Reprinted from: p. 168-193 in: Hasanu Simon, Hartadi, Sambas Sabarnurdin, Sumardi and Heru Iswantoro (eds.) Social Forestry and Sustainable Forest Management. Perum Perhutani, Jakarta. 1995 (ISBN 979-8824-00-8)

AGROFORESTRY TECHNOLOGIES FOR SOCIAL FORESTRY: TREE-CROP INTERACTIONS AND FORESTRY-FARMER CONFLICTS

Meine van Noordwijk and Thomas P. Tomich
ICRAF - S.E. Asia, P.O. Box 161, Bogor 16001, Indonesia

ABSTRACT

The biological conditions are specified under which a tree-crop system can give a yield benefit. Models can be used to explore the wide range of options as regards choice of trees and crops, plant density, plant spacing and soil management. Although ample opportunities exist for tree-crop combinations to outyield monocultures of either trees or crops, the conditions under which both the tree and the crop component as such benefit from the mixing are narrow. If in 'social forestry' systems the stakeholders (forestry organization and farmers) are exclusively interested in the tree and crop component, respectively, little harmony in management decisions can be expected and strict enforcement of rules is needed, but may not be feasible. If other types of sharing arragement can be agreed on, a much wider range of locally adapted solutions can be found, which more fully exploit the opportunities of tree crop synergy.

INTRODUCTION

Agroforestry is a collective name for land use systems and technologies in which woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately combined on the same land management unit with herbaceous crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions among the different components (Nair, 1993).

Although in the recent past expectations were raised that agroforestry systems are always beneficial for both the tree, crop and animal components of the system, we now realized that this is not very realistic. Often, maximum productivity of each component as such can be achieved in single-component systems and trade-offs between productivity of the various components are unavoidable in more complex systems. Under certain conditions, however, the combined productivity of a mixed agroforestry system can be higher than that of the best single-component systems and agroforestry may be the preffered land use system. Progress is being made in formulating general principles of environmental conditions and tree crop combinations for which such complementarities can outweigh trade-offs.

Social forestry is defined by Nair (1993) as the practice of using trees and/or tree planting specifically to pursue social objectives, usually betterment of the poor, through delivery of the benefits to the local people. It can be interpreted as a collective name for (agro)forestry systems based on agreement between a (state) forestry organization and villagers to share resources (land, capital, know-how and labour) and products (timber, crops, animals, non-timber tree products). Specific forms of it can include taungya or tumpangsari systems, where villagers are allowed to grow certain food crops and/or fruit trees in between rows of newly planted timber trees (Simon and Wiersum, 1993).

Just as agroforestry systems involve biological/technical trade-offs between trees and crops, 'social forestry' systems involve trade-offs between the stakeholders, the state forestry organization and the farmers/villagers. Management decisions in agroforestry include decisions on planting (which land, when, by whom, with which trees and crops, at what spacing, under which soil management regime (tillage, fertilization, drainage, irrigation), on crop maintenance and protection and on harvesting. In 'social forestry' setting, the partners have to share responsibility for such decisions (figure 1) about the inputs, as well as the outputs. Outputs of the system consist of harvestable products and environmental functions, such as watershed protection. In general, the management objectives for each partner will be based on the part of the output obtained by and its relative importance to that partner. Under the current 'social forestry' agreements, the state forestry organization will harvest the timber, while the forest farmer may harvest the crop and non-timber tree products. This direct coupling of specific stakeholders interest to specific products of the agroforestry system has direct effects on the degree of perceived or actual conflicts inherent in the system. The villagers might be better off if they had complete freedom to manage the state forest land according to their own objectives (like the 'forest squatters' try), rather than follow the rules set by the state forest organization. Once we accept the objectives of both stakeholders as legitimate, however, certain forms of social forestry can be more effective in meeting all economic, social and environmental objectives on a limited land area. Social forestry may be thus be the preferable land management system for (part of the) state forest lands. Progress is being made in formulating general principles of social relations and forestry-farmer sharing arrangements for which such benefits can be expected.

In this presentation the relationship between the technical and social aspects of using agroforestry technologies for social forestry will be elaborated and new models for social agro-forestry in Indonesia will be discussed.

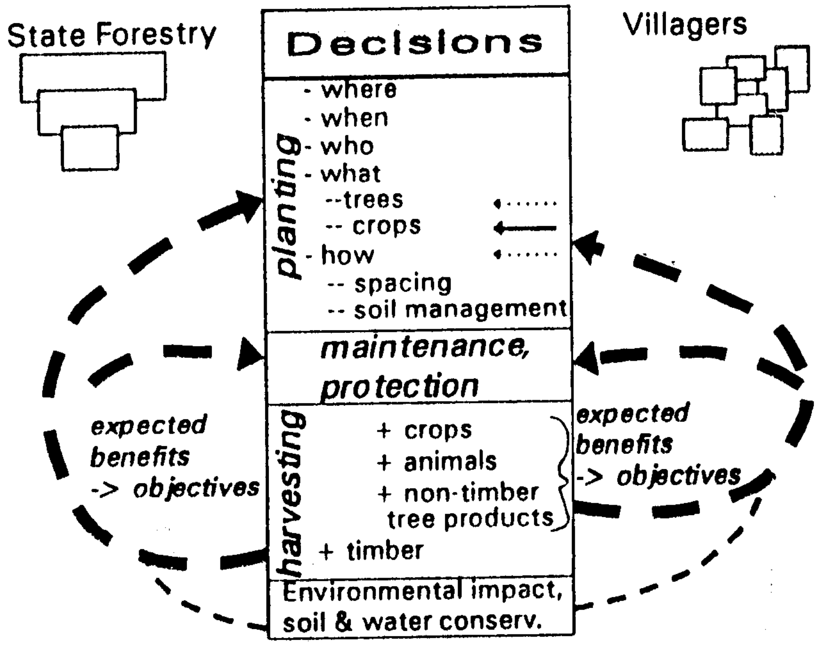


Figure 1. Decisions on the design and management of agroforestry systems; in 'social forestry' the two major stakeholders, the state forestry organization and villagers, benefit from different products of the system, so their management objectives tend to diverge.

OPTIMIZING AGROFORESTRY DESIGN

According to the agroforestry definition used by ICRAF (see above), agroforestry (AF) systems are not simply farming systems where both trees and crops or animals give useful products to the farmer, but systems where tree and crop (and/or animal) production interact (Nair, 1993). Understanding and predicting such interactions should thus be at the heart of an agroforestry research program. Interactions can be ecological or economic in nature, or both, as will most often be the case because the ecological interactions affecting the biological productivity will have economic consequences as well. We will first restrict ourselves to biological interactions and broaden the discussion to economic considerations in paragraph 4.

Biological tree-crop interactions in agroforestry systems may be *indirect*, via changes in soil conditions during a tree phase affecting subsequent possibilities for crop growth in 'sequential' agroforestry systems, such as 'improved fallows', or *direct* as in 'simultaneous' systems. Direct interactions include negatives one, such as competition for light, water and nutrients, allelophatic interactions (specific inhibiting effects of chemical released by living or dead parts of a component species) and stimulation of pests and diseases. Positive interactions can be based on soil fertility improvement (similar to the indirect effects in sequential systems), microclimate improvement (especially in harsh conditions, e. g. with strong winds) and reduction of the impact of pets and diseases (Gajaseni and Jordan, 1992; Nair *et al.*, 1994; Watanabe, 1992). Based on the relative importance of the positive and negative interactions between trees and crops, one may decide that it is worthwhile to combine them into an agroforestry system, or to keep them separate as 'woodlots' and 'cropped fields'. We will explore in general terms which conditions agroforestry systems should be preferred over single-component sys tems.

The total yield of an agroforestry system in given year can be described as the sum of the crop yield, the yield of tree products (or increase in net present value), the yield of animal products and the change in land quality, which reflects the concerns over the long term sustainability of the system. The tree products obtained at the end of the cycle will have to be discounted for the length of the harvest cycle. If we restrict ourselves to agroforestry systems without animal production component, we obtain :

$$Y_{tot} = E_c Y_c + E_t Y_t + E_L \Delta L \qquad (1)$$

where :

Y_{tot} = total yield, [$/ha]
E_c = price per unit crop yield, [$/kg]
Y_c = crop yield, [kg/ha]
E_t = price per unit of tree products, [$/kg]
Y_t = yield of tree products (or 'net present value' of future productivity), [kg/ha]
E_L = price per unit change in land quality, [$/X]
ΔL = change in land quality for future production in Unit X to be further specified, [X/ha].

On the basis of this equation we can explore under which conditions a maximum of total yield will lead to a choice for an agroforestry system, with both a tree and crop component, and under which conditions pure tree or crop production will be preferred.

In the most simple case we may describe all tree-crop interactions as linear functions of the relative tree area α_t. For crop yield Y_c we may formulate :

$$Y_c = (1-\alpha_t)(Y_{oc} + \alpha_t F - \alpha_t C_{tc}) \qquad (2)$$

where :

α_t = relative tree area (for an agroforestry system : $0 < \alpha_t < 1$)
Y_{oc} = crop yield in the absence of trees, [kg/ha],
F = positive effect of trees on crop yield, e.g. due to soil fertility improvement, per unit relative tree density, [kg/ha],
C_{tc} = crop yield decrease due to competition by the tree, per unit relative tree density [kg/ha].

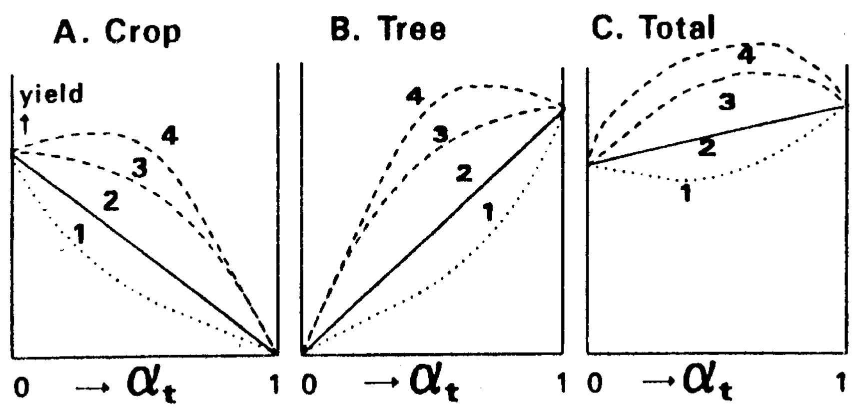


Figure 2. Yield of crops (A), trees (B) and tree-crop system (C) as a function of relative tree density, α_t. Lines 1 indicate negative interactions, 2 neutral ones and 3 and 4 positive ones.

When we see the system purely from the crop's point of view (Figure 2A), agroforestry or at least some inclusion of trees can be beneficial (i.e. lead to higher yield than the crop monoculture), if the yield curve has a positive slope close to a pure crop system ($\alpha_t = 0$); this means that the partial derivative of crop yield per α_t at $\alpha_t = 0$ is positive :

$$\left.\frac{\delta Y_c}{\delta \alpha_t}\right|_{\alpha t = 0} = -Y_{oc} + F - C_{tc} > 0 \qquad (3)$$

or, $F - C_{tc} > Y_{oc}$. The positive effect of including trees on soil fertility F must not only exceed the competition caused by the trees ($F > C_{tc}$) (compare lines 3 and 4 in Fig. 2A), but per unit area the positive effect ($F - C_{tc}$) must outweigh the crop yield per ha obtainable in a pure-crop situation (only line 4 in Fig. 2A meets this criterion). From a crop production point of view, we may conclude that combination with trees is only useful under poor soil fertility conditions (low crop production Y_{oc}, potentially large F) and comparatively non-competitive trees.

For the yield of tree products we may consider a negative interaction by crops through competition and positive interaction via better weed control:

$$Y_t = \alpha_t(Y_{\alpha t} + (1 - \alpha_t)(W - C_{ct})) \qquad (4)$$

where :

$Y_{\alpha t}$ = yield of tree products in the absence of crops, [kg/ha],
C_{ct} = decrease in yield of tree products due to competition by the crop, per unit relative crop density, [kg/ha],
W = reduction in competition by weeds, due to crop cultivation, expressed as increased production of tree products, [kg/ha].

When we see the system purely from the tree's point of view (Fig. 2B), agroforestry or at least some inclusion of crops can be beneficial, if the partial derivative of tree yield per α_t close to a pure tree system (α_t = 1) is negative (line 4 in Fig. 2B) :

$$\left.\frac{\delta Y_t}{\delta \alpha_t}\right|_{\alpha t = 1} = -Y_{\alpha t} - W + C_{ct} < 0 \qquad (5)$$

or, $W - C_{ct} > Y_{\alpha t}$. The positive effect of cropping on reduced weed competition must not only exceed the competition caused by the crops themselves ($W > C_{ct}$), but per unit area the positive effect must outweigh the tree yield per ha obtainable in a pure-tree situation. From a tree production point of view, we may conclude that combination with crops is only useful under severe weed infestation, comparatively non-competitive crops and a low tree production rate (e.g. due to low chances of tree establishment) in a pure tree system.

The change in land quality for future production, ΔL, may be negative for a pure crop system and may become more positive with increasing relative tree density :

$$\Delta L = (1 - \alpha_t)\,\Delta L_c + \alpha_t\,\Delta L_t = \Delta L_c + \alpha_t\,(\Delta L_t - \Delta L_c) \qquad (6)$$

where:

$\blacktriangle L_c$ = (normally negative) change in land quality for future production while under monoculture crop, [X/ha],

$\blacktriangle L_t$ = (possibly positive) change in land for future production while under tree cover [X/ha].

If land qualities are not supposed to degrade ($\blacktriangle L > 0$), then:

$$\alpha_t > \frac{-\blacktriangle L_c}{\blacktriangle L_t - \blacktriangle L_c} \qquad (7)$$

Alternatively, the costs of land degradation may be considered to be outweighed by direct benefits and be restored later.

If we substitute equations (2), (4) and (6) in (1), we obtain a quadratic equation in α_t for the total yield, Y_{tot}. An agroforestry system ($0 < \alpha_t < 1$) as a whole is more productive then either a pure tree ($\alpha_t = 1$) or a pure crop ($\alpha_t = 0$) system, if $Y_{tot}(\alpha_t)$ has a local maximum in the range ($0 < \alpha_t < 1$) (Fig. 2C, line 3 and 4). An optimum tree density $\alpha_{t,opt}$ may be found for $dY_{tot} / d\alpha_t = 0$, provided that $d^2Y_{tot} / (d\alpha_t)^2 < 0$. Only if this optimum tree density is between 0 and 1, agroforestry system are the best choice.

$$\frac{dY_{tot}}{d\alpha_t} = E_c(F - C_{tc} - Y_{oc}) + E_t(Y_{ot} + W - C_{ct}) + E_L(\blacktriangle L_t - \blacktriangle L_c) - 2\alpha_t(E_c(F - C_{tc}) + E_t(W - CL_{ct})) \qquad (8)$$

The requirement $d^2Y_{tot}/(d\alpha t)^2 < 0$ leads to :

$$E_c F + E_t W > E_c C_{tc} + E_t C_{ct} \qquad (9)$$

which shows that the sum of positive interaction terms on the left hand should be larger than the sum of negative ones on the right hand; otherwise it is better to have crops and trees on separate plots. Yet, it is possible to compensate a negative interaction term with a larger positive other term. A positive overall interaction, such as line 3 in Fig. 2C can be obtained for systems where neither the crop nor the tree component shows an absolute benefit (e.g. line 3 in Fig. 2A plus line 3 in Fig. 2B).

For $\alpha_{t,opt}$ we obtain :

$$\alpha_{t,opt} = \frac{-E_c Y_{oc} + E_t Y_{ot} + E_L(\Delta L_t - \Delta L_c)}{2(E_c(F - C_{tc}) + E_t (W - C_{ct}))} \quad (10)$$

which can be rewritten as :

$$\alpha_{t,opt} = \frac{X - 1 + L}{2 (I_{tc} + X I_{ct})} + 0.5 \quad (11)$$

where:

X = $(Y_{ot} E_t) / (Y_{oc} E_c)$, is the ratio of financial returns on a pure tree and a pure crop system,
I_{tc} = $(F - C_{tc}) / Y_{oc}$, is the scaled net tree crop interaction,
I_{ct} = $(W - C_{ct}) / Y_{ot}$, is the scaled net crop tree interaction,
L = $(E_L(\Delta L_t - \Delta L_c)) / (Y_{oc} E_c)$, is the scaled relative importance of changes in land quality

The constraint $0 < \alpha_{t,opt} < 1$ then leads to :

$$\frac{1 - L - I_{tc}}{1 + I_{tc}} < X < \frac{1 - L + I_{tc}}{1 - I_{ct}} \quad (12)$$

Outside the constraints (12) one would prefer either a pure-tree system ($\alpha_t = 0$), depending on the values of $E_c Y_{oc}$ and $(E_t + E_L L)$. The equations also show that the choice for an agroforestry or a more simple system not only depend on the biophysically determined parameters, but also on the 'value' assigned to the various possible products (tree, crops and land). Yet, the possibilities of finding agroforestry to be a desirable land use system from a combined productivity point of view, are far wider if both trees and crops have at least some value, than the severe constraints formulated in equations (3) and (5).

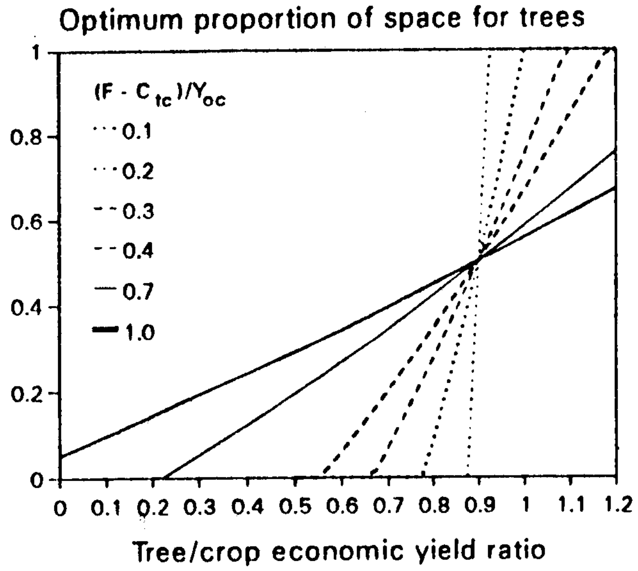


Figure 3. Optimum allocation of land to trees, $\alpha_{t,opt,}$ as a function of the economic yield economic yield ratio of tree and crop products X, and the relative interaction term I_{tc}, for I_{ct} = 0.1 L = 0.1 (based on equation 12).

Figure 3 gives the optimal allocation of land to trees, $\alpha_{t,opt,}$ as a function of the relative value of tree and crop products, X, for different values of the interaction terms. Figure 3 thus gives a general demarcation of the domain for agroforestry on the basis of the economic value of tree and crop production and the strength of the interaction term. The larger the positive interaction on crop production I_{tc} the larger the scope for agroforestry (i.e. the range of price ratio's X which lead to $0 < \alpha_{t,opt} < 1$). For realistic estimates of the interaction term, the tree products need to have some direct value to the farmer to justify agroforestry. If trees have no direct value, the term $(F-C_{tc})/Y_{0c}$ has to be 1.0 or more, i.e. the net positive effect of trees on crop yield per tree unit area has to exceed the monocultural crop yield per unit area.

With these equations one can directly describe approximately stationary system, as approximated in alley cropping, where the normal growth of the tree component is checked by regular pruning. For most other AF systems, however, the tree-crop interactions change from year to year. The equations can still be applied, however when annual yields are averaged over the typical lifespan of a single production cycle. If two years of food crops can be obtained after planting a slow growing tree, with a sixty year cutting cycle, or one year with a fast growing tree, with a 15 year cutting cycle, the average crop yield in the latter system is twice that in the first, when averaged over the cycle length.

The simple model approach as above appear to be restricted to modifying tree - crop land allocation ratio's, at constant plant density in the area's allocated. The production possibility frontier approach or Ranganathan (1993) overcomes this limitation and can optimize plant densities for each component.

TREE-SOIL-CROP INTERACTIONS IN SIMULTANEOUS TREE-CROP SYSTEMS

General

In simultaneous agro-forestry system, trees and food crops are interacting in various ways. As both positive and negative interactions occur, site-specific optimization of the system may be required. The most important interactions probably are:

a. Mulch production from the trees, increasing the supply of N and other nutrients to the food crops,
b. Shading by the trees, reducing light intensity at the crop level,
c. Competition between tree and crop roots for water and/or nutrients in the topsoil,
d. Nitrogen supply by tree roots to crop roots, either due to root death following hedgerow pruning or by direct transfer if nodulated roots are in close contact with crop roots,
e. Effects on weeds, pests and diseases,
f. Long term effects on erosion, soil organic matter content and soil compaction.

Interactions a and d are positive, b and c are normally negative. Effects d and e are difficult to quantify in general terms, but can have a dramatic effect on the acceptability of tree-crop combinations.

Considerable efforts have been made in the past decade to quantify the tree-soil-crop interactions in one of the most simple agroforestry systems: hedgerow intercropping or alleycropping. As the initial high expectations of crop yield benefits were tuned down by often negative or neutral results, we learned more about the nature of the interactions. This knowledge can now be used to select tree - crop combinations on *a priori* knowledge and to optimize hedgerow intercropping systems. In hedgerow intercropping the following choices can be made:

1. Tree species,
2. Distance between hedgerows,
3. Pruning regime ((height and frequency),
4. Crop, cultivar, crop population density and plant spacing,
5. Additional fertilizer input level.

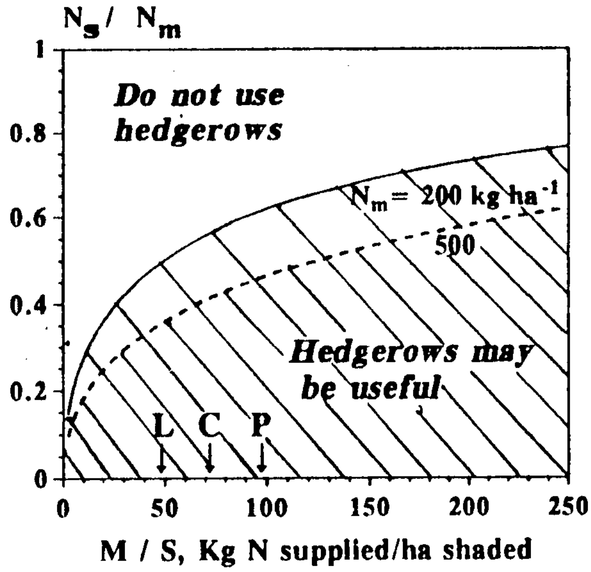


Figure 4. Domain where at least some versions of hedgerow intercropping will give a yield advantage, as determined by the Mulch/Shade ratio of the tree and the relative fertility of the site (N_s / N_m) (Van Noordwijk, *in prep.*).

Figure 4 gives the results of a model based on two types of above-ground interactions, **mulch** and **shade**. The figure identifies the domain where at least some forms of alley cropping, with a near-optimum tree spacing, may increase crop production. The upper limit of the soil N supply relative to crop N demand N_m can be related to the Mulch/Shade ratio, M/S, of the tree, which indicates the N supply per unit fully shaded area. The higher the M/S ratio of a tree, the better its prospects for alleycropping. If one wants alleycropping to work in a range where the control plots allow a crop N uptake near 50% of the maximum, the M/S ratio has to be 50-125 kg N/ ha shaded, for U_m in the range 200-500 kg/ha.

Apparently, hedgerow intercropping, where trees have to be a source of N to the crop, should be restricted to situations with a low soil N supply from other sources and crops which can respond to considerably higher N supply than is available. At the economic level, the labour costs of obtaining N this way has to be compared with the costs of obtaining N From other sources.

Although the model suggests a rather limited 'niche' for hedgerow intercropping, considerable scope remains for selecting hedgerow trees which are most suitable. For the situation described the best hedgerow tree is one with a high M/S ratio, which can be based on a combination of a narrow but dense and compact hedgerow canopy, thick leaves, the major part of the tree canopy not exceeding that of the crop, a high N content and a suitable N-release pattern from the prunings, coinciding with crop demand. The need for fine tuning of the N release pattern increases with decreasing residence time for mineral N in the crop root zone, due to shallow rooting and/or high rainfall infiltration surplus over evapotranspiration (Van Noordwijk *et al.*, 1991).

The evaluation given may be too pessimistic on the scope for alleycropping: spontaneous litterfall from the trees (turnover of leaf biomass) will add to the mulch supply, without causing further shade. With the intensive pruning regimes required to check the tree growth during the cropping period, however, litterfall will be low for most trees. If part of the growing season can be reserved for tree growth, however, litterfall as well as an increased pruned biomass can be important. The prospects for alleycropping greatly improve if the crop is light saturated under full sunlight. This opens the option of 'free light interception' by an upper tree canopy, resulting in mulch supply to the crop without shade costs. In that case sparse open canopies are better than dense hedgerows. This situation is more likely to exist under the clear skies of the semi-arid tropics than under the usually overcast skies of the humid tropics, and more so for C3 than for C4 crops.

Essentially, the approach can also be used for evaluating the optimum tree density for sparse upper story trees with little or no pruning. The example of the tea gardens in Java shows, however, that shade costs of *in situ* N production, are considerable. Tea gardens used to have complete tree cover of trees such as *Paraserianthes* as a source of N and organic matter, before inorganic fertilizer became abundantly available, but now nearly all trees are removed. It would be interesting to see at what timber prices it becomes worthwhile to reintroduce the trees, based on equation [1],

Only in specific situations are widely spaced upper canopy trees compatible with light demanding annual food crops. Peden *et al.* (1993) reported crop yield increases of about 20% in maize and beans over a monocrop control where *Alnus acuminata* was used as an upperstorey tree in Uganda, while all other tree species tested (including *Casuarina, Melia, Maesopsis, Markhamia* and *Cupressus* had negative effects. In Southern China *Paulownia* is widely grown in wheat fields, apparently with little harmful effect on the crop (Zhu Zhaohua, 1991). In North India *Populus* is similarly grown for timber in crop fields (Van den Beldt, *pers. comm.).* The specific tree characteristics which make these trees acceptable are not yet known: a relatively deep root system *(Paulownia)* and N_2 fixation *(Alnus)* probably contribute to the success.

Otherwise, upper canopy trees are usually grown on field contours. Trees such as *Paraserianthes* are widespread in Java around crop fields, *Tectona* is popular among Javanese migrants in Lampung ('North Java'); *Grevillea* is commonly found around maize fields on the lower slopes of Mount Kenya, *Gmelina* is increasingly popular in strip planting (following contour lines) on sloping land in the Philippines (Garrity, *pers. comm.).* In all these cases the value of the tree products to the farmer apparently compensates for the losses of crop yields. Tree management by pruning and pollarding can be used to check tree growth.

The scope for system with simultaneous trees and crops has clear limitations. A partial temporal separation may be needed. If we uncouple the mulch production from the amount of shade cast, e.g.

by having a period of the year devoted to tree growth and thus mulch production and a period in which the trees are set back severely and the crops are growing, the potential for *in situ* mulch production will increase.

Taungya

In the taungya tumpangsari system, the main emphasis is on establishing valuable tree species, but in the initial year(s) crops can be grown in between. Tree - crop interactions (Gajaseni and Jordan, 1992; Watanabe, 1992) are generally negative, as the trees provide little mulch or other benefits to the crop. Crop growth may, however, be positive for the tree, at least in comparison to the weed growth and herbivore (goat) damage which would otherwise occur. From the tree-grower's point of view the advantages may be clear and sufficient; for the crop grower, the presence of trees has to be accepted as land would not otherwise be available. Yet, the competition effects of the tree may become so severe that attempts to grow crops are not worthwhile. The competition effects are based on shading, but also on belowground competition for water and nutrients.

Strong competition effects from old *Tectona* stands were noticed ever since replanting efforts were made. Figures 5 and 6 illustrate attempts by Coster (1932) to separate above-and belowground aspects of competition. Making a deep trench to cut off the roots from the old tree stand from the new patch gave a dramatic improvement in the growth of both *Tectona* seedlings and intercropped maize in several experiments in Java, up to 20 m from the old stand. The shade effect only extended over a few m from the old stand.

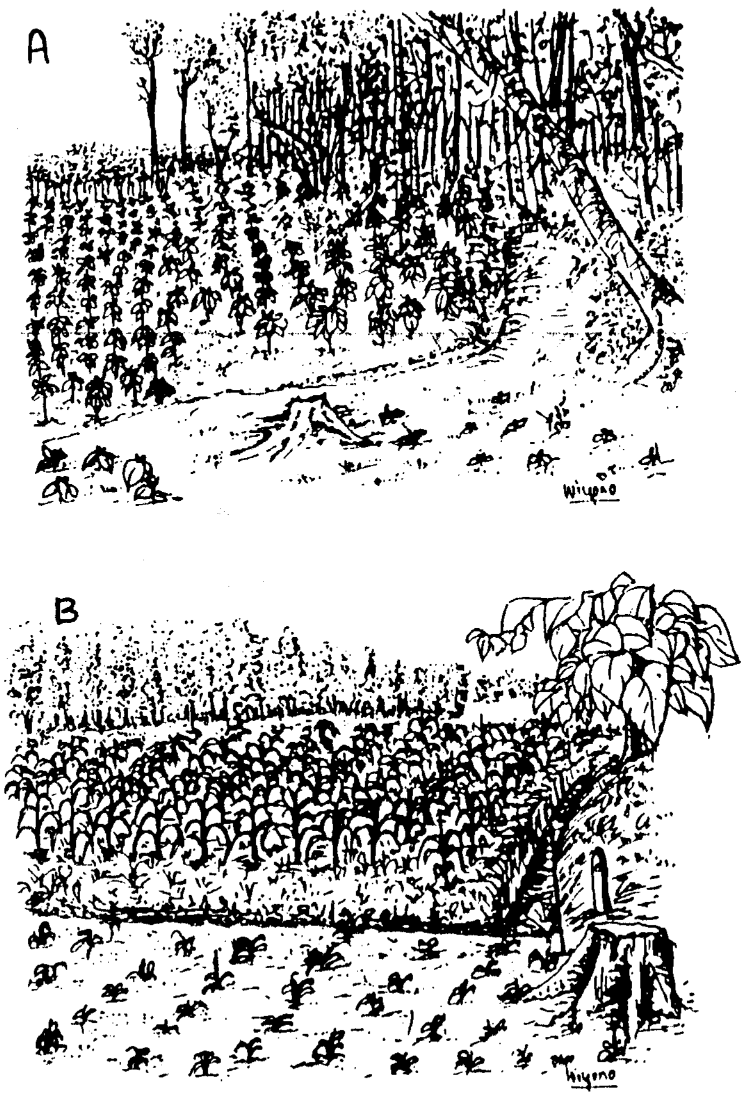


Figure 5. Effects of root trenching (background = with, foreground = without) to prevent the roots of old *Tectona* stands compete for water and nutrients with new *Tectona* seedlings (A) and maize (B); based on photographs of Coster (1933).

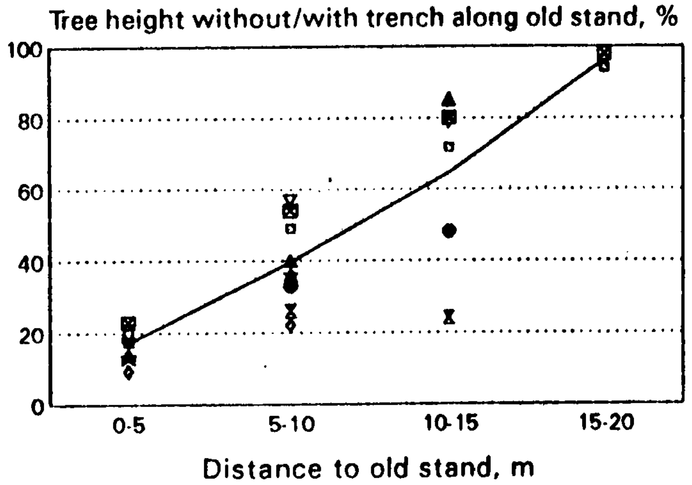
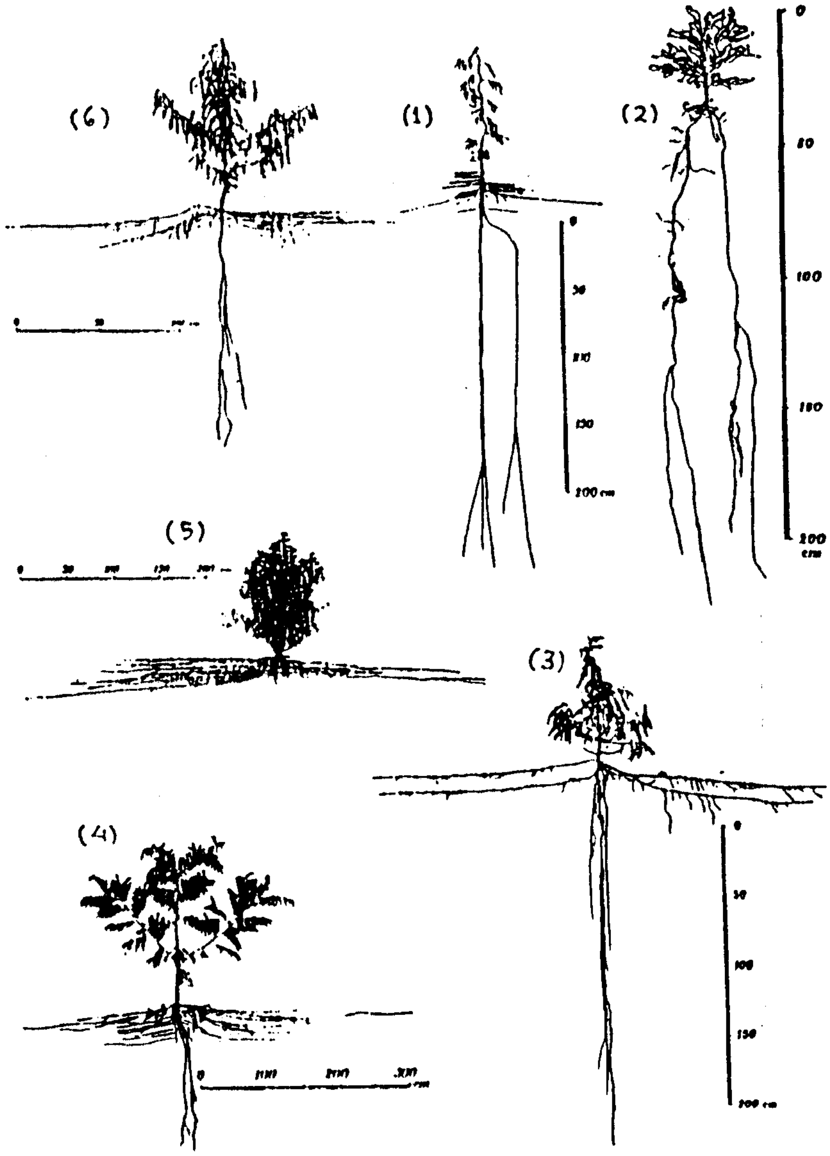


Figure 6. Competition for water and nutrients as evident from the ratio of crop yields with and without root trenching as a function of distance to old *Tectona* stands Coster (1993).

For younger trees the balance between root competition and shading may be different. Considerable variation exists in rooting patterns of trees, both in development or absence of a deep tap root, and in lateral spread. No simple relations between above and belowground dimensions exist, contrary to widespread beliefs that crown diameter and root spread are related (Figure 7). When we consider the evidence for all trees studied by Coster (1932), however, we see that all trees which rely on only a tap root, and which do not form lateral branch roots in the surface horizons, are relatively slow growers in the first years. *Tectona* is relatively shallow rooted, which can explain its strongly competitive effects. Prospects for tumpangsari systems with trees other than *Tectona* might be better. Between the various fruit trees which are commonly included, differences in rooting patterns are to be expected. Initial observations in Lampung (Pratiknyo and Van Noordwijk, *in prep.)* showed that *Artocarpus* (Nangka) and *Durio* (Durian) are relatively deep rooted trees on acid soils. Critical observations on root distribution of fruit trees which can be mixed with timber trees have not been done to our knowledge.

When considering tumpangsari systems the length of the tree growing cycle is of critical importance. Shorter tree production cycles obviously increase the area available for new plantings, and thus for crop production each year. Drawbacks of faster growing trees should be considered as well, however. Bruijnzeel (1992) indicated that fast growing trees may extract more nutrients from the soil than are replenished by weathering and deposition (atmospheric volcanic ash or eroded material from higher elevations). When using faster growing trees in stead of *Tectona*, fertilizer requirements may increase.

Compared to the current system, however, opportunities exist for :
- 'enhanced tumpangsari' with extended cropping periods, reduced timber tree densities (Van der Hout, 1984) and more vigorous pruning management regimes,
- 'continuous revenue generating systems' that involve enhanced tumpangsari systems with mixed timber populations of fast-growing species and teak.



deep 1. Albizzia lebbeck
2. Schleichera oleosa

mixed 3. Leucaena leucocephala
4. Albizzia falcata

shallow 5. Lantana camara
6. Tectona grandis

Figure 7. Root development of trees tested as accompanying for *Tectona* plantations (Coster, 1932).

SOCIAL FORESTRY

A formal framework for analysis of the effects of biological and physical interaction on the aggregate output of trees and crops and on outcomes regarding the quality of land was developed in previous sections. This section presents our first, preliminary effort to extend this framework to include economic and social interactions as well. Like the biological/physical tradeoffs between trees and crops in agroforestry system, social forestry system can involve tradeoffs between the main stakeholders, the state forestry organization and villagers. When villagers only have a financial stake in the crop component and the state forestry organization focuses solely on the financial and environmental aspects of the tree component, potential complementarities can be overshadowed by competitive crop-tree interactions.

The first step required to add economic and social interactions to this framework is to include the main factors in production of crops and trees: land, capital, labor, and management. This can be done by redefining the "yields" in section 2 as economic production functions for a one-hectare plot of crops or trees:

Y_{oc} = production function for crops in absence of trees
= $f_{oc}(K,L,M)$

where:

K = capital/land, L = labor/land, and M = management/land.

Similarly,

Y_{ot} = Production function for trees in absence of crops
= $f_{ot}(K,L,M)$.

As will be discussed below, the qualities of the factor inputs may matter as much as their quantities in determining the efficiency of various organizational models for social forestry.

Constant returns to scale is required for the normalization on land area. This assumption is wellsupported by empirical evidence for agricultural production in countries like Indonesia, including tree-crops as well as annuals (Tomich, Kilby, and Johnston, 1995), but may require additional research in the case of forestry. If it is a valid assumption, it also means that proportions of the plot planted to crops and trees can be varied without affecting relative intensities of use of capital, labor, and management, and we can write:

$Y_{c/t}$ = production function for $(1-\alpha_t)$ crops planted with α_t trees
$= f_{c/t}(\alpha_t, K, L, M)$

and

$Y_{t/c}$ = production function for α_t trees planted with $(1-\alpha_t)$ crops
$= f_{t/c}(\alpha_t, K, L, M)$.

When $Y_{c/t}$ and $Y_{t/c}$ substitute for Y_{oc} and Y_{ot} in equations (2) and (4), respectively, the derivations in equations (3) and (5) remain unchanged only if the optimum factor intensities (K,L,M) in production of crops and trees are independent of α_t. This could only be the case if biophysical interactions were "strongly separable" from the socioeconomic variables. It seems highly unlikely, however, that optimal capital, labor, and ,management intensities in production of crops or trees would be independent of the biophysical interactions between crops and trees. For example, the shade from trees should affect not only crop yields but also choices about the intensity of factor inputs to crop production. On the other hand, land preparation for crops not only reduces the effect of weeds on trees but also reduces the labor required for weed control in tree production.

We hope to explore the implications of a more complete formal model of biological/physical/economic/social interactions in social forestry in the future. This also will require, among other things, redefinition of the E_c and E_t terms of section 2 to reflect expected profit per unit output rather than price. Note, also, that the interactions mentioned so far all are internal to either the villagers or to the forestry agency. Broader objectives of social forestry (including, for example, certain environmental amenities) involve externalities that should be taken into account by policymakers in determining appropriate incentives for the forestry agency and villagers as well the terms of "contracts" between them.

Agroforestry research and development obviously should be directed to areas of greatest crop-tree synergy. Analytical results from more complete models could be the basis for a joint program of empirical research on biological/physical/economic/social interactions. The socioeconomic aspects of crop-tree interactions could enhance the biophysical interactions depicted above in Figure 2, cancel them out, or result in some mix of outcomes. Effort could be badly misdirected if socioeconomic aspects of crop-tree interactions are ignored in the process of setting biophysical research priorities.

For now, instead of pursuing formal extensions, we will draw briefly on some of the modern literature on agricultural contract choice (e.g., Hayami and Otsuka, 1993) to highlight some socioeconomic interactions that may be important for social forestry. Here, there are striking parallels between social forestry and land tenancy. Each is a case of the "principal-agent" problem. In land tenancy, the "principal" (the landlord) and an "agent" (the tenant farmer) agree to combine the landlords' land, capital, and (sometimes) purchased inputs with the tenants' labor and management skill. Typically, the tenant agrees to pay a fixed amount of cash (fixed rent) or a share of the crop (sharecropping). In social forestry as currently practiced on Java, the "principal" (the state forestry agency) supplies land and seedlings while keeping the timber and the "agents" (individual farmers or village groups) supply labor and keep only annual crops and non-timber tree products.

Large-scale landowners in developing countries often take on tenants (either renters or sharecroppers). This is more profitable than hiring labor to operate a large holding as a single unit, largely because tenants have a greater incentive to work hard (and well) than hired labor. Here, the terms of the tenancy "contract" create incentives that solve much of the landlords' problem of monitoring moment-to-moment activities of labor. On-the-spot decision-making is especially important in agriculture; the right decision at the right time at precisely the right place can be the difference between a profit and a loss for the whole crop cycle. Again, compared to wage labor, tenancy provides a superior set of incentives to bring good management where it counts: in the field. This is because tenants get part of the additional profits, while laborers' wages are independent of the landlords' profits. Renters reap all the benefits to superior management, while sharecroppers get a only a portion. Rental rates typically are lower than the effective rent in sharecropping. On the other hand, sharecropping shields tenants from a portion of the yield risk they would face if they were renters. Thus, the tenants' choice of sharecropping or renting largely depends on ability to bear risk. Tenants also can benefit through access to working capital (for seeds, fertilizer, etc) at lower effective interest rates than they would have to pay themselves. This working capital comes in the form of purchased inputs, which the landlord often provides as an additional incentive for the tenant to make choices consistent with the landlords' interests.

Contrary to the conventional wisdom of only a decade or so ago, tenancy contracts (whether for rent or a share of production) are a remarkably efficient way of organizing agricultural production. Perhaps the main lesson from studies of these agrarian contracts is that the arrangement must be mutually beneficial at the outset. These benefits come from the combination of factors according to the comparative advantage of each party: from the landlord comes abundant land and working capital and from the tenant comes labor and on-the-spot management. Also, to the greatest extent possible, compliance with the "contract" must depend on incentives rather than monitoring and enforcement. If incentives created by the contract are incompatible with the agents' desired outcomes, the principals' enforcement costs will be too high. Since, all the interlinked transactions (land, capital, labor, and management) involved in conventional sharecropping of annual crops typically are completed within the course of a single year (or less), sharecroppers' desire to have future access to land provides a strong additional incentive for them to comply with the terms of their agreement.

By contrast with sharecropping, one can appreciate some of the dilemmas faced in developing improved social forestry models. In the current arrangement, farmers provide labor for establishing and maintaining trees but they receive none of the profits from timber. The "working capital" (in the form of seedlings) is provided by the forestry agency, which has a comparative advantage in the supply of good quality planting material, but this is only (a small) part of the long-term costs of establishing a tree. The value of trees as assets also depends on the quantity and quality of labor and management that is supplied. Local villagers have great advantages over the forestry agency in supplying these on-the-spot requirements.

Studies of land tenancy suggest that, if villagers had the "right" incentives, they could provide labor and management inputs for tree production at lower cost and in a more timely fashion than the forestry agency can by itself. It also seems likely that monitoring and enforcement costs for the forestry agency, in the absence of incentives for the villagers, are much higher than for the agriculture. The long gestation period of many timber species compounds the forestry agency's problems of monitoring and enforcement compared to a landlord in agriculture. But, in parallel to land tenancy, one way of establishing the "right" incentives may be to give the villagers a direct interest in the value of timber produced. If villagers shared in the profits from timber, they would have a much greater incentive both to provide more labor and better management.

Compared to a landlord in agriculture, it probably also is much more difficult for the forestry agency to restrict community access to state forest land. Thus, one of the enforcement mechanisms available to landlords (evicting a tenant) is not really feasible for the forestry agency. Giving villagers a stake in timber production may also help alleviate this problem, however. Much as the sharecropper has a direct stake in guarding the crops in the (landlord's) field, local villagers would have a much greater incentive to enforce regulations against unauthorized logging if they had a stake in the trees.

It was emphasized above that no contractual arrangement can work if it does not provide benefits to both parties. The discussion so far has sketched some general opportunities in which social forestry contracts might be changed to make villagers' incentives more compatible with the forestry agency's objectives. From the forestry agency's point of view, this comes at some cost: a portion of timber revenues would be shared with villagers. The question for further empirical research is whether this cost to the agency is offset by increases in timber revenues from more efficient labor inputs, more effective on-the-spot management, and reduced costs of monitoring, enforcement, and timber losses.

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