is not favoured from a private perspective (because of high opportunity costs) except on salt-affected land. She suggests that tree planting can be enhanced by policies that reduce establishment costs.

Cacho et al. (1999) also undertake a catchment-level analysis of farm forestry for salinity control. They use an optimal control model, with most parameters based on the Liverpool Plains, to show that farm forestry plays a significant role in the social solution to salinity, and that research and development which improves growth rates and tree yields may be more efficient than subsidies at encouraging tree planting. They provide results for the optimal area planted to trees and the optimal groundwater trajectory through time for a variety of scenarios.

Soil erosion

Pattanayak and Mercer (1998) design and test a bioeconomic approach for valuing the on-site soil conservation benefits individual farmers receive from adopting contour hedgerow agroforesty in Philippines. They found that the opportunity costs appear to outweigh the soil conservation benefits, and are a major disincentive for adoption. Nelson et al. (1997) also found this in his study. Pattanayak and Mercer (1998) conclude that additional studies are required to measure both the off-site soil benefits and the on-site nonsoil benefits associated with hedgerows to help evaluate adoption incentives. Although private benefits may be negative, social benefits may be positive, and incentive schemes may be warranted.

Pattanayak and Mercer (1998) report that few economic analyses of soil conservation from agroforestry have been undertaken, and that almost none disentangle the soil conservation benefits. Ehui et al. (1990) investigate the soil erosion effects of alley cropping systems on agricultural productivity and profitability in Nigeria, but they do not evaluate soil conservation benefits. Magcale-Macandog et al. (1998) consider forage grass planted along hedgerow contours for soil erosion control in Philippines. Their results highlight the biophysical and economic importance of maintaining grass strips as fodder for livestock and to control soil movement, however they do not provide an empirical estimate of the benefits of soil erosion control.

Carbon sequestration

Sonneborn (1999) presents an overview of greenhouse gas emissions trading pilot schemes and activities in Australia and overseas. She comments that although there are problems estimating, verifying and monitoring carbon sequestration, tradeable credits through forestry projects have attracted considerable interest and support.

Dixon (1995) analyses agroforesty data from over 50 countries representing diverse environmental conditions, and concludes there are a range of agroforestry systems that could be used to sequester carbon. Kort and Turnock (1999) undertook an econometric study to determine the carbon reservoir in Canadian prairie shelterbelts. They highlight that the value of shelterbelts as carbon offsets will depend on their management and fate.

Tomich et al. (1997) evaluate the conversion of grasslands to tree-based agroforestry for carbon sequestration in Indonesia. They suggest that it may not be financially profitable to do so under current technologies, prices and costs. Plantinga et al. (1999) present an econometric analysis of the costs of sequestering carbon, using land-use share models (where land is allocated between forestry and agriculture) to simulate carbon sequestration programs in the United States. They find that tree planting is a cost-effective way to offset greenhouse emissions.

Insights for this research

Two particular insights of relevance for this research are gained from a review of the literature. Firstly, most studies have been static and therefore failed to capture the dynamic interactions between enterprise components in agroforestry systems; and secondly, there may be a divergence between the private and social benefits of farm forestry due to the non-market environmental services it can provide.

In the following section, a general model is developed for the purpose of economic analysis of agroforestry systems in the WSZ. The model is dynamic and explicitly accounts for changes in land productivity due to trees. The model is appropriate for both private and social normative analyses of the optimal mix of forestry and agriculture in an agroforestry system. In the model, multiple forest benefits are derived from timber, carbon sequestration and non-market environmental services. Benefits are also derived from agricultural production. In the private problem, the value of carbon sequestration is currently zero given there is no established market for carbon trading.

A general agroforestry model

For the purpose of economic analysis the present value of net benefits (*B*), obtained over a forestry cycle of *T* years, per hectare of a farm forestry operation, can be represented as:

$$B = kB_T^m \, e^{-rT} + \int_{t=0}^{T} \left[kb_t^f \left\{ k, t, l_t \right\} + \left(1-k\right) b_t^a \left\{ l_t \right\} \right] e^{-rt} \, dt \; ; \qquad (1)$$

where k is the proportion of land devoted to forestry; B_T^m is the benefit obtained from timber harvested at time T net of harvesting costs; b_t^f is the flow of net benefits, other than timber, provided by the standing forest at time t; b_t^a is the flow of net benefits produced by one or more agricultural enterprises; l_t is a measure of land productivity; and r is the discount rate.

This model applies to a system where the farm forestry and agriculture enterprises occupy different areas of land. This includes systems such as shelterbelts and trees used for flood control and/or mitigation of salinity and soil erosion problems. There are some cases, such as grazing-forestry systems where animals graze the forest floor until the canopy closes and hinders pasture production, where both enterprises occupy the same area of land. The model would require modification to represent the later type of system.

Timber benefits depend on the volume harvested (V_T), the price per cubic meter of timber (P_v) and the harvest cost (C_v):

$$B_T^m = V_T P_v - C_v \; ; \tag{2}$$

and the actual volume of timber harvested depends on the growth history of the forest:

$$V_T = \int_{t=0}^{T} v_t \{l_t, \mathbf{z}\} dt \; ; \tag{3}$$

where v_t represents timber growth rate and depends on land productivity and $\mathbf{z}$ is a vector of forestry management practices. The vector $\mathbf{z}$ may include variables such as planting density, fertiliser application and thinning strategy, which are taken as given exogenously in the foregoing analysis.

The flow of benefits from the standing forest is defined as:

$$b_t^f = b_t^c + b_t^n - C_t^f \; ; \tag{4}$$

where b_t^c is the benefit provided by carbon sequestration, b_t^n represents non-market benefits, and C_t^f represents forest establishment and maintenance costs. The benefits provided by carbon sequestration depend on the mass of carbon contained not only in the timber but also in the forest floor, thus:

$$b_t^c = \left[v_t \{l_t, \mathbf{z}\} D\{\mathbf{z}\} + \psi\{t, \mathbf{z}\} \right] P_c \; ; \tag{5}$$

where D is carbon content per m^3 of timber, or the carbon-density of timber; thus the first term in brackets represents the rate of carbon sequestration per hectare of timber. The function ψ is the rate of carbon fixation in the forest floor and roots as determined by the age of the forest and the given management practices. The flow of non-market benefits can be represented as:

$$b_t^n = \varphi(k, t) \; ; \tag{6}$$

where φ is a complex function representing the monetary value of non-market benefits such as water quality conservation, wildlife refuge and amenity. Both the area and age of the forest are likely to affect wildlife and amenity values. This function may be discontinuous if there is a minimum area of forest required to maintain a viable animal population or to provide a given type of amenity. The function is also likely to contain multiple minima and maxima.

The benefits provided by agricultural enterprises on the farm at any time t are:

$$b_t^a = P_a y_t^a \eta(l_t) - C_a ; \qquad (7)$$

where y_t^a is expected yield per hectare under ideal conditions, and P_a and C_a represent price of output and input cost respectively. The function η scales yield according to land productivity, and has a value of one in fully productive land and decreases towards zero as land quality deteriorates. The actual shape of this function depends on the enterprise in question and the nature of the land productivity measure. In general η will be nonlinear, with $d\eta/dl > 0$ and $d^2\eta/dl^2 < 0$.

For an area susceptible to dryland salinity emergence, for example, the value of l_t will be negatively related to soil salinity. Whereas for a livestock enterprise l_t may represent the effect of shelter, provided by trees, on wool output.

Changes in land productivity will generally be related to the area and age of forest planted:

$$\frac{dl}{dt} = g(k,t,l_t) . \qquad (8)$$

The form of this function depends on the type of system under study. In general, we expect $\partial g/\partial k \geq 0$, as the positive effect of trees on agricultural enterprises is one of the main arguments in favour of farm forestry practices. The effect of forest age on land productivity changes is generally expected to be positive ($\partial g/\partial t > 0$), although this is not necessarily the case. In a dryland-salinity situation, larger (older) trees will have a greater effect on the water table, and hence a more positive effect on land productivity, than younger trees. However, large trees planted next to crops and pastures may have a negative effect, through competition for light, water and nutrients, compared to smaller trees, thus $\partial g/\partial t < 0$ may occur for certain forest ages.

For a fixed set of forest management strategies, **z**, the general optimisation problem, can now be stated as:

$$\underset{T,k}{Max}: \quad B = kB_T^m\, e^{-rT} + \int_{t=0}^{T} \left[kb_t^f \{k,t,l_t\} + (1-k) b_t^a \{l_t\} \right] e^{-rt}\, dt\,; \tag{9}$$

subject to equations (2) to (8).

For an infinite planning horizon problem, the objective function becomes:

$$\underset{T,k}{Max}: \quad B^{\infty} = B\{k,T,l,\mathbf{z}\}\left[1 + \frac{1}{e^{rT}-1}\right]. \tag{10}$$

This is a convenient representation of both the social and private optimisation problems. The main distinction between social and private objectives is introduced through (6); $\varphi(.)$ may assume large values for society as a whole, but it may be zero or fairly small for a private landholder. At present, another distinction between the private and social versions of the problem is in the value of carbon sequestered, as P_c in equation (5) equals zero for a private individual. This, however, may change in the near future as governments develop mechanisms to transfer carbon credit payments to farmers.

The analytical solution of the forest rotation problem in the presence of non-timber benefits has been derived by several authors (eg. Hartman 1976, Swallow et al. 1990). The forest-area decision (*k*) has been analysed by Cacho (1999). The actual solution for a particular farm-forestry system can be achieved by converting the model to a nonlinear programming problem, provided that estimates of equations (2)-(8) are available.

Conclusion

This paper has investigated the potential role of farm forestry in farming systems in the NSW WSZ. It has highlighted the need for farm forestry to provide multiple benefits so that farming systems can achieve environmental and economic sustainability. A general model was developed for the purpose of economic analysis. Given the current interest in farm forestry, a research priority should be to collect the information required to implement the model, perhaps for a small subset of promising systems. Some data, particularly regarding timber growth (ie. equation (3)) may already be available, while other data will have to be collected by ecologists, agronomists and foresters, preferably in consultation with economists to help ensure that the relevant information is collected.

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