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Optimum pruning intensity for reducing crop suppression in a *Gmelina*–maize smallholder agroforestry system in Claveria, Philippines

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Abstract On-farm trials were conducted to assess the effects of four branch pruning levels on maize grain yield, tree growth and stem shape. The experimental plots consisted of *Gmelina* (*Gmelina arborea* R.Br.) trees planted at 1 × 10 m with maize intercropped in the 10 m-wide alleys between lines of trees. Pruning levels consisted of retaining a live crown ratio of 60–70% (T_1), 40–50% (T_2); 30–40% (T_3) and of 20–30% (T_4). At the end of the experiment, the total maize grain yield was highest under the high pruning intensity (T_4) (18.06 t ha^{-1}) and lowest under T_1 (14.48 t ha^{-1}). Maize grain yield under the pruning regime T_2 and T_3 were 16.08 and 17.21 t ha^{-1}, respectively. Mean annual increment (MAI) in tree diameter was greater (5.0 cm year^{-1}) under T_1 than those at T_4 (4.1 cm year^{-1}). Pruning regimes T_2 and T_3 resulted in a MAI of 4.7 and 4.5 cm year^{-1}, respectively. Financial analysis showed that maize-tree systems under T_4 were more profitable than under T_1 as long as the reduction of the average dbh at harvest were not greater than 1 cm. Pruning trees intensively also generated greater returns from labour than moderate pruning, as the greater maize grain yields under T_4 compensated for the cost of pruning and the lower timber yield. In the context of resource-poor farmers, intensive branch pruning was a practice that prolonged the period of profitable intercropping and was compatible with commercial timber production.

Keywords Pruning · Timber trees · Financial analysis · Tree intercropping · Tree–crop interactions · *Gmelina arborea*

Introduction

For the past three decades, the integration of fast-growing timber trees in smallholder farming systems in the Philippines has been extensively promoted to diversify farm output and produce timber for household use and sale. As a result, trees planted on farms are today an important source of raw materials for the local timber industry, and income for smallholders.

One of the unique advantages that smallholders have in tree production is the practice of intercropping: the continuous land cultivation, weeding and fertilization for crops improves tree survival and promote faster tree growth by preventing weed infestation and improving site conditions (Garrity et al. 1996; Kapp and Beer 1995). In Mindanao, Philippines diameter at

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breast height (dbh) and total height of 2-year-old intercropped Falcata (*Paraserianthes falcataria* (L.) I. C. Nielsen) were, respectively, 33 and 21% greater than non-intercropped trees (Nissen et al. 2001). Growth of associated crops may also benefit by the presence of trees which reduce weed invasion and growth (Gajaseni and Jordan 1992). Miah (1993) reported that weed infestation and weed dry matter yield in an upland rice (*Oryza sativa* L.)-tree association were respectively 30–38% lower than in the sole rice plots.

Planting trees and crops in association can also produce direct financial benefits. In Latin America, it has been estimated that the costs of soil preparation, weeding, and pest and fire control were 51–68% lower in an intercropping system than in pure reforestation plantings (Beer et al. 2000). Nissen et al. (2001) found that in the first 2 years after planting management costs of intercropped Falcata were less than half the costs of Falcata monocultures. For all these reasons, the century-old system of Taungya reforestation in which intercropping is practiced during the first few years after tree planting, is a popular strategy for tree establishment and survival, to reduce reforestation costs and to produce timber for on-farm use and sale (Jordan et al. 1992).

In spite of the above advantages, there is substantial evidence that competition effects in intercropping systems may reduce or override overall productivity gains and financial returns compared with tree monocultures. When fast-growing timber trees are combined with light-demanding annual crops, the growth of the understorey crop could be inhibited as a result of competition between trees and crops for both above- and below-ground resources (Ong et al. 1996). With few exceptions, the common timber tree species promoted for farm forestry have been reported to depress yields of those associated crops which are generally cultivated under full sunlight. The genetic potential of trees for rapid growth makes them more ‘aggressive’ and hence successful competitors for site resources. In Guatemala, for example, 4 years after planting trees at 3 × 2 m, the yields of maize (*Zea mays* L.) and green bean (*Phaseolus vulgaris* L.) intercrops were reduced by 35% by *Casuarina equisetifolia* J. R. & G. Forst, 83% by *Eucalyptus globulus* Labill and 91% by *Alnus acuminata* Kunth compared to the first year crop (Leiva and Borel 1994). In Uganda, Okorio et al. (1994) found that of 17 timber trees intercropped with maize and beans, only *A. acuminata* did not have a negative effect on annual crop yields, probably because of minimal shading and nitrogen-rich litter. Interestingly, *A. acuminata* was the most competitive species in the Guatemala study (Leiva and Borel 1994). Across five seasons, the maximum average reduction in annual crop yield was 60%. In India several studies quantified the substantial decline of annual crop production due to intercropping with eucalypt trees (Ahmed 1989; Malik and Sharma 1990; Saxena 1991). Consequently serious concerns have been raised over the sustainability and appropriateness of tree farming for resource-poor farmers (Shiva and Bandyopadhyay 1987).

When water and nutrients are freely available, as in areas in the wet tropics with well-distributed rainfall and where fertilizers are commonly used, light availability may be the most important limitation to production of understorey annual crops (Ong et al. 1996). Branch pruning is effective in reducing light interception by the tree canopy, and thus prolonging the period of intercropping (Watanabe 1992). Miah (1993) found that the yields of rice and mungbean [*Vigna radiata* (L.) R. Wilczek] planted in alleys between lines of severely pruned multipurpose trees [*Gliricidia sepium* (Jacq.) Walp., *Acacia auriculiformis* A. Cunn. ex Benth., and *Acacia mangium* Willd.] were comparable with those of the sole crop plot. In a hedgerow agroforestry system with *Gmelina* (*Gmelina arborea* R.Br.) planted at 1 × 6 m, the grain yield of rice in association with severely pruned trees increased three-fold over the yield in the unpruned plot (Gonzal 1994). Thus, in the Philippines, farmers often practice severe branch pruning every season before the planting of crops to reduce tree–crop competition as well as to improve tree shape (Bertomeu 2004). In Indonesia, some small-scale timber farmers start severe branch pruning (retaining live crown ratios of 40% or less) at 6 months to reduce tree-annual crop competition, improve tree shape, and reduce wind damage to trees (Roshetko et al. 2004).

While intensive pruning benefits the understorey crops, the practice may reduce the profitability of tree farming as it slows tree growth (Smith 1962), reducing tree dbh and final timber yield and resulting in lower timber revenue. Miah (1993) reported that the total biomass of intensively pruned 2-year-old trees was 34% smaller than that of unpruned trees. Gonzal (1994) found that 2-year-old intensively pruned trees had a significantly smaller stem dbh (7.38 cm) than unpruned trees (9.83 cm).

Farmers instinctively anticipate crop yield losses as trees grow, and positive crop increases with severe pruning. However, it is unlikely that they are able to accurately predict the period of profitable intercropping and the net financial returns of alternative management regimes across a full tree rotation. On-farm trials were initiated in Claveria, Philippines, to investigate the effect of several pruning regimes on tree growth and maize yield and their implications for farmers in terms of financial returns. These trials were part of a larger study undertaken to examine the appropriateness, profitability and technical feasibility of planting timber trees at wide spacing in smallholder farming systems (Bertomeu 2004; Bertomeu 2006).

Materials and methods

The study site

The field research was conducted in Claveria, an upland municipality of the Philippines located 42 km northeast of Cagayan de Oro City, in northern Mindanao. The municipality covers an area of 112,175 ha, and has a mountainous (390–2,000 m.a.s.l.) topography with 62% of the area having slopes >18%. Soils are derived from volcanic parent material and classified as deep acidic oxisols with pH of 3.9–5.2 and texture ranging from clay to silty clay loams, with low available P, low cation exchange capacity (CEC), high Al saturation and low exchangeable K (Magbanua and Garrity 1988). The average rainfall is 2,500 mm with the wet season from June to December (>200 mm rainfall per month) and a short dry season from March to April (<100 mm rainfall per month) (Kenmore and Flinn 1987). Temperatures vary little throughout the year, with an average monthly maximum of 28.6°C and average monthly minimum of 21.3°C.

The average farm size in Claveria is 2.5–3 ha, with farmers commonly cultivating two or more parcels of land. At lower elevations (400–700 m.a.s.l.), maize is the dominant crop, cultivated twice a year or in rotation with cassava (*Manihot esculenta* Crantz) or upland rice. Typically, a crop planted at the onset of the rainy season (May) is followed by a dry season crop planted in September or October. Tomatoes and other vegetable cash crops are commonly grown at the higher elevations (700–900 m.a.s.l.).

Research plot set-up and management

The study consisted of on-farm trials with experimental plots laid out in a randomized complete block design with four treatments and four replications, established at two farms (two replications at each site). Both farms were located in the same village (Cabacungan), at the same elevation (around 400 m a.s.l.), with similar slope (20–30%) and orientation (14 degrees north), but differed notably in their land management histories. Before the establishment of the experimental plots, the farm at site 1 had been used for maize cropping and contained 3-year old natural grass strips. The farm at site 2 was pasture land, grazed by goats, with evidence of rill erosion. Before the establishment of trial plots, soil samples from each farm were taken with a soil auger. One composite sample from the upper, middle, and lower part of the slope was derived from several sub-samples. All soil samples were analyzed at the International Rice Research Institute (IRRI) at Los Baños, Philippines. The farms differed in some physical and chemical soil properties (Table 1). The soil at site 1 had a slightly higher pH, lower clay content, and notably greater CEC and exchangeable K, Ca and Mg than the soil at site 2.

Plots were 300 m^2 (15 × 20 m) containing three lines of *Gmelina* planted at 1 × 10 m, i.e., 1,000 trees per hectare (tph), with 16 trees per line (i.e., 48 trees per plot), and 15 rows of maize planted for six cropping seasons in each of the 10 m-wide alleys. The 10-m tree interrow spacing was chosen based on field observations of agroforestry systems in Claveria where fruit and timber trees are planted widely spaced on contour lines 6–8 m apart. This planting design was also considered most appropriate for smallholder timber production systems by Santiago (1997).

Four pruning regimes were chosen: (a) T_1 (control): retaining a live crown ratio (LCR) (i.e., the percentage of total tree height retaining live branches) of 60–70%; (b) T_2: retaining a LCR of 40–50%; (c) T_3: retaining a LCR of 30–40%; and (d) T_4: retaining a LCR of 20–30%.

In the last week of September and first week of October 1997, *Gmelina* seedlings were planted in 40 × 40 × 40 cm holes manually cultivated at the

Table 1 Physical and chemical soil properties at the trial sites before the start of the experiment in Claveria, Philippines

Site	Depth (cm)	Slope zone	pH (1:1 H_2O)	Clay (%)	Silt (%)	Sand (%)	Organic C (%)	Total N (Kjeldahl) (%)	Available P (Bray II) (mg kg^{-1})	Exch. K (me/100 g)	CEC (me/ 100 g)	Exch. Al (me/100 g)	Exch. Ca (me/100 g)	Exch. Mg (me/100 g)
Site 1	0–15	Upper	5.0	53	39	8	1.47	0.133	1.0	0.905	16.8	0.422	5.81	2.24
	15–30		4.9	58	35	7	1.29	0.105	0.37	0.548	15.2	1.57	4.46	2.21
	30–60		nd*	nd	nd	nd	0.845	0.070	0.48	0.401	17.7	2.35	3.74	2.86
	60–100		nd	nd	nd	nd	0.478	0.035	0.51	0.417	15.4	1.90	4.03	3.35
	0–15	Middle	4.9	55	37	8	1.20	0.103	0.46	0.754	17.4	1.99	3.81	2.44
	15–30		4.9	57	35	8	0.845	0.066	0.27	0.326	15.4	2.62	3.46	2.69
	30–60		5.2	57	35	8	0.718	0.049	0.43	0.351	16.2	1.87	3.94	3.15
	60–100		5.0	54	37	9	0.585	0.039	0.50	0.535	14.5	1.15	4.62	3.69
	0–15	Lower	4.8	59	32	9	1.50	0.128	1.0	0.495	15.0	0.694	4.38	1.64
	15–30		5.0	62	30	8	1.31	0.115	0.43	0.212	14.2	0.945	3.27	1.44
	30–60		nd	nd	nd	nd	0.805	0.076	0.44	0.100	12.1	1.43	1.31	0.850
	60–100		nd	nd	nd	nd	0.565	0.051	0.50	0.136	11.5	1.69	0.900	0.660
Site 2	0–15	Upper	4.8	65	29	6	1.60	0.134	0.39	0.496	13.7	1.14	2.10	1.26
	15–30		4.7	72	24	4	0.838	0.071	0.07	0.527	14.5	2.56	2.06	1.25
	30–60		nd	nd	nd	nd	0.591	0.049	0.23	0.198	11.8	2.91	1.39	0.840
	60–100		nd	nd	nd	nd	0.464	0.041	0.29	0.155	11.5	2.89	1.23	0.940
	0–15	Middle	4.6	73	22	5	1.51	0.147	0.39	0.110	9.24	2.22	1.37	1.08
	15–30		4.8	82	15	3	0.898	0.089	0.28	0.155	11.8	1.25	1.24	0.710
	30–60		5.0	85	13	2	0.605	0.068	0.46	0.106	8.09	1.53	1.03	0.540
	60–100		5.1	87	11	2	0.471	0.053	0.21	0.058	8.49	1.78	0.670	0.270
	0–15	Lower	4.5	69	26	5	1.65	0.160	1.1	0.053	9.53	2.42	0.330	0.170
	15–30		4.7	79	27	4	1.25	0.125	1.8	0.103	9.47	1.39	1.27	0.560
	30–60		nd	nd	nd	nd	0.798	0.084	1.8	0.074	7.97	0.976	0.890	0.320
	60–100		nd	nd	nd	nd	0.545	0.054	0.23	0.073	8.15	1.20	0.340	0.120

* *nd* no data, *Exch.* exchangeable, *me* milliequivalents, *CEC* cation exchange capacity

trial sites. Dead trees were replaced at the end of December 1997. From January to May 1998, trees were watered twice a month due to severe drought conditions. In July 1998, following the drought, dead seedlings were replaced to maintain homogenous plot conditions. Replacement trees were not included in the calculations of tree growth parameters, except for the assessment of stem shape at the end of the experiment.

Contours of natural grass were established in the research plots by leaving strips of grass unplowed. Trees were planted immediately uphill from the grass strips. Maize cropping commenced in May 1998 and continued for six consecutive cropping seasons with the last harvest in January 2001. Every year, a wet season maize crop was planted in May and harvested in early September, followed by a dry season crop sown in early October and harvested in January. Draught animal power was used for land preparation, consisting of two ploughings and one harrowing operation. Maize fertilizing and weeding were performed manually following local practices. Every cropping season, a hybrid maize variety (Pioneer 3014) was sown into furrows at a spacing of 30 cm along each row and 60 cm between rows. Each maize crop was fertilized with the recommended dose of 80–30–30 kg N–P–K ha^{-1}. Phosphorus (solophos 0–18–0) and potassium (muriate of potash 0–0–60) fertilizer and the insecticide–nematicide furadan 3G were applied at sowing. Maize re-sowing occurred 5–7 days after emergence (DAE). Nitrogen (urea 46–0–0) was applied as equal split doses by side dressing at 15 and 30 DAE. Nitrogen application was followed by interrow cultivation to cover the fertilizer with soil and control weeds. Manual weeding of the maize crop was also conducted as needed, usually one to 2 weeks after the second interrow cultivation at 30 DAE.

Weeding around trees was conducted at planting. Subsequent weed suppression operations were conducted twice per cropping season in the first and second year.

Removal of double stems and form pruning were conducted when trees were 1-year-old to retain a single stem and improve shape. From May 1999 to October 2000, four branch pruning operations were performed before or immediately after the planting of maize. A 50% stem thinning was conducted at 30 months after planting by removing the smaller and suppressed trees.

Data collection and analysis

Maize grain yield data were recorded row by row from a 6 m-wide centred net plot. At harvest, fresh grain and total biomass were measured and two plant samples randomly taken from the five maize rows of each of the upper, middle and lower alley zones. Grain yield at 14% moisture content was obtained after oven-drying the sample.

Tree dbh and total tree height were recorded twice a year from the trees in the net plot (i.e., excluding border trees) until the age of 42 months. The mean annual increment (MAI) in dbh was estimated as the average of the two annual increments in dbh during the period 18–42 months. Analysis of variance (ANOVA) from General Statistic 11 edition (Genstat) program was used to analyse variations of tree dbh increment, maize grain yield and tree height increment across the four pruning regimes and research sites. The least significant difference (LSD) test was used to identify means differences. At the end of the experiment, stem shape was assessed by visual inspection. Trees were rated as: A = trees with crooked or knotty stem; B = trees with medium stem shape; and C = trees with excellent, straight and nearly cylindrical stem shape. This rating was comparable to the three grading categories of *Gmelina* sawn timber used by local timber traders reported by Bertomeu (2008).

The financial net benefits of the maize–*Gmelina* agroforestry system under the four pruning regimes were assessed in terms of the land expectation value (LEV) per hectare and the net returns to labour, as this indicator is relevant for labour-constrained farmers and those with off-farm jobs that compete for their labour time.

Returns to labour were estimated as noted
by Franzel et al. (2002)

Returns to labour = discounted net benefits to labour (1)/discounted labour days (2)

$$(1) = \sum_{j=1}^{n} \left[\left(\mathrm{B}_j - I_j \right) / \left((1+r)^j - 1 \right) \right],$$

where B_j = benefits in year j, $j = 1, 2, \ldots, n$, and I_j = input costs in year j, $j = 1, 2, \ldots, n$.

$$(2) = \sum_{j=1}^{n} \left[\mathrm{WD}_j / \left((1+r)^j - 1 \right) \right],$$

where WD_j = labour work-days.

For each pruning regime, six scenarios are presented by assuming two discount rates (15 and 20%) and three scenarios for the average dbh at harvest: (a) 30, 29, 28 and 27 cm for T_1, T_2, T_3 and T_4, respectively (scenario 1); (b) 30 cm for T_1, 29 cm for T_2 and T_3 and 28 cm for T_4 (scenario 2), and; (c) 30 cm for T_1 and T_2 and 29 cm for T_3, and T_4 (scenario 3). The annual discount rates of 15 and 20% were assumed based on the cost of borrowing capital in the study area and farmers' perception of the risk of the agroforestry practice.

For each treatment, four pruning operations (one form pruning and three lift pruning) and two thinnings (each at 50% intensity) were considered in the financial calculations (Table 2). Based on experience at the site, pruning labour rates were assumed as: (a) Form pruning: 1-man-day ha^{-1} for all treatments; (b) First lift pruning: 6-man-day ha^{-1} for T_1, 8-man-day ha^{-1} for T_2, 10-man-day ha^{-1} for T_3 and 13-man-day ha^{-1} for T_4; (c) Second lift pruning: 4-man-day ha^{-1} for T_1 (500 tph), 10-man-day ha^{-1} for T_2 (1,000 tph), 13-man-day ha^{-1} for T_3 (1,000 tph) and 15-man-day ha^{-1} for T_4 (1,000 tph); (d) Third pruning: 3-man-day ha^{-1} for T_1 (250 tph), 7-man-day ha^{-1} for T_2 (500 tph), 17-man-day ha^{-1} for T_3 (1,000 tph) and 19-man-day ha^{-1} for T_4 (1,000 tph).

A discounted cash flow analysis (DCF) was made assuming an 8-year tree rotation and a final tree–crop of 250 tph. Annual maize yields used in the DCF analysis are those reported in Table 3 which are above the break-even yield of 5 t ha^{-1} year^{-1} (3 t ha^{-1} for the wet season crop and 2 t ha^{-1} for the dry season crop) found by Bertomeu (2006) for a similar *Gmelina*–maize system with the same level of inputs and management as in this study. Costs, prices and revenues used in the DCF are also based on Bertomeu (2006).

Results

Maize grain yield

There was a significant difference in maize production between sites, treatments and crops (F prob = 0.048) (Table 3). Maize production was generally greater at site 2, most notably in crop 2 and 4 (dry season crop of the first and second year). This may indicate that during the dry season water was more limiting in site 1 than in site 2. Compared to the first year (crop 1 and 2), maize production in the third year (crop 5 and 6) was substantially reduced at both sites (crop 1 was around 50% greater than crop 5 at both sites, and crop 2 was 3–34% greater at site 1 and 37–54% greater at site 2 than crop 6) due to competition from *Gmelina*. This reduction in maize production as trees grew occurred in all treatments but was more pronounced in maize under T_1 than under T_4. Differences in grain yield between T_1 and T_4 were clearly significant after the first year (except in crop 6 at site 2). In the second year (crop 3 and 4) maize grain yield under T_4 was around 23–52% greater at site 1 and 20% greater at site 2 than

Table 2 Schedule for maize cropping, tree pruning and tree thinning operations used in the financial calculations

	T_1	T_2	T_3	T_4
Year 1	Tree planting	Tree planting	Tree planting	Tree planting
	Form pruning	Form pruning	Form pruning	Form pruning
	Maize first crop	Maize first crop	Maize first crop	Maize first crop
	First lift pruning	First lift pruning	First lift pruning	First lift pruning
	Maize second crop	Maize second crop	Maize second crop	Maize second crop
Year 2		Second lift pruning	Second lift pruning	Second lift pruning
		Maize third crop	Maize third crop	Maize third crop
			Third lift pruning	Third lift pruning
			Maize fourth crop	Maize fourth crop
Year 3	First thinning	First thinning	First thinning	First thinning
	Second lift pruning	Third lift pruning		
Year 5	Second thinning	Second thinning	Second thinning	Second thinning
	Third lift pruning			

Table 3 Effect of four pruning levels on maize production (grams per linear meter) at two farms in Claveria, Philippines

	Grain yield (g lm^{-1})			
	T_1	T_2	T_3	T_4
Crop 1				
Site 1	325.1b*	323.3b	320.7b	336.8b
Site 2	275.6c	327.7b	326.7b	369.3a
Crop 2				
Site 1	91.2i	90i	113hi	103.1hi
Site 2	156.9f	165.9f	167f	171.4ef
Crop 3				
Site 1	157.4fg	185.1e	199.7e	204.5d
Site 2	170.2fe	191.9de	213.2d	222.4d
Crop 4				
Site 1	43.3j	61.7j	77.4j	90.2i
Site 2	112.7hi	134.8g	133.4g	138.2g
Crop 5				
Site 1	115.2hi	156.3fg	157.4fg	164.9f
Site 2	120.1h	143.8g	179.6fe	182.1e
Crop 6				
Site 1	59.4j	74.7j	84.8i	100.2hi
Site 2	71.9i	80.8i	102.6hi	107.7hi
F prob	0.048			
Least significant difference (5%)	26.38			

* Means in a row/column followed by the same letter are not significantly different from each other at the 5% level; LSD test

under T_1. In the last year (crop 5 and 6) maize grain yield in T_4 at both sites was 30–40% greater than under T_1 (Table 3).

In each year, the pattern of the maize grain yield across the alley conformed to a bell-shaped curve and maize yields differed significantly ($P < 0.05$) among the pruning regimes and with the distance from the tree line (Table 4). During the first year, yields under pruning regime T_4 were greatest for all maize rows except for rows 3, 11, 12 and 14. However, only the yield of the first maize row under T_4 (398 g lm^{-1}) was significantly different from that of T_1 (272 g lm^{-1}). In the first year, differences in grain yield between T_4 and T_1 ranged from 5 to 14% in rows 7 and 9 (center of the alley) up to 32% in row 1. Across the alley, in all pruning regimes the grain yield of rows next to the trees (rows 1 and 15) were significantly different from the rows in the middle of the alley (rows 5–10).

In the second year, as trees grew taller, the bell-shaped pattern of the maize grain yield in the alley became more marked due to competition from *Gmelina*: maize grain yield of the three rows next to the trees (rows 1, 2, 3, 13, 14 and 15) were 40–90% lower than the grain yields at the center of the alley (maize row 8). The differences between treatments also became more marked and regular. Yields under pruning regime T_4 were greatest for all maize rows except in row 3 (in which the yield under T_4 was equal to the yield under T_2), and rows 5 and 6 (in which yields under T_3 were greatest). Compared to T_1, grain yields under T_4 were 40–50% greater in the two rows next to the tree lines and 25–35% greater in the center of the alley, although only maize rows 2, 9, 11 and 12 differed significantly.

In the third year, the bell-shaped curve of maize grain yield became less pronounced, indicating the dispersion of competition effects across the alley as trees grew taller. Yields under pruning regime T_4 were highest for all maize rows, except for rows 3, 11 and 13 which showed greater yields under pruning regime T_3, but only the grain yield of maize rows 3, 4, 5, 14 and 15 under T_4 differed significantly from the grain yield under T_1.

The analysis of maize grain yield in each pruning treatment and cropping season showed that the wet season (first crop) yield was consistently greater than

Table 4 Effect of pruning on grain yield (grams per linear meter) of maize rows intercropped on a 10-m wide sloping alley between rows of *Gmelina arborea* (upper tree row at $x = 0$ m; lower tree row at $x = 10$ m) in Claveria, Philippines

Year	Treatment	Maize row (meters from upper tree row)														
		1 (1.1)	2 (1.7)	3 (2.3)	4 (2.9)	5 (3.5)	6 (4.1)	7 (4.7)	8 (5.3)	9 (5.9)	10 (6.5)	11 (7.1)	12 (7.7)	13 (8.3)	14 (8.9)	15 (9.5)
1	T_1	272c*	378b	393b	408b	431ba	453ba	486a	462ba	503a	456ba	472ba	462ba	452ba	405ba	332cb
	T_2	354cb	429ba	432ba	442ba	448ba	509a	507a	495a	508a	457a	479ba	520a	454ba	402ba	356cb
	T_3	311cb	414b	470ba	452ba	497a	467ba	509a	449ba	536a	488ba	522a	502a	496a	437ba	405b
	T_4	398b	439ba	457ba	468ba	498a	514a	514a	539a	538a	579a	510a	507a	552a	432ba	412b
2	T_1	32e	95e	157d	248cd	344cb	381ba	441ba	427ba	409b	347cb	292c	195d	123ed	85e	51e
	T_2	46e	159d	265cd	333cb	386ba	445ba	444ba	453ba	468ba	422b	343cb	245cd	138ed	97e	79e
	T_3	72e	169d	248cd	332cb	422ba	467ba	468ba	489ba	489a	451ba	373b	305cb	202cd	116ed	75e
	T_4	116ed	182d	265 cd	345cb	400ba	449ba	507a	494a	511a	458ba	435ba	315cb	210 cd	133ed	94e
T	T_1	71e	145ed	163d	167d	198d	217cd	236cd	266c	224cd	241cd	181d	182d	145ed	160d	156d
	T_2	110ed	193d	206cd	242cd	278c	283c	299c	295c	278c	257cd	226cd	210cd	166d	201cd	173d
	T_3	136ed	237cd	279c	286c	296c	319cb	298c	323cb	287c	266cd	249cd	236cd	252c	227cd	243cd
	T_4	153ed	254cd	265c	295c	320cb	329cb	315cb	353cb	314cb	300cd	238cd	244cd	239cd	267c	275c
LSD				0.8576												
SE				0.4371												

LSD least significant difference, *SE* standard error

[*] Means in a row/column followed by the same letter are not significantly different from each other at the 5% level; LSD test

Table 5 Effect of pruning regime of *Gmelina arborea* on grain yield of intercropped maize in Claveria, Philippines

Treatment	Grain yield (t ha^{-1})[a]					
	First crop 1998	Second crop 1998	First Crop 1999	Second crop 1999	First Crop 2000	Second crop 2000
T_1 (60–70% LCR)	5.31a[b]	2.06a	2.78a	1.30a	1.95a	1.08a
T_2 (40–50% LCR)	5.32a	2.13a	3.21b	1.63b	2.50b	1.29ab
T_3 (30–40% LCR)	5.30a	2.34a	3.48b	1.75b	2.80bc	1.54bc
T_4 (20–30% LCR)	5.69a	2.28a	3.59b	1.90b	2.90c	1.70c
Least significance difference (5%)	0.969	0.324	0.390	0.293	0.366	0.277
Coefficient of variation (%)	11.2	9.2	7.5	11.1	9.1	12.3

LCR live crown ratio

[a] Figures are yield per hectare, excluding the area occupied by tree lines

[b] Means in a column followed by the same letter are not significantly different from each other at the 5% level

that of the dry season crop (second crop) (Table 5). In the first year, no statistically significant differences ($P < 0.05$) in maize grain yields across the treatments was detected. But as trees grew, grain yield under T_4 became significantly greater ($P < 0.05$) compared to those under T_1. The cumulative difference in grain yield between T_1 and T_4 across the six cropping seasons was 3.58 t ha^{-1}. In the first year, all pruning treatments had annual maize yields greater than the break-even yield of 5 t ha^{-1} year^{-1}. In the second year, however, only the maize yields under T_3 and T_4 (5.23 and 5.49 t ha^{-1}, respectively) were above the break-even yield.

Tree growth

During the first 18 months after planting, trees grew notably faster at site 1 than at site 2. The average dbh of 18-month-old trees was 4.8 cm for T_1, 4.9 cm for T_2, 4.0 cm for T_3, and 3.9 cm for T_4 at site 1, and 1.1 cm for T_1, 1.2 cm for T_2, 1.1 cm for T_3, and 1.1 cm for T_4 at site 2. However from the second year (month 24) until the end of the experiment (month 42), tree dbh increment was consistently larger at site 2 than at site 1. The difference in dbh increment between sites was statistically significant during the periods 30–36 and 36–42 months (Table 6). The large difference in early tree growth between site 1 and site 2 may be explained by the differences in soil physical and chemical properties, whereas the subsequent larger increment in tree dbh at site 2 may have been due to improved soil physical and chemical conditions as a result of ploughing and fertilization.

Tree dbh increment was highest under pruning regime T_1 and lowest under T_4 (Fig. 1). The effect of pruning on tree dbh increment was statistically significant ($P < 0.001$) only in site 1 during the 18–24 month and 30–36 month periods. At site 2, trees under T_1 consistently showed greater dbh increment than all other treatments. However, observations were not statistically significant, probably because of variable soil conditions within the site. This assumption is supported by analysis that demonstrates that the site-treatment interaction at site 2 was highly significant. Pairwise comparisons of treatments means showed that the difference in mean diameter increment between T_1 and T_4 was statistically significant in both sites and in all periods except at site 1 during the period of 36–42 month. Comparisons between T_2 and T_4 showed that differences in mean dbh increment were significant only at site 1 during the periods of 18–24 and 30–36 month, and at site 2 during the period of 36–42 month (Table 6).

The MAI in dbh was greatest for trees under moderate pruning (T_1). At site 1, MAI in dbh was 4.6 cm year^{-1} for pruning regime T_1, 4.5 cm year^{-1} for T_2, 4.1 cm year^{-1} for T_3 and 3.8 cm year^{-1} for T_4. At site 2, the MAI in dbh was 5.4 cm year^{-1} for pruning regime T_1, 4.9 cm year^{-1} for T_2, 4.8 cm year^{-1} for T_3 and 4.4 cm year^{-1} for T_4. Mean maize grain yield was greatest under T_4 pruning regime, with an average difference between T_1 and T_4 of 0.56 ton ha^{-1} at site 1 and 0.63 ton ha^{-1} at site 2 (Figs. 2 and 3).

There was no significant difference in tree height increment among treatments throughout the

Table 6 Mean diameter increment (cm) of *Gmelina arborea* under the four pruning regimes in Claveria, Philippines

Time period (month)	18–24[a]	24–30		30–36		36–42		*N*[b]	
	Site 1	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Treatment									
T_1	2.6	2.8	3.0	2.0	2.7	1.8	2.5	39	35
T_2	2.5	2.7	2.8	1.9	2.3	1.9	2.3	41	37
T_3	2.4	2.5	2.7	1.7	2.3	1.7	2.2	36	37
T_4	2.0	2.4	2.5	1.5	2.2	1.8	1.9	43	39
F-prob									
Site		0.16		<0.001		<0.001			
Treatment	<0.001	0.12	0.04	0.005	0.019	0.792	0.009		
LSD (5%)									
Site		0.1866		0.1476		0.1957			
Treatment	0.3144	0.3815	0.3518	0.2769	0.3128	0.4198	0.3628		

[a] The dbh increment for site 2 is not included for the 18–24 months as few trees had sufficient diameter to measure

[b] Number of trees included in the analysis

LSD least significance difference

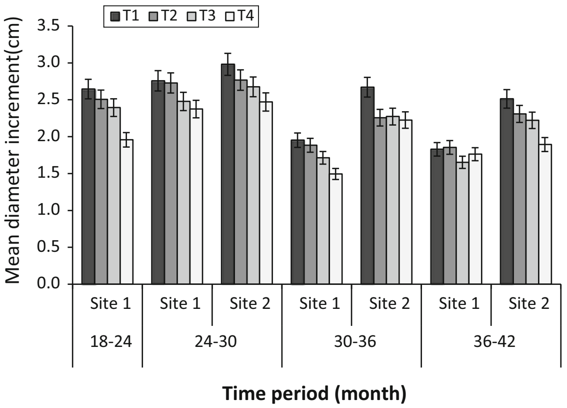

Fig. 1 Mean diameter increment (cm) of trees under four pruning regimes at the two experimental sites in Claveria, Philippines

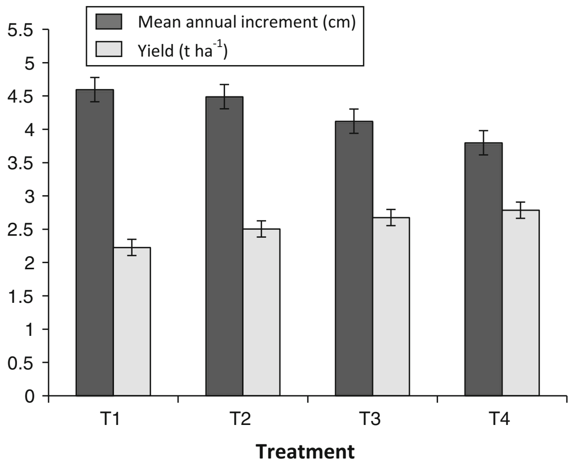

Fig. 2 Mean annual increment at diameter breast height (cm) and annual maize grain yield (t ha^{-1}) under four tree pruning regimes at site 1 in Claveria, Philippines

observation periods. There was, however, a significant difference ($P < 0.001$) in tree height increment between sites, with more growth at site 1 than at site 2, probably as a result of differences in soil properties. Mean height increment ranged from 3.4 to 4 m year^{-1} at site 1 and 2.7–3.1 m year^{-1} at site 2. At the end of the experiment, the average tree height was 14.0 m for T_1, 14.1 m for T_2, 12.7 m for T_3 and 11.8 m for T_4 at site 1, and 9.8 m for T_1, 9.6 m for T_2, 10.9 m for T_3 and 11.0 m for T_4 at site 2.

No significant difference was found in stem shape between treatments. About 50% of the trees assessed in each treatment presented crooked or knotty stems, around 46–47% presented medium stem shape and only 3–4% were rated as excellent in shape.

The results of the financial assessment showed that for a 15% discount rate, moderate tree pruning regimes (T_1 and T_2) were more profitable than high pruning regimes (T_3 and T_4) if the difference in average dbh at the end of the rotation was 2 cm (11% difference in timber yield) (Table 7). However, in all scenarios the pruning regime T_4 showed the most returns to labour, indicating that greater maize yields

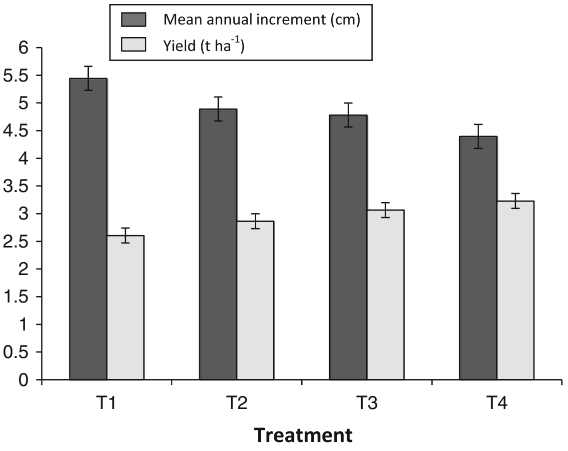

Fig. 3 Mean annual increment at diameter breast height (cm) and annual maize grain yield (t ha^{-1}) under four tree pruning regimes at site 2 in Claveria, Philippines

as a result of reduced crop suppression effects could compensate for lower timber yields. The returns to labour of T_1 (at a 15% discount rate) would be equal to that of T_4, only if the average dbh at harvest of T_4 was 24 cm (a difference of 6 cm), which is equivalent to a timber yield of 50 m^3 ha^{-1}. The results of this study, however, did not indicate such a large difference in dbh between trees under T_1 and T_4.

Discussion

These on-farm trials revealed that intensive pruning was an effective practice to increase the yield of maize intercropped with *Gmelina* and prolong the period of profitable intercropping. However, intensive pruning also slowed tree growth, resulting in reduced diameter growth and lower timber yields. These results were consistent with other studies conducted in the Philippines and Indonesia (Gonzal 1994; Manurung et al. 2009; Miah 1993). The current study provided further evidence that while intensive pruning was beneficial for grain production, the practice may reduce the profitability of timber production below levels acceptable for farmers choosing to grow commercial timber. Financial analysis showed that under intensive pruning, grain yield compensated for reductions in timber yields of up to 6% (1 cm difference in average dbh at harvest). Even if average dbh were reduced by 3 cm (or a corresponding 16% reduction in timber volume) as a result of intensive pruning, the returns to labour would be greater than systems with moderately pruned trees (T_1). The returns to labour under moderate pruning will be the same as that of the high pruning treatment only in the unlikely event that the average dbh at the end of the timber rotation under intensive pruning was 24 cm (6 cm less than the dbh under T_1). In the context of this study intensive pruning of timber trees during the 2-year period of intercropping provided greater returns to the labour and greater profitability providing that timber yields are not excessively reduced.

The intensively-pruned *Gmelina*–maize agroforestry systems of this study required a total of 24 man-days ha^{-1} of labour more than the systems with moderate pruning. As farmers need to provide this labour during the cropping season (before the emergence of maize plants), labour availability may be the main impediment for farmers who want to adopt intensive pruning. To overcome this, and reduce the costs of tree establishment and management, it may be advisable to plant trees at final or quasi-final spacing (250–400 tph). Analysis using modelling of native timber species with maize in the Philippines supports this proposition (Martin and van Noordwijk 2009). However, timber trees planted at wider spacing will probably require more labour for pruning than trees at higher densities, as more and larger branches are likely to grow. Moreover, producing quality timber by minimizing the number of trees planted and applying formative pruning may fail, as shown by Kerr and Morgan (2006) with a study of 4 temperate timber trees planted at densities ranging from 600 to 1,370 t ha^{-1}. Future research should assess the trade-offs of planting timber trees at final spacing.

Another option for farmers to reduce pruning labour is to plant timber species that have an architecture more favourable for intercropping (i.e., narrower crowns). In a survey of tree management practices conducted in Claveria, growers of *Swietenia macrophylla* King. (mahogany) and *Eucalyptus deglupta* Blume (bagras) responded that they save considerable labour because those species require less intensive pruning than *Gmelina* (Bertomeu 2004). Tree farmers cited the narrow crown and smaller branches of mahogany and the straight stem and self-pruning habit of bagras as the most notable advantages of those species over *Gmelina*.

In the Philippines smallholder-produced timber has become an important source of raw material for the

Table 7 Returns to land and labour of agroforestry with *Gmelina arborea* and maize intercropped across an 8-year tree rotation under four pruning regimes and two timber yield scenarios in Claveria, Philippines

Treatment	Maize ($t\ ha^{-1}$)	Timber ($m^3\ ha^{-1}$)[a]	Return to land (LEV in US$ ha^{-1})[b]		Net return to labour: (US$ $work\text{-}day^{-1}$)[c]	
			$r = 15\%$	$r = 20\%$	$r = 15\%$	$r = 20\%$
Scenario 1						
Maize–tree intercropping (T_1)	7.4	71.7	1,318	830	4.7	3.9
Maize–tree intercropping (T_2)	10.7	67.7	1,284	816	4.9	4.2
Maize–tree intercropping (T_3)	12.9	63.8	1,231	788	5.1	4.4
Maize–tree intercropping (T_4)	13.5	60.0	1,236	806	5.0	4.4
Scenario 2						
Maize–tree intercropping (T_1)	7.4	71.7	1,318	830	4.7	3.9
Maize–tree intercropping (T_2)	10.7	67.7	1,284	816	4.9	4.2
Maize–tree intercropping (T_3)	12.9‘	67.7	1,297	828	5.2	4.5
Maize–tree intercropping (T_4)	13.5	63.8	1,299	845	5.2	4.5
Scenario 3						
Maize–tree intercropping (T_1)	7.4	71.7	1,318	830	4.7	3.9
Maize–tree intercropping (T_2)	10.7	71.7	1,350	857	5.1	4.3
Maize–tree intercropping (T_3)	12.9	67.7	1,297	828	5.2	4.5
Maize–tree intercropping (T_4)	13.5	67.7	1,364	885	5.3	4.6

[a] Timber yields have been estimated with the tree volume equation Log $V_m = -3.8579 + 1.6844 \log \mathrm{Dbh} + 0.8671 \log H_m$, found by (Virtucio et al. 1986) for *Gmelina arborea* (Dbh in cm, H_m merchantable height in m, V_m merchantable volume). A stocking density of 250 trees per hectare (tph) at harvest and a $H_m = 9$ m have been assumed in all treatments. The average dbh at the end of the rotation assumed 30 cm (highest timber yield of 71.7 $m^3\ ha^{-1}$), 29 cm (timber yield of 67.7 $m^3\ ha^{-1}$), 28 cm (63.8 $m^3\ ha^{-1}$) and 27 cm (60.0 $m^3\ ha^{-1}$). H_m has been estimated based on a taper of 2 cm per meter and a small-end diameter of 14 cm as found by Bertomeu (2006) for *Gmelina* in the study site

[b] *LEV* land expectation value. All costs and revenues (as of 1998) as in Bertomeu (2006). The exchange rate in 1998 was US$1 = PhP40 (data from: exchange Rate_(1990–2002) www.bsp.gov.ph/statistics/exrate/usd/year_htm)

[c] Pruning labour rates assumed were: (a) form pruning: 1 man-day ha^{-1} for all treatments; (b) First lift pruning: 6 man-day ha^{-1} for T_1, 8 man-day ha^{-1} for T_2, 10 man-day ha^{-1} for T_3 and 13 man-day ha^{-1} for T_4; (c) Second lift pruning: 4 man-day ha^{-1} for T_1 (500 tph), 10 man-day ha^{-1} for T_2 (1,000 tph), 13 man-day ha^{-1} for T_3 (1,000 tph) and 15 man-day ha^{-1} for T_4 (1,000 tph); (3) Third pruning: 3 man-day ha^{-1} for T_1 (250 tph), 7 man-day ha^{-1} for T_2 (500 tph), 17 man-day ha^{-1} for T_3 (1,000 tph) and 19 man-day ha^{-1} for T_4 (1,000 tph)

local wood industry (Bertomeu 2008). However, current timber management practices (no thinning, intensive pruning and inappropriate pruning methods) result in undersized, and low quality timber. Over the past 10 years the market has been saturated with such timber, resulting in low prices for farm-grown trees. A market survey indicated that local timber traders and wood processors were willing to pay a premium for quality timber (Bertomeu 2008). Therefore managing for larger, better quality trees is recommended to enhance the financial returns from small-scale tree farming. In traditional forestry, moderate pruning is a common practice to improve tree form (taper and stem shape), to reduce wood defects and thus, produce high yields of quality timber. But in the context of resource-poor farmers (with a priority to grow food crops) intensive pruning increased profitability of maize-timber production systems by enhancing crop yield without excessively reducing timber yields. The question remains now whether this pruning strategy can result in quality timber that commands a higher price. Our opinion is that high and frequent pruning (during the 2 or 3 years of intercropping) should be compatible with knot-free quality timber production as long as pruning operations are properly implemented. Future research should study this issue, as well as assessing what impedes farmers from adapting proper pruning ratios and recommended pruning for different timber species and different smallholder timber production systems.

The observed slower early growth but subsequent faster dbh increment of trees at site 2 also highlighted the importance of intensive management to enhance tree growth and compensate for poor site properties. It also demonstrated the need to develop better tree growth evaluation methods by integrating site quality information with general spatial information as identified by Martin et al. (2010). Finally, there is also a need to conduct long-term studies, throughout a full timber rotation, to better assess final timber yields and the potential benefits of integrating shade-demanding crops or animals on overall system productivity and profitability.

Conclusion

When fast-growing timber trees are intercropped with light-demanding annual crops, intensive pruning (i.e., retaining LCR of 20–30%) before crop production generates greater returns than moderately pruned trees (as recommended in classical forestry text books). The gains in yield of annual crops resulting from reduced shading compensate for labour costs associated with pruning and the detrimental effect on tree growth resulting from intensive pruning. Farmers whose immediate objective is to produce food crops, but who are also interested in producing short rotation (8–12 years) commercial timber, should prune trees intensively in order to prolong the period of profitable intercropping. Once grain yields decrease below the break-even point, intercropping should be discontinued and trees should be managed for quality timber production.

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