5. PRUNING STRATEGIES FOR REDUCING CROP SUPPRESSION AND PRODUCING HIGH QUALITY TIMBER IN SMALLHOLDER AGROFORESTRY SYSTEMS

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In the Philippines, smallholder farmers have become major timber producers and trees planted on farms are an important source of raw materials and income for them and for the local timber industry. The smallholder mode of timber production has several advantages over traditional reforestation. The frequent and intensive tending operations (land cultivation, weeding and fertilization) for annual intercrops improve tree survival and growth. Intercropping reduces tree establishment and weeding costs because these are charged to annual crop production. The cropped alleys between tree lines function as effective firebreaks. However, the planting of timber trees in association with light-demanding annual crops often leads to a drastic suppression in crop production as a result of competition for both above- and below-ground resources. With few exceptions, the most common timber trees promoted for farm forestry have been reported to decrease yields of associated crops. Therefore, concerns have been raised over the sustainability and suitability of tree farming for resource-poor farmers. Branch pruning effectively reduces light interception by the tree canopy, and thus prolongs the number of years that annual crop production can be practiced. However, to minimize crop yield suppression, farmers often practice intensive pruning annually before planting annual crops. Intensive pruning may enhance crop yield, but it is incompatible with commercial timber production because the growth rate and quality of the overstorey timber trees are severely reduced. This paper reports the results of on-farm trials conducted to assess the effects of four pruning levels on maize grain yield and also on tree growth and form. Plots consisted of three rows of the timber tree *Gmelina arborea* planted at 1 x 10 m with maize planted in the 10 m alleys during seven cropping seasons. The study shows that high pruning intensity (retaining a live crown ratio of 20–30%) results in significantly higher maize grain yields but reduced tree diameter. In economic terms, these higher maize grain yields are not enough to compensate for the costs of pruning and the lower market value of smaller-diameter timber. Therefore, if crop production is a priority, tree farmers should plant timber species that are less competitive or plant trees at low densities in other farm niches away from crops.

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 the market. As a result, smallholder farmers have become major timber producers and trees planted on farms are today an important source of raw materials and income for smallholders and for the local timber industry. One of the unique advantages of smallholders in tree production is the practice of intercropping. Because early and timely weed control is imperative to successful tree growing, (Lowery *et al.* 1993, Kosonen *et al.* 1997), the frequent and intensive tending operations for crops, such as land cultivation, weeding and fertilization, ensure tree survival and promote faster tree growth by preventing weed infestation and improving site conditions (Garrity *et al.* 1997). Kapp and Beer (1995) observed lower mortality rates of *Acacia mangium* in agrisilvicultural plots (16%) compared to pure plots (41%), probably related to faster tree growth and greater distances between the roots, which reduced the spread of fungus infection. They also found that *Cordia alliodora* trees associated with crops were 3.4 m taller than in monocultures because of the positive effect of fertilization and reduced weed competition in the agrisilvicultural plots. Conversely, growth of associated crops may benefit by the presence of trees because these reduce weed invasion and growth (Gajaseni and Jordan 1992). Miah (1993) reported that weed infestation and weed dry matter yield in an upland rice-tree association were 30 to 38% lower than in the sole rice plots.

Planting trees and crops in association is also economically advantageous. According to Garrity and Mercado (1994), the practice of intercropping reduces tree establishment and weeding costs because these are charged to the land preparation operations for crops, and also reduces

protection costs because cropped alleys function as effective fire-breaks. In Latin America, it has been estimated that the costs of soil preparation, weeding and pest and fire control were 51 to 68% lower in an intercropping system than in pure reforestation (Rodriguez 1998, cited in Beer *et al.* 2000). For all these reasons *taungya*, the century-old system of reforestation in which intercropping is practiced during the first few years after tree planting, is a good strategy for tree establishment and survival, to reduce reforestation costs and to produce timber for farmers and the industry (Lamb 1968, Jordan *et al.* 1992, Verissimo *et al.* 1995, Mayhew and Newton 1998, Beer *et al.* 2000).

In spite of the above advantages, there is substantial evidence that in intercropping systems competition effects may reduce or override productivity gains as well as the positive economic aspects of growing crops in association with trees. 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[1] 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 decrease yields of associated crops, as the genetic potential of trees to grow fast makes them more 'aggressive' (Huxley 1999).

In Guatemala, four years after planting trees at 3 x 2 m, the yields of maize (*Zea mays*) and green beans (*Phaseolus vulgaris*) intercropped, were reduced by 35% by *Casuarina equisetifolia,* 83% by *Eucalyptus globulus* and 91% by *Alnus acuminata* compared to the first year crop (Leiva and Borel 1994). In Uganda, Okorio *et al.* (1994) found that of seventeen timber trees intercropped with maize and beans, only one species did not have a negative effect on annual crop yields[2]. Over five seasons, the maximum average reductions in annual crop yields was 60%.

In India, serious concerns have been raised over the sustainability and appropriateness of tree farming for resource-poor farmers (Shiva and Bandyopadhyay 1987) in view of its negative impact on food crop production and rural employment. Subsequent studies quantified the substantial decline of annual crop production due to intercropping with timber trees. Ahmed (1989) found that planting eucalyptus on farm bunds increasingly reduced wheat yields starting in the second year after planting, until total wheat yields were 49% less in the 9th and 10th year. Malik and Sharma (1990) found *Eucalyptus tereticornis* not suitable for intercropping in semi-arid regions with deep water table conditions after observing a 41% average reduction of wheat and mustard yield in a 10 m strip on both sides of a tree row[3]. Based on data collected on site inspection and interviews with farmers, Saxena (1991) estimated that crop losses due to bund planting of a eucalypt in north-west India ranged from two to eight times the total direct investment in raising trees. Consequently, even though farmers were better off after planting a eucalypt, when crop losses were taken into account the profits were not high enough to cover the risk of production and of fluctuating output prices (Saxena 1991). Similarly, Predo (2002) found that although tree farming was more profitable than annual crop production, uncertain market conditions deterred tree planning; timber was planted only when profits from annual crops declined.

When water and nutrients are freely available, as in areas of 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). The pruning of tree branches 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 planted in alleys between lines of severely pruned multipurpose trees (*Gliricidia sepium, Acacia auriculiformis* and *Acacia mangium*) were comparable with those of the sole crop plot. In a hedgerow agroforestry system with gmelina planted at 1 x 6 m, the grain yield of rice in association with severely pruned trees increased by 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 form (Bertomeu 2004). In Indonesia, small scale timber farmers start severe branch pruning (live crown ratios of 40% or less) at six months to reduce tree-annual crop competition, 'improve' tree form, and reduce wind damage to trees (Roshetko *et al.* 2004). However, such intensive pruning slows tree growth (Smith 1962), reducing tree diameter and final timber yields, resulting in lower timber value. Miah

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[1] In reality, crop yield suppression is the net result of both competitive and facilitatory processes occurring between trees and crops above and below ground level (Ong and Huxley 1996, Huxley 1999). If associated crops had different environmental requirements (i.e. tolerance to shading), facilitation might have been the net outcome of the association, as is the case in the *Paraserianthes falcataria* coffee systems.

[2] Interestingly, *Alnus acuminata,* the most competitive specie in the Leiva and Borel (1994) study, had a positive effect on crop yields.

[3] Observations made on a single row of a eucalypt during one cropping season only.

(1993) reported that at the age of two years, the total biomass of the pruned trees was 34% lower than that of unpruned trees, and Gonzal (1994) found that pruned trees had a significantly smaller stem diameter (7.38 cm) than unpruned trees (9.83 cm). Therefore, even though intensive pruning is beneficial for the understorey crops, the practice may reduce the profitability of tree farming below levels acceptable for farmers with a priority to grow trees for the market (Midmore *et al.* 2001).

Farmers can instinctively anticipate crop yield losses as trees grow, as well as the positive benefits of severe pruning on crop yield. However, they are probably unable to accurately predict the period of viable intercropping and the net profits of different management regimes over a full tree rotation. Therefore, this study was designed to investigate the effect of several pruning regimes on tree growth and crop yield and its implication for the farmer in terms of food security and profitability. The aim is to provide information to help farmers decide whether to integrate or segregate timber trees and crops and more specifically when, and at what intensity, to prune. The tree and crop species examined in this study are *Gmelina arborea* R.Br. (hereafter referred to as gmelina) and maize (*Zea mais*). In the late 1980s, gmelina became popular among farmers because of its rapid growth, acceptable timber quality and market demand. Maize farming is the dominant agricultural system in the Philippine uplands, at low to medium elevations (300–700 m) as a major food and cash crop (Kenmore and Flinn 1987).

DESCRIPTION OF THE STUDY SITE

The study was conducted in Claveria, an upland municipality located 42 km northeast of Cagayan de Oro City, in northern Mindanao. The municipality covers an area of 112,175 ha, has a mountainous topography with 62% of the area having slopes of 18% or greater and elevation ranging from 390 to 2000 m. a.s.l. (DTI and PKII Engineers 1996). Soils are derived from volcanic parent material and classified as deep acidic Oxisols with pH of 3.9–5.2, texture ranging from clay to silty clay loams, with low available phosphorus, low cation exchange capacity, high aluminium saturation and low exchangeable potassium (Magbanua and Garrity 1988). The average rainfall is 2500 mm with a 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 maximum of 28.6 ˚C and average minimum of 21.3 ˚C.

At lower elevations (400–700 m), maize is the dominant crop, cultivated twice a year or in rotation with cassava (*Mahinot esculenta* Crantz) or upland rice (*Oryza sativa* L.). Typically, a crop planted on 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 on the higher elevations (700–900 m). The average farm size is 2.5 to 3 ha with farmers commonly cultivating two or more parcels of land.

In the past 50 years, land-use in Claveria has experienced a rapid transformation from natural forests to grasslands to a mosaic of intensive cash and food cropping and perennial land-use systems (Garrity and Agustin 1995). Recently, the use of strips of natural grass (NVS) along contours as a measure to control soil erosion has become common among farmers in the area. This practice is also the base for the incorporation of fruit and timber trees (Stark 2000).

RESEARCH METHOD

The performance of *Gmelina arborea* (gmelina) intercropped with maize under four pruning regimes was assessed and compared through field trials. Gmelina is a fast-growing medium-sized deciduous tree native to various countries, including Pakistan, Sri Lanka, and Myanmar and Australia. It has been widely planted in Southeast Asia, tropical Africa and Latin America in plantations to produce wood for light construction, crafts, veneers, pulp, fuel and charcoal. It has been also planted in *taungya* systems with short-rotation crops and as a shade tree for coffee and cacao. Rotations are usually about six years for pulpwood and ten years for sawnwood (Hossain 1999, Lamb 1968). Under smallholder conditions, gmelina timber rotations may be as short as six years (Roshetko *et al.* 2004). During the late 1980s and 1990s, gmelina was extensively planted across the Philippines (Garrity and Mercado 1994, Pasicolan and Treacy 1996, Magcale-Macandog *et al.* 1999).

The study consisted of researcher-designed and managed on-farm trials with experimental plots laid out in a randomized complete block design with four treatments and four replications. Plots were 300 m^2 (15 x 20 m) containing three lines of gmelina planted at 1 x 10 m, with 16 trees per

line (i.e. 48 trees), and 15 rows of maize planted for 6 cropping seasons in each of the two 10 m wide alleys (Figure 1). The slope of the experimental plots ranged from 20–30%.

Based on the prevalent farmers' practice of intensive pruning of intercropped trees, four pruning regimes were chosen: (a) T_1 (control): tree branches were pruned on 30 to 40% of the total bole height (i.e. trees with a live crown ratio[4] of 60 to 70%); (b) T_2: tree branches were pruned on 50 to 60% of the total bole height (i.e. trees with a live crown ratio of 40 to 50%); (c) T_3: tree branches were pruned on 60 to 70% of the total bole height (i.e. trees with a live crown ratio of 30 to 40%); (d) T_4: tree branches were pruned on 70 to 80% of the total bole height (i.e. trees with a live crown ratio of 20 to 30%). The trial was part of a larger study undertaken to examine the appropriateness (viability and feasibility) of planting timber trees at wide spacing in smallholder farming systems.

Research Plot Set-up and Management

Seeds of gmelina were collected from local trees, de-pulped and soaked in water for 24 hours, and then sowed in plastic nursery bags filled with topsoil. Tree seedlings were raised for about three months in a nursery at Claveria until they were 25 to 30 cm tall. In the last week of September and first week of October 1997, seedlings were planted at the trial sites. Dead trees were replaced until the end of December 1997. From January to May 1998, trees were watered twice a month due to the severe drought. In June and July 1998, after the dry spell, dead seedlings were replaced to maintain homogenous plot conditions. Trees replaced after the drought were not included in the calculations of tree parameters.

Contour hedgerows of natural grass (NVS) were established in the research plots by leaving a 50 cm wide unplowed strip along the contour and trees were planted just above the grass strip. Maize cropping commenced in May 1998 (wet season crop, 1998) and continued for six cropping seasons until the last harvest on 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 plowings and one harrowing operation. All other maize farming operations (i.e. 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 NPK/ha. 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 was done five to seven days after emergence (DAE). Nitrogen (Urea 46-0-0, 46% N) was applied as equal split doses by side dressing at 15 and 30 DAE. After nitrogen application, interrow cultivation was performed to cover the fertilizer with soil and as a weed control measure. Manual weeding of the maize crop was also done as needed, usually one to two weeks after second interrow cultivation.

Fertilizer was applied only to the crop as described above. However, the trees have probably benefited from the fertilizer applied to the maize. Ringweeding was conducted at planting. Subsequent weeding operations consisted of two grass slashings per cropping season throughout the first and second year.

One singling and form pruning was conducted when the trees were one year old to retain a single stem and improve form. From May 1999 to October 2000, four branch pruning operations were performed before or immediately after the planting of maize. A 50% intensity thinning was conducted at 30 months after planting.

Data Collection and Analysis

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

Diameter at breast height (dbh) and tree height were recorded twice a year until the age of 54 months. Tree height, average dbh and basal area per plot were calculated with these parameters of trees inside the net plot (i.e. excluding border trees). Tree height reported corresponds to the Lorey mean height, which is the average height weighted by basal area (Philip 1994). Average tree diameter at breast height was estimated as the diameter corresponding to the mean basal area

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[4] The percentage of length of stem clothed with living branches. If the ratio is allowed to decrease to 30% or less the general reduction in vigour will cause substantial loss of diameter growth (Smith 1962).

following Philip (1994). Variations of tree dbh and maize grain yield across the four pruning regimes were studied using the General Statistics Software (Genstat) program (Lawes Agricultural Trust, 2000). A paired-sample t-test was conducted on the average dbh per plot at some selected time points and an ANOVA was conducted on maize grain yield. At the end of the experiment, stem form was assessed by visual inspection. Trees were rated as: A = trees with crooked or knotty stem; B = trees with medium stem form; and C = trees with excellent, straight and nearly cylindrical stem
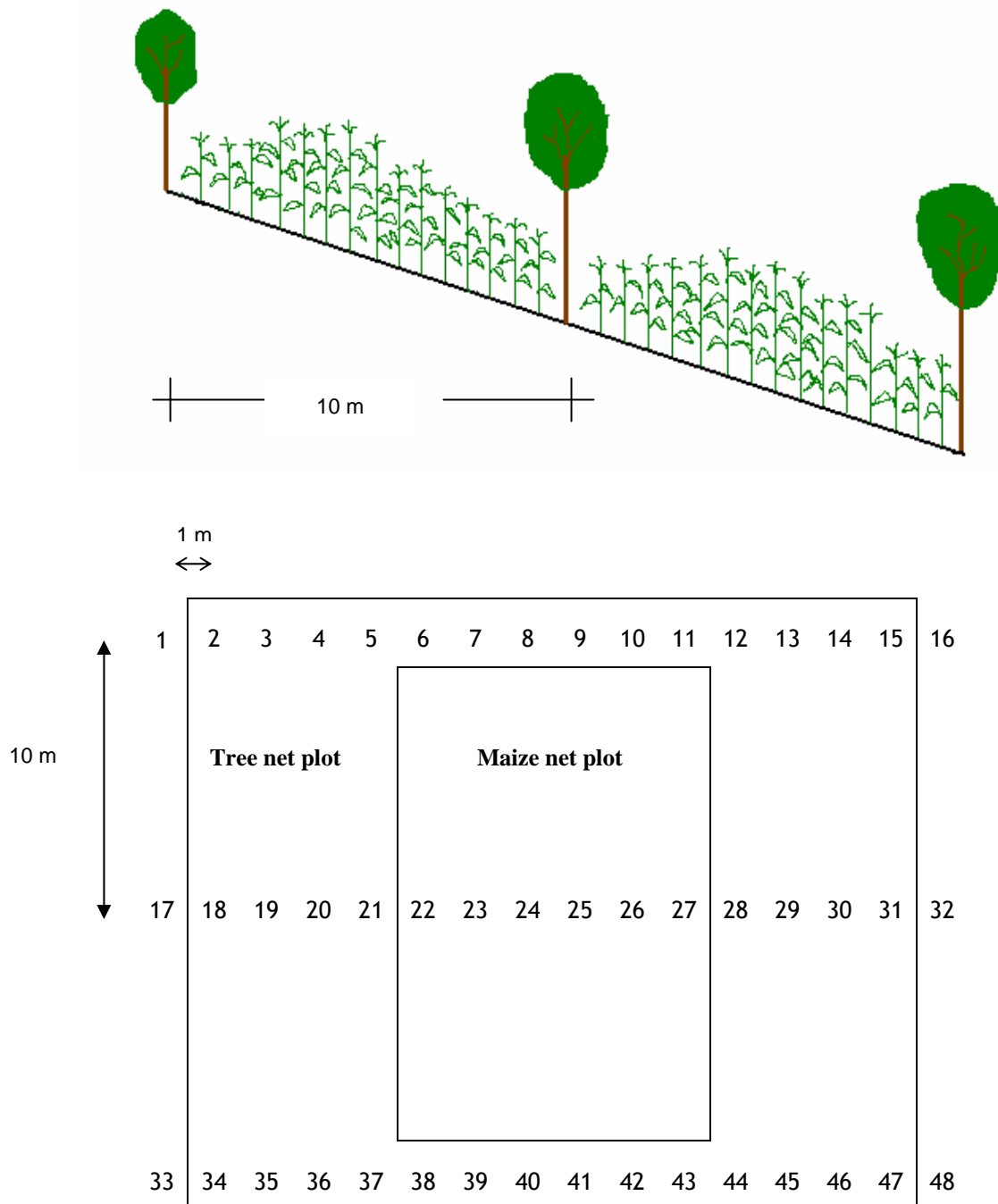

Figure 1. Layout of tree-maize experimental plot

EFFECTS OF THE PRUNING REGIMES

The effect of the four pruning regimes on dbh growth and maize grain yield are presented in Figure 2. At the age of three years, the mean dbh of trees intensively pruned (T4) was 1.7 cm less than that of trees in T1 (control treatment) (14.1 vs. 12.4 cm). However, maize grown under the light canopy of heavily pruned trees (T4) produced 1.55 t/ha more grain than maize under the control (T1).
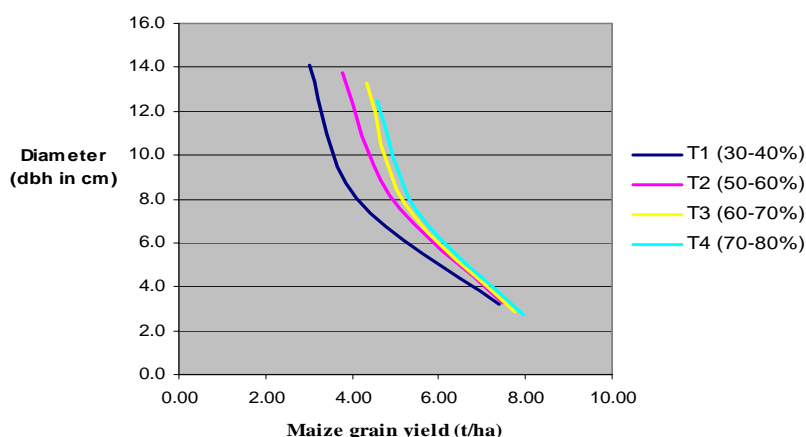

Figure 2. Diameter of *Gmelina arborea* and grain yield of intercropped maize under four pruning regimes

Maize grain yield on the wet season crop (1st crop) was consistently higher than those of the dry season crop (2nd crop) (Table 1). In the first year, no significant difference across the treatments' maize grain yields was detected. But as trees grew, grain yield under T4 became significantly different to that under T1. The aggregate difference in grain yield between T1 and T4 throughout the six cropping seasons was 3.58 t/ha.

Table 1. Effect of pruning regimes of *Gmelina arborea* on grain yield of intercropped maize

Treatment	Grain yield (t/ha)[a]					
	1st crop 1998	2nd crop 1998	1st crop 1999	2nd crop 1999	1st crop 2000	2nd crop 2000
T1 (30-40%)	5.31 a[b]	2.06 a	2.78 a	1.30 a	1.95 a	1.08 a
T2 (50-60%)	5.32 a	2.13 a	3.21 b	1.63 b	2.50 b	1.29 ab
T3 (60-70%)	5.30 a	2.34 a	3.48 b	1.75 b	2.80 bc	1.54 bc
T4 (70-80%)	5.69 a	2.28 a	3.59 b	1.90 b	2.90 c	1.70 c
LSD (5%)	0.969	0.324	0.390	0.293	0.366	0.277
CV (%)	11.2	9.2	7.5	11.1	9.1	12.3

a. Yield per hectare, discounting 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; LSD test.

The difference in dbh between trees under light pruning (T1) and trees under heavy pruning (T4) increased with age. At the age of 3.5 years, trees under treatment T1 attained a larger dbh than trees under T4 (14.1 vs. 12.5). Although the difference in dbh growth under different pruning regimes was 12.8%, statistical analysis did not show convincing evidence of the influence of pruning on dbh growth (Table 2).

Table 2. Dbh growth of *Gmelina arborea* under different pruning regimes

Pruning regime	18 months		30 months		42 months	
	N[a]	dbh (cm)	N	dbh (cm)	N	dbh (cm)
T1 (30-40%)	113	3.2	165	8.0	79	14.1
T2 (50-60%)	117	3.3	165	8.1	91	13.7
T3 (60-70%)	134	2.9	162	7.8	76	13.3
T4 (70-80%)	141	2.7	167	7.4	83	12.5
SED[b]		0.29		0.45		0.72
F-test probability		0.235		0.442		0.196

a. N represents total number of trees (excluding border trees)
b. SED and p-values have been calculated for plot averages, not individual trees.

No significant difference was found in stem form between treatments. About 50% of the trees assessed in each treatment presented crooked or knotty stems and only 3 to 4% were rated as excellent in form (Table 3).

Table 3. Stem form assessment of *Gmelina arborea* under different pruning regimes

Pruning regime	Stem form (%)[a]		
	A	B	C
T1 (30–40%) (n = 88)	51	45	3
T2 (50–60%) (n = 101)	48	49	4
T3 (60–70%) (n = 91)	54	42	4
T4 (70–80%) (n = 100)	49	46	4

a. A = trees with crooked or knotty stems; B = medium stem form; and C = excellent, straight and nearly cylindrical stems.

DISCUSSION

On-farm trials revealed that high and frequent tree branch pruning is an effective practice to increase the yield of maize intercropped between gmelina. However, intensive pruning also slows the growth of trees and results in increasingly reduced diameter growth and, ultimately, smaller timber yields.

Logically, tree farmers will want to know about the financial implications of these results. In a financial analysis of gmelina-maize agroforestry system with the same tree-crop arrangement and level of inputs and management as in this study, Bertomeu (2006) reported that maize break-even grain yields were 3 t/ha for the wet season crop and 2 ton/ha for the dry season crop. Therefore, the period of profitable intercropping under the pruning regime T4 is two years, just one year longer than the period of profitable intercropping under T1 (Table 2). Intensive pruning would only be slightly more advantageous than pruning regime T1 under the assumption that there is no difference in diameter growth at the end of the rotation period. If a conservative difference of only 3 cm in the dbh at the end of the rotation period is assumed, then T4 is not more profitable than T1 (Table 4). Moreover, it should be noted that calculations in Table 3 assumes a static price (i.e. PhP4 per board foot) for smaller and larger diameter timber, when in reality the value per unit volume for smaller diameter timber is 25 to 50% lower than for larger diameter, better quality timber (Bertomeu 2004). It can be concluded, therefore, that maize yield increases as a result of reduced shading due to high and frequent pruning do not compensate for the reduced tree growth and increasing labour costs of intensive pruning as trees grow taller.

Table 4. Returns to land and labour of agroforestry with *Gmelina arborea* and maize intercropped over an 8-year tree rotation period under two pruning regimes

Treatment	Maize (t/ha)	Timber (m³/ha)	Return to land (LEV in US$/ha)[a]		Net return to labour: (US$/work-day)[c]	
			r = 15%	r = 20%	r = 15%	r = 20%
Maize-Gmelina intercropping (T1)	7.4	69	1288	815	0.74	0.62
Maize-Gmelina intercropping (T4)	13.5	69[b]	1,437	941	0.82	0.71
Maize-Gmelina intercropping (T4)	13.5	58	1,248	826	0.71	0.63

[a.] A timber price of PhP4/bdft or US$42.4/m³ is assumed. The exchange rate for 1998 is US$1 = PhP40 (Central Bank of the Philippines, 2002).

[b.] This is calculated assuming the same timber yield as in T1 (average dbh at harvest of 30 cm, stocking density of 250 trees per hectare).

[c.] Labour rates for pruning are: 1. First pruning: 6 man-day per ha for T1 and 7 man-day per ha for T4; 2. Second pruning (after first thinning): 5 man-day per ha for T1 and 8 man-day per ha for T4; 3. Third pruning (after second thinning): 5 man-day per ha for T1 and 8 man-day per ha for T4.

This conclusion has been manifested in a recent shift in farmers' preferred timber species as reported by Bertomeu (2004). When asked about tree pruning, 53 growers of *Swietenia macrophylla* (mahogany) and 32 growers of *Eucalyptus deglupta* (bagras) responded that they can save considerable labour time because these species do not have to be pruned as heavily or as frequently as gmelina. They cited the narrow crown and smaller branches of mahogany and the straight bole and self-pruning habit of bagras as the most notable advantages over gmelina. Experiments conducted in Indonesia comparing mahogany and other trees (*Paraserianthes falcataria, Acacia mangium and Hevea brasiliensis*) confirm this. Sitompul *et al.* (2005) found that the Relative Canopy Density (RCD) (i.e. the ratio of tree canopy diameter/the space between tree rows) was highest in *Paraserianthes falcataria* and lowest in rubber (*Hevea brasiliensis*) and mahogany. As a result, the yield of cassava intercropped with mahogany was higher than under *Acacia mangium* and *Paraserianthes falcataria*. Thus, the best bet tree-crop combination in the first five years of tree growth is cassava with mahogany (Sitompul *et al.* 2005).

CONCLUSION

In agroforestry systems that combine fast-growing timber trees with light demanding annual crops, tree side-branch pruning is an effective management practice to reduce light interception by the tree canopy, and thus prolong the period of viable intercropping. However, to reduce light interception sufficiently to obtain acceptable yields, farmers must practice high and frequent branch pruning (i.e. leaving a live crown ratio of 20–30% every season before the planting of crops). This intensive pruning slows the growth of the trees and reduces the final timber yield. The gains in yield of annual crops derived from reduced shading do not compensate for increasing labour costs and the detrimental effect on tree growth as a result of frequent and intensive pruning. Therefore, farmers with an interest in timber production but whose main objective is to produce food crops have no option but to halt crop production once grain yields decrease below the break-even point (after one or two years in this study) or discontinue tree farming. Other options may be to interplant trees with narrow crowns and small branches and self-pruning habit or to plant trees at low densities in farm niches away from crops.

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