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Biophysical and economic tradeoffs of intercropping timber with food crops in the Philippine uplands

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Abstract

Steadily rising prices for timber on Mindanao in the Philippines have given an incentive to farmers to devote some of their land to fast-growing tree species. The costs and benefits of intercropping young timber trees with food crops was studied in a 1000 stem ha^{-1} stand of *Paraserianthes falcataria*. At 2 years of age, diameter at breast height and height of intercropped trees were 33 and 21% greater, respectively, than sole trees. Management costs of intercropped trees were less than half of sole trees. Allometric equations for Mindanao falcataria were used to project future tree growth and system returns. In the base scenario (1000 trees ha^{-1}, 5-year rotation), the sum of biophysical and economic benefits of intercropping trees with a maize/vegetable rotation for two years were less than the costs of reduced intercrop yield, compared to sole cropping of each component. A linear relationship of crop decline to the increase in basal area of the stand was used to predict returns to intercropping under alternative tree densities and intercropping periods. Intercropping becomes more attractive as labor becomes scarcer relative to land, the need to minimize cash inputs becomes more important to farmers, and trees increase in value relative to annual crops.

Keywords: Agroforestry; Timber intercropping; *Paraserianthes falcataria*; Economics; Cost-benefit-analysis; Bioeconomic modeling

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1. Introduction

An alignment of several socio-bioeconomic factors has propelled increasing rates of timber planting on small farms in the Philippine uplands. Farmers exploiting a climatic niche by growing vegetables find more of their capital and labor resources concentrated on smaller parcels of land, offering them opportunities for more land-extensive operations. The climate is also excellent for growing trees, with abundant and consistent rainfall, but no typhoons, allowing farmers to plan 4–10 year tree rotations. In addition, the Philippines, once a large exporter of tropical timber, is now a net importer (World Resources Institute, 1998) and prices for farmer-grown timber have been steadily rising (Kummer, 1992; Garrity and Mercado, 1994).

Smallholder farmers are inclined to intercrop young timber trees with well-fertilized annuals to confer nutrient and weeding benefits to the trees while gaining a short-term return on the land. Tall or unfertilized intercrops can compete for light or soil resources with young trees and inhibit tree growth (Redhead and Maghembe, 1982; Wannawong et al., 1991; Agbede et al., 1987; Couto et al., 1994), but intensively managed, short-stature intercrops generally improve tree growth (Couto et al., 1995; Kapp and Beer, 1995). Charging the cost of timber establishment to the intercrop (Couto et al., 1994; Roder et al., 1995), as well as reducing fire risk, perhaps provides smallholders with comparative advantages not enjoyed by industrial plantations (Garrity and Mercado, 1994), and suggests that smallholders can play an expanded and profitable role in national reforestation efforts (Current and Scherr, 1995; Pasicolan et al., 1997; Spears, 1983). Compared to high-input monocropping of upland vegetables or maize, often on steep slopes, intercropping with trees may generate more long-term returns, improve fertilizer-use efficiencies, and reduce erosion on steep lands.

Successful timber intercropping requires that farmers design efficient systems, in which complementary effects of intercropping on net returns exceed competitive effects (Ong, 1996). Relatively little information exists on designing optimal timber-intercropping systems, and under what conditions they would be preferable to sole cropping of either or both components (Niskanen, 1998). To evaluate the biophysical and financial tradeoffs of timber intercropping, an experiment was established in Lantapan, Mindanao to compare vegetable and maize growth under *Paraserianthes falcataria* with sole-cropped growth of each of the components. These data were used to estimate a bioeconomic model to explore the appeal of timber intercropping under land, labor, capital, and fertility constraints, and evaluate alternative planting densities and length of intercropping.

2. Materials and methods

2.1. Site description

The study was conducted on a farm on the footslopes of Mt. Kitanglad in Lantapan, Bukidnon Province, the Philippines ($8^\circ 2'$ N, $124^\circ 54'$ E, 1150 m altitude). The climate is warm tropical, with a mean annual temperature of 18.5°C and a mean annual precipitation of 2400 mm. The soil is a Humic Kandiudox derived from volcanic ash. Initial soil properties included pH of 5.3, 51.3 g OM kg^{-1}, 2.9 g N kg^{-1}, 2.6 mg Bray P kg^{-1}, and 8.6 cmol(+) ECEC kg^{-1} soil. The topography was undulating, with slopes ranging between 8–27% within the experimental site. The site had previously grown maize (*Zea mays*), but was fallow for 6 months preceding the experiment. Tree seedlings and the first intercrop were planted in December, 1995; the last intercrop was harvested in January, 1998.

2.2. Experimental design

The experiment was a 2×2 factorial design with four blocks. Factor 1 was (+/−) intercropping of trees (intercropped trees, sole trees) with annual crops (intercrops). Factor 2 was (+/−) direct fertilization of the trees through three side-dressings. In addition, four control plots of non-intercropped annuals (sole crops) were established in the same blocking design but at a distance of 10 m from the tree plots to avoid competition. Plot size was 15×12 m.

Seedlings of *P. falcataria*, grown in a farmer nursery from seed of local trees, were planted in the field at a spacing of 5×2 m (1000 trees ha^{-1}), the spacing used by a local reforestation project. Trees in the side-dressing treatment received a basal fertilizer application of 60 g 18-46-0 (diammonium phosphate DAP) and 100 g DAP at 4, 8, and 20 months after tree planting (MATP). Trees in the non-side-dressing treatment received the basal application only. All trees were pruned at the beginning of each cropping season, and once again in the middle of the second season, to promote the growth of a single stem and to reduce shading. Branches were pruned up to 67% of the length of the stem. Pruned branches were collected and placed outside the plot following farmer practice. Sole trees were pruned on the same schedule. Severely stunted or dead trees were replaced by new seedlings twice in the first year and once in the second year. Weeding in a 50-cm radius around all stem bases was done once per crop, with an additional weeding towards the end of the first crop when trees were still small. To minimize weed pressure in sole-tree plots, grasses and weeds were slashed on the same schedule as weeding.

Five crops were grown sequentially as intercrops in the first two years after tree planting. In Year 1, two crops of cabbage (*Brassica oleracea* L. var. *capitata* L.), followed by one crop of Chinese cabbage (*Brassica chinensis* L.), were grown in the intercrop and sole-crop plots at a spacing of 0.5×0.3 m. Cabbage rows started 0.25 cm to either side of the tree rows, giving 10 rows of cabbage between tree rows and the same number of cabbage rows in both the intercrop and sole-crop plots. Cabbage was fertilized according to farmer practice, receiving a basal application of 125-55-104 kg ha^{-1} elemental N-P-K from inorganic fertilizer and approximately 32-28-18 elemental N-P-K from chicken dung. Side dressing was applied at a rate of 66-36 kg ha^{-1} N-K. Chinese cabbage was grown the same as cabbage.

In Year 2, two crops of maize (*Zea mays* L.) were grown in the intercrop and sole-crop plots at a spacing of 0.7×0.25 m. There were equal numbers of maize rows in the intercrop and sole-crop plots. Maize was fertilized according to farmer practice and received a total application of 170-62-35 kg ha^{-1} elemental N-P-K from inorganic fertilizer, with half the N and all the K applied as side-dressing. The second maize harvest occurred 25 months after tree planting, after which all plots remained fallow.

Crop protection followed local practices for both vegetables and maize. Vegetables were sprayed with fungicides (Kocide, Dithane-M) every 7-10 days and with insecticides (Bushwhack, Karate, Furadan) upon pest outbreak.

2.3. Sampling

The sampling area for both trees and crops was a 10×10 m area in the middle of each plot, containing 10 trees. The following measurements were taken for each tree in the first 2 years of growth: 0.3 and 1.3 m diameter at breast height (dbh), stem length, canopy diameter (in two perpendicular directions), and canopy height. Trees were measured every three months in year 1, every four months in year 2. At 37 MATP, only dbh was measured. Height at 37 months was estimated by deriving a dbh-height relationship, using data from the literature where *P. falcataria* was grown at densities between 500 and 1250 stems ha^{-1} (Anino, 1997; Bumatay et al., 1997; Dhyani and Tripathi, 1998; Kumar et al., 1998; Otsamo et al., 1995).

Stem width was measured with a caliper in year 1 and with a tailor's tape in years 2 and 3. Stem height 5 m or less was measured with a pole; height of taller trees was read with a clinometer. To more accurately assess intercropping dynamics, plot means for tree measurements included stunted and dead trees.

Marketable weight of cabbage and Chinese cabbage is 75% of total weight. Maize grain yield is reported on an air-dry weight basis. Economic data, including labor requirements, were recorded daily and converted to a per-hectare basis. All prices are presented in Philippine pesos. Soils were analyzed by the Soil and Plant Tissue Testing Laboratory of Central Mindanao University, Musuan, Bukidnon.

Data were analyzed with the GLM procedure of the Statistical Analysis System (SAS Institute Inc., 1985). Means separation was performed with Duncan's Multiple Range Test. To account for rodent damage in the first maize crop, an analysis of covariance in the GLM procedure of SAS was performed, with a "stand" factor as a covariate. The yield data presented for that season are the least squares means estimate of maize yield controlled for random stand variability.

2.4. Estimating future tree yields and optimal rotations

In order to estimate economic returns from total systems (crops + harvested trees), the three years of measured tree data were used to estimate future timber yields and optimal rotation lengths. Tree-growth projections were based on stand-yield equations for *P. falcataria* on Mindanao (Uriarte and Piñol, 1996). The equations estimate stand volumes with minimum diameters of 10, 15, and 20 cm, since timber mills often require logs to be a minimum 10 cm in diameter, and large-diameter logs are worth more per volume than small-diameter logs. Yield for the three size classes is a function of age, planting density, and site quality, the latter reflecting climate and soil limits to tree growth. Uriarte and Piñol (1996) site-quality indices represent mean tree height (m) at Year 10, but can be calculated for trees of any age. Given that the experimental trees were exposed to the same climate and inherent soil conditions, site quality was used to reflect growth differences resulting from management treatments. However, management treatments were stopped after the second year; in subsequent years, treatment differences in growth were expected to remain but not expand (Schönau, 1977). Therefore, site quality for the intercropped trees was calculated by adding the Year 3 difference in tree height (m) between intercropped and sole trees to the Year 10 site-index value of sole trees.

Projected tree growth and increases in timber value were used to estimate optimum tree rotations, evaluated on the basis of annualized net present value (NPV). A base discount rate of 7.5% was employed based on national inflation rates over the previous five years (Asian Development Bank, 2000) and discussions with farmers. The rate of annual increase in tree value was conservatively set equal to the discount rate at 7.5%, lower than the 12% annual increase reported for *P. falcataria* in the province between 1984 and 1993 (Garrity and Mercado, 1994), and lower than the estimated 15% annual increase between 1993 and 1997 (Arturo Mercader, Asiatic Wood Industries, personal communication).

2.5. Modeling economic returns

Spreadsheet modeling was used to evaluate economic returns from alternative intercropping and sole-cropping systems over the length of an optimal tree rotation. Biophysical and economic data, competition functions, and tree growth projections were incorporated into a spreadsheet model, following the structure of the TANZ-MOD model of the BEAM project (Thomas et al., 1994). The central competition function estimates marginal declines in crop yield based on marginal increases in tree size, specifically the stand basal area of the trees (Nissen and Midmore, Submitted). Stand basal area (G) is commonly used in forestry to integrate the number of trees per unit area and their size, with the equation:

$$G = \pi/40000 \times \text{width}^2 \times \text{density}^{-1}$$

where, G = stand basal area ($m^2\ ha^{-1}$); $\pi = 3.14$; width = dbh (cm); and density = trees ha^{-1}.

To model with an annual time-step and prevent crop type and price variations from affecting the model, the input and output of the five sole crops grown over a 2-year period were averaged into a 1-year rotation representing 1.5 crops of vegetables and one of maize. The mean of stand basal area at the beginning and end of the year was the value used to calculate crop decline in a year.

Initial investment costs for all treatments were designated as Year 0 costs in the model. For trees, purchase and planting costs were assigned to Year 0, and first-year management costs assigned to Year 1. For crops, one-half of total annual gross costs was assigned to Year 0, with the other half assigned to Year 1. Returns began in Year 1.

2.6. Evaluating the base scenario

The experimental treatments served as the base scenario, in which crops grown for 2 years under trees planted at 1000 trees ha^{-1} were compared to sole crops and sole trees grown for the length of the optimal tree rotation. Sole-crop yields were assumed to remain constant over the length of the rotation.

In this and the alternative scenarios, the balance of competition and complementarity in intercropping systems was evaluated by comparing its returns to the mean of its components grown as sole crops (Ong, 1996). Returns to costs (capital + labor expenses) were calculated for all scenarios in addition to returns per unit land area since, for farmers more constrained by capital and labor than land, return:cost ratios may be a more relevant indicator of a system's desirability.

2.7. Evaluating alternative tree-density and intercropping-length scenarios

The effects of changing tree density and/or the length of intercropping in the model were examined in order to evaluate optimal combinations. Tree densities ranged from 8 to 10,000 trees ha^{-1}, and intercropping lengths ranged from 1 year to the entire length of the rotation. The model incorporated two assumptions:

One, potential fertilization and weeding benefits of intercropping do not decline at lower tree densities since all agricultural operations remain the same. Therefore, site-quality indices were equal at all tree densities. Tree growth in the Uriarte and Piñol (1996) equations however is also a function of density, with growth-limiting competition occurring earlier at higher densities.

Two, because only one intercropping length was studied (2 years), we could not evaluate the marginal effects on tree growth of marginal increases in intercropping lengths. Therefore, for modeled intercropping lengths of more than 2 years, the site-quality index was equal, i.e. intercropping beyond two years conveyed no further effects on tree growth. Likewise, given the experimental design, it was not possible to evaluate which portion of the total effect on tree growth was derived from the first year of intercropping and which from the second, especially when the modeled rotation is less intensive in Year 1 than the experimental rotation. Therefore, the 1-year intercropping scenario uses the most conservative assumption that intercropping confers no one-year effects, and that the intercropping site index is equal to that of sole trees.

2.8. Evaluating a fertility constraint

Given frequent declines in crop productivity in the region (Poudel et al., 1999b), the model was also used to evaluate a fertility constraint by introducing a 10% annual decrease in crop yield as a result of continuous cropping. In intercropped plots, these losses were in addition to yield reductions due to tree competition.

3. Results and discussion

3.1. Tree growth

Growth of *P. falcataria* was rapid in all plots, but more so in intercropped plots (Table 1). Significant differences appeared in stem width at 12 MATP and in height 16 MATP. At month 25, intercropped trees were 33% wider and 21% taller than sole trees. One year later, the width difference was 25%. Annual volume growth of the stand was estimated to be 29.7 m^3 ha^{-1} for intercropped trees and 25.5 m^3 ha^{-1} for sole trees. This is well within the range of published falcataria plantation-forestry values (Evans, 1982) and indicates the good growth rates upland tropical smallholders can attain. Fertilizer side-dressings had no effect on tree growth.

A portion of the difference in mean growth is explained by significantly more mortality and severe stunting in sole trees (15%) than intercropped trees (7%). This difference is perhaps due to vigorous weed pressure in sole-tree plots, despite quarter-annual removal of weeds around the tree base and slashing of remaining weeds. The diffuse canopy of *P. falcataria* did little to reduce weed pressure around its stem during its early growth.

Treatment differences remain after removing mortality as a consideration. At 37 months, the best 25% of intercropped trees were significantly wider than the best 25% of sole trees by 15% (Table 1). This difference may have resulted from higher levels of fertilization. Over the first two years, 1000 and 373 kg P ha^{-1} were applied to intercrops. Assuming crop N concentrations of 4% for cabbage and 2.5% for maize, and crop P concentrations of 0.5% for cabbage and 0.3% for maize, an estimated 321 and 40 kg P ha^{-1} were removed by plants, with 679 and 333 kg P ha^{-1} remaining for tree uptake. This is more than 10 times the level of N and two times the level of P applied as side dressing to fertilized sole trees. Sole crops had an estimated 27% greater uptake of N and P than intercrops because of greater yields, yet estimated sole-crop excesses of 496 and 243 kg P ha^{-1} after 2 years suggests that fertilizer application in these systems is highly inefficient.

Table 1
Mean diameter at breast height (dbh) and stem length of *Paraserianthes falcataria* grown with (Intercropping) and without (Sole trees) intercrops for the first 2 years

System	Diameter (cm)				Height (m)		
	Month				Month		
	12	25	37	37-Top 20%[a]	12	25	37[b]
Intercropping	5.4 (.16)	11.6 (.34)	14.8 (.50)	20.2 (.58)	4.7 (.18)	11.6 (.39)	14.1
Sole trees	4.1 (.18)	8.6 (.40)	11.7 (.66)	17.6 (.56)	4.1 (.27)	9.6 (.57)	11.6
P>*F*	0.0001	0.0001	0.0004	0.0001	N/S	0.0001	

[a] Mean of the largest 20% dbh of sampled trees.
[b] Estimated from equation: ln height (m) = 4.2036−(5.9975×dbh (cm)$^{-0.5}$).

Future crops may benefit from previous inefficient applications of relatively immobile P; Bray P levels increased from 2.7 mg kg^{-1} soil at the beginning of the experiment to 14.0 and 7.9 mg kg^{-1} in the sole-crop and intercrop plots, respectively, after 2 years. However, mobile nutrients such as nitrogen may volatilize or leach below the rhizosphere of ensuing crops, and unless captured by deeper-rooted trees, may escape the system. Total N levels in the top 30 cm of soil did not significantly increase in cropped plots after 2 years despite the 496–679 kg N ha^{-1} unaccounted for in crop uptake. The apparent benefit to tree growth of residual fertilizer gives support to the safety-net hypothesis (Cannell et al., 1996) and the idea that this can be a significant source of biophysical and financial complementarity.

3.2. Tree costs and returns

The cost of establishing a 1000 tree ha^{-1} stand of falcataria without intercropping was P12,597 over the first two years (Table 2). Seedlings accounted for 20% of these costs. Despite fewer weeding operations, the cost of maintaining trees increased in the second year because of higher and thicker tree branches that took longer to prune than in the first year. These figures are probably higher than a typical tree monoculture, for while some pruning would be done to promote good stem form, it

Table 2
Labor and input costs for planting and maintaining stands of *Paraserianthes falcataria* planted at 1000 trees ha^{-1} in Lantapan, Philippines[a]

Period	Sole trees			Intercropping		
	Labor (days ha^{-1})	Frequency (times year^{-1})	Cost (pesos ha^{-1})	Labor (days ha^{-1})	Frequency (times yr^{-1})	Cost (pesos ha^{-1})
Establishment						
Site clearing	23.7	1	1518		Charged to crop	
Seedlings			2500			2500
Fertilizer			582			582
Planting	10.5	1	672	10.5	1	672
Total			5034			3754
Maintenance Year 1						
Slashing	10	3	1920	0	0	0
Weeding	7.7	3	1478	1.9	3	364
Pruning	1.4	3	272	1.4	3	272
Total			3670			636
Maintenance Year 2						
Slashing	10	2	1280	0	0	0
Weeding	8.7	2	1108	2.1	2	243
Pruning	11.7	2	1505	11.7	2	1505
Total			3893			1748
Total			12,597			6138

[a] Labor costs are calculated at P64 day^{-1}.

would likely be done at less intensity than under intercropping in order to promote shading and reduce weed pressure. Adoption of chemical weed control, as is common in plantations, would also lower these costs, but at some risk to the survival of the seedlings.

Intercropping reduced costs by 51% by charging site preparation and weeding costs to the intercrop (Table 2). The savings of P6,459 represent one of two main sources of complementarity in the intercropping system. The second is improved tree growth, the value of which is projected based on growth trends and local sawmill prices.

3.3. Estimates of tree yields and optimal rotations

Year 3 measurements and the equations of Uriarte and Piñol (1996) produced a site-index value for sole trees of 21.6. Intercropped trees were 2.5 m taller at Year 3; maintaining this through to Year 10 resulted in a site-index value of 24.1 for intercropping, 1.0 less than its value if calculated directly from its Year 3 height.

Estimated maximum mean annual increment of merchantable timber (the total accumulated volume divided by the age of the stand) occurred in Year 2 for intercropped trees (Fig. 1). However, since timber value increases with size, large increases in value are realized in years three and four as tree diameters surpass minimum diameter thresholds.

The effects of tree growth rate and timber-price increases on optimal rotation lengths are shown in Fig. 2. When the prices of timber are expected to outpace a discount rate by 10%, annualized NPV continues to rise as trees continue to grow.

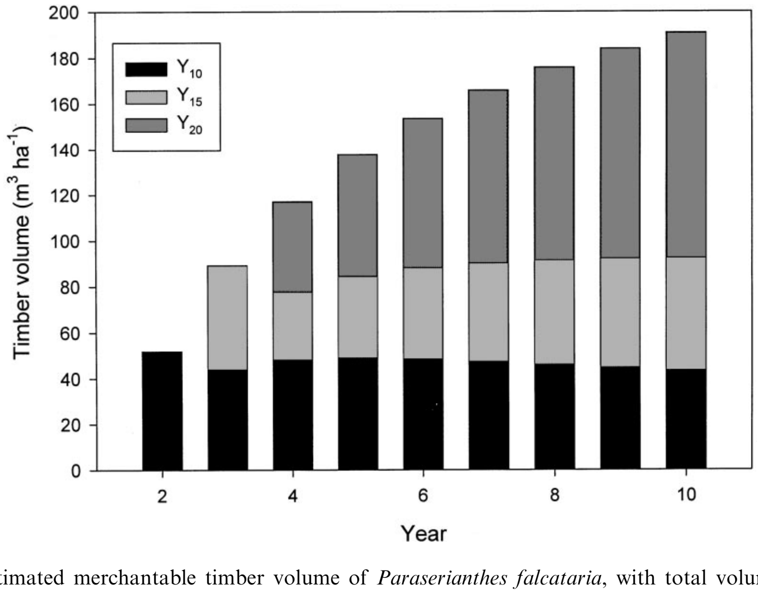

Fig. 1. Estimated merchantable timber volume of *Paraserianthes falcataria*, with total volume in each year comprising portions with diameter of minimum 20 cm (Y_{20}), between 15 cm and 20 cm (Y_{15}), and between 10 cm and 15 cm (Y_{10}). Estimates generated using equations of Uriarte and Piñol (1996), density of 1000 trees ha^{-1}, and site index value of 24.1, based on tree measurements in Year 3.

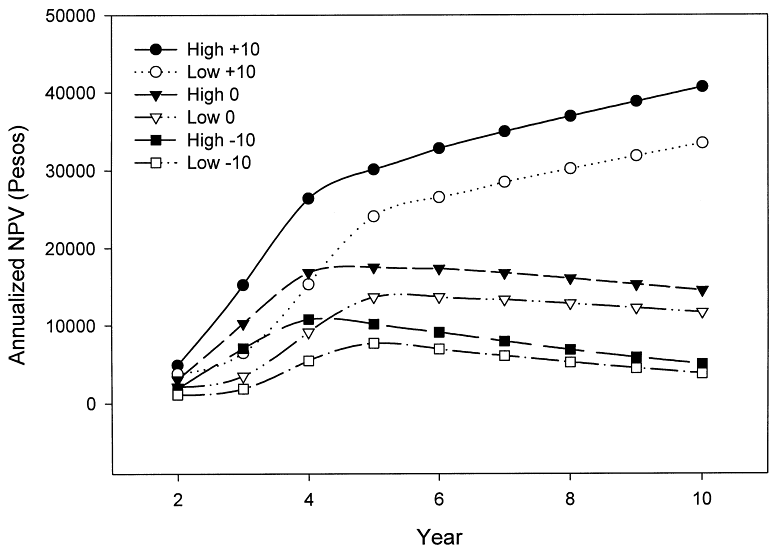

Fig. 2. Sensitivity analysis of tree net present value (NPV) to site index and discount rate. Estimated annual NPV of *Paraserianthes falcataria*, with site index of either 24.1 (High) or 21.6 (Low) and annual increase in tree value exceeding by 10 percent (+10), equaling (0), or trailing by 10 percent (−10) the discount rate.

In scenarios where the increase in tree value is equal to or less than the discount rate, maximum annualized NPV occurs in either Year 4 or Year 5 depending on the site index. The difference in any one year between the high and low site index is a complementary value of intercropping.

Personal interviews with farmers suggested that the personal discount rates for trees in Lantapan are low. No tree-planting farmer expressed an interest in managing trees on optimum rotations; instead, they placed a higher value on the liquidity trees provided in times of unexpected or severe financial need and were likely to keep trees in the ground until such a need presented itself. However, farmers who have not yet planted trees will likely have higher personal discount rates.

Under these discount-rate and tree-value conditions, a 5-year rotation was selected. This is the optimal rotation for monocropped trees, and although intercropped trees grew faster and would be optimally harvested at 4 years, annualized NPV drops off little if extended to a 5-year rotation (Fig. 2). In this scenario, the value of increased tree growth due to intercropping is estimated to be P26,616, or P5323 annually. The sum of labor saving and tree growth benefits from intercropping was therefore an estimated P33,075, or P6,615 annually.

3.4. Crop yields

Mean yields of intercrops were not significantly different from mean yields of sole crops until season 3 (9–11 MATP), in which intercropped Chinese cabbage averaged 22% less than the sole-crop control (Fig. 3). The first maize intercrop, grown 14–18

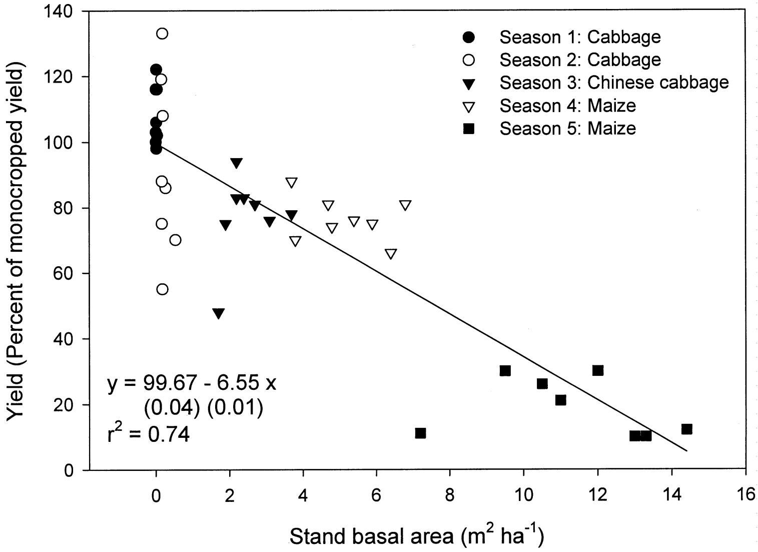

Fig. 3. Relationship of stand basal area of *Paraserianthes falcataria* and percent yield reduction of intercrops (S.E. in parentheses). Observations shown from each of eight intercropped plots in each season.

MATP, remained at the same relative level as Chinese cabbage despite much larger trees. The second maize intercrop, grown 21–25 MATP, dropped off drastically relative to the control. The five intercrop yields were 107, 83, 78, 76, and 19% of the control respectively.

No relationship was found between crop yield and distance from tree row. Reduction in yield relative to the control was fairly consistent across all crop rows, as was the level of shading caused by the diffuse canopy of falcataria (data not shown).

3.5. Crop costs and returns

Returns to sole cropping in these systems, especially for vegetables, were largely dependent on fluctuating market prices (Table 3). Prices for cabbage ranged from P2-13 kg^{-1} over the course of the experiment, highlighting the inherent risks and tempting payoffs of vegetable farming. On an annual basis, the differences are even greater, since one can grow three vegetable crops in the same time as two maize crops. However, vegetable plots are generally smaller than maize plots because of their intense capital and labor demands (Table 3). The total annual net returns of P220,628 ha^{-1} from sole-cropped vegetables and P15,701 ha^{-1} from sole-cropped maize is at the high end of the range of surveyed farmers of the area (Poudel et al., 1999b).

3.6. Economic analysis of intercropping system

In this experiment, reduced crop yields due to tree competition were worth P63,169 (Table 3), nearly twice as much as the estimated intercropping benefits.

Table 3
Variable costs and returns from sole crops (SC) and intercrops (IC), grown over five consecutive growing seasons spanning 2 years in Lantapan, Philippines[a]

		Cabbage (1–3)		Cabbage (5–7)		Ch. cabbage (9–11)		Maize (14–18)		Maize (21–25)	
		SC	IC	SC	IC	SC	IC	SC	IC	SC	IC
Returns	Yield (kg)	31,390	33,650	22,708	18,820	33,677	26,200	3860	2950	4240	795
	Marketable Yield (kg)[b]	23,543	25,238	17,031	14,115	25,257	19,650	3860	2950	4240	795
	Price (pesos kg^{-1})	7	7	11	11	3	3	6	6	6	6
	Gross returns (pesos)	164,798	176,663	187,344	155,265	75,772	58,950	23,160	17,700	25,442	4770
Costs	Labor (days)	590	590	557	557	591	591	190	190	109	109
	Labor (pesos)[c]	37,767	37,767	35,628	35,628	37,794	37,794	12,135	12,135	6953	6953
	Inputs (pesos)	35,977	35,977	30,532	30,532	29,588	29,588	8423	8423	5390	5390
	Total costs (pesos)	73,744	73,744	66,160	66,160	67,382	67,382	20,558	20,558	12,343	12,343
Net returns (pesos)		91,053	102,918	121,184	89,105	8391	−8432	2602	−2858	13,099	−7573

[a] Numbers in parentheses beside crop name indicate months after tree planting in which crop was grown. All data, except for price, are on a per hectare basis. 1 US dollar = 25 pesos for crops 1–3, 40 pesos for crops 4–5.

[b] Fresh weight of leafy vegetable crops decreased by 25% to get marketable weight.

[c] Labor = 64 pesos day^{-1}.

Although crop-yield reduction was more severe in the second year, when maize was planted, more value was lost in the first year because of vegetables' high prices. A percent loss in vegetable yield was worth P735 compared to a percent loss of maize of P157. Where the value of the crops far exceed the value of the trees, as in the case of high-value, consistently well-yielding vegetables, the marginal declines in intercrop yield are worth far more than the marginal savings to labor and marginal gains to tree size.

In several respects, the experimental system was not optimized for intercropping. First, intercrops were planted for a year after net returns became negative. This was done to learn more about competition in the system and gather data for calibrating the model. Second, only light-demanding crops were planted (and none after Year 2), although farmers typically follow light-demanding crops with more shade-tolerant crops such as taro (*Colocasia esculenta* L. Schott).

No estimates were made of the costs and benefits to an intercropping system of extending the intercropping period with alternative crops. Instead, a bioeconomic model was used to examine the effect of extending viable intercropping periods through reductions in tree density.

3.7. Modeling the base scenario

Experimental data was used to calibrate the bioeconomic model. Gross annual returns for experimental sole crops (sum of five crops divided by 2 years) were P238,258 (Table 3). Gross annual sole-crop returns for the model rotation was P238,249 (Table 4). Differences between experimental and model gross returns, as well as gross costs, are less than 0.02% and result from rounding errors in the model.

To estimate intercropping returns, a central competition function, based on stand basal area, was derived from intercrop yields compared to the sole-crop control (Fig. 3):

$$Y_{ic} = 99.67 - 6.55 \times G$$

where: Y_{ic} = yield of intercrop (as a percent of sole-crop yield); and G = stand basal area ($m^2\ ha^{-1}$).

Based on this function, mean intercrop yield as a percent of sole cropping over 2 years was 75% in the model compared to 73% from experiment results (Tables 3 and 4).

By replacing the sequential vegetable-maize rotation of the experiment with a generic vegetable/maize rotation, intercrop yields and net returns could not be calibrated simultaneously. Unlike the experimental rotation, which had only maize in Year 2, the model grew 1.5 vegetable crops in Year 2, when yield losses were far greater. The larger costs associated with vegetable losses resulted in 2-year intercrop net returns of P116,065 in the model compared to P173,160 in the experiment. Where rotations will be used, planting the most valuable crop first will exploit the least competitive phase of timber intercropping. However, issues of total

Table 4
Financial analysis of a 1 ha, 5-year rotation of food crops only (Sole crops), *Paraserianthes falcataria* only (Sole trees) and intercropping of *P. falcataria* and food crops for first two years (Intercropping)[a]

System	Intercropping component	Year						Rotation total	Annualized value
		0	1	2	3	4	5		
Benefits									
Sole crops		0	238,249	238,249	238,249	238,249	238,249		
Sole trees		0	0	0	0	0	85,629		
Sole crops		0	217,344	13,861	0	0	108,361		
	Crops	0	217,344	138,861	0	0	0		
	Trees	0	0	0	0	0	108,361		
Discounted benefits[b]									
Sole crops		0	221,627	206,165	191,781	178,401	165,954	963,928	192,786
Sole trees		0	0	0	0	0	85,629	85,629	17,126
Intercropping		0	202,180	120,161	0	0	108,361	430,702	86,140
Costs									
Sole crops		60,035	60,035	120,070	120,070	120,070	120,070		
Sole trees		5034	3673	3893	0	0	17,671		
Intercropping		63,789	60,671	121,818	0	0	20,654		
	Crops	60,035	60,035	120,070	0	0	0		
	Trees	3754	636	1748	0	0	20,654		
Discounted costs									
Sole crops		60,035	55,847	103,900	96,652	89,908	83,636	489,978	97,996
Sole trees		5034	3417	3369	0	0	12,309	24,128	4826
Intercropping		63,789	56,438	10,5413	0	0	14,387	240,027	48,005
Net Present Value									
Sole crops		−60,035	165,780	102,264	95,129	88,492	82,319	473,950	94,790
Sole trees		−5034	−3417	−3369	0	0	73,320	61,501	12,300
Intercropping		−63,789	145,742	14,748	0	0	93,974	190,675	38,135

Table 4 (*continued*)

System	Intercropping component	Year						Rotation total	Annualized value
		0	1	2	3	4	5		
Benefit/Cost ratio									
Sole crops									1.97
Sole trees									3.55
Intercropping									1.79

[a] Tree revenues are calculated to increase equal to the discount rate of 7.5%. Values in Philippine pesos. (US$1 = 25 pesos, 1996).

[b] Effective discount rate (%): Sole crop costs, benefits = 7.5; Sole tree costs = 7.5; Sole tree benefits = 0.

intercropping length and tree density were best examined by removing crop value as a variable.

In the base model scenario, in which annual crop yields remain constant over the 5-year rotation and tree density is 1000 stems ha^{-1}, intercropping annualized net returns of P38,135 are 26% less than the P51,411 mean of sole crops and sole trees (Table 4). This is primarily due to the 36% decrease in intercrop yield in the second year.

Although tree values have been rising steadily on Mindanao, their net returns are still small compared to high-value crops. However, measuring returns to land area does not capture the attractiveness of trees. As access to inputs increases and upland farmers shift more of their resources to vegetable farming, the land area in cultivation annually, per farm, is decreasing (Poudel et al., 1998). Landuse intensity (total cultivated area under all crops in a year/arable land) among farmers for whom vegetables are the major crop (on a annual per area basis) is only 0.7 (Poudel et al., 1998); given that vegetable rotations are typically 3–4 months and done successively on the same parcel of land, vegetable farms typically have large areas of short fallow at any given time. Results from a survey showed that 22% of all vegetable farmers had land that had been fallowed for longer than a year and with no plans for bringing it back into cultivation (Poudel et al., 1999b). Off-farm employment opportunities are also increasing in the rapidly developing local economy.

Under these conditions, the returns to labor and capital are frequently more important than net returns to land. The benefit:cost ratio of growing trees is 80% higher than high-value crops (Table 4), and helps explain the growing popularity of tree planting in the area. The mean benefit:cost ratio of trees and crops grown independently in the base scenario is 2.04, 14% higher than intercropping.

3.8. Evaluating optimal tree densities and rotation lengths

The effects of changing tree density and intercropping lengths are shown in Fig. 4. Because sole-cropping returns are unaffected by these factors, the shape of the sole tree/sole crop curve reflects the influence of these factors on tree returns. Based on returns to both land and labor, optimal sole-tree densities appear to be between 500 and 2000 trees ha^{-1}.

Returns to land are maximized by getting as close to a sole-crop system as possible, the expected outcome in a system where crops greatly exceed the value of trees. In contrast, returns to costs are maximized by limiting intercropping to one year and planting 500–1000 trees ha^{-1}. In this scenario, intercropping losses as a result of tree competition are so small as to subtract only slightly from the savings in labor costs. However, there is no combination of density and years of intercropping in which both returns to land and costs exceed sole tree/sole crops.

3.9. Evaluating the fertility constraint

For upland cropping sytems in the tropics, it is prudent to examine the sensitivity of the model to declining crop yields over time. The mean natural slope for the main

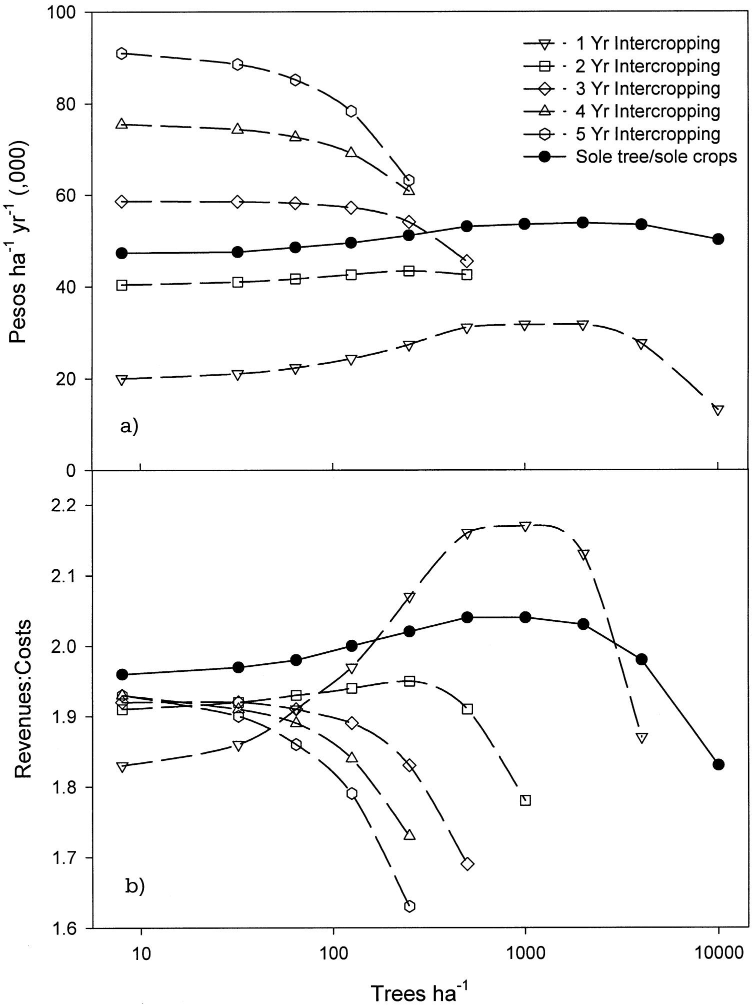

Fig. 4. Effect of tree density and years (Yr) of intercropping on returns to (a) land and (b) input costs of tree/food-crop systems. Sole trees/sole crops values (=0 Yr Intercropping) are the means of trees and crops grown independently. Density axis is logarithmic.

vegetable parcel in Lantapan is greater than 15% (Poudel et al., 1998). Large erosion events are common, despite high infiltration rates for the soils in the region. At nearby experimental erosion plots on a 40% slope, a single rainfall caused 24 t ha^{-1} soil loss (Poudel et al., 1999a). Seven cropping seasons over 2.5 years at this site resulted in a decrease of pH from 5.3 to 3.8, a 22% loss of organic matter, and cabbage yields 78% higher on the lower half of the plot than the upper half. Cabbage yields in the last two cropping seasons combined were 17% of the first two (Poudel et al., 1999b). These data strongly suggest that continuous cropping on sloping lands will probably incur either significant yield losses or require significantly higher levels of inputs, and help explain the frequency with which farmers shift their parcels on sloping land.

The effects of an annual 10% decline in productivity, for both sole crop and intercrops, is shown in Fig. 5. Annualized returns from agriculture drop from P94,790 to P46,266, and this fertility constraint creates a set of intercropping scenarios that equal or exceed sole cropping in both the returns to land and to costs: 2 years intercropping at 64–500 trees ha^{-1} and 3 years intercropping at 8–64 trees ha^{-1}. Where crop-yield decline is expected to exceed 10% annually, the range of superior intercropping options would expand. Assumed in this scenario is that

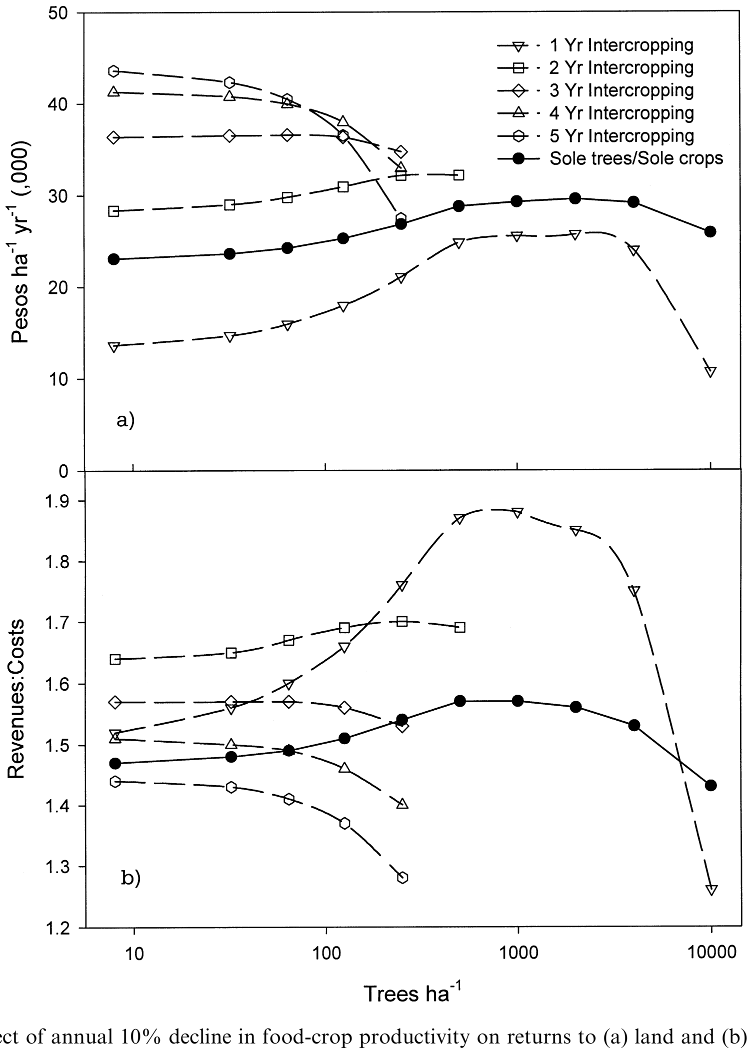

Fig. 5. Effect of annual 10% decline in food-crop productivity on returns to (a) land and (b) input costs of tree/food-crop systems of different intercropping lengths (Yr = years) and tree densities. Sole trees/sole crops values are the means of trees and crops grown independently. Density axis is logarithmic.

fertility-based yield losses are equal in both systems. However, as was observed on other farms, trees planted on the contour provide a perennial no-till strip that, like other perennials, promotes formation of natural terraces and inhibits soil erosion (Alegre and Rao, 1996; Poudel et al., 1999a). Research on the efficacy of timber trees planted at different densities on the contour is needed to improve our accounting of possible long-term benefits of trees in the system.

4. Conclusion

The growth of *P. falcataria* on a farmer's field was enhanced by five seasons of intercropping with vegetables and maize, and was comparable to that of professionally managed plantations. However, where good yields of high-value vegetables can be maintained over several years, overall return to crops is much higher than return to trees. Experimental and survey data from the region suggest that maintaining good yields on steeply sloping lands is difficult, and where parcels are frequently abandoned, trees become an attractive component in the cropping system. Trees also gain increasing value as farmers encounter labor limitations that prevent them from utilizing all their available land. The decision whether or in what design to intercrop the trees largely depends on whether the farmer seeks to maximize returns to land or input costs, the relative values of the components (including discounting), and yield stability. Under conditions typical in the Philippine uplands, the complementary benefits of a well-designed agroforestry system can exceed its competitive costs.

A relatively simple model such as the one developed here can be used in extension to help farmers understand the near- and long-term tradeoffs of intercropping and design a system to meet specific objectives. Forest companies and local and national governments may wish to produce locally adapted models to support small-farmer transitions to timber farming, for it appears that smallholders may enjoy comparative advantages over private or national re/forestation projects. Cost estimates for establishing plantations of *Eucalyptus deglupta* in Papua New Guinea averaged US \$356 ha^{-1} in 1974 — \$1159 in 1997 dollars (Bureau of Labor Statistics, 2000) — with 14% of the costs for management salaries (FAO, 1979). By comparison, in 1997 US dollars and exchange rate, the establishment costs at this site were \$228 ha^{-1}, with all management salaries absorbed by the farmer. It is not clear how much economies of scale related to harvesting erode some of the farmer's advantages in cultivation. Nevertheless, for countries such as the Philippines where land issues are critical, the opportunity exists to address land distribution and reforestation efforts simultaneously.

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