Improving Smallholder Farming Systems in *Imperata* Areas of Southeast Asia: Alternatives to Shifting Cultivation

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Preface

THIS PUBLICATION CONTAINS a report of a research project: *Improving smallholder farming systems in* Imperata *areas of Southeast Asia: a bioeconomic modelling approach*. The project was formally a collaborative effort between the Centre for Resource and Environmental Studies, the Australian National University (CRES, ANU), Canberra, the SEAMEO Regional Center for Graduate Study and Research in Agriculture (SEARCA), Laguna Philippines, and the Centre for Agro-Socioeconomic Research (CASER), Bogor, Indonesia. However, many additional collaborations were undertaken, as evident from the list of contributors.

The project received substantial funding assistance from the Australian Centre for International Agricultural Research (ACIAR) and the Center for International Forestry Research (CIFOR).

The introduction to the report outlines the nature of the *Imperata* problem and the methodology used. *Imperata* is essentially restricted to upland areas, since it does not coexist with lowland rice farming. Section 1 contains a bioeconomic analysis of traditional smallholder 'shifting cultivation' farming systems where the fallow is *Imperata.* Section 2 contains a series of case study descriptions of successful tree growing by smallholders on *Imperata* grasslands. The core modelling work of the project is reported in Sections 3 and 4. Various tree-based interventions are modelled with and without an animal component. Some of these modelled farming systems are already in place in farmers' fields. In these cases, possible management or policy interventions analysed with the models can point the way to productive and economic improvements. In other cases, the farming systems modelled are 'experimental' in nature. *Imperata* grows on uplands of various slopes, but some special attention is given to *Imperata* on

steeply sloping land where soil erosion is a particular problem. Finally, in Section 5, two key issues in relation to tree growing on *Imperata* grassland are addressed: fire control and carbon sequestration. These are viewed both from the viewpoint of the individual smallholder and from the viewpoint of the broader society. Abbreviated descriptions of the models used are given in the Appendix, with fuller descriptions available in other publications.

SHIFTING CULTIVATION ON *IMPERATA* AREAS OF SOUTHEAST ASIA (SLASH-AND-BURN AGRICULTURE)

Shifting cultivation represents the situation faced by the majority of the (especially poorer) inhabitants of the *Imperata* grasslands. The environmental consequences of shifting cultivation in upland areas can be severe. There has been almost no previous long-term economic analysis of shifting cultivation systems in any context, and certainly not in the context of *Imperata* grassland.

In typical upland *Imperata* areas of Southeast Asia, shifting cultivators face falling economic returns as fallow lengths shorten. The bioeconomic modelling of shifting cultivation has enabled a more precise quantification of the problem than has hitherto been available. The future of low input shifting cultivation is grim. Where economic viability is still being achieved, this is not likely to last. The challenge is to facilitate the inevitable change in a manner which is positive in terms of poverty alleviation and in terms of the environmental parameters of soil, smoke/fire and carbon sequestration by trees. Shifting cultivation forms the 'baseline' farming system against which various tree-based systems can be gauged.

With reductions in *Imperata* fallow lengths (from a 20-year starting point), the modelling indicated an initially modest, approximately linear, reduction in economic returns. With fallow lengths of less than seven years, economic returns fall dramatically. The explanation is revealed in terms of total soil loss and reductions in the level of labile soil carbon and nitrogen, with all three being reflected in a loss of rice yield.

For most smallholders, the area of land available implies that it is not economic to reduce the cropped area sufficiently to maintain yields and soil parameters at sustainable levels. While it is feasible to operate farms of say 5 ha on a twenty-year fallow rotation, only one quarter the level of profitability is achieved compared to cropping a larger area of available land on a two-year fallow. This increase in profitability with the shorter fallow occurs despite the negative implications of the two-year fallow for biological sustainability. In other words, there is an

economic incentive to operate in an unsustainable manner. Land areas typically available to each farm household are insufficient to economically maintain a long fallow.

Land clearing on shifting cultivation in *Imperata* areas is mostly undertaken by burning. The extent to which the practice of burning *Imperata* has long-term (on-farm) environmental and economic impacts on smallholder upland farms was traced via modelling. The environmental impacts of burning on soil quality were shown to be clearly negative, but burning had less impact on soil erosion and quality than did shortening fallow lengths.

Despite the negative impacts of burning on soil, the modelling indicated that burning is the most profitable method of clearing *Imperata* in a shifting cultivation system, under prevailing biophysical and economic conditions. A herbicide cost reduction of 25% would make herbicide use more profitable than burning. Rising wages would also lead to a shift away from burning. Since traditional smallholder upland farms are marginally profitable at present, a significant increase in labour prices (a likely consequence of economic growth in Southeast Asia), would make herbicide use more attractive.

Consideration of the serious off-site consequences of burning, as evident in the smog and haze during 1997, provides an economic basis for the promotion of herbicide, via subsidies or other means (such as extension of knowledge about herbicide use). In this manner, the soil erosion and other off-site consequences of burning could be reduced, while simultaneously giving an boost to smallholder farm incomes.

SPONTANEOUS TREE GROWING BY UPLAND SMALLHOLDERS

Subsequent to the baseline analysis of shifting cultivation, a series of case studies documenting tree growing by smallholders, on current, or former *Imperata* is presented in Section 2. Despite facing difficulties such as fire control and capital constraints, some smallholders *are* growing trees on *Imperata* grassland. A decision was made to document a number of these cases, since:

- there are direct lessons to be learnt from such documentation; and
- the case studies provide guidance and direction for the subsequent modelling analysis which explores technology, management and policy options.

Farmers in Claveria, Northern Mindanao, Philippines are planting *Gmelina arborea,* (sometimes on what were originally grass strips aimed at erosion control)

along with the annual crops of maize, upland rice and cassava. The first major harvest of *Gmelina* is now underway. Surveys of farmers in the area, revealed that farmers perceive, and are obtaining, both economic and environmental benefits from growing *Gmelina*. Virtually all farmers who are growing *Gmelina* plan to continue to do so, or to switch to alternative trees. The current production and marketing systems, and potential improvements in these systems (as perceived by the farmers) were described.

Documentation was also undertaken of smallholder tree-growing and marketing of *Paraserianthes falcataria* on erosion-prone land, former *Imperata* land in Indonesia. This tree growing is on a spontaneous basis, virtually unaided by government. The economic benefits from growing trees is evident in the analysis. Marketing infrastructure, and possibly higher farm wage rates have helped to create the favourable economic climate for tree growing. (Tree growing is less laborious than cropping).

Direct government involvement in sponsoring tree planting and husbandry in the Philippines has not been successful. During the course of a study on government programs, evidence of successful smallholder tree growing was detected, sometimes in close geographical proximity to the government schemes. Five Philippines case studies identified conditions necessary for farmers to spontaneously grow trees. These are: assured access or property rights, interest in other related tree uses, practice of intercropping, good financial situation of farmers and a potential for a strong wood products market. As demand for wood products increases due to scarcity of supply, the potential to encourage tree growing by farmers is great. Preliminary results from this study indicate that by providing farmers with these types of non-fiscal incentives to grow trees, the Philippine government may be able to control *Imperata* and rehabilitate upland areas.

One of the above five case studies contained some unique elements that were examined in a special follow-up study. A five km strip of *Samanea saman* trees was identified growing in a communal pasture area for water buffalo and cattle. The land covered by *Samanea saman* trees has expanded over time with little human intervention besides protection from fire. One explanation for the rapid spread of these trees is attributed to the grazing animals. The grazing animals feed on the fallen fruits of the *Samanea saman* tree and the indigestible seed of the tree is excreted as the animal moves, thereby dispersing the seed. *Samanea saman* seedlings are unpalatable to ruminants which allows them to become established, and the animals' waste provides an organic fertilizer which enhances growth.

This symbiosis between *Samanea saman* and grazing animals has attributes that are promising for the rehabilitation of overgrazed and degraded pasture areas. The in-depth follow-up study on this system was undertaken to better understand and delineate its features and to assess its potential for broader applicability.

In order to better understand the constraint to tree growing caused by fires, a survey was undertaken in Northern Luzon, Philippines, to examine factors affecting the occurrence of grassland fires. Fire was used as a management tool to clear the land of vegetation debris in preparation for cultivation and planting activities. However, there are a significant number of unintentional fires. The frequency of fires is high (more than two per year). Farmers typically light fires during slow to moderate wind velocities. Farmers in the more developed survey areas supervise their fires and establish fire breaks or fire lines to control the spread of fire to neighbouring farms. Barangay ordinances also exist which successfully controls fires in the area.

Fire was not an insurmountable constraint to tree establishment on lands occupied by smallholders in the Isabela region as evidenced by the number of trees growing. Fire is less under control in other nearby areas. The more important socioeconomic factors that affect the decision process of the individual farmers to plant trees are land tenurial security and economic benefits. With the knowledge that they will not be pushed away from their lands, farmers may be motivated to plant perennial species and thus have more motivation to control fires.

Rubber is the major tree planted by smallholders on *Imperata* grasslands in Southeast Asia. This success has been well documented elsewhere, and is not repeated here in a descriptive vein. However, a substantial effort was undertaken to model various strategies for improving the welfare of various smallholder rubber producers.

So there are some success stories, although admittedly limited in geographic scope (except for rubber). However the success stories give confidence that more can be achieved.

Rubber

Rubber growing by Indonesian smallholders on *Imperata* grassland is marginally profitable (after attributing a return to labour inputs) under low intensity management. However, the modelling work demonstrated that profitability can be substantially enhanced by management aimed at reducing the competitive effect of *Imperata* on the rubber. A number of cost-effective options for achieving this were revealed, including intercropping, chemical control, and enhanced shading with faster-growing rubber trees, such as clones. The only one of these options that is currently being implemented by the majority of smallholders is intercropping. The immediate economic return that is obtainable from intercropping plays a big part in its attractiveness to smallholders.

However, profitability can be enhanced by other forms of management aimed at reducing the competitive effect of *Imperata* on the rubber — *Imperata* control within a smallholder rubber plantation was found to be highly profitable in most circumstances. Many smallholders in Indonesia do not yet use clonal planting material—unavailability and expense are cited as the main reasons. *Imperata* management options, such as chemical spraying, are reported to be imperfectly performed by smallholders. Given the potential economic pay-offs demonstrated here, greater extension efforts to promote these various technologies would appear to be warranted.

The impacts of *Imperata* on rubber growth, and thus on the economic benefits derived from controlling *Imperata*, are highest *in the first year following rubber planting*. Economic benefits from reducing *Imperata* groundcover decline subsequent to year one, but remain significant up to approximately the fifth year after planting (for clones).

Hedgerow intercropping in upland maize systems

The traditional methods of open-field (non-hedgerow) maize farming that are commonly employed in the uplands tend to be preferred by farmers with limited planning horizons. Alternatively, hedgerow intercropping has potential to better sustain maize yields by reducing soil erosion and contributing nitrogen. However, in the modelling work using SCUAF, the benefits of hedgerow intercropping, while being evident in the longer term, were often not realised rapidly enough to make them an attractive investment to farmers by recouping

establishment and maintenance costs. Natural vegetation, and grass, strips which incur lower establishment costs were demonstrated to be more economically attractive to farmers. These also seem to be the forms of 'hedgerow' that are gaining most acceptance by farmers. (High discount rates and insecure land tenure reduce the value to farmers of sustained economic returns from all forms of hedgerow intercropping).

Because many farmers have moved towards the lower input grass strip hedgerow system, an analysis was undertaken of several possible end uses of the grass. The integration of cattle into a hedgerow napier grass strip system was found to enhance the economic attractiveness of that system. The feeding of napier grass to cattle (especially when manure is returned to the field) is the most profitable end use of the napier grass. The *biophysical* results were similar for using napier as animal feed or as mulch. However, *economic* analysis showed that higher economic returns were gained when napier grass cuttings were applied to the soil as manure after feeding to animals, rather than directly as mulch. In other words, passing the forage through an animal was profitable. This conclusion, that using fodder production for animal feed is profitable, was a common result over the range of farming systems examined. The result implies that the value of the animal production typically exceeded the direct soil conserving benefits of the fodder when the latter was cut and applied used as mulch. (In either case, the *growing* of fodder as grass or shrub, *does* provide a soil conserving benefit).

Shrub legumes as improved fallows

Hedgerow intercropping, with shrub legumes, apart from being laborious, requires a management intensity that is beyond the capacity of many smallholders. A system of planted tree fallow avoids the need to intensively manage the hedgerow/crop interaction on a simultaneous basis. A *Gliricidia* fallow/maize rotation was modelled as an example of a planted tree fallow. A *Gliricidia* fallow system can provide significant improvements to a range of soil biophysical measures. So both from environmental and productivity perspectives, a *Gliricidia* fallow system is attractive. The analysis showed that, at prices currently encountered, a *Gliricidia* fallow system is substantially more profitable than a traditional *Imperata* fallow cropping system. The value of firewood is a major factor in this result. The system would be far less attractive if there were no market for firewood. *Gliricidia* as a fallow without fertilizer additions gave an economic return of the same order of magnitude as a *Gliricidia* hedgerow system with fertilizer additions.

Unlike hedgerow systems with shrub legumes which have been fairly thoroughly tested on farm, the *Gliricidia* fallow has, so far, received little experimental attention. It seems that more substantive research efforts into such systems could be undertaken.

Animals would appear to have a profitable place within an improved shrub legume fallow.

Timber (*Gmelina*)

Gmelina is a fast-growing timber tree that has considerable potential to provide increased economic and ecological benefits. There are numerous types of farm forestry systems that are being undertaken with *Gmelina*. The system examined here involved planting *Gmelina* trees as hedgerows along contour strips with maize in between the rows of Gmelina seedlings in the first two years. When the canopy started to close, the land was left to bush fallow. During the fallow period, *Gmelina* trees grew and natural vegetation was allowed to grow and grazed by livestock. By the end of the five-year fallow period (seven years in all), the farmer has harvestable timber and animal gains.

The *Gmelina* improved fallow system integrates agroforestry and animal pastoral systems with increased income obtained from timber and fuelwood; from animal weight gain and services, and from maize crop during the initial two years of *Gmelina* growth.

Some comparisons

The following table shows all of the systems that were modelled for Claveria using SCUAF and the associated economic outcomes of the modelling. These systems were modelled using a similar data base. All tree-based interventions were found to be substantially superior to traditional shifting cultivation when no external inputs are used (e.g. as in the case of a four-year *Imperata* fallow cropping system).[1] Of the various tree-based systems examined, the *Gmelina* timber production system was most profitable.

The inclusion of cattle into the farming system enhanced net farm income in all of the cases examined. (In other words, passing fodder through the animal was more profitable than the direct application of fodder to the ground as mulch, albeit with some increase in soil erosion vis a vis the no animal case).

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1. Where the external input of fertilizer is used, the advantage obtained by using trees is less. However the use of fertilizer by smallholders in the uplands is exceptional, so the more relevant comparison is for the no fertilizer case

NPV/ha for a range of modelled farming systems at Claveria, Mindanao, Philippines.

	Net Present Value	
	10–12% discount rate (₱ '000)	25% discount rate (₱ '000)
Traditional shifting cultivation		
1 year maize — 4 years *Imperata* fallow[a]	2	–ve
ditto with cattle[a]	9	5
Traditional cropping + fertilizer		
2 year maize — 2 year *Imperata* fallow[b]	16	10
Continuous maize[b]	34	22
Hedgerow		
Gliricidia[b]	40	21
Napier grass[b]	44	23
Napier grass with cattle[b]	54	33
Improved fallow		
1 year maize—5 years *Gliricidia*[a]	36	15
ditto with cattle[a]	65	33
Timber		
Gmelina maize[b]	94	40
Gmelina maize cattle[b]	88	31

[a]without fertilizer; [b]with fertilizer

The time taken for smallholders to convert to a new system is important. For example, in adopting the *Gliricidia* fallow system, a loss will be incurred in the first year, and it will take approximately four years for smallholders to begin making a profit above that achievable with the *Imperata* fallow system. This was a common kind of result for many of the systems examined. Unless smallholders are capable of accepting lower profitability in these years, or unless there is some government assistance, they are unlikely to adopt the new system. Also, given the long-term nature of the investment in *Gliricidia* (requiring four years to be profitable), secure land tenure is required if smallholders are to adopt the system. A somewhat similar pattern was observed for most of the 'improved' systems examined.

Soil erosion features throughout the report, as a key parameter in determining the sustainability of the various upland smallholder systems analysed. Soil erosion is given special emphasis, in terms of estimating the 'cost' of soil erosion. Within that context, the two main methodologies for estimating the costs of soil erosion are utilised and contrasted.

THE COSTS OF SOIL EROSION

The long run productivity effects of soil erosion were taken into account in all of the analyses of alternative farming systems that used the SCUAF model (see previous section). However, additional analysis was undertaken with more detailed attention paid to the costs of soil erosion.

The opportunity cost approach to estimating the cost of soil erosion is essentially a comparison of the economic returns from alternative systems, where those systems are characterised by different levels of soil erosion. This is the approach that is inherent in the table shown in the previous section (although soil erosion is not shown in that table). Another way to estimate the costs of soil erosion is to use the replacement cost approach. An advantage of the replacement cost approach to estimating the cost of soil erosion is that it is simple to apply, especially if estimates of nutrients lost via erosion are available. When such estimates are not available, a model such as SCUAF, which predicts nutrient loss in erosion over the long term, is essential. In the replacement cost approach, comparisons between farming systems, or techniques (e.g. comparing the cost of soil erosion in an erosive system versus a soil conserving system) can be made by subtracting the replacement cost of soil erosion in one system from the other.

The replacement cost approach, by using a more direct soil-based calculation, abstracts from the income streams associated with each farming system. The average annual cost of soil erosion for open-field farming using the replacement cost approach was calculated to be ₱ 75/t. In contrast, the opportunity cost approach determined the annual average cost of soil erosion to be ₱ 29/t. If data are only available on one farming system, then using the replacement cost approach may be the only feasible option for calculating the cost of erosion.

Tomich et al. (1997) emphasised the importance of distinguishing between (private) financial feasibility and social profitability in economically evaluating alternative land uses in *Imperata* areas. In this report, the focus of much of the analysis relates to private financial profitability at the farm level. Two aspects of the divergence between the private and social profitability of tree growing are considered in Section 5 — fire control and carbon sequestration. Other aspects of this divergence are implicitly or explicitly addressed throughout the report with respect to: interest rate differentials between poor upland farmers and the rest of society and the availability of information about new technologies for upland smallholders.

FIRE MANAGEMENT AND CARBON SEQUESTRATION AS KEY ISSUES INFLUENCING THE DECISION REGARDING TREE PLANTING

In rubber planting areas on *Imperata* grasslands in Indonesia, the risk of fire was demonstrated to be an economic disincentive to tree growing. Even a modest fire risk of 10% per year was shown to considerably reduce expected profit from rubber growing. A fire risk greater than 13% per year resulted in economic non-viability of rubber growing under the specified conditions. Total control of fire, in a plantation surrounded by 100% *Imperata*, would give a substantial economic return in terms of NPV.

A simple, low cost, fire risk reduction technique in highly *Imperata*-infested areas, would be for all smallholders to simultaneously plant rubber. This policy would provide approximately one half of the benefits obtained by complete elimination of fire. Other forms of fire risk reduction such as fire breaks and care with lighting fires in windy conditions are feasible. An experiment to test the combined effects of shading by *Gliricidia* and deliberate burning of *Imperata* was conducted under the auspices of the project. The approach seems feasible, at least for some circumstances.

In addition to the direct economic impact of fire risk on the profitability of neighbouring farms, there are other external costs associated with fire (land degradation, smoke haze, reduction in carbon sequestration) which were not examined in this monograph. For example, in Indonesia in 1994 and in 1997, smoke haze from fires was a major health hazard, caused airline flight disruptions and crashes in the area, and spread to Singapore and Malaysia, becoming a diplomatic issue with these countries. The issue of fire risk is particularly pertinent in the less densely populated, *Imperata*-dominated areas.

Some of the responsibility for fire control appropriately rests with communities, or governments as their representatives, rather than resting solely with individuals. Government intervention may well be justified in promoting fire control techniques. An empirical example of the benefits from community action, through a coordinated approach to rubber planting was demonstrated, based upon the modelling work.

A global dimension of tree growing on *Imperata* grassland is the net addition to carbon sequestration that is achieved by transforming the grasslands into trees. Carbon will eventually be released into the atmosphere as the products of the harvested wood decay. However, there are still sequestration benefits resulting from the transformation of grassland into trees. These were examined in the context of smallholder rubber growing, where carbon is sequestered in latex and wood and rubber wood is becoming increasingly popular for furniture. The sequestration benefits of transformation of grassland into trees for wood pulp

were examined and were revealed by the modelling work to be quite large — in some cases larger than the private benefits.

The extent to which smallholders would change their decision about growing trees, on the basis of a possible carbon subsidy is less clear. It will depend upon individual circumstances. However, a careful examination of the smallholder rubber situation revealed that the provision of improved planting materials to smallholders would have three dimensions of benefits:

- private benefits via faster growth and hence higher latex and wood production from the inherently higher yielding clones;
- private and public regional benefits via *Imperata* control and fire risk reduction and the subsequent increase in rubber tree growth;
- public global benefits via carbon sequestration.

However, in most cases, the private benefits obtained from the technology of using clonal planting material are not being obtained by smallholders due to the unavailability of a suitable distribution infrastructure for the seedlings, or due to a lack of extension advice. The three dimensions of benefits, taken together, constitute a strong case for public assistance with the provision of clonal rubber planting materials. A similar case could be made with respect to other trees being considered for planting on *Imperata* areas.

OTHER ISSUES

Even at the high interest rates currently facing upland farmers, many of the conservation farming systems are more profitable than traditional shifting cultivation in the long term. There are examples where tree growing and grass strip farming systems have been spontaneously put in place by smallholders.

Limited availability of savings, or restricted access to capital, may hinder the adoption of some of these conservation systems. A common result was that many of the systems took 3–5 years before becoming more profitable than traditional systems. To encourage adoption by upland farmers, governments could consider policies to lower the cost of credit to upland farmers to a level approaching the opportunity cost of capital to society. Alternatively, some critical inputs (herbicide, tree seedlings) might be subsidised on the basis of the public good characteristics of the benefits they produce.

The bioeconomic approach to assessing tree-based interventions in *Imperata* grassland areas has merit in being relatively inexpensive, yet powerful. An existing, simple biophysical model was linked with a benefit cost analysis, using data obtained from focussed farm surveys. The time frame and cost involved in this analysis were minute in comparison to what would be involved in field experiments. Furthermore, the modelling approach allows the researcher to exert full 'control' over the relevant variables. This factor becomes more important as the number of variables of interest increases, and as the time frame of the experiment increases. the latter is an especially important consideration with tree growing.

In the Appendix to this report, a brief outline of the models developed, and used, in the project is presented. Both the rubber agroforestry model (BEAM) and the Soil Changes Under Agroforestry Model (SCUAF) underwent considerable development as the project proceeded.

1 INTRODUCTION

KEN MENZ
DAMASA MAGCALE-MACANDOG

THERE ARE AN estimated 35 million ha of *Imperata* grassland in Asia. Approximately 8 million ha are in Indonesia and 2 million are in the Philippines (Garrity et al. 1997). These are the two countries where much of the work reported here was undertaken.

In this monograph, the term *Imperata* grassland is used to denote grasslands dominated by *Imperata cylindrica* var. *major*. Other common names for *Imperata* are alang alang, cogon and blady grass. A full list of common names is given in Turvey (1994).

Much forested land has been converted to *Imperata* grassland through the processes of logging, shifting cultivation and burning (e.g. Pasicolan et al. 1996). Fires in the grasslands perpetuate *Imperata*, by inducing the rhizomes to sprout. Frequent fires also discourage the planting of trees, which could otherwise shade out *Imperata*.

Imperata grasslands in Southeast Asia are generally occupied, or utilised, by poor smallholders, undertaking low input cropping in the context of shifting cultivation (Turvey 1994; Rusastra et al. 1996). *Imperata* is an aggressive competitor with crops, having the potential to substantially reduce crop yields (Brook 1989). *Imperata* is often associated with low soil fertility. However, this does not imply that *Imperata* is restricted to, or grows better, on such soils. Rather, it implies that low fertility soils dominated by *Imperata* are the end product of shifting cultivation cropping systems where there is a high human population density. In some areas, cattle or buffalo graze *Imperata* grassland. Cattle 'ranches' are typically owned by wealthier community members (Turvey 1994).

CHARACTERISTICS OF *IMPERATA*

Imperata is a pandemic genus, found throughout the tropics. It is a rhizomatous perennial grass, with a spreading habit. The key biological features of *Imperata* have been documented quite extensively, including a number of BIOTROP publications (e.g. Soerjani 1970; BIOTROP 1980; Eussen 1981; Brook 1989; Sabarnurdin et al. 1991; Turvey 1994). Consequently no further comprehensive review is attempted here. However the main features of *Imperata* which have implications for the transformation to more productive systems are listed below.

Seeds

- prolific seed producer
- seed widely dispersed by wind
- seeds remain viable in soil
- quick germination of seeds
- seed production encouraged by physical attack on plant (e.g. cutting)

Rhizomes

- perennial rhizomes can remain dormant but viable
- rhizomes are extensive and prolific
- rhizomes concentrated in upper 20 cm of soil
- rhizomes allow regeneration after fire
- cultivation stimulates rhizome bud growth

Ability to impact on other crops

- fast growth rate
- large biomass production
- highly flammable in dry season
- can grow on all soil types
- strong ability to extract nutrients and moisture from the soil

Susceptibility

- susceptible to herbicide
- intolerant of shade

IMPERATA CONTROL METHODS

Weeds may be broadly defined as plants growing 'out of place' (i.e. where they are not wanted). In an ecological sense however, *Imperata* is very much '*in place*', being well adapted to conditions prevailing in the uplands of Southeast Asia. *Imperata* control may take different forms (Table 1.1).

Table 1.1. Summary of *Imperata* control methods.

Physical	Manual Mechanical or animal powered
Chemical	Herbicides
Biological	Classical, augmentative, inundative
Ecological	Shading by competing plants
Integrated	Especially physical, chemical and ecological

Physical

Physical methods of *Imperata* control include manual cultivation with a hoe and cultivation using animal traction. Slashing and burning are other options for physical attacks. Manual cultivation in Indonesia has been reported as taking 235 days/ha (Barlow and Muharminto 1982), 270 days/ha (Mangoensoekarjo 1980) and 175 days/ha (Anwar and Bacon 1986). Using the first estimate, and a wage rate of 3000 Rp/ha , (approximately US$1in June, 1997) total costs of *Imperata* clearing would be 705 000 Rp. In all cultivation techniques multiple passes will be required, with the rhizomes being brought to the soil surface to dry. Slashing (Soerjani 1970) may exhaust the rhizome reserves, but this will require repeated application and will not be effective in removing *Imperata*. Slashing should be thought of as a containment, rather than a population-reducing, policy. Burning will clear the area of surface *Imperata*, but there will be rapid regeneration from the underground rhizomes. As burning can get out of control, there may be large social costs associated with it.

Chemical

Glyphosate has become the market leader for the chemical control of *Imperata cylindrica*. The translocation of glyphosate to *Imperata* rhizomes is a major factor behind the success of this herbicide for *Imperata* control. The recommended rate of spraying is 5 L of glyphosate/ha, followed up by a 1 L correction spray. The effectiveness of the herbicide is greater if applied to new shoots after slashing or burning. A recent survey (Bagnall-Oakeley et al. 1997) indicates that some smallholders are using herbicide, but at only about one half of the recommended dose rate, and without slashing which is seen to be too laborious. On-farm costs of glyphosate are 22 000 Rp/L, i.e. 110 000 Rp/ha , per spraying at the recommended

rate. Following herbicide spraying *Imperata* will typically reinvade after 6 to 12 months.

Biological

'Classical' biological control using a control agent that can 'search out' *Imperata* and control it, would provide major economic benefits compared to chemical and mechanical control, where human effort and other resources are required to link the control method to the weed. Furthermore, the biological control agent may be able to spread to areas inaccessible to humans. However Ivens (1980) considered that there was little hope of controlling *Imperata* by introducing insects or plant diseases. Since *Imperata* is ubiquitous, the chances of finding a classical control agent are thought to be slight. Augmentative or inundative techniques using known enemies of *Imperata* may be feasible, but are unlikely in practice to be cheaper than spraying with glyphosate.

Shading (ecological)

While the population of *Imperata* can be drastically reduced by mechanical or chemical methods, this can only be achieved at a relatively high resource cost and with almost certain reinvasion. In order to avoid repeated application of these resources, the follow-up planting of commercial crops should be such as to hinder reinvasion by *Imperata*. *Imperata* is known to be susceptible to shading from trees, and to competition from food crops under more intensive management conditions. So planting of one, or both, of these as a follow-up to physical or chemical control, is desirable.

For this and other reasons (soil erosion control, potential marketability of product), there is a focus in the report on the transformation of *Imperata* grassland into tree-based farming systems.

RESEARCH METHODOLOGY

A bioeconomic modelling approach is used to delineate the major biophysical and economic features of existing, and potentially new, tree-based smallholder farming systems in *Imperata* grassland areas. Bioeconomic modelling was chosen as being cheaper, and as providing more or less instantaneous results, in comparison with conventional field experimentation. This is especially true in relation to experiments with tree growing. Of course modelling involves some abstraction from real world complexity. However, the consequent ability to isolate cause and effect due to particular factors is a major benefit of this abstraction. Results from long-term experimentation will inevitably be confounded by 'unusual' weather events, pests etc. While this is reality, it makes the interpretation and extrapolation of experimental results difficult — and it is unlikely that this same set of real world complex influences will re-occur in any future replication of the experiment (or in other treatments within an existing experiment).

Two types of models are commonly used in this report:

- SCUAF (Soil Changes under Agriculture and Forestry)
- The BEAM models RRYIELD and RRECON. (BEAM: Bioeconomic AgroEconomic Modelling group at the University of Wales; RRYIELD: Rice/Rubber YIELD model; RRECON: Rice/Rubber ECONomics)

SCUAF was applied to a range of shifting cultivation farming systems Indonesia (for typical, but hypothetical, sites in Chapters 2 and 3) and for conservation systems in Indonesia (Chapter 13) using actual experimental data. While some extrapolations and assumptions were necessary, the authors feel confident about the representativeness of these sites to conditions of the Southeast Asian uplands generally. SCUAF was also applied to Claveria, Northern Mindanao, Philippines. In this case, the choice of site was driven by the availability of comprehensive experimental and farm level data on a range of conservation farming systems. Nevertheless, the area is typical of poorer upland areas of Southeast Asia, although the soils may be somewhat less prone to erosion than some other areas. This would tend to make the conservation farming systems relatively less attractive in Claveria than they might be elsewhere. In other words, the value of conservation farming might be somewhat underestimated.

BEAM was exclusively applied to conditions relevant to South Sumatra, Indonesia. Conditions there are very typical of smallholder rubber production in Indonesia. So the selected site are representative, but in any event, SCUAF and BEAM can be easily adjusted to represent conditions prevailing at any site, if the relevant data are available.

SCUAF

SCUAF is a computer model which predicts the effects upon soils of specific land-use systems under given environmental conditions. It is designed to include the distinctive features of agroforestry, that is, land-use systems which include both trees and crops. However, it can also be used to compare agroforestry systems with land use under agriculture or forestry, treating these as limiting cases of agroforestry, agriculture with 100% crops and 0% trees, forestry with 0% crops and 100% trees. SCUAF is a process-response model.

In outline, the user specifies:

- the physical environment;
- the land-use system;
- the initial soil conditions;
- the initial rates of plant growth;
- the rates of operation of soil–plant processes.

The land-use system is based on two plant components, trees and crops. The primary basis for description of the land-use system is the proportion of trees and crops in each successive year. Other elements of the land-use system are additions (organic additions, fertilizers), removals (harvest, losses), and prunings (of the trees) and transfers (e.g. transfer of tree prunings to soil under crops). As well as the above-ground parts of the plants (leaf, fruit, wood), the effects of roots are modelled. An animal component is not modelled, but can be included in the land-use system indirectly.

SCUAF simulates, on an annual basis:

- changes in soil conditions;
- the effects of soil changes upon plant growth and harvest.

Earlier in the project, version 2 of SCUAF was used, but via the experiences gained with extensive use of that version, certain possible improvements were identified, and subsequently implemented by the model developers. A new version of SCUAF (version 4) resulted and this version is now available (Young et al. 1998) and was used in the later stages of the project. In one or two cases, essentially the same farming system was simulated with both versions 2 and 4 of SCUAF. The results were broadly comparable.

Analyses using SCUAF were generally conducted in the manner portrayed in Figure 1.1. Research data were used to calibrate, or parameterize SCUAF to the particular location of interest. If no experimental data were available to be used in the calibration, then farm level data were used. Cost and revenue data used for the

economic dimension of SCUAF were obtained from farmer survey (or sometimes from secondary data). The biophysical outputs from SCUAF were combined with that economic data in a spreadsheet framework to derive the economic performance of the particular system being modelled.

As evident in Figure 1.1, SCUAF is an integrative model. The modelling is necessarily at a higher level of abstraction in comparison to more specialised crop growth or carbon cycle models. However it is the integrative capacity that makes SCUAF attractive. The modelled results from SCUAF have proved to be credible and have given trend results similar to more 'sophisticated' models.

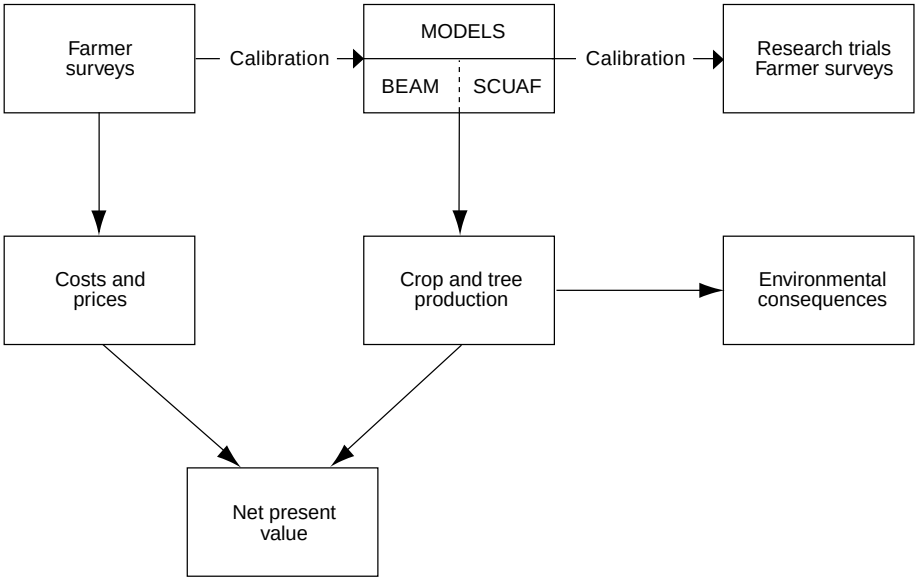


Figure 1.1. General modelling framework

BEAM

The BEAM rubber agroforestry model was designed originally from the perspective of a rubber estate (Thomas et al. 1993). Subsequently, the model was made relevant to smallholders by calibrating it to conditions representative of smallholders in the Palembang region of South Sumatra. There were also a number of other modifications made to the model.

The model simulates the economic and biological output of a rubber plantation (annual latex production, final wood harvest and annual intercrop harvest) with respect to site-specific environmental and input factors, silvicultural regimes and financial parameters The model is a composite of two spreadsheet sub-models. The first, RRYIELD, deals with the biophysical interactions in a rubber plantation. Rubber tree growth is specified as being primarily a function of tree girth increment, which, in turn, is a function of tree age and planting density. Latex yield is a function of tree girth and time since tapping commenced.

The second submodel, RRECON (Willis et al. 1993), is concerned with economic relationships. Financial costs and returns are linked with the physical inputs and outputs extracted from RRYIELD to determine the overall discounted economic returns in terms of net present value (NPV). Annual net revenues from latex, wood and rice are discounted back to net present values using a discount rate.

The BEAM models were designed as extension/research tools to analyse information on the viability of various management or technological regimes for rubber. The framework for the application of BEAM was somewhat similar to the framework for SCUAF (Fig. 1.1). A major difference is that soil degradation consequences were not derived from the BEAM model.

Project framework

The framework for the project is presented in Figure 1.2. Existing farming systems on *Imperata* grassland are described and analysed. This analysis is sometimes undertaken with bioeconomic models and sometimes not. Potentially new tree-based systems were analysed with the models. The performance of various systems is assessed in terms of both economic and environmental indicators over a multi-year time period. Thus the sustainability of various systems is explicitly considered.

The factors that are responsible for the transformation of the *Imperata* grassland into tree-based systems can be thought of as technology, management, policy (including fire control). The impact of the transformation factors are examined both via modelling and via farm survey methodologies with a view to determining appropriate options for developing tree-based systems on *Imperata* grassland. The definition of tree-based systems includes hedgerow (alley cropping) systems, and although it is stretching the definition of 'tree-based', grass strip hedgerows are also included in the analysis.

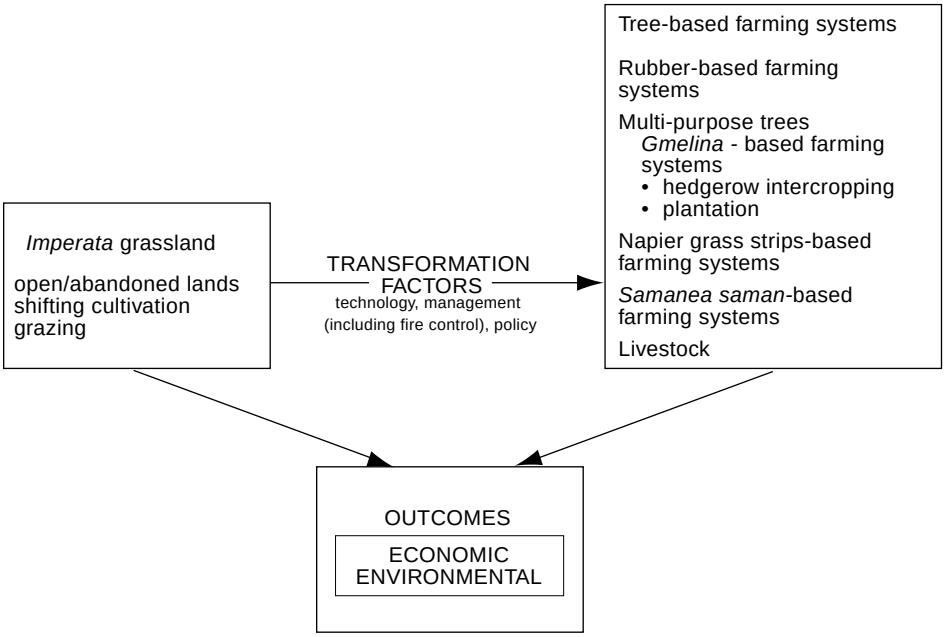


Figure 1.2. Project framework

The environmental consequences shown in Figure 1.1 for SCUAF are primarily levels of soil erosion and fertility. No attempt is made here to assess the off-farm costs of land degradation. For BEAM, the primary environmental consequence that was traced was carbon sequestration by trees. An assessment of the farm level externalities from fire risk was also considered.

While the framework for the analysis with SCUAF and BEAM is similar, the models themselves are quite different. SCUAF places an emphasis on soil quality factors and erosion. The emphasis in the modified version of BEAM used here is on the competition for sunlight between *Imperata* and rubber and the risk of fire to rubber occasioned by the presence of *Imperata*. The BEAM analyses in this report were conducted using the final (November 1997) version of the model, and thus the results may be at variance with the results presented in the *Imperata* Project Papers produced earlier in the project.

In some cases, farm survey results were end products of research in addition to, or in lieu of, their incorporation in the bioeconomic models.

The most common unit of analysis in the report is either a plot of land (e.g. 1 ha), or an aggregation of plots to represent a farm. There is an emphasis in the report on assessing the impact of the transformation factors *on farmers*. Opportunity costs are imputed to the farm labour provided by smallholders, but adjustments are not typically made to other input and output costs to capture such items as subsidies.

Because farm labour is a critical input, a sensitivity analysis on labour costs is usually undertaken. So there is a financial, or farm level impact, orientation to the research. It is a somewhat different matter to assess changes that are most desirable from a societal viewpoint, but the on-farm impact will be a critical component of that broader assessment. Farmers, as rational decision makers, will only adopt a soil conservation technology if they perceive that doing so will improve their own economic welfare. That is, farmers may only consider soil loss to the extent that it is perceived to affect economic returns through present and future crop yields. By focusing on farmer responses to various circumstances, a far greater range of topics were covered, in comparison to a situation where attempts would be made to estimate an array of relatively intangible social and economic factors.

Discount rates and sensitivity analysis

Tree-based systems require an investment of labour and/or capital for planting, accompanied by a time lag of several years or more, prior to yielding a positive economic return. In order to make these economic returns comparable over different years, a discount rate is used. Real interest (discount) rates for upland farmers of over 100% pa have sometimes been reported. However, the amounts of money that are borrowed, when these high rates prevail, may be negligible (Nelson et al. 1997), and so not really representative of the opportunity cost of funds. Government-sponsored co-operatives or similar have been reported as providing real discount rates of approximately 10–12% (Nelson et al. 1997).

The cumulative farm level net present value (Fig. 1.1) of a farming system over n years can be calculated from the following equation, where B_t and C_t are the benefits and costs in year t, and r is a real (after allowing for inflation) discount rate:

$$NPV = \sum_{t=0}^{n} \frac{\left(B_t - C_t\right)}{\left(1 = r\right)^t}$$

Two levels of discount rates are used in this report: 10 or 12% to represent the lower end of the market discount rate (approximating the social discount rate where risks of default/high transaction costs are less relevant issues). Twenty five percent is used to represent the higher end of market discount rates faced by upland farmers. Farmers facing even higher rates than this are not likely to be considering any tree-based farming systems.

SECTION 1

MODELLING SHIFTING CULTIVATION

The predominant form of land use by smallholders on *Imperata* grassland is shifting cultivation. Shifting cultivation is also the land use with the most damaging ecological consequences, in terms of soil erosion and fire.

In this section, the biological and economic consequences of shifting cultivation on *Imperata* grassland are examined within a modelling framework. No previous dynamic bioeconomic analysis of shifting cultivation systems could be found in the literature.

The analysis in this section is based upon a 'typical' upland *Imperata* grassland site in Indonesia. On the basis of a literature review, a typical *Imperata* area in the Indonesian uplands was defined as follows: 200 m above sea level with a slope of 5–17%; rainfall greater than 1500 mm per year, with up to four dry months. The shifting cultivation crop is upland rice, with an *Imperata* fallow.

2 Impacts of Reductions in Fallow Length

KEN MENZ
PETER GRIST

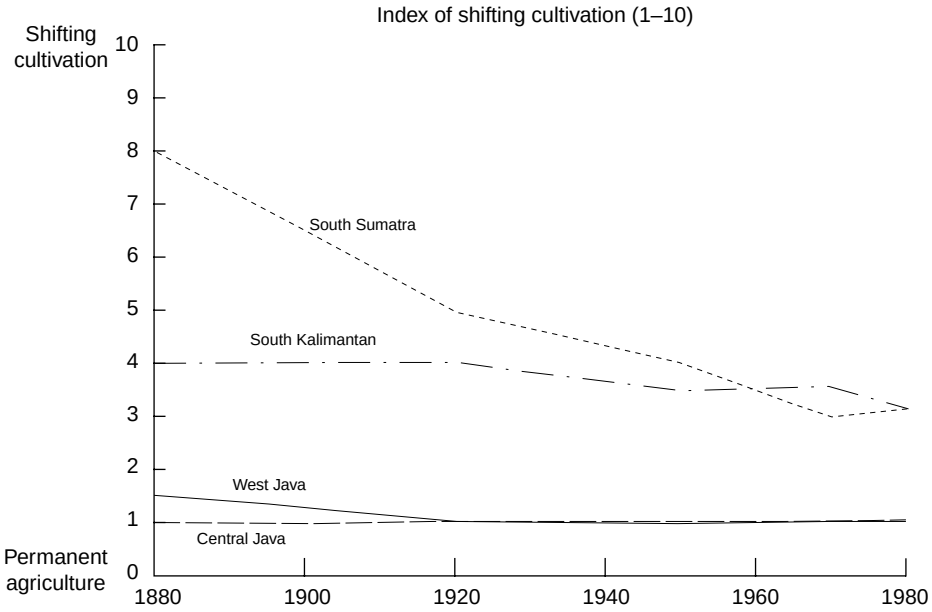
THERE HAS BEEN an historical trend in Southeast Asia for human population increase to result in a transformation of land use from native forest to shifting cultivation (e.g. Garrity and Agustin 1995; Pasicolan et al. 1996), then from shifting cultivation to permanent agriculture, via a shortening of the time period of the fallow, eventually reaching zero (Richards and Flint 1993). For Indonesia, Richards and Flint schematically portray the latter part of this trend for a number of provinces. A version of their graph, focusing on South Sumatra and South Kalimantan (two provinces with heavy concentrations of *Imperata*) and Java (where little *Imperata* remains) is presented as Figure 2.1. The figure indicates that the provinces containing large areas of *Imperata* also have a preponderance of shifting cultivation.

In this chapter, the SCUAF model (see Appendix) is used to trace the effects of fallow length changes on soil quality, and on the economic performance of shifting cultivation regimes on sloping *Imperata* uplands. The choice of SCUAF (Young and Muraya 1990) followed an exploratory analysis with the only other operational model of shifting cultivation that could be found in the literature (Trenbath 1984). Chapter 4 contains details of the exploratory analysis using the Trenbath model.

Modelling the linkage between soil degradation, crop production and economic outcomes is the core of the analysis. SCUAF represents a tool for tracing the linkages between soil processes (including erosion) and physical outputs. While SCUAF does not directly include an economic dimension, such can be readily added outside the model (e.g. Nelson et al. 1997). The economic model used here was designed to run parallel to SCUAF, enabling the economic consequences of various fallow lengths to be evaluated.

The focus is on smallholder annual upland rice cropping/*Imperata* fallow systems, the predominant form of shifting cultivation in Indonesia. The analysis is pertinent to the current circumstances of many smallholders, especially in more remote parts of the region. However, the study can also be viewed in an historical context, as tracing some of the consequences of population pressure (= shorter fallow periods) on land use.

Figure 2.1. Degree of shifting cultivation in four provinces of Indonesia



CALIBRATING SCUAF TO CONDITIONS TYPICAL OF UPLAND RICE/*IMPERATA* FALLOW FARMING SYSTEMS

Although *Imperata* areas in Southeast Asia are spread rather evenly across soil types, Ultisol is the predominant soil order in the upland humid tropics of Southeast Asia. Thus Ultisol is taken as the 'baseline' soil type (Ultisols include the previously labelled 'Red Yellow Podzolics'). These are poor quality soils, being acidic and of low fertility (Szott et al. 1991). The parameters used to calibrate SCUAF to conditions typical of *Imperata* areas of Southeast Asia are discussed.

Soil organic matter

van Noordwijk et al. (1995) examined a comprehensive set of soils data from the Center of Soil and Agroclimate Research, Bogor, Indonesia. They developed, for Indonesia, a regression equation relating average levels of organic matter to soil type, ground cover (including *Imperata*), slope, altitude, pH and clay/silt percentage. The equation is used here to estimate organic matter under an *Imperata* fallow with the following parameters as explanatory variables: Ultisol, 200 m altitude, pH of 5.1, slope of 17% and a 25% silt and clay content of the soil. The average figure for the organic matter level in topsoil, determined using van Noordwijk's equation, was 2.2%. This compares with a number of specific measurements of organic matter under *Imperata* (Table 2.1). These specific measurements are broadly supportive of the 2.2% obtained using the van Noordwijk estimate. The figure was chosen to calibrate the (top)soil organic matter component of the SCUAF model to represent the circumstances of interest.

Table 2.1. Selected soil characteristics under *Imperata*

	Organic C (%)	N (%)	pH
a	2.2	0.16	5.3
b	1.7	0.14	4.8
c	2.0	0.11	5.2
d	2.2	0.13	5.1

The information in the respective rows in Table 1 were from: a) Turvey (1995), (Tropuldult); b) Shiddieq and Setyarso (1991), (Ultisol); c) Almendras and Serohijos (1994), (Paleudult); d) Soepardi (1980), (Typic Humitropept). Only the poorer Kalimantan soils are included from the Soepardi reference.

Other soil parameters

Soil nitrogen levels surveyed under *Imperata* (Table 2.1) were in a reasonably tight range around 0.135%, and a pH of 5.1 is representative of the survey results. Other soils variables required for the initialisation of SCUAF include subsoil carbon, which was determined to be 0.5%, based on measurements by Turvey (1995) and Shiddieq and Setyarso (1991). The soil depth of one metre and the topsoil depth of 20 cm, used in these calculations, are also based on measurements by those researchers. Soepardi (1980) provides the only measurement of bulk density under *Imperata* discovered on the representative soil type, at 1.3 for topsoil and 1.5 for the subsoil.

Agroclimatic considerations

Although the focus of this report is on rainfed sloping lands, the *Imperata* areas of Southeast Asia are classified by the criteria used in SCUAF as 'humid lowlands'. Soils

are considered to be medium-textured, acidic and free draining. The slope in many *Imperata* areas is between 5 and 17 degrees.

For other parameters, the default values in SCUAF were used, corresponding to the climate, slope and soil conditions. Slight downward adjustments were made to the default values for the litter to humus conversion losses and the fraction of labile humus annually transformed to stable. In terms of modelling soil erosion control and leaching, *Imperata* was regarded as equivalent to a tree (see Manan 1980). The 'crop cover' factor, used in SCUAF to calculate soil erosion, was regarded as being intermediate between *Imperata* and rice, since the ground is covered by each, during the course of a year where one crop is grown.

The shifting cultivation system

A series of *Imperata* fallow lengths between twenty and zero years (zero fallow = continuous cropping) are considered in this paper followed, in each case, by a single year of upland rice. It is assumed that no burning takes place during the cycle, in either the fallow or crop phase. The long run impacts of burning *Imperata* are examined in Chapter 3.

Within the SCUAF model, calibrated to the site conditions described earlier, a twenty-year fallow followed by one upland rice crop, provides a sustainable farming system (Fig. 2.2). The twenty-year fallow is taken as the 'baseline' farming system, which is used to gauge the physical and economic consequence of reductions in fallow length below twenty years. Shorter fallow lengths are the most obvious sign of increasing population pressure on land (Baker 1984; Syers and Craswell 1995).

For consistency the first rice crop occurs after a fallow, so in year 21 for a twenty-year fallow and year 11 for a ten-year fallow cycle. In order to provide for continuity of harvest, it is assumed that smallholders divide their land into equal sized plots. For a twenty-year fallow/one year crop, the available land area would be divided into 21 plots. A new plot of land is cropped each year.

Castillo and Siapno (1995) found average above-ground *Imperata* yields of 4.02 t/ha/year in their survey of Northern Luzon, Philippines, slightly above the yield reported by Sajise (1980). Higher levels of above-ground dry matter have been measured (e.g. Soerjani 1970), but these measurements appear to represent standing material rather than annual yields. A rhizome/shoot ratio of 0.6 was found in standing material (Soerjani 1970). Leaf tissue composition was determined by Sajise (1980) to be 0.94% N and 0.7% P. These orders of magnitude for N levels in the plant were supported by figures presented in Holmes et al. (1980).

All systems are based on an 'initial' rice yield (corresponding to the soil conditions used to calibrate SCUAF) of 1.0 t/ha. This is based on the research of Fujisaka et al. (1991), and is also supported by work of Nakano (1980) and Swamy and Ramakrishnan (1988). Although many references to measured upland rice yields are lower, in the 600–700 kg/ha range (e.g. Barlow and Muharminto 1982; Gouyon and Nancy 1989), these lower yields appear to result from shorter fallow periods. This point is made explicitly by Fujisaka et al. (1991) and Swamy and Ramakrishnan (1988). Because the first rice harvest occurs after fallow in the model, the modelled yield will be greater than the 1.0 t/ha 'initial' rice yield used for calibration. This is so because of the improvement in soil conditions that occurs during the fallow. For ease of visual comparison, all rice yields are portrayed as starting at the same point in Figure 2.2.

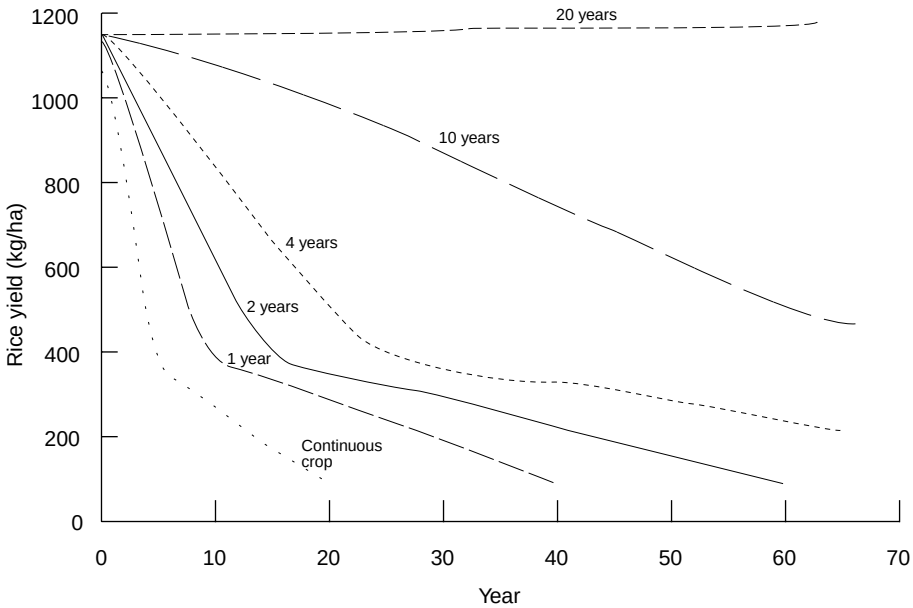


Figure 2.2. Modelled rice yields over time for various lengths of *Imperata* fallow

The economic model

An economic model was developed to evaluate the physical effects of the changes specified in SCUAF. The model determines the viability of each fallow system in terms of the economic returns from rice. It is a straightforward cost-benefit analysis spreadsheet, providing the discounted net present value corresponding to each fallow length (see Chapter 1). In addition to rice yield emerging from SCUAF, inputs to the economic model include land and labour availability, labour usage rates, rice price and the economic discount rate.

Labour availability on smallholder upland farms of 450 man-equivalent days per year is assumed. This is based on one male and one female worker per year, and corresponds to the average labour availability found during an extensive survey of smallholder upland areas in the Philippines (Menz et al. 1995). The labour requirement for growing upland rice in *Imperata* areas was derived from the research of Barlow and Muharminto (1982), who estimated 278 days/ha. Support for a figure of this magnitude is given by Mangoensoekarjo (1980), Anwar and Bacon (1986), and Fujisaka et al. (1991). Based upon this labour requirement, the maximum area that can be cropped within each smallholding is 1.62 ha.

The length of fallow places a ceiling on annual rice area. For example, if the total available land is 5 ha, then to achieve a twenty-year fallow, the maximum area that can be cropped annually is 0.24 ha (5 ha/20+1 plots of land).

In each fallow cycle, it is assumed that each plot has an identical cropping history. Thus the yield of each plot is the same within a given cycle. For example, if the rice yield in the first cycle of a twenty-year fallow was 1 t/ha, then for the first 21 years, each new plot brought into production would also yield 1 t/ha. The total harvest produced depends on the area of each plot. Continuing with the 5 ha/twenty-year fallow example, the annual harvest would be 240 kg (1000×0.24), with a labour requirement of 67 days per year (278×0.24).

The discount rate used is 12%, which approximates current real interest rates in Indonesia (Anon. 1996). All economic information is specified in Indonesian Rupiah (Rp) and US$1 equals approximately Rp 2900. A price of Rp 400/kg was used for rice in South Sumatra in 1995 (Grist et al. 1995).

Some additional detail on the economic model is presented under this same heading in Chapter 3. The models are similar in the two Chapters, but one important distinction relates to the treatment of labour costs. In Chapter 2, labour is treated as a finite resource whose level cannot be exceeded. No charge is made per unit of labour used within that finite constraint. However, in Chapter 3, the concept of fixed labour availability is dispensed with, and all labour is charged per unit of time. This was done

to facilitate comparisons of different clearing methods which differ largely on the basis of labour usage.

Biological outcomes from the SCUAF model of shifting cultivation for various fallow periods

The twenty-year *Imperata* fallow, or 'baseline' system, was modelled as being sustainable in terms of upland rice yield (Fig. 2.2), and in terms of the levels of labile soil carbon and nitrogen (Figs 2.3 and 2.4). Soil erosion and soil depth were also stable (Figs 2.5 and 2.6). The negative impacts of the rice crop on soil are ameliorated during the twenty years of fallow. A long *Imperata* fallow was measured as being sustainable in terms of soil parameters by Shiddieq and Setyarso (1991), who found that soil parameters under a long *Imperata* fallow were similar to levels under forest. The sustainability of the twenty-year fallow rotation system is also in accordance with the findings of Palm et al. (1994), who suggested that a stable/sustainable system could be achieved with a 16–17 year fallow.

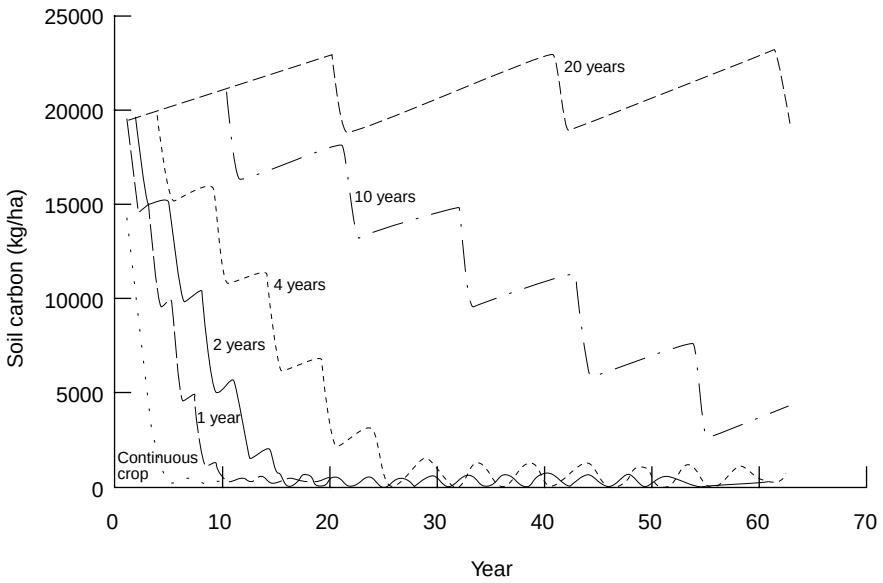


Figure 2.3. Available soil carbon over time for various lengths of *Imperata* fallow

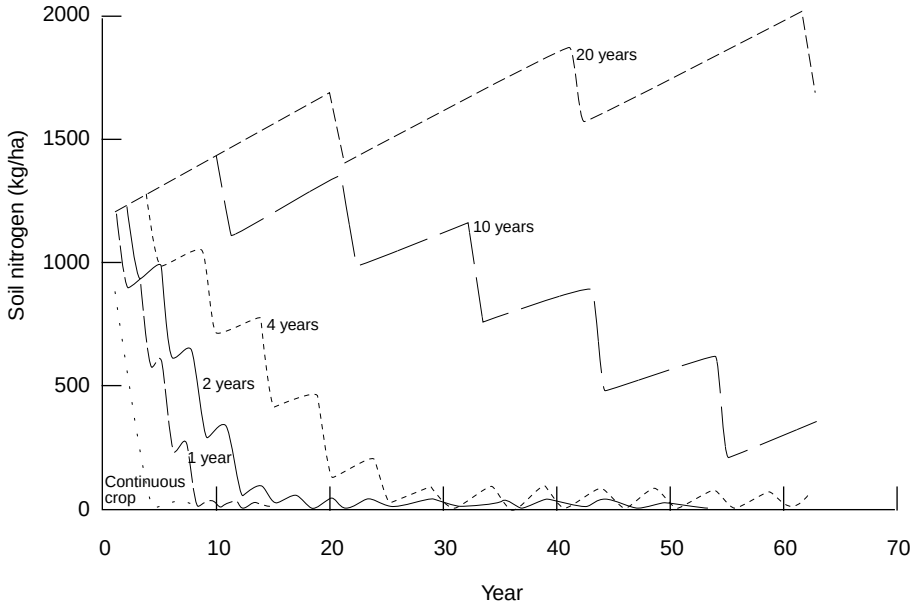


Figure 2.4. Soil nitrogen over time for various lengths of *Imperata* fallow

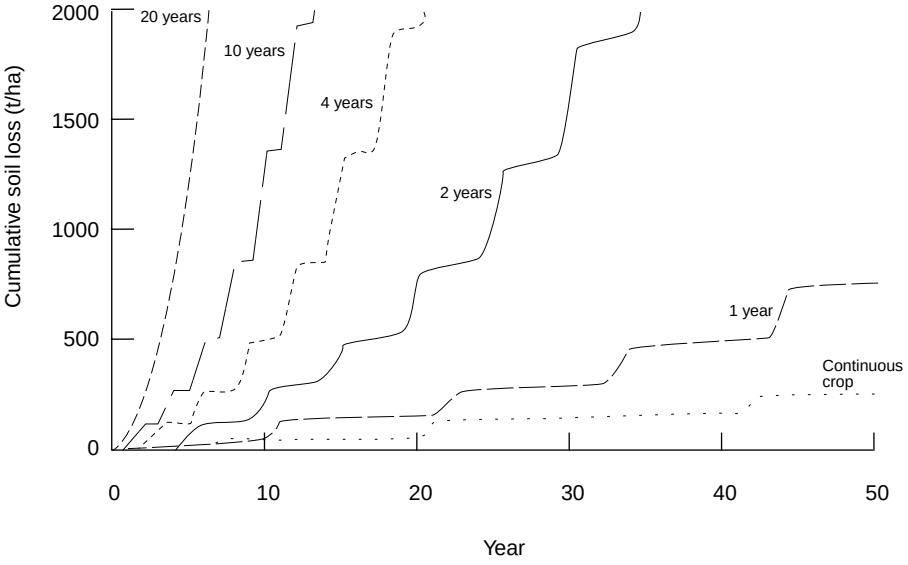
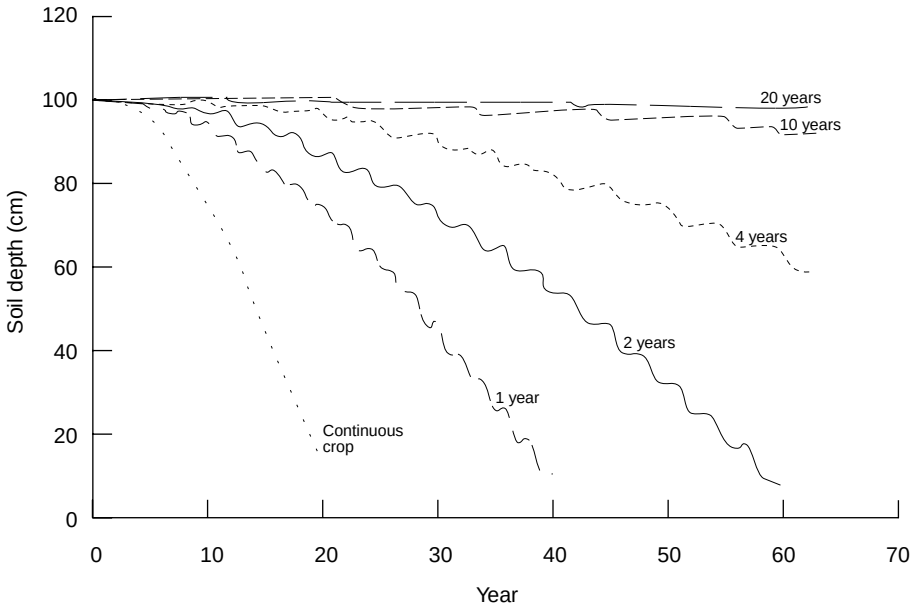


Figure 2.5. Cumulative soil loss over time for various lengths of *Imperata* fallow

In moving from a twenty- to a ten-year fallow, a marked change is observed. With the ten-year fallow, rice yield declines to under 50% of the original yield by year 55 (Fig. 2.2). With this length of fallow, soil fertility is not able to recover sufficiently to provide a sustainable system. This is best observed in the labile soil carbon and nitrogen parameters, which fall to below 20% of their initial levels by year 55 (Figs 2.3 and 2.4). This deterioration in the soil factors causes a significant increase in soil erosion. By year 55, annual soil erosion in a crop year rises to over 280t/ha (Fig. 2.5). The depth of soil declines by almost 10%, from 100 cm to 92 cm (Fig. 2.6). The rate of erosion increases over time, as soil fertility declines and the capacity of the soil to maintain ground cover is reduced.

Figure 2.6. Soil depth over time for various lengths of *Imperata* fallow



With a four-year fallow the pronounced downward trends in physical indicators of sustainability, as observed in the ten-year fallow system, are exacerbated. Yet a four-year fallow (or less) represents the current experience of many upland farmers. It is a profoundly unsustainable system by any obvious physical measurement, in the absence of input supplementation. With a four-year fallow, rice yield falls to less than one-third of its initial level by year 60 (the end of the twelfth cycle). The yield decline has levelled out by year 25 (or the fifth cycle). This is associated with the exhaustion of stored, labile, soil carbon and nitrogen, which have fallen to zero by year 25. After 25 years, the soil must rely on the labile soil carbon and nitrogen recovered during the fallow. Associated with the deterioration in soil factors is a higher rate of soil erosion and a significant reduction in soil depth. Almost 40% of soil is lost by year 60.

With shorter fallow lengths (two-year and one-year fallows), labile soil carbon and nitrogen are depleted even sooner. Stored, labile, soil carbon and nitrogen are exhausted by year twelve with a two-year fallow, and by year eight with a one-year fallow. Once that store is exhausted, the increase in labile soil carbon and nitrogen is significantly less during the shorter two- and one-year fallows (barely rising above the x-axis in Figures 2.3 and 2.4).

All trends described in the previous paragraph (labile soil carbon and nitrogen depletion, soil erosion and rice yield decline) are exacerbated in the continuous cropping case.

Economic outcomes

A longer *Imperata* fallow period results in a significantly greater rice yield (Fig. 2.1), and hence a greater gross revenue *per hectare of rice grown*. But a prerequisite to a longer fallow is that more land be available. The optimum fallow length (defined as the fallow length that maximises discounted net present value) corresponding to a range of land area availabilities is shown in Figure 2.7.

As fallow length falls below 20 years there is, at first, only a small decline in discounted economic returns (Fig. 2.7). When the fallow length is around seven years, further reductions in fallow length cause significant declines in yield. Discounted economic returns show a concomitant rate of decline. The effect of fallow lengths around four years is dramatic.

The application of the discounting formula (Chapter 1) ameliorates the negative economic effect of a shortened fallow. Despite this, when fallow lengths are reduced from 20 years to a level around four years, the impact on economic returns, from the ensuing long term rice yield decline, is large.

In order to maintain a biologically sustainable 20-year fallow, when total area available is 5 ha, only 0.24 ha of land per year can be cropped. However, a twenty-year fallow length is contrary to the economic objective of maximum economic return, which is around 3 years for a 5 ha farm (Fig. 2.7). With a 5 ha farm, a 20-year fallow results in a net present value (NPV) of Rp1 million, but an NPV of over Rp 4 million can be obtained from a two-year fallow (Fig. 2.8). This is so, despite the negative yield, and other sustainability indicators associated with the two-year fallow (Figs 2.2 to 2.6). This four-fold difference in discounted revenue shows the economic sacrifice that a smallholder would have to incur in order to achieve biological sustainability. The fundamental reason why there is such a drop in NPV, with the longer fallow, is the reduction in cropping area that is implied by that longer fallow.

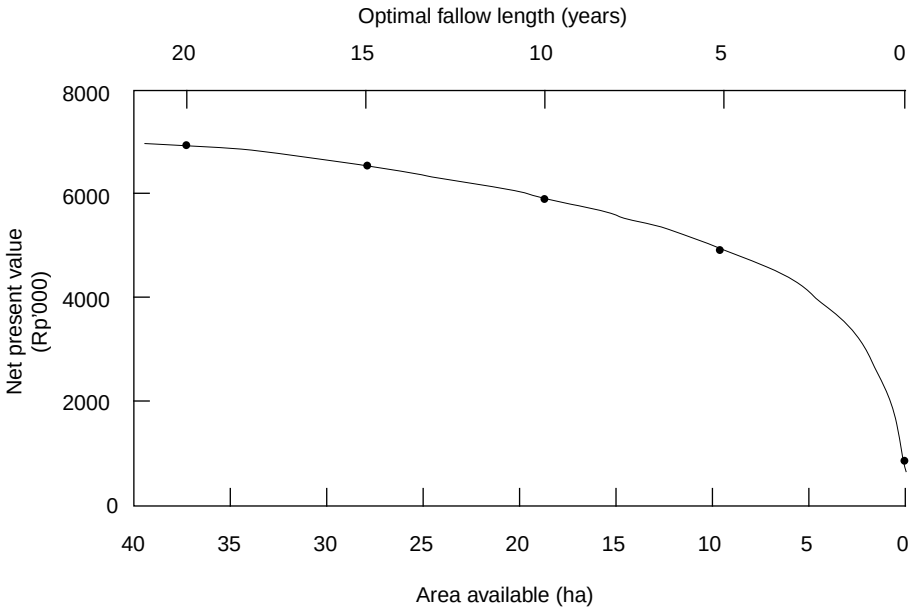


Figure 2.7. Net present value from the optimal fallow length corresponding to land area availability, 12% discount rate, 63 years time horizon

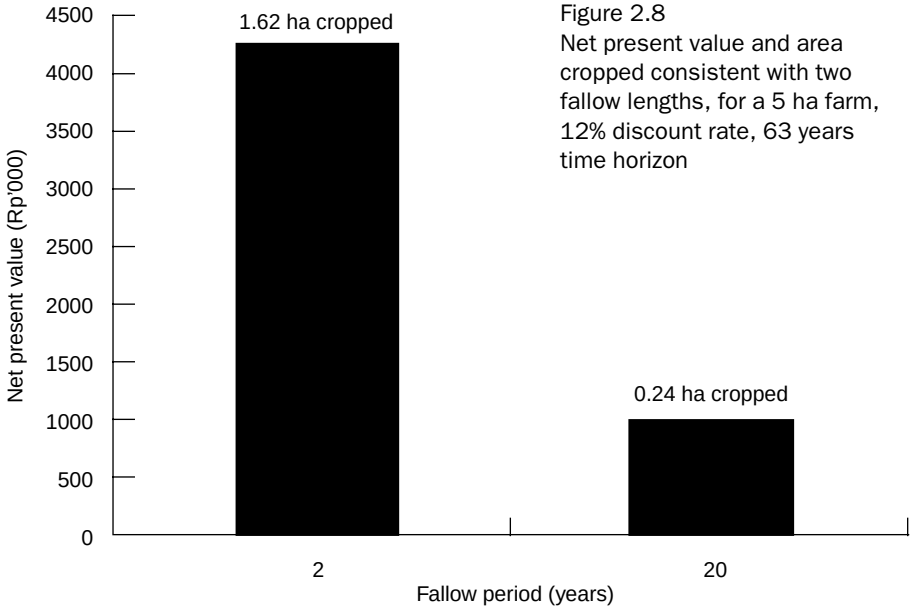


Figure 2.8
Net present value and area cropped consistent with two fallow lengths, for a 5 ha farm, 12% discount rate, 63 years time horizon

CONCLUSION

With reductions in *Imperata* fallow lengths (from a 20-year starting point), the modelling work indicated an initially modest, approximately linear, reduction in economic returns. With fallow lengths of around seven years, economic returns fall dramatically. The explanation is revealed in terms of total soil loss and reductions in the level of labile soil carbon and nitrogen, with all three being reflected in a loss of rice yield.

For most smallholders, the area of land available implies that it is not economic to reduce the cropped area to the low level that is required to maintain yields and soil parameters at sustainable levels. Farms of say, 5 ha, can operate on a twenty-year fallow rotation, but in doing so can achieve only one-quarter the level of short-term profitability (NPV) as with a two-year fallow. This is despite the negative implications of the two-year fallow for biological sustainability.

Thus an economic imperative exists for upland smallholders to engage in shifting cultivation systems that are patently unsustainable. In the absence of the application of new technology or inputs, labour productivity will fall to the point that most of these smallholder upland farms will cease to be viable.

Shifting cultivation forms the 'baseline' farming system against which various tree- and animal-based systems can be gauged (Sections 3 and 4 of this report).

3 Evaluation of Fire Versus Non-fire Methods for Clearing *Imperata* Fallow

PETER GRIST
KEN MENZ

INTENTIONAL AND ACCIDENTAL fires are common in *Imperata* grassland areas of Indonesia. Fire is often used by smallholders as a means of temporarily clearing *Imperata* land in preparation for upland (usually rice) cropping.

Trees have been mooted as a possible use for *Imperata* areas, and the Indonesian government is involved in some significant reforestation initiatives. However trees planted in, or adjacent to, grassland areas are often killed by fire—fires in *Imperata* grassland, therefore, are an economic disincentive to tree planting. Fires in *Imperata* are also regarded as significant sources of forest fires (Wibowo et al. 1997). Substantial grassland fires may add to global warming and to smoke pollution. The latter has been a source of some political friction between Indonesia and Malaysia/Singapore over recent years. Thus there appear to be significant social costs associated with fire as a method of *Imperata* clearing in addition to the disincentive to tree planting.

Manual clearing and herbicide use avoid the need for fire. The chemical herbicide, glyphosate, is effective, and has become cheaper over recent years, following the expiration of patents. Meanwhile farm labour costs are rising. These changes increase the economic attractiveness of herbicide. However, to date there has been limited adoption by smallholders of herbicide as a method of clearing. Burning remains the major control technique.

In this chapter, an examination is made of the on-farm economic consequences of clearing *Imperata* fallow by fire, within the context of a shifting cultivation, smallholder cropping system. A comparison is made with the less destructive methods

of herbicide-spraying and manual cultivation. In order to trace the biophysical, and economic impacts in a realistic, but cost-effective manner, a bioeconomic modelling approach is used, similar to that in the previous chapter. The focus here is on a narrower range of *Imperata* fallow lengths from one to four years. Fallow lengths of this duration are common in the Indonesian uplands (van Noordwijk et al. 1995).

THE ECONOMIC MODEL

A framework was developed to evaluate the economic viability of three different systems of clearing *Imperata* fallow. That framework is a traditional benefit-cost analysis, similar to Chapter 2. The long-term impacts of various methods of *Imperata* control are traced for fallow lengths from one to four years. A period of fallow plus the year of crop is defined as a cycle, so a four-year fallow implies a five-year cycle. Data for the first cycle were obtained from a review of the relevant economic and biophysical literature. Levels of crop production and soil conditions in subsequent cycles were obtained from simulations with the SCUAF model. The net present value (NPV) of each farming system was then calculated.

Rice yield is assumed to be identical for all years *within* a particular fallow/crop cycle. For a 2 ha farm with say, a four-year fallow (five-year cycle), total rice production per year would be the yield per hectare predicted from SCUAF, multiplied by 2/5 ha. This rice production is multiplied by the market price of rice to calculate the annual gross revenue per farm for the year.

The area available to a smallholder is important in determining the relationship between the length of the fallow period and the area available for cropping. In this chapter, the 2 ha chosen as a representative farm size is consistent with the average area granted to transmigrants in Indonesia (RePPProT 1990). Transmigration areas are often heavily infested with *Imperata.* (For example, South Kalimantan received approximately 180 000 transmigrants between 1971 and 1985, according to Davies 1995).

The labour requirements for clearing *Imperata* fallow are shown in Table 3.1. Clearing *Imperata* by burning commences with slashing the *Imperata*, usually at the beginning of the dry season. This allows the *Imperata* to dry before burning. Land preparation through slashing and burning requires 25 workdays (Conelly 1992). However, burning stimulates *Imperata* growth (Menz and Wibawa 1995), so a significant amount of follow-up weeding, by hand or with a hoe, is required when planting rice after burning. This further weeding requires 65 days (Fujisaka et al. 1991). Rice planting and harvesting require 65 days (Conelly 1992).

Table 3.1. Annual labour requirements associated with three *Imperata* fallow/upland rice farming systems (workdays per rice crop).

Activity	Systems of clearing *Imperata*		
	Burning	Manual cultivation	Herbicide
Land preparation	25	}	40
		}210	
Weeding	65	}	5
Rice planting and harvesting	65	65	65
Total	155	275	110

Source: Conelly 1992; Fujisaka et al 1991.

Manual clearing of *Imperata* has a large labour cost, at 210 days/ha, in terms of land preparation and weeding (Barlow and Muharminto 1982; Anwar and Bacon 1986). Soil is turned over with a hoe, exposing the *Imperata* roots, which are then left to dry. This is carried out two or three times so as to fully clear the site of *Imperata*. Following clearing, rice planting and harvesting time is the same as after burning.

Controlling *Imperata* with herbicide has a low labour requirement, but it has a significant cash cost. The current market rate for the herbicide 'glyphosate' is Rp 22 000/L, with 5 L required per hectare to control *Imperata*. Herbicide spraying takes five days (Mangoensoekarjo 1980; H. Bagnall-Oakeley pers comm. 1996), followed by 40 days for preparation of land for rice planting (Fujisaka et al. 1991).

The economic model utilised 12 and 25% discount rates to determine the NPV of upland rice cropping. The NPV of each system was then compared at two labour rates: (a) wage rate applicable to a farmer's 'own labour' of Rp 1600 per day; and (b) hired labour wage rate of Rp 3200 per day (Grist et al. 1995). Smallholders normally place a lower opportunity cost on their own labour than the rate applicable to hired labour.[1]

In summary, burning has significantly lower labour requirements (cf. manual clearing). Spraying with herbicide also has a significant labour-reducing effect, but requires additional cash outlay.

1. Compare this treatment of labour with that of Chapter 2, where labour was not charged per unit of time, but was regarded as a fixed resource, up to a maximum level of availability, at zero cost.

Application of SCUAF

SCUAF was calibrated to represent biophysical conditions typical of the upland *Imperata* grasslands, and then run for a period of 30 years. Thirty years is thought to be about the maximum long-term view that would be held by most farmers. The longer time horizon (63 years) in Chapter 2 was to allow at least three cycles of a twenty-year fallow to be manifest. The shorter fallows considered in this Chapter allow the thirty-year time horizon to be used. Comparisons were undertaken of the physical consequences of clearing *Imperata* by burning, versus the two non-burning methods—manual and herbicide. The latter two are regarded as being identical in their biophysical consequences, since following manual clearing, *Imperata* was deemed to be placed on the soil as a mulch.

The farming system modelled consists of a range of lengths of *Imperata* fallow from one to four years, followed in each case by one year of upland rice cropping. The outputs from SCUAF were inputs to the benefit-cost analysis framework described earlier.

The biophysical conditions used in the calibration of SCUAF for this analysis were the same as detailed in Chapter 2. Thus the biophysical results for the two non-burning *Imperata* control methods in this chapter *are identical* to the results shown in Chapter 2 (Figs 2.2 to 2.6).

The effects on soil of burning *Imperata*

Burning *Imperata* fallow has a short-term positive effect on plant growth—some nutrients, previously accumulated in the *Imperata* biomass become available as nutrients for plant growth (Roder et al. 1992). Burning also has disadvantages. Over 90% of the organic matter stored in the plant biomass, which would otherwise be recycled to the soil, is lost when burned (Roder et al. 1993). A *direct* effect on soil only occurs when soil temperature rises above 150°C (Andriesse and Schelhaas 1987). However an experiment to measure soil temperature following a fire in *Imperata*, found temperatures well below the critical 150°C level (Pacardo and Samson 1979).

The above-ground temperature reached during burning is dependent on the type, moisture content and quantity of the material to be burned, and upon whether the material is heaped or evenly spread. Unless heaping occurs, the average above-ground temperature reached in a smallholder vegetation reduction burn is unlikely to exceed 400°C (Andriesse and Schelhaas 1987). In a smallholder *Imperata* fallow situation, the burnt material is evenly spread, so above-ground temperatures will be less than 400°C. Andriesse and Koopmans (1984) outline the following changes in chemical structure of the above-ground biomass associated with a fire within this temperature range:

- Carbon content of ash drops to less than 10% of initial levels in the above-ground biomass. The carbon is lost through oxidation and is released to the atmosphere as carbon dioxide (CO_2).
- Nitrogen content of ash is also reduced compared to initial nitrogen levels in the above-ground biomass. Approximately 60% of the plant biomass nitrogen is lost through oxidation and released to the atmosphere as nitrous oxide (NO_2) The remaining 40% is transformed into a mineral form which becomes an addition to soil nutrients.

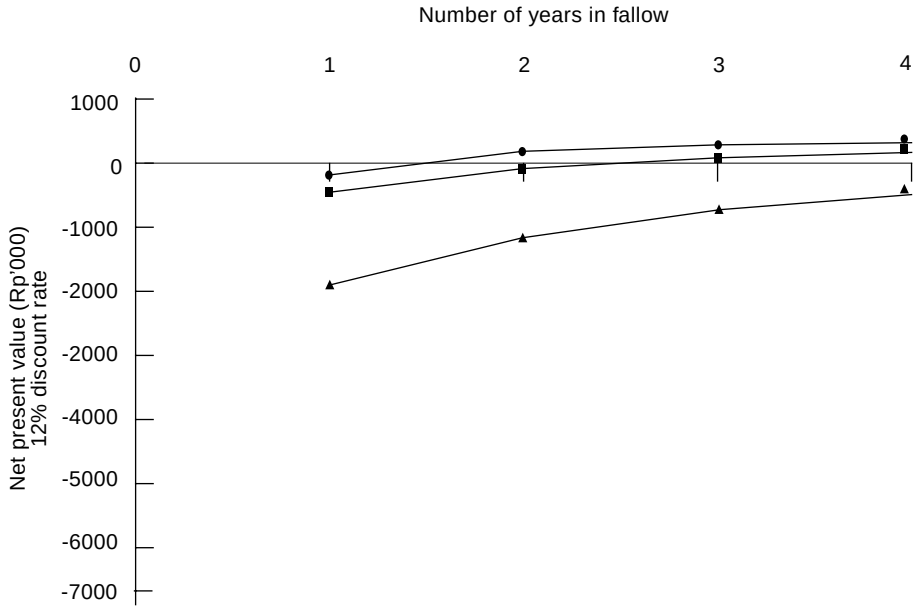
To replicate the removal of organic matter and minerals by burning, *Imperata* biomass is modelled in SCUAF as being removed from the site in accordance with the findings from the above literature review.

RESULTS AND DISCUSSION

Choice of *Imperata* control method

With wage rates at Rp 1600 per day, burning *Imperata* is currently the most profitable method of clearing *Imperata* fallow in preparation for upland rice cropping (Fig. 3.1). This higher profitability of burning occurs despite the negative long-term consequences for land degradation and crop yields described in the next section of this chapter. The profitability of burning stems from the low labour and cash requirements. Herbicide use is a profitable method of removing *Imperata* under some circumstances while manual methods are not profitable under any of the circumstances examined here. These results coincide with observations of actual farmer practice, where burning is the most common method of *Imperata* fallow removal, some smallholders use herbicide to control *Imperata*, and manual control of *Imperata* is rare.

Changing the economic parameter values does not generally affect the profit ranking of burning relative to the other methods of *Imperata* control. The exceptional case is with hired labour wage rates and a 12% discount rate (top half of Figure 3.2). In that case, the higher charge for labour makes herbicide use marginally more profitable than burning.



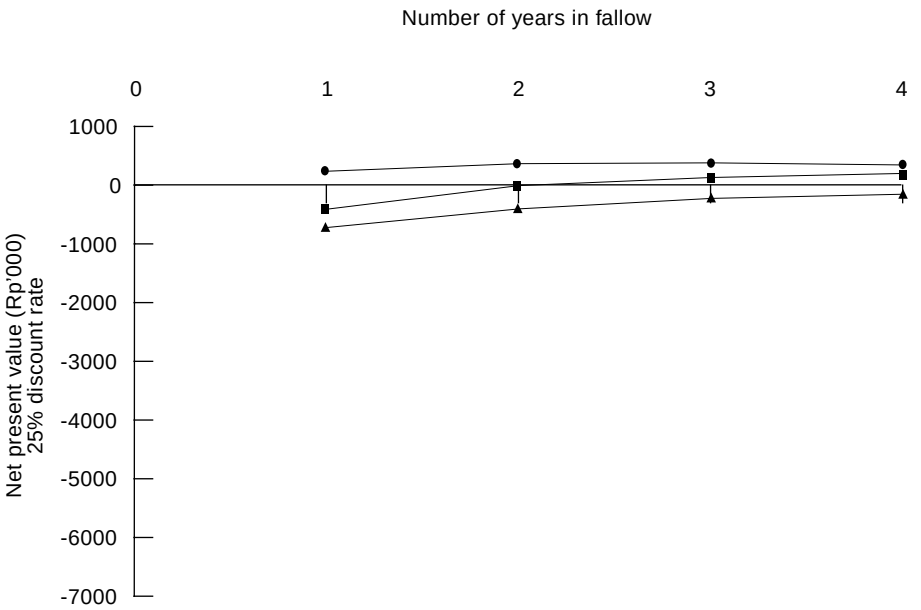
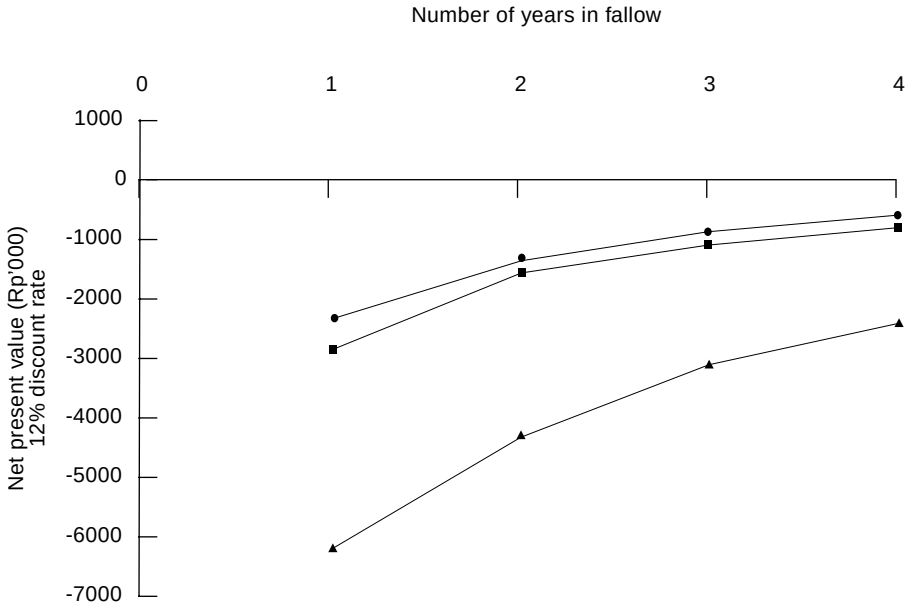


Figure 3.1. Net present value per 2 ha farm of three *Imperata* control methods, 12 and 25% discount rates, 30-year time horizon, wage rate of Rp 1600 per day (● = burning; ■ = manual cultivation; and ▲ = herbicide)



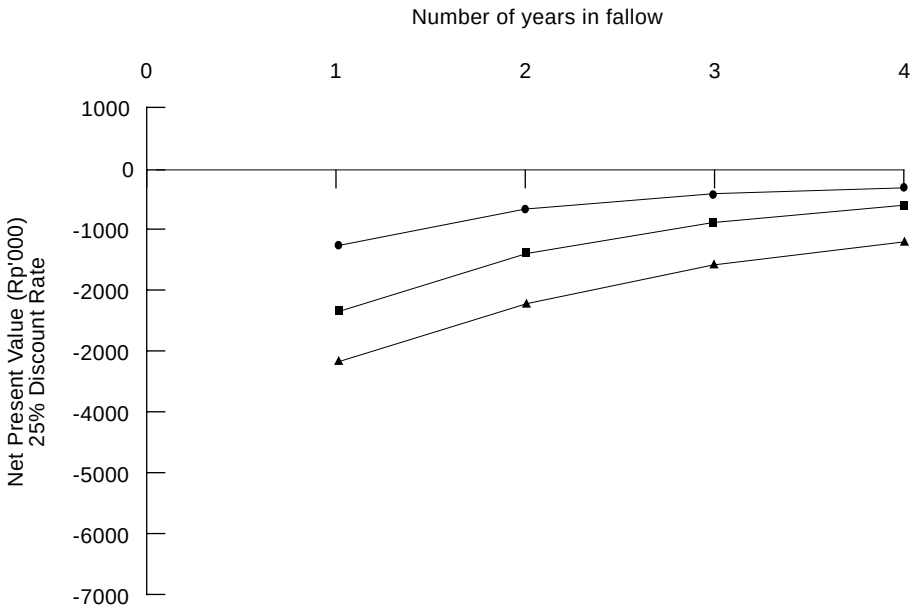


Figure 3.2. Net Present Value per 2 ha farm of three *Imperata* control methods, 12 and 25% discount rates, 30-year time horizon, wage rate of Rp 3200 per day (● = burning; ■ = manual cultivation; and ▲ = herbicide)

Level of profitability

Under wage rates currently pertinent to upland smallholders, food crop production within *Imperata* fallows is marginally profitable. Higher wage rates decrease profitability under all circumstances, as labour is a major input to all of the farming systems examined. Changing the discount rate from 12% to 25% inevitably causes reductions to NPV's, but an examination of Figures 3.1 and 3.2 indicates that these changes are rather small.

With labour costed at the Rp 3200 rate, upland rice production is unprofitable for all fallow clearing methods used (Fig. 3.2). This accords with the observation that use of own labour predominates on smallholder shifting cultivation farms. Off-farm employment at Rp 3200 is attractive to many upland smallholders. Indeed, 16% of smallholders' income in *Imperata*-infested regions of South Kalimantan is derived off-farm (Rusastra et al. 1996).

An increase in labour costs from the own labour rate, to the off-farm rate (compare Figure 3.1 with Figure 3.2), or a modest reduction (calculated to be 25%) in herbicide prices, would result in a shift away from burning, towards herbicide use.

Longer fallows increase profitability slightly, despite the concomitant reduction in land area available for rice. One-year fallows gave the lowest NPV. There is a reasonable increase in NPV, in moving from a one- to a two-year fallow, then small increments thereafter. This pattern is consistent with diminishing returns due to increasing fallow lengths (Figs 3.1 and 3.2). The reduction in burning frequency with longer fallows is partially responsible for the increased returns. However, the direct effect of fallows on soil nutrients and erosion has more influence than burning (see below).

This positive effect of increasing fallow length on NPV (for a given, small area of land availability) is in contrast to the result of Chapter 2. There was a difference in methodology which explains this result. In Chapter 2, no opportunity costs were charged to smallholder labour, whereas in Chapter 3, they were. This changes the pattern of annual net benefits and thus the NPVs .

Soil and crop yield changes

The immediate impact of burning is the removal from the plant/soil system, of carbon and nitrogen contained in the burnt plant biomass. Consequently, there is an overall faster rate of depletion of soil carbon and nitrogen with burning. There are also some *indirect* effects of burning—less organic matter and nitrogen in the soil leading to less plant growth, so less ground cover, and more soil erosion. Available soil carbon and nitrogen is exhausted earlier with burning than without.

In SCUAF, upland rice yields are a function of soil conditions, since there is no short-term 'weather' effect. Rice yield declines faster over time with burning. When available soil carbon and nitrogen is exhausted, rice production is lower, but more stable, being dependent upon soil carbon and nitrogen that become available during the fallow period. The amount of plant groundcover, either rice or *Imperata*, determines the susceptibility of the soil to erosion. Most soil erosion in this type of farming system occurs during the rice crop stage, since *Imperata* generally provides a good groundcover, even under low fertility conditions. When the levels of soil carbon and nitrogen are reduced by burning, the subsequent groundcover provided by crops is reduced. Therefore soil erosion is exacerbated by burning.

However, in all of these situations, the effect, on soil and rice crop yield, of reducing fallow length from four years to one year, is more significant than the effect of burning at a given fallow length. The full set of graphical output is available in Grist and Menz (1996b). An examination of all combinations of fallow lengths and burning versus non-burning *Imperata* control treatments indicates that burning *Imperata* has approximately the same effect on soil quality as a one-year reduction in fallow length. As an example, the graph of soil carbon, with and without burning, for a four-year *Imperata* fallow is shown below as Figure 3.3.

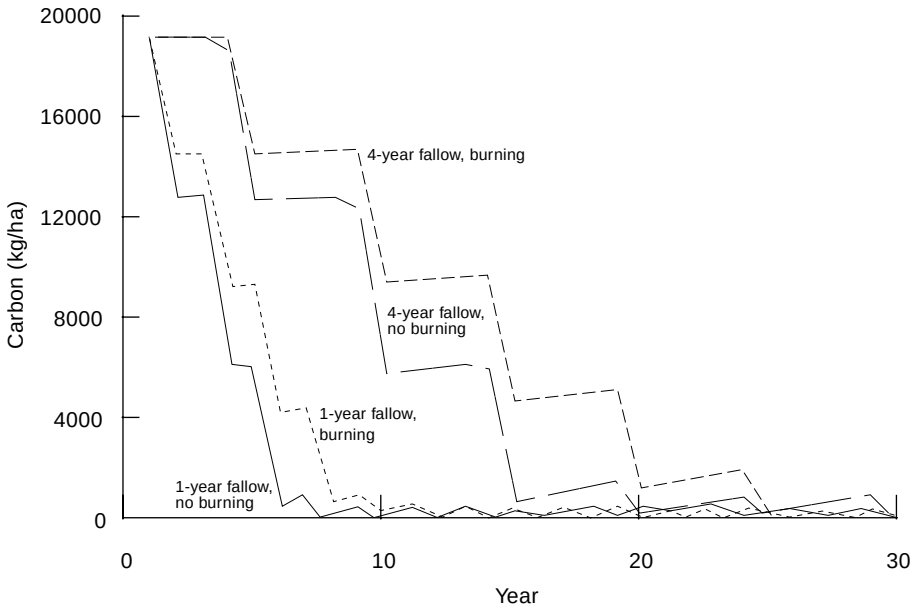


Figure 3.3. Available soil carbon levels for 4 shifting cultivation systems

CONCLUSIONS

This research has traced the extent to which burning *Imperata* has long-term (on-farm) environmental and economic impacts on smallholder upland farms in Indonesia. The environmental impacts of burning on soil quality were found to be clearly negative. Shorter fallow lengths increase the frequency, and thus the negative consequences, of burning. However the direct impacts of shorter fallows on long run soil fertility decline and land degradation are much larger than the effects of burning.

Burning appears to be the most profitable method of clearing *Imperata* in a shifting cultivation system, under prevailing biophysical and economic conditions. A herbicide cost reduction of 25% would make herbicide use more profitable than burning for smallholders. Alternatively wages rising, relative to herbicide prices, would lead to a shift away from burning.

Traditional smallholder upland farms are marginally profitable at present. A significant increase in labour prices, while making herbicide use more attractive relative to burning, would render these systems unprofitable.

It may well be that the more significant negative impacts of burning *Imperata* occur off-site (e.g. smoke haze, carbon dioxide release into the atmosphere, soil erosion leading to siltation of dams and rivers). Consideration of the off-site consequences of burning might provide an economic basis for the promotion of herbicide use, via subsidies or other means, such as extension of knowledge to smallholders regarding herbicide spraying technology. Despite the likely significance of the off-site consequences of burning, only the on-farm perspective was examined in this paper. The on-farm perspective is important however, since farmers will only change practices to the extent that their economic welfare is affected.

4 An Analysis of Shifting Cultivation Using the Trenbath Model

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THIS CHAPTER CONTAINS details of an analysis of a shifting cultivation system in the Philippines using the model developed by Trenbath (1984). Some valuable insights were obtained with the model as presented below. The description of the model may appear somewhat complex, and can be skipped without penalty.

TRENBATH MODEL DESCRIBED

Major components of the model are the size of the total land area (A), size of the cropped area (a), number of crops planted (n), number of cropping years (t_c) and fallow years (t_f). Food production (H) is a function of the area under cropping and crop yield at the current soil fertility level. Food production is measured in terms of the food subsistence requirement of one person (b).

Following the traditional *kaingin* (shifting cultivation) farming system, the crop yield of each parcel declines, as the number of cropping periods increases, at an exponential rate (calculated by the term $[1-x]^{i-1}$). Total food production within a cycle is provided by Equation 1.

$$H = a\,F_{oc}\sum_{i=1}^{nt_c}(1-x)^{i-1}/b \qquad \text{(Equation 1)}$$

where:

H = food production per person (in terms of the number of people that can be fed for a year from the labour of one person)

a = area under cropping (ha)

F_{oc} = soil fertility at start of the initial cropping phase, measured in terms of t/ha of unhusked rice

x = exponential rate of decline in soil fertility (per crop) in cropping phase

b = subsistence requirement of one person (tonnes of unhusked rice per person per year).

During cropping, the fertility level of the soil declines at a rate that is dependent on the nutrient uptake of the crop. The farmer will continuously crop the area until the crop yield declines to a non-viable level. At this point, the farmer will leave the plot fallow for a number of years so that the soil fertility level can rejuvenate. It is assumed (Trenbath 1984) that the rejuvenation of soil fertility follows the shape of a rectangular hyperbola. The farmer will move on to other plots in the rotation area, before returning to the initial cropped plot, or reference plot. The fertility level at the start of the next cropping phase is F_{oc}^*.

The *change in yield potential of the soil* (S) of the reference plot after one cycle of a crop and fallow phase is calculated by subtracting the ratio of F_{oc}^*/F_{oc} from one (Equation 2).

$$S = -100\left(1 - F_{oc}^* / F_{oc}\right) \qquad \text{(Equation 2)}$$

Crop labour requirement (L) includes clearing, planting, weeding and harvesting activities. The amount of labour required is also a function of the area, with greater areas requiring proportionately more labour. Newly-opened forested areas would require additional labour to cut and clear the area of standing trees and other vegetation (Equation 3).

$$L = \mathrm{a}\left[nt_c P + P_\alpha\left(t_f + t_f'\right)\right] \qquad \text{(Equation 3)}$$

$$K_f + t_f + t_f'$$

where:

nt_c = number of crops taken per cycle

P = annual labour needed to crop one hectare, measured in person years

P_α= annual labour needed to clear one hectare of fallow, measured in person years

t_f' = time equivalent of the residual level of fertility left after t_c years of cropping

K_f= time in years needed for the level to reach $F_\alpha/2$, where F_α is the maximum soil fertility as defined by the level under virgin forest

(Other variables have been defined above)

The following assumptions apply to the Trenbath model:

- the management of the system is in a steady state with the available land being divided into equal-sized plots, each at different points on a cropping/fallow year cycle;
- each of the plots has the same 'soil fertility' (F_{oc}) at the start of its cropping phase;
- there is an exponential decline in yield during the cropping phase;
- the fallow phase is associated with an increase in soil fertility with time, according to a rectangular hyperbola, with the starting point on the curve determined by the final level of fertility reached after cropping.

TRENBATH MODEL APPLICATION

For ease of use, the Trenbath model (1984) was rewritten in a spreadsheet format. This was done using Excel version 5.0 and Visual Basic, which provided a user-friendly interface.

The input values for the model were obtained by interviewing two traditional kaingin farmers. The farms were located on a north-facing slope on the western side of Mt. Makiling at Puting Lupa, Calamba, Laguna, in the Luzon island of the Philippines, at 500 m elevation. The area is mapped as an Ultisol characterised by an acidic, highly leached A-horizon and an accumulation of clay in the subhorizon. The soil has a poor structure causing packing of soil particles, poor water holding capacity and low aeration characteristics (Arai 1996).

The farms have been cropped with upland rice, during the rainy season (Mayber), since 1966. The upland kaingin farms are dotted with tree species including ipil-ipil (*Leucaena leucocephala*), kakawate (*Gliricidia sepium*) and hawili (*Ficus hawili*) (Nguu and Corpuz 1980). The area was formerly dominated by *Imperata*.

Two pieces of information required by the Trenbath model could not be reliably obtained from farmers. These were: the x-value for equation 1 (the exponential rate of decline in soil fertility, or crop nutrient uptake over time), and the K_f value for equation 3 (the soil fertility recovery factor). These factors were determined using the SCUAF model (Young and Muraya 1990). Prior to deriving those factors from the SCUAF model, SCUAF was first calibrated to an upland site (Tranca) near Puting Lupa, using experimental information from that site (Nelson et al. 1997).

Data obtained for Puting Lupa, from farmers and by running the SCUAF model, was used as parameters for the Trenbath model. These parameters are presented in Table 4.1.

Table 4.1. Required model parameters

Parameter	Description	Value (Puting Lupa)	Unit
F_{oc}	Soil fertility at start of cropping phase	1.23	t/ha of unhusked rice
F	Maximum soil fertility	1.63	t/ha of unhusked rice
x	Rate of proportional reduction in soil fertility during cropping phase	0.29	/crop
b	Subsistence requirement in terms of unhusked rice	0.52	t/person
P	Labour required for cropping	0.16*	/ha/crop
P	Labour required for clearing forest	0.20*	/ha/yr
K_f	Time under fallow needed to reach F_α /2	7.00	year
n	Number of crops per year	2.00	/year
A	Total area of land in the rotation	2.50	ha
t_c	Duration of cropping phase	1.00	year
t_f	Duration of fallow phase	7.00	year
t_f	Time equivalent of the residual level of fertility after t_c years of cropping, or the time under fallow that would be needed for soil fertility to reach a level F_{of}	8.08	year
a	Plot size at different points on a (t_c+t_f) year cycle	0.16	ha
F_{of}	Fertility at the start of fallow	1.11	t/ha of unhusked rice

n = 2,with the second crop as a non-rice crop. However, for simplicity, it was assumed that in terms of food production, it was measured in rice equivalents. t_f= 7,making the cropped area and the total available area consistent. * = labour is measured as the labour provided by one person.

RESULTS

The general nature of the model's results is presented here. The specific relevance of the results for farmers at Puting Lupa is held over until the Discussion section.

In the model, a subsistence level of production is defined as the amount of food required by one person for one year. (Therefore in Equation 1, a subsistence level of production is where $H = 1$). From the model's results, the combination of number of crops (nt_c) and fallow lengths (t_f) required to maintain a subsistence level of production was determined (Fig. 4.1). Looking at the left-hand side of Figure 4.1, a subsistence level of production can be achieved for a range of crop numbers and fallow lengths where the fallow:crop ratio is around 4:1, for example, where $t_f \sim 8$, and $nt_c \sim 2$. However, when the number of crops within the cycle is beyond about five, further increase in crop numbers will necessitate reducing the fallow length in order to maintain $H = 1$ (the $H = 1$ curve flattens out, then declines). Recall that a cycle is defined as the sum of the years of crops (t_c) and years of fallow (t_f). Therefore, on the right-hand side of Figure 4.1, there are increasing numbers of crops relative to fallow, within the cycle. Consequently, the higher cropping intensities represented in the right-hand side of Figure 4.1, will result in lower crop yields than the less intensive crop/fallow cycle (left-hand side of Figure 4.1).

As the cropping intensity of the farming system increases, the impact on soil fertility is greater (Fig. 4.2). Soil fertility is a consequence of the number of crops grown in producing a given level of food production, such as $H = 1$. Not only do more crops deplete soil nutrients faster, but, with more intensive cropping, there is less opportunity for fertility recovery during the shorter fallow phase of the cycle. With a less intensive cropping system, there is a lower impact on soil fertility due to a shorter crop phase and more opportunity for recovery due to the longer fallow phase. However, for all of the crop/fallow combinations examined, achievement of a subsistence level of food production will result in a decline in soil fertility. These declines are significant, ranging from 20% to 40% (Fig. 4.2).[1]

Labour is the major input to a subsistence farming system. Thus the impact of intensification on labour-use efficiency is a key indicator of the economic attractiveness of the system. Labour-use efficiency is defined as the ratio of food production per labour unit (H/L). Labour-use efficiency declines with cropping intensification (Fig. 4.3), in line with the reduction in soil fertility shown in Figure 4.2. At low levels of cropping intensity, labour use efficiency is about five and this declines to below one under intensive cropping systems (e.g. beyond seven crops and two years of fallow, Fig. 4.3).

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1. In Figures 4.2 and 4.3, the number of crops taken, as shown on the x-axis, corresponds to a particular duration of fallow (t_f) as shown in Figure 4.1.

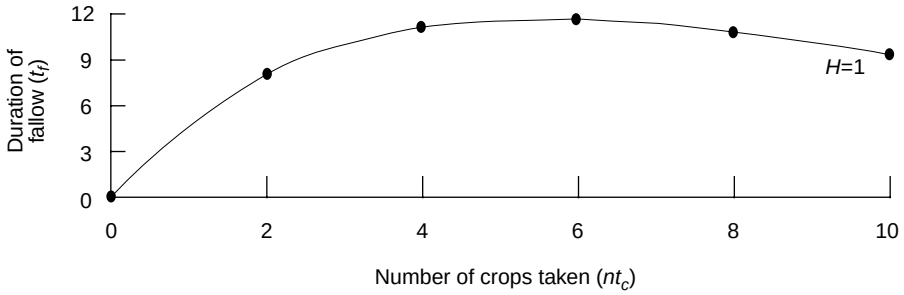

Figure 4.1. Subsistence food production curve ($H = 1$) for varying cropping intensities

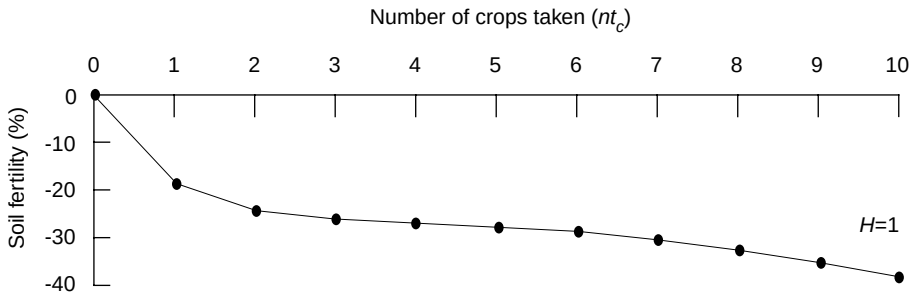

Figure 4.2. Soil fertility changes for varying cropping intensities

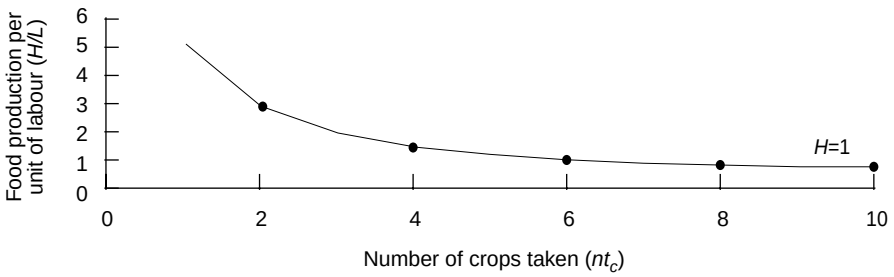

Figure 4.3. Subsistence food production per unit labour for varying cropping intensities

DISCUSSION AND CONCLUSION

Farmers at Puting Lupa are operating at two crops per cycle, followed by seven years fallow. The level of food production from this system is close to a subsistence level. This can be seen in Figure 4.1, where the coordinates (2,7) lie close to the $H = 1$ curve.

With the crop/fallow cycle currently operating at Puting Lupa, soil fertility is declining by around 25% per cycle (Fig. 4.2). Labour efficiency (Fig. 4.3) is close to three (i.e. one person year of labour is producing at a rate sufficient to feed three people for a year). However, because of an overall land availability constraint, farmers are operating at $H = 1$, rather than $H = 3$, by using only one third of a labour unit.

In the face of soil fertility decline, there is scope to maintain subsistence production by cropping more intensively (Fig. 4.1). This will require more labour and will cause an even faster rate of soil fertility decline. A point will be reached where a person unit of labour will produce less than the food requirement of a person (i.e. where $H/L < 1$ in Figure 4.3). The future of low input subsistence farming looks bleak for Puting Lupa, and other areas faced with similar circumstances.

The analysis in the original Trenbath model was based on a single crop/fallow cycle. The results in this chapter have also been presented in a single cycle framework. A full assessment of the long-term consequences of intensification however, requires a longer time frame of analysis. If Puting Lupa farmers crop more intensively in the first cycle, the reduction in soil fertility, and thus labour-use efficiency, will mean that, in the second cropping cycle, even more intensive cropping will be required to maintain subsistence than is indicated in Figures 4.1, 4.2 and 4.3.[2] All measures of production and labour use efficiency will spiral downward, corresponding to the extra loss of soil fertility.

In summary, the farming system operating at Puting Lupa can be regarded as biologically unsustainable now. However, the labour of one person can currently produce more than the rice requirements of one person. Maintenance of this level of production will require intensification of cropping. As the system approaches one of continuous cropping, the farming system will become economically unsustainable, in that the labour of one person will not be able to produce sufficient food for one person to subsist. Economic enhancement through new technologies or inputs, or completely new farming systems may provide solutions.

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2. The $H = 1$ curve will become lower than shown in Figure 4.1, also in Figures 4.2 and 4.3

The Trenbath model was able to provide considerable insights into the status and likely future direction of the shifting cultivation system operating at Puting Lupa, Philippines. However, project personnel judged that the model was overly simplistic in terms of the project objectives. To be specific, two of the key parameters required to drive the Trenbath model were not readily available and had to be obtained through simulations with another model (SCUAF). These parameters were the rates of crop yield decline over time and the rate of soil fertility recovery over time, following the cessation of cropping. Consequently it was decided to use the more detailed SCUAF model for the whole analysis of shifting cultivation, as reported in previous chapters.

SECTION 2

SPONTANEOUS TREE GROWING BY SMALLHOLDERS

In Indonesia, and in The Philippines, government and NGO-sponsored land conservation projects and policies have usually not led to sustained changes in land use. A history of many of the broader-ranging policy attempts that have been made in Indonesia is presented in Gunawan et al. (1996b).

However, there are also some 'success stories'. The most notable of these would be smallholder rubber production, especially in Indonesia. The case of rubber is well documented. Later sections of this report analyse and specify various possible improvements to smallholder rubber production systems on *Imperata* grassland.

In this section, some lesser-known case studies of tree-growing by smallholders in the uplands of The Philippines and Indonesia are presented. The underlying aim of the work is to demonstrate that smallholders on *Imperata* grassland can grow successfully grow trees.

5 *Paraserianthes falcataria* Growing in Sumadang West Java

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I. WAYAN RUSASTRA

THE SUSTAINABLE SMALLHOLDER timber-food crop farming system (TFS) found in the Regency of Sumedang is an interesting case. TFS has been practiced for generations without major changes in its implementation methods or crop composition. Farmers grow sengon (*Paraserianthes falcataria*) and food crops, especially dryland rice, maize, peanut, cassava and bananas, in an arrangement that provides farmers with adequate food and cash income in a successful land conservation model.

The willingness of farmers to grow trees is a result of many factors, mainly economic incentives. The main hypotheses are as follows:

- TFS generates greater income for farmers when compared with alternative systems;
- Labour demand in the urban sector will cause a gradual change in the farming system from labour intensive to labour saving technology such as TFS.

THE TWO CASE STUDIES

Two villages in the Sumedang Regency of West Java were selected for this case study. Cikaramas (subdistrict Tanjungkerta) and Citaleus (subdistrict Buah dua) represent villages where TFS is most commonly practiced by farmers. The altitude of the Regency of Sumedang ranges from 26 to 1000 m with most of this area (43.7%) within the range of 101–500 m. Only 11.47% of the area is classified as lowland (altitude less than 100 m). Average temperature and humidity in the lowland is 26°C and 50%, and in the upland is 15°C and 70% respectively. Average rainfall is

2031 mm a year, with total effective rainfall of 94 days a year. The type of soil is generally latosol (53%), grumusol (15%) and andosol (12%). The Sumedang Regency is dominated by sloping land. The mountain Tampomas which is located in this area is 1684 m high. About 27.4% of the Sumedang area has a steepness of greater than 40%, and 43.6% has a steepness of more than 25%.

Cikaramas and Citaleus are typical Indonesian rural upland villages. The altitude of Cikaramas is 560 m and Citaleus is 367 m. Differences in climatic conditions between the two villages are probably very minor. The total area of Cikaramas is 533 ha and Citaleus is 403 ha, and the population in 1993 was 3013 people and 1817 people respectively. The area used for dryland agriculture is 82% and 58%, respectively, of the total village, and the average area of land ownership is 0.58 ha/farmer and 0.96 ha/farmer respectively. Average land holding in Citaleus is larger and land quality is better because the portion of irrigated land is much higher (compare 18% to 42%).

The average area of irrigated land per farmer is 0.11 ha in Cikaramas and 0.41 ha in Citaleus, and dryland area per farmer is 0.66 ha and 0.36 ha respectively. Clearly, Cikaramas has a greater proportion of dryland-based agriculture whereas Citaleus has a more even mix of dryland and irrigated land.

Citaleus is less accessible to the Regional and Provincial capital cities and therefore, the market. It takes four times longer to reach the Regional and Provincial capital cities from Citaleus compared with that from Cikaramas.

A Rapid Rural Appraisal (RRA) was conducted in June 1995, and then a small survey was conducted in July of the same year. Twenty households were randomly selected from the TFS households in each sample village for this survey. The reasons farmers gave for growing trees are listed in Table 5.1.

Table 5.1. Main reason for growing trees

Reason	Frequency	
	Cikaramas	Citaleus
More profitable than food crop	10 (29)[a]	6 (20)
Physical soil condition (suitability and as prevention of erosion or landslide)	9 (26)	10 (33)
For saving	7 (21)	8 (27)
For own use	6 (18)	3 (10)
Others	2 (6)	3 (10)
Total	34 (100)	30 (100)

[a]Figures in brackets represent percentage of total

CIKARAMAS

The agroecosystem, as well as economic conditions, distinguish the species of tree grown in the two villages. In Cikaramas, 80% of farmers grow sengon (*Paraserianthes falcataria*), and the rest grow trees such as mahogany, mango, coconut, jackfruit (*Arthocarpus integra*), jengkol and petai (*Arenga pinata*). Sengon has become popular in Cikaramas due to its suitability to the local agroclimate and its high profitability. The price of sengon wood is increasing with increasing demand for timber, decline in production of forest timber by companies holding HPH (Hak Pengusahaan Hutan = Forest Exploitation Rights), and tighter forest exploitation policy. The environmental movement has also had a great impact in driving the price of timber upwards.

Generally there are two production cycles in a timber-food crop farming system:

- In the first cycle farmers grow sengon from seeds. In Cikaramas farmers do not grow sengon seeds in a seedbed, instead they collect naturally grown plants from under the stock trees. The young trees are then replanted in high density (spaced at 3 m intervals, or about 800 sengon trees/ha). The cost is Rp 350 per seedling. After thinning, the number of trees is reduced to between 500 and 600 trees, and food crops, especially dryland rice, maize, peanut, cassava, and banana, are planted between the sengon trees. The costs and planting densities for the food crops are given in Gunawan et al. (1996a). Maize, rice, and peanut can be harvested after four months; cassava after one year; and bananas throughout the year. The same food crops will generally be grown in the second year. Early in the third year, when the sengon trees are 4–6 m high, food crops are no longer planted. On average, farmers cut the trees after 6–8 years when their diameters are about 40–40 cm.
- In the second cycle, after the trees are cut down (beginning of the 7th or 8th year), farmers grow food crops by the same process as in the first cycle. At the same time farmers grow buds from the remains (stumps) of the sengon trees. Land preparation is usually very minimal, limited to clearing of the land and a little hoeing. The most important product for farmers are the buds grown from the stumps. These grow much faster because a well developed root system already exists. Farmers usually keep the best three or four buds which they then harvest after four or five years.

This system may last for two to four production cycles, but usually the farmer has to start again from seeds after 12 years. The highest income from TFS is achieved in the second and third production cycles because during this time the trees grow faster and

therefore their diameters are larger when harvested. Almost all farmers will keep the best two to four sengon trees as mother trees or seed bearing trees. This method is also recommended by the field forestry extension workers. The system is depicted in Table 5.2.

Table 5.2. Composition of crops in TFS in Cikaramas, Sumedang, 1995

Year	Trees	Rice	Maize or Peanut	Cassava	Banana
1	x	x	x	x	x
2	x	x/H	x/H	x/H	x/H
3	x	H	H	H	x/H
4	x	–	–	–	x/H
5	x	–	–	–	x/H
6	x	–	–	–	x/H
7	H	–	–	–	x/H
8	x	x	x	x	x/H
9	x	x/H	x/H	x/H	x/H
10	x	H	H	H	x/H
11	x	–	–	–	x/H
12	H	–	–	–	x/H

Note: X = crops in the field; H = harvest.

Farmers use seed from the stock/mother trees. The fallen seeds which lie around the base of the trees have to be stimulated to promote better germination, the farmers usually slightly burn dry leaves and branches around the trees right before the rainy season in order to achieve this. The seeds germinate soon after the first rainfall, and shortly after that the farmers can collect the seedlings and replant them in an orderly manner. In this way farmers can grow a large number of seedlings. The plants get thinned out after the first year in order to ensure better growing conditions for the healthiest of the trees. The discarded trees are sold for firewood.

According to farmers' experience, sengon is one of the fastest yielding trees because it can be harvested in 6 years or even in 4 years. Turi and lamtoro may be harvested after five years, whereas the harder woods such as mahogany and teak are harvested at 10 or even 20 years.

For a detailed economic analysis of the TFS system, refer to the Gunawan et al. 1996a. Smallholder timber in Cikaramas has developed into more commercial oriented farming because of the high demand for timber. Good accessibility to the market (buyer) is probably the main reason that TFS is sustained.

The main tree grown by farmers in Cikaramas is sengon which, from both technical and economic points of view, has advantages such as:

- It is easily grown in diverse agroecological conditions;
- Seeds are easily obtained from the farmers' trees;
- The price is increasing. Currently the price of sengon firewood is Rp 8000/m^3, but the log price is Rp 50000–60000/m^3. In both cases cutting and transport is paid by the buyer.
- Farmers can plant food crops in between the trees in the first two years.

Sengon is used in the construction of wooden boxes, housing and furniture, as well as for pulp. The prices of almost all kinds of wood are increasing, due in part, to declines in production and increases in demand. Other trees such as mahogany, kihiang and fruit trees are considered to be insignificant in numbers. The food crops grown in the first and second years are rice, cassava, peanut and banana.

One hectare of dryland can be planted with 800 sengon trees spaced at 3 m intervals, and food crops may be grown in between the trees. Two to three-month-old seedlings cost Rp 350 each, however most farmers use their own seedlings from stock trees. In the second year farmers will cut (thin-out) some of the trees to allow for the best level of growth. There are usually around 500 trees left in the field after thinning. Farmers also grow fruit and other timber trees. However, the most important tree is sengon.

There is almost no special care of sengon trees, but fertilisation, weeding and insect eradication are undertaken for the food crops (see Gunawan et al. 1996a). During weeding farmers sometimes cut the tree roots to stimulate development of small new roots. Most farmers also do not trim to get long-straight stems, although this is recommended by the field extension workers. According to farmers, the cut (injured) trees will provide a place for insects to lay eggs, larvae will then make holes that decrease the quality of the timber. Labour use for the TFS and levels of production of various food crops is detailed in Gunawan et al. (1996a) by gender and by year. Most labour used is for food crops.

The main constraint for cost and revenue analysis of a long period production process is the unavailability of reliable data on price. A one-off survey visit is not sufficient for collection of price data for a 12-year period. In this analysis, the real price and wages in the production time are assumed to be unchanged over the period studied. Cost and revenue comparison between years and production cycles, therefore, can be undertaken, because all calculations are in real prices. Sengon production involves two cycles. In the first cycle, sengon is grown from seeds which naturally fall from the matured sengon trees. It takes 7 to 8 years until the trees are ready to cut down and

sell. In the second cycle, since the trees are grown from buds, they grow faster and take only 4 or 5 years to produce timber of the same size as in the first cycle.

When the trees are three years old and are being thinned out, farmers sell some of them, often to the pulp factory in Padalarang (around 60 km west of Sumedang). In the eighth year the whole plantation is cut down except for three or four trees which are maintained to bear seeds. In the twelfth year when the secondary branches are four years old, farmers sell all the trees and the cycle starts again. With these harvesting methods, the cycle is shorter. On average farmers will start with new seeds after two or three harvests. This is possible because a developed market for sengon timber exists.

Compared to monoculture food crops, TFS generates higher, or at least comparable, net revenue. CBS (1994) defines family labour income as income to the family when family labour is not inputed. The CBS data show that annual family labour income from rice, cassava, corn, soybean, mungbean, and sweet potato ranges from Rp 937000 to Rp 487000 (see Gunawan 1995). This compares to an average profit of around Rp 1.2 million from the TFS system. These are undiscounted figures. The biggest constraint to TFS is that it requires initial capital and the distribution of net revenue is skewed over time.

The summary of cost and revenue of the timber-food crop farming system is presented in Table 5.3.

Table 5.3. Cost and revenue per hectare of TFS, Cikaramas, 1995

Year	Cost (Rp)	Revenue (Rp)	Net revenue (Rp)
1	738950	0	
2	129475	986900	857425
3	64480	398200	333720
4	61000	220500	159500
5	33000	84000	51000
6	31000	163000	132000
7	35500	125000	89500
8	602525	4250000	3647475
9	292225	949100	656875
10	82000	544200	462200
11	61000	395500	334500
12	61000	8194000	8133000

Source: Survey Data 1995

CITALEUS

In Citaleus, timber production is more diversified, with teak, mahogany, tisuk, kihiang, sengon, lamtoro, johar and turi among the most common. The first three of these species are high quality hardwood that is usually cut after 20 years or more, they comprise 50% of the total number of timber trees in Citaleus. Although TFS commenced less than 10 years ago in Citaleus, an intensive tree farming system began there a lot earlier when turi (a legume) was introduced to farmers by the government. The government promotes growing trees and turi so as to provide firewood to the inhabitants, and therefore avoid destruction of forest for this purpose. Turi also helps improve soil fertility and shades the main crops, preventing high rates of evaporation. Unfortunately, the price of turi trees is very low at the farmgate, because of the poor quality of its wood. Turi is branchy and has low quality timber, but a large number of farmers grow it for firewood and as shading trees. Through the introduction of turi, rural people have been able to see the advantages of growing trees, not only to meet the need for firewood, but also to improve soil quality and to prevent landslides. Currently the government is promoting the growth of teak (*Tectona grandis*) and *Paraserianthes falcataria*. However due to the insufficient availability of plant materials, farmers grow many different tree species such as tisuk, kihiang, kadoya, and mahogany.

The most constraining factor to farmers growing teak is the tight control by the government of teak plantations and the market, in an attempt to inhibit the frequent stealing from the government owned teak plantations and the illegal teak market. The government has therefore enforced tight regulations regarding cutting, transporting and marketing of teak. Farmers are required to have permission from the authority of the village, sub-district, district and State Owned Forest Corporation (Perum Perhutani) before they can get a license to cut and sell their own teak. These complicated bureaucratic procedures have created an unnecessary burden on farmers.

In contrast to Cikaramas, timber species grown in Citaleus are more diverse (Table 5.4). Teak, mahogany, kihiang, sengon, turi, johar, lamtoro, and tisuk are grown in the same area of land. Despite the positive impacts on land conservation and erosion prevention, growing trees in Citaleus has not had the support of a good timber market system. Hardwoods such as teak and mahogany are grown as a long-term investment. Timber farming in Citaleus is still in the early stages.

Observation in the field has not covered the whole timber production cycle as it has done in Cikaramas. However as in Cikaramas, food crops are grown in the first two years, before the tree crop canopy covers the soil surface. The seed cost and typical tree composition per hectare is exhibited in Table 5.4.

Table 5.4. Tree seedling cost and number of trees grown/ha dryland, Citaleus, 1995

	Units used	Price/unit (Rp)	Value (Rp)
Timber trees			
Teak (tree)	130	500	65000
Mahogany (tree)	121	400	48400
Kihiang (tree)	27	400	10800
Sengon (tree)	52	400	20800
Turi (tree)	126	400	50400
Johar (tree)	109	400	43600
Lamtoro (tree)	50	400	20000
Tisuk (tree)	117	400	46800
Others (tree)	22	400	8800
Fruit trees			
Coconut (tree)	13	2000	26000
Mango (tree)	9	2000	18000
Jack fruit (tree)	12	2000	24000
Others (tree)	3	2000	6000

The foods most commonly intercropped during the first two years are rice, banana, maize and cassava. Fertilizer and labour use, as well as food crop productivity under the TFS system are given in Gunawan et al. (1996a).

There are no historical data available on the production of timber however, farmers regularly cut down the trees for firewood and for their own use. On average around two to six trees per year are consumed for firewood or other domestic purposes. This indicates that, from the point of view of land conservation, timber/food crop farming systems have reduced deforestation of natural areas by the villagers.

Similar to the situation in Cikaramas, distribution of yearly income during the TFS production period is skewed (Table 5.5). At the end of the twelfth year farmers may receive around Rp 5 800 000 but during the earlier years the income is mostly around Rp 100 000. In the third and fourth years the income is approximately Rp 500 000 and Rp 330 500 respectively, with most of this coming from food crops, particularly bananas. Remember that there is no timber market in Citaleus. The calculations have not included the higher income which is possible when high quality timber is used, such as teak and mahogany which are usually harvested after more than 20 years.

Table 5.5. Cost and revenue per hectare from timber farming systems, Citaleus 1995

Year	Cost	Revenue	Net Revenue
1	1158400	0	– 1158400
2	477175	555500	78325
3	138500	645000	506500
4	42500	370000	327500
5	47000	132500	85500
6	55500	178155	122655
7	39750	110850	71100
8	46500	161478	114978
9	60000	186380	126380
10	71500	208890	137390
11	76000	212565	136565
12	35500	5655375	5619875

Source: Survey Data 1995

The optimal age for the harvesting of trees, according to the farmers, is presented in Table 5.6. Sengon is best harvested at the age of 10–15 years and teak at 20 years while lower quality timber may be cut down after 10 years (Table 5.6).

Table 5.6. Farmers' opinion about optimal harvesting age of timber trees in Citaleus, 1995 (% of farmers)

Species	5 years	6 years	7 years	10 years	15 years	20 years	25 years
Sengon	–	18	–	36	36	10	–
Teak	–	–	–	7	–	86	7
Mahogany	–	–	–	50	36	14	–
Johar	–	–	–	–	67	33	–
Tisuk	31	–	15	54	–	–	–
Kihiang	–	–	–	56	33	11	–
Turi	75	–	–	25	–	–	–
Lamtoro	100	–	–	–	–	–	–

Source: Survey Data 1995.

The difference in harvesting age affects the farmers' decision as to which trees they are going to grow. Rich families and large landowners in Sumedang grow teak as a long-term investment. However, small farmers in Cikaramas and Citaleus usually grow lower quality but faster yielding species of trees such as sengon, kihiang, and fruit

trees. Therefore, the smallholder tree plantation program has to consider not only the technical aspects but also the socioeconomic conditions of farmers and the market for the timber.

CONCLUSION

Smallholders are growing trees on erosion-prone land in Indonesia that was previously *Imperata*. They are doing so without any direct government assistance. The economic incentives to grow trees are evident from the analysis. Marketing infrastructure and possibly higher farm wage rates have helped to create the favourable economic climate. The tree component of the TFS system is relatively undemanding of labour, and wage rates in the area have risen substantially in line with the requirements for labour by the non-agricultural sector.

Compared to monoculture food crops, TFS generates higher, or at least comparable, net revenue. The biggest constraint to TFS is that it requires large initial capital, and the distribution of yearly net revenue is skewed. Smallholders cannot usually afford a negative net revenue of about Rp 700 000. However, this problem can be alleviated by moving gradually into TFS production over time.

6 Five Case Studies in Luzon, Philippines

PAULO PASICOLAN
JACQUELINE TRACEY

MANY REFORESTATION PROJECTS on degraded grasslands can be cited. The Philippine government incurs huge loans from the Asian Development Bank and other overseas lending institutions for its reforestation projects. According to Vandenbeldt (1993) the average cost for rehabilitation which includes infrastructure establishment, nursery and plantation activities, maintenance and protection was about 35 000 to 40 000 pesos (₱) (US$1 400–1600)/ha in 1993. Despite the government's commitment to reforestation and the large sums of money it spends on these projects, many reforestation projects have not been successful. In most cases, the failures can be attributed to the lack of maintenance and protection of areas after plantation establishment (Vandenbeldt 1993).

In stark contrast to many failed government sponsored reforestation projects, successful tree growing is being carried out by a number of farmers with no direct cash incentives from the government. The question that arises is what determinant conditions are necessary for farmers to carry out spontaneous tree growing? For the purpose of this study, spontaneous tree growing is defined as tree growing that is carried out with no direct funding from the government. This exploration of spontaneous tree growing activities by farmers seeks to identify the critical determinant factors of tree growing success. First, the methodology employed is discussed. A brief description and history of the case studies follows. The determinant success conditions for spontaneous tree growing are identified and the relevance to each of the cases is observed.

METHODOLOGY

Five spontaneous tree-growing sites are included as contrasts with government tree-growing projects. Participant observation and in-depth interviews were the primary methodologies employed. In-depth interviews using a semi-structured format were carried out with fourteen respondents in five localities. Respondents were asked to give an account of how they were able to establish tree farms without government support. The interview focused on tree growers' perceptions, motivations and options with regard to tree growing. The different success conditions and determinant factors of spontaneous and sustainable tree-growing initiatives were noted. No statistical analysis was carried out, rather a descriptive account of each of the case studies was employed and comparisons of success conditions analysed.

DESCRIPTION OF CASE STUDIES

Five case studies of spontaneous tree growing by farmers were identified in the following localities: Quibal, Penablanca, Cagayan; Maguirig, Solana, Cagayan; Nagtimog, Diadi, Nueva Viscaya; Timmaguab, Sta. Ignacia, Tarlac; and Namambalan, Tuguegarao, Cagayan (for location map see Pasicolan and Tracey 1996).

Case study 1: Quibal, Penablanca, Cagayan

Quibal, Penablanca, Cagayan is a community at the foothills of the Sierra Madre Mountain Range in Northeastern Luzon. Quibal originated, in the 1960s, as a farming settlement on public forest lands. Progressively declining farm productivity prompted farmers to switch from farming to firewood extraction in nearby forests. This activity in combination with the beginning of carabao logging (small scale timber cutting at the household level using water buffalo for log transport) in the 1970s, meant that most households were dependent upon fuelwood and timber sales. Over time, this dependence resulted in over-exploitation of the forest area in the region and by the 1980s timber gatherers had difficulties in maintaining their level of extraction. As a result of this over-exploitation a logging moratorium was imposed in the area by the Bureau of Forestry in 1980 which forced most timber gatherers to seek other livelihood options.

In response to the scarcity of timber resources and a ban on logging, carabao loggers were forced to move to other areas, while other residents resumed farming, or shifted to firewood extraction. Firewood gatherers were less affected than carabao loggers by over-exploitation of the forest and the ban on logging. Although their production levels declined, they did not consider moving to another site. Instead they began planting *Leucaena leucocephala* and *Gmelina arborea* for fuelwood (Pasicolan and Paguirigan 1993).

Case study 2: Maguirig, Solana, Cagayan

Maguirig, Solana, is located on the southwestern side of Cagayan province in the foothills of the Cordillera Mountain Range. Historically, the dominant land-use practice in the area was agriculture. In 1978, a reforestation project was introduced to the area and original claimants were assured their right to continue using the land for agricultural production. In spite of these assurances and the fact that agricultural practices still continued, the area was reclassified as a forest zone due to its rugged topography.

Since the 1980s the tenurial status of the area has been constantly transformed from one property regime to another. In 1980, this site was designated as a communal tree farm area,[1] while a portion of the area was used as pastureland by a local politician. In 1985, the site was declared an Integrated Social Forestry Project[2] and then in 1989 it reverted to a regular reforestation project.[3] Finally, in 1990 it became a contract reforestation[4] site known as the Maguirig Reforestation Project (see Pasicolan 1996 for more details). These changes have resulted in overlapping tenure over the area.

While government sponsored schemes were being carried out in the area, Mang Casimiro, an 80-year-old farmer who resisted the forestry department's attempt to include his private lots in the reforestation project, began planting fast growing trees on his farm for household use.

Although farming was his main occupation, he planted *Gliricidia sepium*, *Leucaena leucocephala* and *Gmelina arborea*, fruit trees such as jack fruit, mango, banana and citrus fruit interspersed with other farm crops such as sweet potato and cassava.

He has successfully established a woodlot in his three ha farm that sufficiently meets his yearly needs for household fuelwood and fencing materials. At present, the farm-based tree-growing system has evolved to a state where the woodlot regenerates itself and planting of trees for fuelwood and fencing is not required. However, grassland fire protection is required to maintain the woodlot. This success is in stark contrast to the reforestation project which was considered a failure and has since been abandoned.

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1. Communal tree farm: public tree growing without defined ownership rights.
2. Social forestry project: farm-based tree growing. Land rights, in the form of a 25-year stewardship contract, are given to farmers who are willing to grow trees alongside their subsistence crops.
3. Regular reforestation project: government administered tree-growing projects on public land where the government employs local labour to plant, maintain and protect trees. No ownership rights are vested on the tree growers.
4. Contract reforestation: tree-growing is done on public lands by contracting private individuals. Incentives such as contract payments, daily wages, land tenure and benefit sharing arrangements are used to stimulate strong public involvement.

Case study 3: Nagtimog, Diadi, Nueva Viscaya

Nagtimog is an upland farming community, 7 km from the main town of Diadi, Nueva Viscaya. A reforestation project was introduced to this community in the 1970s and most of the local people simultaneously grew trees and vegetables. Eventually this project was abandoned due to inadequate funding for protection and maintenance. This area is fire prone and the project experienced yearly grassland fires, some of which it was alleged were deliberately lit.

The abandoned reforestation site lay idle for many years because most of the local people were reluctant to farm the area as it still belonged to the Department of Environment and Natural Resources (DENR). Farmers began to explore the possibility of cultivating this land after 1989 when the site was not chosen for a contract reforestation project. At first, only two farmers applied for usufruct rights over the area on the condition that they would reforest a portion of the site. In return for their efforts the DENR assured them tenurial rights over the trees.

The farmers cultivated short-term agriculture crops in the first year, and later interplanted trees between their main crops. After five years, the *Gmelina arborea* they planted in between their main crops grew to such a height that it was no longer feasible to interplant the site with agricultural crops due to shading. This prompted the farmers to move to another portion of the site and apply for usufruct rights, increasing the size of the land they had access to. Over time, the farmers became confident of their tenurial rights to the trees they planted which provided them with further incentive to protect them. Once again, the tree-growing carried out by farmers on their own initiative has succeeded, while the government sponsored reforestation project in the area has failed.

Case study 4: Timmaguab, Sta. Ignacia, Tarlac

Timmaguab, Sta. Ignacia, Tarlac is a rice-farming community in an area where *Imperata* infestation occurs. Since 1987, following the example of a new occupant in the area who grew trees on his 6 ha of land, many farmers in the area have been planting trees on their *Imperata*-infested land to improve soil nutrient levels and to provide fuelwood, fencing material, fodder, and fruit for household consumption. More recently, tree growers are realising the income potential of growing trees and selling wood products on the local market. The increasing local demand for wood products has heightened farmers' interest in growing and protecting trees. Today, eight of the twenty-five farmers in the community have established farm-based woodlots.

Most farmers have established woodlots of *Leucaena leucocephala* and *Gliricidia sepium* and allowed naturally occurring species such as *Vitex negundo*, *Albizia procera*, *Philiostigma malabarica* and *Pithecelobium dulce* to regenerate. In addition, they have planted fruit trees such as *Sandoricum koetjape*, *Anona mauricata*, *Anona squamosa*, *Mangifera indica* and some citrus fruit trees, interplanted with short-term agricultural crops. Many farmers are experimenting with different planting regimes and have found that the problem of pests decreases as the diversity of species planted rises. They have also discovered that as the trees become established they require little in the way of protection or maintenance.

Case study 5: Namambalan, Tuguegarao, Cagayan

Namambalan, Tuguegarao is the southern gateway to Cagayan province, situated near the border of Isabela and Cagayan Provinces. Near this community, along the national highway, is a five-kilometre strip of *Samanea saman* trees growing in a communal pasture area for water buffalo and cattle. Although this land is used as a communal grazing area, it is in fact a homestead under lease. The owner has long been conserving the *Samanea saman* trees because of the future timber value of the trees for wood carvings and housing timber. Besides the fact that conservation of these trees is part of the lease condition, the tenants also have an interest in conserving the trees for animal food and shelter. As a result, the amount of land covered by *Samanea saman* trees has grown over time with little human intervention besides protection from fire.

One explanation for the rapid spread of these trees is attributed to the grazing animals. The grazing animals feed on the fallen fruits of the *Samanea saman* tree and the indigestible seed of the tree is excreted as the animal moves from one grazing site to another, thereby dispersing the seed. *Samanea saman* seedlings are unpalatable to ruminants which allows them to become established, and the animals' waste provides an organic fertilizer which enhances growth.

This symbiosis between *Samanea saman* and grazing animals has promising attributes for the rehabilitation of overgrazed and degraded pasture areas. With further research this system may have the potential to develop into a cost effective silvo-pastoral system which would have the potential to restore the ameliorative and productive value of vast marginal grasslands in the Philippines for pasture and forestry use. Indeed, it was decided during the course of the project to undertake a more a more rigorous evaluation of this system. The results are presented in the following chapter.

DETERMINANT FACTORS OF TREE GROWING SUCCESS

The success conditions identified as being critical for spontaneous tree-growing were: assured access or property rights to the land or trees, interest in other related tree uses, the practice of intercropping, good financial situation of farmers and a potential wood products market. With the exception of a potential wood products market, the success conditions identified for spontaneous tree growing were also identified in government reforestation projects in the same region by Pasicolan (1996). Table 6.1 shows the critical determinant factors of tree-growing success for each case study, and the relevance of each success condition to specific case studies is discussed in the following section.

Assured access or property rights

It is widely recognised that individual or community participation in tree growing is improved or constrained by the level of access or control they have over the land or trees (Cernea 1985; Bruce and Fortmann 1989; Cornista and Escueta 1990; Arnold 1992; Subedi et al. 1993). It is not surprising then, that this was the most important condition for farmers successfully growing trees in each of the five cases studied. Farmers in Quibal, Maguirig, Nagtimog and Timmaguab were interested in growing trees because they were certain that the future products or benefits would accrue to them. In Nagtimog, DENR's provision of usufruct rights and tree tenure provided an incentive for farmers to plant trees without payment. The Maguirig and Timmaguab cases also illustrate how security of land ownership provides an incentive for farmers to grow trees, a critical factor missing in many of the unsuccessful government sponsored tree planting projects in adjacent areas (Pasicolan 1996). In Quibal, tree growing was done on public land, but the long occupation of farmers in the area gave them a sense of de facto ownership. They were confident that the benefits of the trees they planted would accrue to them. The Namambalan farmers felt it in their interest to protect the Samanea saman trees in order to ensure that they would have continued communal access to this privately owned grazing area.

Table 6.1. Determinant factors of tree-growing success in the five case studies

Site	Success conditions
1. Quibal	Assured access/ownership rights
	Wood products market prospect
2. Maguirig	Assured access/ownership rights
	Interest in other related uses
	Practice of intercropping
	Good financial situation of farmers
3. Nagtimog	Assured access/ownership rights
	Interest in other related uses
	Practice of intercropping
	Good financial situation of farmers
4. Timmaguab	Assured access/ownership rights
	Interest in other related uses
	Practice of intercropping
	Good financial situation of farmers
	Wood products market prospect
5. Namambalan	Assured access/ownership rights
	Interest in other related uses

Interest in other related tree uses

Farmers were more interested in growing forest tree species if those trees had other related uses such as food, fodder or an ability to improve the soil. With the exception of the farmers in Quibal, where the local people were primarily timber gatherers and the prime motive for tree-growing was for fuelwood and other wood products, 'other related tree uses' was an important criteria in farmers planting trees. In Timmaguab and Maguirig, farmers recognised the important role of *Leucaena leucocephala* and *Gliricidia sepium* in nitrogen fixation of the soil. Farmers in Nagtimog used the tree litter from *Gmelina arborea* as a compost to increase the productivity of the crops they had planted between the trees. Leaves and pods of *Leucaena leucocephala* were also used as fodder for goats and hogs in Timmaguab and Maguirig, and in Namambalan the fruit of *Samanea saman* was used as a supplementary feed for cattle.

Practice of intercropping

For farmers whose subsistence, or income, is derived from agricultural crops, the ability to intercrop trees with agricultural crops is an important consideration in their decision to grow trees. In Nagtimog, Maguirig and Timmaguab farmers intercropped agricultural crops or fruit trees between forest tree species. Farmers in

Nagtimog successfully planted *Gmelina arborea* intercropped with maize, peanuts and mungbeans on a failed reforestation project site. Farmers in Maguirig and Timmaguab adopted wide planting of forest tree species to interplant with fruit trees. Aside from these mixed tree stands they also established woodlots along the periphery of their farms. Intercropping was not considered feasible by farmers in Quibal because fuelwood gathering was their main livelihood so they planted mainly forest tree species.

An added benefit of intercropping agricultural crops between tree crops was that farmers showed a greater willingness to protect the area from grassland fire than if the site was planted with forest tree species only. This is largely due to the fact that the farmer is dependent on agricultural crops for subsistence and income and it is in their immediate interest to protect them, and thus the tree species, from fire. For example, in Nagtimog farmers constructed fire lines and planted bananas around their agricultural and forest tree crops as a protective belt.

Good financial situation of farmers

The financial situation of farmers is an important condition for successful tree growing. Farmers in Maguirig, Nagtimog and Timmaguab were above the subsistence level which enabled them to invest some of their time and land for tree-growing activities. However, the Quibal case is an exception. Most farmers in this site were almost totally dependent on daily fuelwood sales to subsist. The incentive for them to grow trees in their home gardens or in their farmlots was the scarcity of timber resources in nearby forests.

Wood products market prospect

Another incentive for farmers to grow trees is the potential to generate income through the sale of wood products. If there is a perceived demand for forest products farmers are more likely to consider the option of growing trees alongside, or instead of, agricultural crops. In Quibal, for example, a number of timber gatherers reverted much of their farm land to woodlots as demand for fuelwood grew due to scarcity of supply. In this region, firewood constitutes the major source of household cooking fuel and there was demand from individual households as well as from the hotels, restaurants, blacksmith shops and other small scale industries in Tuguegarao, the capital of the Cagayan Valley Region. A growing wood products market was also important in providing additional incentives for farmers in Timmaguab to expand their woodlots.

Farmers in the other case study areas were less dependent on fuelwood for their livelihood and they grew trees to meet their domestic need for fuelwood, fencing and other timber products.

CONCLUSIONS

Analysis of these case studies identifies five success conditions for farmers to spontaneously grow trees. These are assured access or property rights, interest in other related tree uses, practice of intercropping, good financial situation of farmers and a potential for a strong wood products market. In this exploratory study assured access or property rights over the land and trees, along with a demand for trees for wood products and other related uses, were important conditions for spontaneous tree-growing. As demand for wood products increases due to scarcity of supply, the potential to encourage tree growing by farmers is great. Preliminary results from this study indicate that by providing farmers with non-fiscal incentives to grow trees, the Philippine government may be able to control *Imperata* and rehabilitate upland areas. Examples include: tenure rights and infrastructure to support a burgeoning wood products market.

7 The Role of Grazing Animals in the Natural Regeneration of *Samanea saman* in Degraded Pasture Areas in the Philippines

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THE NATURE OF the symbiotic relationship between water buffalo (*Bubalus bubalis*) and naturally grown leguminous tree species (*Samanea saman*) in the Philippines was introduced in Chapter 6. Grazing animals were observed feeding on Samanea seed pods. The indigestible seeds, when excreted by the animals, germinate in the fertile medium of the animal dung. Over time, a continuous natural regeneration of *Samanea* has occurred.

This unique system has the potential to convert marginal grasslands to silvopastoral sites through natural means. A more in-depth analysis is undertaken here to help formulate the dimensions of what seems to be a sustainable tree/animal-based production model.

In this chapter the bioecological basis for the symbiotic relationship between grazing animals and *Samanea* is analysed. The contributory factors which enhance such relationships are examined, with the aim of evolving a successful reforestation model which builds on the natural process of regeneration on degraded grasslands.

STUDY SITE

The study site covered an area of 384 ha. It was located at Sitio Gulipatan, Barangay Namabbalan, Tuguegarao and Baliuag, Peñablanca both in the Province of Cagayan, Philippines. The site is accessible by motor vehicles year round. It is bounded on the northern and southern sides by Pasture Lease Agreements and to the West by 'Alienable and Disposable land'. The study site is 1 km from the National Highway to Manila.

The area is dominated by grasses, *Imperata cylindrica* (cogon), *Themeda triandra* (bagokbok) and *Chrysopogon aciculata* (amorseco). Stands of other tree species, such as Moraceae, Meliaceae, Sapindaceae and Euphorbiaceae, grow naturally along the creek banks.

Within the area under consideration the soil is a reddish to dark brown with a clay loam texture. The soil is relatively shallow with an effective depth of 20–30 cm. The climate is classified as Type III, with a dry season of six months. Rainfall is scarce during dry season, but the Dausuin and Abanduan creeks can sustain the year-round water requirements of the animals. The area is gently sloping with the gradient gradually increasing towards the eastern portions.

METHODOLOGY

The methodology consisted of a series of bioecological experiments, plus a socioeconomic survey. The bioecological experiments addressed such issues as seed germination, seed digestibility and forage preference by grazing animals. A socioeconomic component is included to determine the income gains to the farmer from *Samanea*.

Both structured and unstructured interviews were also carried out with farmers grazing cattle near *Samanea* trees. Fifteen respondents were selected based on their period of residency in the locality and engagement in pasture management.

The interviews included socioeconomic aspects. The socioeconomic component of the study included the economic benefits that can be gained from *Samanea*. These were inferred from the interviews and the measurements conducted during the socioeconomic survey.

THE ROLE OF THE GRAZING ANIMALS IN *SAMANEA* REGENERATION

A total of 94 water buffalo (*Bubalus bubalis*) and cows grazed in the area. They played a significant role in dispersing and regenerating *Samanea*, by feeding on the pods and then excreting the indigestible seed in their dung. The following are the main attributes of animals affecting seed germination and plant growth of *Samanea*:

Pretreatment of seed in the animal system

To ensure easy and fast germination, seeds of most leguminous trees and shrubs require soaking in sulfuric or hydrochloric acid prior to sowing. Seeds of *Samanea* eaten by ruminants receive this germination pretreatment via the digestive system of the animals. The animal's gastric juice (which is acidic in nature) and digestive

enzymes in its stomach, induce the softening or breaking of the tough *Samanea* seed coat.

An experiment was conducted to test the effect of animal ingestion on seed germination of *Samanea*. Treatments were as follows:

1 animals (cow and carabao) fed with *Samanea* pods;

2 seeds exposed to HCl;

3 seeds exposed to HCl with agitation;

4 seeds directly planted to soil; and

5 pods placed on soil.

Each treatment had three replicates and three sub-replicates. Other factors influencing germination and growth of *Samanea* were closely examined through periodic field observations. The field observations were carried out in the study site and in three other places outside Cagayan Province.

Shortened seed dormancy

Mature *Samanea* trees can bear fruit as early as February. By the start of March, ripened pods begin to fall and grazing animals feed on them. Seeds imbedded in the dung, having been pretreated by the animals digestive system, germinate after a week. The seedlings germinate and grow well before the beginning of the wet season. Under ordinary conditions, it takes about four to six months for seeds to germinate, as they require the beginning of the wet season to provide the required moisture.

Animal dung as an ideal micro-environment

Most of the grassland soils in the Philippines are highly eroded, acidic, low in organic matter, deficient in nitrogen, phosphorus, potassium, calcium, magnesium and zinc, and contain high levels of aluminium, iron and manganese (Dela Cruz 1987). Overgrazed and degraded pastures typical of this area, are generally characterised as brittle, compact, marginal and acidic. Under these soil conditions, germination and survival of seedlings is limited, especially given the long dry season.

Seeds germinating in animal dung grow well, even at the peak of the dry season. The dung in many ways serves as an ideal soil medium containing the nutrients needed for plant growth. It also stores a substantial amount of moisture which can keep the young seedling from dehydration during dry months.

Nodulation effect on young seedlings

Leguminous species are nitrogen fixers, the presence of nodules, i.e. small knots or lumps on the roots, indicates the activity of nitrogen-fixing bacteria. Based on the

field experiment in this study, it was found that seedlings of *Samanea* growing in cow dung produced more root nodules than those sprouting on the ground. An analysis of 100 seedling root samples taken from both animal dung and bare soil, found an average of 262 nodules on the roots of seedlings growing in dung, compared to an average of 208 nodules on the roots of seedlings in bare soil. Nodules in seedlings grown in cow dung have two colours, brown and pinkish, while nodules of seedlings grown in bare soil show only one colour, brown. The number and colour of nodules is seen to affect the potential of the plant to fix nitrogen.

From these findings, it appears that there is a certain substrate in the animal dung not present in ordinary soil which accounts for the difference in the number and colour of nodules at the seedling stage. This gives the seedlings grown in animal dung a distinct advantage.

FACTORS SUSTAINING THE GROWTH AND DENSITY INCREASE OF *SAMANEA*

Palatability of *Samanea* fruit

Samanea pods serve as forage substitute for grazing animals during the dry season. The *Samanea* pods are available in abundance from March to June, a time when there is a scarcity of fresh grasses available and the pods fill the food supply gap of the animals.

The sugary taste of the *Samanea* pods make them palatable to ruminants and wild animals. In terms of food value, the pods contain the following nutrients: Carbohydrate (23%); Crude Protein/Dry Crude Protein (17%); Ether (0.6%); Crude Fibre (12%); Ca (0.4%); and Total Dry Nitrogen (63%).

Availability of seeds

Samanea trees bear fruit as early as seven years old, and mature trees produce abundant seeds. One tree can bear between 3000 to 5000 pods per season with an average of 10 seeds per pod (i.e. 30000 to 50000 seeds per fruiting season). However, the fruiting pattern is not uniform, with some trees producing fruit as early as January, while others don't begin fruiting until May. The peak of fruit maturation occurs between May and June, at which time the ripened fruits fall to the ground. The seeds can be stored for a year without losing viability (Saplaco and Dela Cruz1990).

High rate of seed germination

Seeds of *Samanea* require moist conditions to germinate. The study revealed that a high moisture content triggers germination. In the absence of rain during the dry

season, germination only occurs in the animal dung which litters the area. The survey, carried out between March and May, found an average of six seedlings in each dung pile. The arrival of the rains in June triggered a sudden mushrooming of *Samanea* seedlings especially along the banks of the creek. Observation of other sites outside the study area found that seeds rarely germinate under the broad canopy of emergent species, due to the lack of sunlight at ground level.

Absence of sporadic and unmanaged fire

Management practices at the study site involved the use of prescribed burning of grasses in preparation for the dry season, in March or early April. Local herders cooperating in the fire control reduce the risk of the fire spreading to neighbouring areas.

Samanea is a relatively fire resistant species and is only vulnerable to fire damage during the seedling stage (Saplaco and Dela Cruz1990). Once past this critical stage, it recovers well after fire. Young seedlings are rarely threatened by fire, as prescribed grassland burning occurs prior to when *Samanea* germination peaks in May.

Lower incidence of damage by grazing animals to surviving seedlings

According to the herders in the study area, seedlings and leaves of Samanea trees are palatable to ruminants. Water buffalos and cows often feed on the leaves of young Samanea trees during dry season. The following conditions enable the seedlings to survive this grazing by animals:

- Protective role of associated tree species: *Samanea* trees are interspersed with thirty other tree and shrub species found in the area. Seeds dispersed by animals in scrub and thickets are often hidden from foraging animals and are thus protected. In terms of growth performance in competition with other species, *Samanea* thrives quite well as long as there is sufficient sunlight reaching the understorey.
- Heavily grazed areas: As animals graze in relatively flat open areas, they also discharge their waste containing *Samanea* seeds. Later the seeds germinate but because there is minimal new growth of grasses during the dry season, the animals do not go back to areas that have been heavily grazed. They move to other grazing areas where at the same time they can obtain additional forage from *Samanea* fruits as the dry season progresses.
- Forage preference: While *Samanea* leaves are eaten by cattle in the dry season they are not the animals preferred forage. During the wet season, an abundance of fresh grasses are available, so the animals will leave the *Samanea* leaves and seedlings untouched. This was validated by field testing. Two sets of grazing

animals (five water buffalo and five cows) in the study site were used as test samples. Prior to their release into a plot with young *Samanea* seedlings and fresh grasses, the animals were not pastured or given any food for a day. Initially, they grazed on the fresh shoots of young grasses and were not interested in the leaves of the *Samanea* seedlings.

When fresh forage is available in abundance, the choice by the animals between grass and *Samanea* can best be viewed in terms of palatability and the species' effect on the animals. Farmers claim that over-dosage of *Samanea* leaves can cause severe gas pains in the animals and can even result in death. Examination of its chemical composition in laboratory tests revealed that legumes contain a greater variety of toxic constituents than other plant families (National Academy of Science 1979). These include compound flavonoids, alkaloids, non-protein amino acids, and uncommon proteins, which were found in the leaves, pods and seeds.

Presence of network of creeks

One contributing factor to the increase in *Samanea* stands in the study area is the presence of a network of creeks. Water is a sought after resource for grazing animals and at same time is a critical requirement for seed germination and plant growth.

The oldest stands of *Samanea* are typically found along the banks of creeks. Water courses play a very important role in facilitating the pace and direction of *Samanea* regeneration. They aid in distribution, carrying downstream the seeds that are dropped from trees on the creek bank. They provide the main source of drinking water for animals, and the presence of trees on the banks provides shade during summer. The high stand density of the species along the creek compared to other sections of the pasture area indicates the importance of water in the regeneration process.

CRITICAL SIGNIFICANCE OF THE ANIMAL–TREE SYMBIOSIS

Shortening the process of seed germination through digestive process

The germination cycle of *Samanea* from the ripened fruit stage until the seeds germinate takes four to six months under ordinary conditions. The fruits fall to the ground within a month of reaching maturity. It then takes another three to five months before the seeds are released from the pods to the ground. Seeds that discharge from the pods after the early rains, in May, are likely to germinate after a week or two. Under ordinary conditions, the peak of germination is from August to September.

Grazing animals feeding on the *Samanea* fruits, reduce the germination process by three to five months. This allows the hardening off of the young seedlings, the stems become rigid and woody, with short but vigorous crowns, and the root system is compact and well developed. Hence, when the rain arrives, the seedlings are ready to bear new shoots and roots.

Under nursery conditions, hardening off is carried out two to six months prior to transplanting the seedlings to the field. This is achieved by gradual reduction of watering frequency and exposure of the seedlings to full sunlight (Saplaco and Dela Cruz 1990).

High certainty of seed germination under the animal system

Seeds ingested by the animals have greater chance of germinating than those remaining in the ground. An experiment using three different treatments for seed germination, found that more seeds germinated in animal dung than in garden soil or grassland top soil. Furthermore, in animal dung the seeds germinated after a week, compared to more than two weeks for seeds in soil.

In related findings from observation sites outside the study area, seeds which remain enclosed in the fruit after falling to the ground may be affected by the following conditions:

- *Late germinants* Seeds unable to come out completely from the pod but germinate once they are watered, germinate haphazardly. They survive a short period but wilt and die because of poor root anchorage.
- *Food for seed borers and other insects* The sugary pulp of the *Samanea* fruit attracts many insects such as small ants, seed borers etc. These insects also lay their eggs inside the pod rendering the seeds completely non viable.
- *Attack by agents of decay* Seeds undetached from their pods throughout the dry season, later decompose. Inundated with moisture when it rains, the seeds become infested with moulds, fungi and other microorganisms, leading to decay.

Widespread seed dispersal by animals

Samanea seeds are not air borne, unlike some other leguminous seeds which can be dispersed freely by wind. This makes it difficult for the species to disperse and regenerate. The marginal soil condition of most pasture areas (brittle, dried and compacted), further lessens the opportunities for germination. Animals feeding on the *Samanea* fruits while simultaneously grazing in the same area, improve the potential for natural regeneration and improve the dispersal of the seeds.

In five different pasture areas visited, regeneration and dispersal on the site was closely associated with the animals' feeding patterns. In areas with no mother tree, or only young trees of *Samanea*, species' stand density was low. However, where *Samanea* trees were bearing fruits, there was also the emergence of many young *Samanea* seedlings. The widespread and rapid increase of *Samanea* tree stands in pasture areas is mainly attributed to the role of grazing animals feeding on the fruits. This provides an indication of the biointeraction between ruminants and *Samanea* trees.

Sustainable seedling growth in animal dung

Seedlings sprouting on animal dung appear sturdier than those germinating on ordinary soil. This is associated with the presence of nitrogen-fixing bacteria in the soil and nodulation on the roots of seedlings grown in the animal dung.

It was also noted in the observation sites, that most seedlings which instantly emerged with the onset of the rains, later withered and died despite the availability of moisture.

Provide good root anchorage

Root anchorage is critical to tree growth. Seedlings with roots superficially anchored in the top layer of mixed humus and undecomposed debris of dead leaves and twigs, were short-lived. For a time, they seemed robust but later turned yellowish pale and died. The same is true for young seedlings growing on steep sloping ground. Shallow rooting completely impairs the growth and sustainability of seedlings.

In contrast, seedlings growing in animal dung have deep roots, embedded strongly in the dung. Since germination usually takes place during the dry period, which is the peak of the *Samanea*'s fruiting season, there is no premature watering down the animal dung. By the time the rain arrives, the roots of the young plants have already gained a strong hold in the ground.

Improved soil fertility

There has been no investigation as yet to establish the effect of the animal–tree biointeraction on improving soil fertility of the area. However, the interaction can be viewed as a closed loop of nutrient cycling between the animal and the tree but also a continuous pumping of nutrients into the system.

Samanea, like any other leguminous species is a good soil conditioner. According to the National Academy of Science (1979), the fresh foliage of most legumes usually contains from 0.1 to 1% nitrogen. Furthermore, the foliage of vigorous perennial

legumes may accumulate 100–600 kg of nitrogen/ha. When incorporated into the soil, the foliage improves fertility and moisture/nutrient retention.

SOCIOECONOMIC SURVEY

Of the fifteen respondents, all were married with an average of five children. The average farm size was 2.2 ha, with rice, or corn with legume production being the main farming activity. Respondents' monthly income ranged from ₱ 3000 to ₱ 7500. The bulk of this income went on food, education and farm inputs, with the remainder being used for clothing, housing materials, medicine and other household expenses.

The structured interviews indicated that two-thirds of the farmers recognise the importance of *Samanea* as shade for grazing animals and also the use of its timber for housing (Table 7.1). Most farmers (60%) observed animals consuming the pods of *Samanea* in the dry season.

The quantity of *Samanea* consumed by animals as a percentage of their total diet was specified to be low, at 5% of the total annual feed intake (8330 kg) by grazing animals.

Charcoal has the potential to provide the farmer with a significant income. A 20- to 30-year-old *Samanea* tree can yield as much as 80 to 100 stacks of charcoal, which will provide the farmer with an additional income of ₱ 12000 to ₱ 15000.

Table 7.1. Respondents' perceptions of the benefits derived from *Samanea*

Benefits	Frequency (% of responses)
Shade for grazing animals	66
For housing	66
As feed supplement	60
Maintenance of creek	53
For charcoal	40
For fuelwood	33
For furniture	27

Farmer's estimated income from *Samanea* wood products
Basic assumptions:

1 Data used for analysis was based on the information gathered in the study site.

2 Pricing is based on current prices (1997).

3 Benefits are estimated for on a 25-year-old tree (dbh of 45 cm and mh of 5 m) derived from the field inventory that was undertaken at the study site.

Table 7.2 shows the quantity, gross income and net income of the main wood products derived from *Samanea*. The combination of charcoal and wood carving provides the highest gross income, ₱ 27600. This combination also provides the highest net income, ₱ 16920. Converting the whole tree into charcoal would yield a net income per ha of ₱ 6720, while a combination of charcoal and timber would only yield ₱ 5005/ha.

Table 7.2. Quantity and income derived from wood products of *Samanea*, at Namabbalan, Tuguegarao, Cagayan, 1997, per 25-year-old tree

Product	Price per unit (₱)	Charcoal (bags)	Timber (boardfeet[a])	Wood carvings (no)	Gross benefit	Processing cost (₱)	Net income (₱)
Charcoal	150/bag	80	–	–	9600	2880	6720
Charcoal + timber	150/bag + 25/bdft.	30	198.8	–	8570	8570	5005
Charcoal + carvings	120/bag + 3000/carving	30	–	8	27600	10680	16920

Note: Processing is estimated at 30% of gross benefits for charcoal and wood carving and 50% for timber.
[a] One board foot is a piece of wood measuring 1×1×12 inches.

CONCLUSIONS

There is much to learn by studying natural systems. Building on them is cost-effective and likely to be sustainable. Biological niches, such as the symbiotic relationships between *Samanea* and animals observed here, not only ensures natural regeneration but also restore biodiversity.

The case of the *Samanea* regeneration by grazing animals is a good example of how natural processes can be enhanced to address multiple concerns. The grazing animals need the *Samanea* to supply forage as well as shade. In return, the animal waste provides soil nutrients and facilitates seed germination. The net result of this animal–tree interaction is an increase in farmer's income from the animal and tree products as well as improvement in environmental factors.

The *Samanea* animal/tree model may be replicated, or modified for other promising reforestation species. In areas without *Samanea* mother trees as an initial seed bank, ripened pods could be collected from neighbouring areas and fed to cattle as a feed

supplement in the dry season. Likewise, other species whose seeds can be distributed in a similar way should be explored.

This particular example of animal–tree symbiosis is technically feasible for the following reasons. *Samanea saman* fruit is palatable to cattle; seeds are indigestible; gastric juices in the animal system serve as pregermination treatment for the seeds; early germination due to advanced pretreatment by the animals allows sufficient hardening period for the young seedlings; and animal dung serves as an ideal micro-environment for plant nourishment.

Factors that enhance the growth, and increase in stand density, of *Samanea* in a pasture area include: the presence of mother trees; high rate of seed germination; absence of sporadic and unmanaged fire; protective role of associated plant species on the young *Samanea* seedlings; adequate solar energy; an the presence of bodies of water.

Significant attributes of the animal–tree symbiosis include: shortened process of seed germination; high certainty of seed germination; widespread seed dispersal; high seedling growth sustainability; deep seedling root anchorage; and improved soil fertility.

The system can be replicated in other areas where there are distinct dry and wet seasons of the year. However, in regions with uniformly distributed rainfall throughout the year, the year round abundance of fresh grasses makes it unlikely that animals would feed on *Samanea* pods.

RESEARCH RECOMMENDATIONS

- Pilot test the animal–tree symbiosis model in other degraded areas;
- Extend the research to *Pterocarpus indicus* building on the *Samanea saman* model;
- Nodulation study to compare seedlings grown in animal manure to those from ordinary soil;
- Soil nutrient budgeting study of the animal–*Samanea saman* symbiosis model;
- Study the fire tolerance of *Samanea saman*.

8

Gmelina Timber Production and Marketing in Claveria, Philippines

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Smallholder farmers in Southeast Asia have begun farming timber trees using their own capital resources (Garrity and Mercado 1994; Garrity 1994a). In recent years, there has been an increase in the number of smallholder timber plantations of fast-growing tree species in Claveria, Misamis Oriental, Mindanao. The smallholder timber plantations in this area are mostly planted to *Gmelina*. The first substantial harvest of *Gmelina* took place in late 1996. A survey was undertaken at that time to capture the major features of the harvest, and farmers' opinions about it.

Gmelina timber production is attractive due to its fast growth (Garrity and Mercado 1994). Under Philippine conditions, *Gmelina* can attain an average height of 13.2 m with a total clear bole of 8.22 m in 8 years (Generalao et al. 1977). There is also an increased demand for fuelwood and timber — a demand is brought about by the decrease in hardwood species planted and harvestable in Philippines natural forest, and is a major factor in the development of smallholder *Gmelina* timber plantations (Garrity and Mercado 1994).

Timber prices have risen greatly in the past decade (1984–1993). It has been reported that prices of hardwoods like lawa-an (*Pentacme contorta*) increased from US$0.19 to 0.97/bdft (Garrity and Mercado 1994). Prices of medium-sized logs of falcata (*Paraserianthes falcataria*) increased from US$0.06 to 0.15/bdft[1] during the same period. The current price of small size logs of *Gmelina* is similar to that of falcata (US$0.15/bdft) while medium size logs are similar in price to lawa'an timber (US$0.97/ bdft). With the increasing timber prices, it is expected that yield from

1. bdft = boardfoot. One boardfoot is a piece of wood measuring 1×1×12 inches.

Gmelina can improve the farmers' income (Garrity and Mercado 1994). The first significant harvesting of *Gmelina* trees in Claveria is now underway.

This study has the following objectives:

(a) to quantify the economic benefits obtained by farmers growing *Gmelina* trees;

(b) to elicit farmers' opinions of the benefits obtained from growing *Gmelina* trees;

(c) to determine farmers' future intentions with regard to tree planting in the light of (a) and (b); and

(d) to find out what lessons the farmers learned from the experience and improvements that they can suggest in relation to planting *Gmelina* trees in the future.

The study used two survey instruments, one for farmers and one for sawmill operators. The first survey was conducted from September to October 1996 in Claveria, Misamis Oriental, consisting of interviews of farmers who had planted *Gmelina* trees and of sawmill operators in nearby coastal towns.

The selection of farmer respondents were based on two criteria:

1. the farmer should have harvested *Gmelina* trees within the last 12 months; and
2. *Gmelina* trees were more substantively planted than merely as borders or farm margins.

Seventeen farmers who met these criteria were selected from lower Claveria barangays including Patrocinio, Tunggol Estate, Ane-I-Lupok, Minsacuba, Hinaplanan, Cabacungan and Wilcom.

A second survey was conducted, on the same farmers interviewed in the first survey, in November 1996. This was done to validate data gathered from secondary sources regarding the labour requirements for planting, maintenance, harvesting and post-harvesting *Gmelina* trees.

Five sawmill operators from the nearby coastal towns of Villanueva and Jasaan were interviewed. These sawmill operators buy and process *Gmelina* trees. The processed logs are marketed locally and internationally. Additional data were obtained from existing publications and other secondary literature sources. The raw data were analysed using simple descriptive statistics such as frequency and percentage distribution tables.

Description of study area

Claveria is a municipality of Misamis Oriental, Mindanao, about 40 km southeast of Cagayan de Oro city (Fig. 8.1). Claveria is the only inland town and is the biggest municipality with an area of 89 500 ha, occupying 30.5% of the province. The area

lies in an undulating plateau between a coastal escarpment and a mountainous interior, and is divided into two topographic regimes: the upper Claveria with an elevation range of 650–915 m above mean sea level (MASL) and lower Claveria with elevation of 390–650 MASL. Upper Claveria is located along the north and northeast areas of the town while lower Claveria lies on the west and northwest section of the municipality. Soils from Claveria are classified as acid-upland (fine mixed, isohyperthermic, Ultic Haplorthox) with a depth of more than 1 m (Garrity and Agustin 1995). Generally, the soils are characterised by high organic matter content, low pH, and low CEC (Hafner 1996). The dominant crop planted is maize with some upland rice, cassava and tomatoes. Maize production has prospered in Claveria because of its adaptability to local conditions. White maize is a staple food andyellow maize is in great demand as an animal feed.

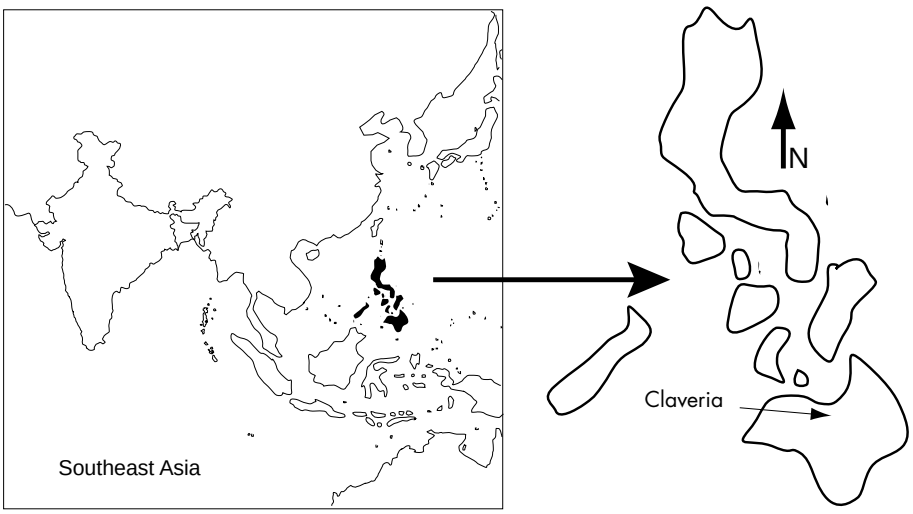

Figure 8.1. Geographic location of Claveria, Mindanao, Philippines

The two pronounced seasons in the area are the wet season, from June to December, and the dry season from January to May. The average annual rainfall in the area is 2000 mm (Garrity and Agustin 1995). There is a cemented road going up to Claveria town proper from Cagayan de Oro City. Most of the selected study sites have cemented and dirt roads making them quite accessible from Claveria town proper. Patrocinio is within 4 km of Claveria, Cabacungan is 12 km, Hinaplanan is 15 km, Minsacuba is 7–8 km from Claveria town proper and all these sites are accessible from Claveria. The unsurfaced road in Tunggol (8 km away from Claveria) may become inaccessible during rainy seasons when the soil becomes wet and sticky.

Farm profile in relation to *Gmelina* planting

Farm size of those farmers interviewed ranged from 0.5 to 8 ha and averaged 2.5 ha. Area planted to *Gmelina* trees ranged from 0.25 to 4.0 ha (Table 8.1). The majority of farmers (88%) allocated less than half of their farm to planting *Gmelina* trees, i.e. 47% of the farmers had less than 25% of their farm planted to *Gmelina* and 41% of the farmers had 25–50% of their farm planted to *Gmelina*. Only one farmer (6%) had devoted her whole farm to *Gmelina* trees.

Gmelina planting

The prime objective of most farmers who planted *Gmelina* trees (88%) was for future housing needs of their families. About 41% of the farmers indicated that they planted *Gmelina* for additional income for their children's education; to buy appliances, farm equipment like a brush-cutter; and for other financial needs. For the total respondents, about 24% are aware of the ecological benefits from planting trees on their farms.

The availability of *Gmelina* planting materials is also an important factor in the decision of the farmers to plant the trees. *Gmelina* seedlings were made available by the ICRAF office in Claveria. DENR's tree plantation program also encourages farmers to plant *Gmelina* trees and other fast-growing tree species. Free *Gmelina* seedlings provided by close relatives is also another important source of planting materials. Local nurseries sell *Gmelina* tree seedlings at P100 each.

The majority of farmers planted *Gmelina* by block planting design (70%), while the others planted them along hedgerows (30%). The spacing in the block planting design varied (Table 8.1), with 35% of the farmers using 3 ¥ 3 m2 spacing. About 41% of the farmers planted fewer than 100 *Gmelina* trees on their farm, while another 41% planted between 100 to 500 trees. Only a few farmers interviewed planted more than 500 trees.

Table 8.1. Area, spacing and number of trees planted in Claveria smallholder farms

Farmer respondent number	Location	Area planted to *Gmelina* trees (ha)	Proportion of farm planted to *Gmelina* trees (%)	Spacing (m^2)	Number of trees planted
1	Patrocinio	0.25	63	5 × 5	63
2	Patrocinio	0.25	50	2 × 6	250
3	Patrocinio	0.75	50	3 × 3	200
4	Lupok, Ane-I	0.75	75	3 × 3	850
5	Minsacuba	0.25	25	4 × 3	200
6	Cabacungan	0.06	12	2 × 2	35
7	Cabacungan	0.75	20	3 × 4	1000
8	Cabacungan			3 × 3	5
9	Cabacungan	0.06	100	5 × 5	25
10	Cabacungan			3 × 3	8
11	Hinaplanan	0.60	100	3 × 3	150
12	Tunggol	0.50	29	3 × 5	100
13	Tunggol	0.09	24	4 × 4	9
14	Tunggol	0.42	16	4 × 4	42
15	Tunggol	2.90	56	3 × 8	1020
16	Hinaplanan	0.10	39	3 × 3	200
17	Hinaplanan	0.14	100	3 × 4	350

Gmelina harvesting

About 49% of the total number of trees planted on these farms have been harvested since August 1995. Before cutting the trees, a permit must be secured either from the Barangay captain or the local office of DENR (Department of Environment and Natural Resources) — the Community Environment and Natural Resources Office (CENRO). If only a few trees will be cut, a permit from the barangay captain is enough. If large number of trees are to be cut, it is usually the buyer who gets the cutting permit from the DENR office. A recommendation letter from the mayor and a copy of the land tax declaration are needed in securing a DENR cutting permit. The permit to transport the cut trees is also secured from the barangay captain.

In some cases, the farmer cuts the trees and delivers the timber or processed logs to the sawmiller in nearby coastal towns. In other cases, the buyer takes charge of cutting and transporting the cut timber or processed logs.

Farmers harvested the bulk of the trees during dry season (November–April, 53%) while the remainder were harvested during the wet season (May–October, 47%). Farmers prefer to harvest trees during dry season because of the better harvesting conditions and easier access to the area. Also, demand for timber is higher during the dry season.

The age of trees harvested ranges from 3–8 years, with 76% of the trees cut at ages between 5 to 7 years. Farmers prefer to cut trees at 7 years, when the trunk diameter is at least 20 cm dbh (diameter at breast height) and the average timber yield is 56 bdft. The average growth rate of *Gmelina* in the southern Philippines was estimated to be 8 bdft per tree per year, up to 8 years (Magcale-Macandog and Rocamora 1997a, b). Greater wood biomass is harvested when trees are allowed to grow to 8 years (Fig. 8.2). The high variation among sampling points in Figure 8.2 can be attributed to variation in soil properties and microclimatic conditions between sites. Gunawan et al. (1996a) reported that sengon (*Paraserianthes falcataria*), mahogany (*Swietenis* spp.) and teak (*Tectona grandis*) are harvested at 10–15, 10 and 20 years, respectively. Other tree species are harvested much earlier, such as turi (legume) and lamtoro (*Leucaena leucocephala*) at the age of five years.

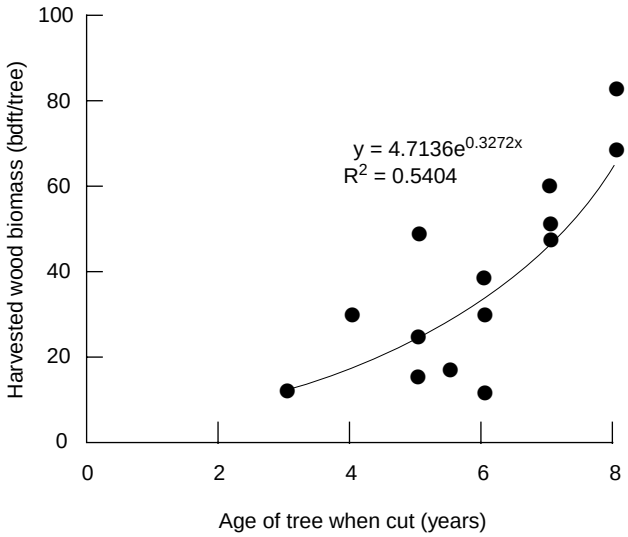

Figure 8.2.
Relationship between age of *Gmelina* tree and harvested wood biomass

Reasons for cutting trees

Farmers stated preference is to cut *Gmelina* at 7 years and use the timber for house construction (35%). However, in some cases they are forced to cut the trees earlier due to financial needs. They have to sell the trees to pay for the school fees of their

children, to pay loans, to buy animal feed, appliances and food. In some cases, farmers borrow money from private traders and use the young trees as their collateral. Upon reaching the maturity of their loan, the tree is cut and sold to pay the debt.

Postharvest activities in the farm

After harvesting the trees, most farmers (47%) leave the stumps of trees to grow shoots for coppicing. They leave 1–2 siblings per stump and prune the branches of the young trees up to 2 years. Other farmers (14%) cultivate the area in between stumps for planting maize and other annuals. Another 14% of farmers leave the area for use of grazing animals. One farmer (6%) removed the stumps and planted another tree species instead of *Gmelina*.

Planting of annual crops

In farms where *Gmelina* is planted in blocks, annual crops like rice, maize and cassava are planted in the remainder of the farms. In *Gmelina* hedgerow planting, alley cropping is undertaken in areas between contour strips in the first two to three years of *Gmelina* growth. Afterwards, when the tree canopy starts to close, the alley area is left fallow. During the fallow period, natural vegetation grows in between the *Gmelina* trees, which mostly serves as a source of livestock feed (Magcale-Macandog et al. 1997b). Commonly growing natural vegetation includes *Chromolaena odorata*, *Paspalum conjugatum*, *Imperata cylindrica*, *Pennisetum polystachium* and *Mimosa pudica* (Stark 1996).

MARKET STRUCTURE

Form of product sold

Harvested trees are sold either as logs or processed into flitches. Log processing includes cutting and sawing, which costs about ₱ 3.50/bdft. Flitches are sold at a higher price than unprocessed logs. Despite the expenses incurred in processing logs, most farmers report higher incomes from selling flitches compared with selling logs. However, most Claveria farmers cannot afford the additional labour cost for sawing and processing, and so end up selling logs or even standing timber. In Cebu, farmers are satisfied with the price of ₱ 0.33/kg of *Leucaena* firewood because wood splitting, drying and debarking takes too much time away from their regular farm activities. Such processing would ensure a price of ₱ 0.85/kg (Bensel 1994).

Gmelina is also sold for electric posts. This brings the highest price (₱ 12.00/bdft) but trees for electric posts should have a minimum straight stand of 14 m and trunk diameter of 61 cm or more. Trees for electric posts should have a minimum age of 8

years. Only trees selected for this purpose will be cut and processed, at the buyers expense. In Davao del Norte, *Albizia falcataria* trees used for poles should have an average length of 4.88 m (Cruz 1994).

Other tree products

Gmelina trees are pruned regularly from the second to the fourth year to improve the growth of the tree and to produce long, straight logs. The pruned branches are used as domestic firewood by most of the farmers (70%). Other farmers (24%) sell the branches as fuelwood to bakery owners in Claveria. Farmgate price of *Gmelina* branches at Claveria is ₱ 1200.00 /t fresh weight basis. The bakery owners handle all costs related to loading, unloading and transportation of the cut branches. Marketing of fuelwood is an additional income for farmers. Bakery owners in Cebu are buying *Leucaena* fuelwood at the price of ₱ 800/t (Bensel 1994).

Another product derived from *Gmelina* trees is slabs of wood that are used as flooring materials in houses. Leaf litter from *Gmelina* trees improve soil fertility upon decomposition, thus it serves as an organic fertilizer in the farm. In Cebu, leaves of *Paraserianthes falcataria* are dried and bagged to be sold to roving buyers as fuel (Cruz 1994).

Selling point and transport

There are two selling points through which harvested trees or flitches are sold, i.e. farmgate and sawmiller points. In farmgate selling, the buyer comes to the farm, negotiates the price with the farmer and cuts the trees. In sawmiller point selling, the farmer cuts the trees and delivers the wood (processed or unprocessed) to the sawmiller.

Transport of cut logs from the farm to the nearest road is through hauling by cattle. From the road, the farmer gets a jeepney to take the logs to the sawmill. A one-way jeepney trip costs ₱ 700.00 (US$26.92).

Source of timber price information

The availability of market information such as price and demand is important to farmers' welfare. Poor access to market information can lead to exploitation by traders or middlemen (Carandang 1994). Claveria buyers are taking advantage of the farmers' lack of knowledge of the selling price of *Gmelina* and the exact measurements of standing timber or processed logs. In most cases, it is the sawmiller (Asiatic Corporation and traders) or the buyers, like the Pilipinas Kao (shampoo company) and PICOP, that dictate the price of *Gmelina*. Only 24% of the farmers interviewed reported that the price of *Gmelina* was determined by them.

Gmelina timber price and price fluctuation

The price of *Gmelina* timber or flitches varies depending on the point of sale (Table 8.2). Logs delivered to the sawmillers' gate are priced higher to cover transportation and handling costs.

Currently, harvested *Gmelina* trees are sold either as standing timber, with a price of around ₱ 375.00/tree at a minimum age of five years (depending on height and diameter), or as cut logs scaled on bdft basis at ₱ 3.50 (unprocessed). A standard price of ₱ 3.50/bdft is charged for the purposes of cutting and sawing (processing) standing timber.

Based on results from the interviews with farmers and sawmillers, there is some discrepancy on the price of trees between farmer and sawmiller. Sawmill operators reported a higher price paid (₱ 4.50/bdft) than the farmers reported receiving (₱ 3.50/bdft). The above mentioned prices are based on farmgate prices of cut, unprocessed logs scaled at bdft.

Table 8.2. Average annual farmgate and sawmillers' gate prices of *Gmelina* timber and flitches.

Form of timber	*Gmelina* price (₱/bdft)	
	Farmgate	Sawmillers' gate
Flitches	7–10.00	12.00
Unprocessed timber	3.50	4.50

Gmelina price fluctuates seasonally, with a higher farmgate price during the dry season (as high as ₱ 7.00/bdft of unprocessed logs) than during the wet season (₱ 3.50/bdft of unprocessed logs). These dry and wet season prices exclude processing costs (cutting and sawing from standing timber to squared log), because the buyers incur the cost of processing. The fluctuation in price of *Gmelina* is also influenced by market demand for *Gmelina*. There is a higher demand for timber for construction materials during the dry season. Another major factor affecting *Gmelina* price, is the accessibility of the farm to nearby roads. The farther the farm is from the road, the lower the farmgate price offered by the buyer, to cover the hauling and transport cost.

Price as related to volume

The price of *Gmelina* varies depending on the volume of logs sold. Selling *Gmelina* trees in large volumes is based on the area planted. This should be a minimum of 0.1 ha. A higher price can be obtained for trees sold in bulk. The price range of *Gmelina* trees sold by large volume is ₱ 7–8/bdft, compared to a price for individual trees of ₱ 3–5/bdft. Volume selling carries with it some negotiating power for the

farmer in terms of the price of trees. This may be misleading however because it is more likely that farmers get a lower revenue from volume selling due to underestimation of the total volume of trees harvested. The method practised in the area for estimating the volume of large numbers of trees is known as scaling, which is very crude and biased. The buyer counts the total number of trees in the area and then selects sample trees for girth measurement. Selection of the sample trees is biased towards the smaller ones. After measuring the girth of sample trees, the buyer subtracts 5 cm (2 inches) from the measured girth length to account for 'bark thickness'. From this average girth length, they compute, very crudely, the total volume. In some cases, if there are dead knots in the log, they discard the length with dead knot and start measuring the rest of the length of the log.

One reason why farmers prefer to cut trees for volume selling is that they can use the alley areas for growing cash crops while the trees are still in the initial stages of growth. This is not possible with selective cutting. On the other hand, the advantage of selling individually selected trees is that they only sell those trees which give them a good price while leaving small trees that can still develop to be sold for future needs. It is better to sell *Gmelina* by boardfoot because it is based on exact measurement and agreed price/bdft. Scaling is not exact and some buyers are not honest in the computation of the volume of trees harvested. One farmer preferred to sell the trees by contract marketing. In this mode of selling, there is a specific time agreed by both the farmer and buyer when the tree will be cut and sold.

Igorots and Kalanguya people of the Cordillera and Caraballo Mountains of Northern Philippines cut trees with inferior growth and disease to further enhance the growth of the forest cover following the technology of Timber Stand Improvement (TSI). Harvesting at the right tree age will result in good wood quality, and a better price can be negotiated by the farmers/foresters from the sale of the remaining trees.

Gmelina consumers

Sawmillers and traders account for 53%, while direct sale to end-users constitutes 47% of the buying market. End-users include Pilipinas Kao Co. for forklift production, farmers for tomato box production, electric post use, and neighbours for house building. The biggest buyer and processor of timber trees in the area, both for local and export markets, is the Asiatic Corporation at Cagayan de Oro City. Another company that buys trees is the Paper Industries Corporation of the Philippines (PICOP) which processes trees for pulp and fibre for paper. Private companies, like the Pilipinas Kao shampoo company, buy *Gmelina* tree slabs (cut-out finished logs with a dimension of 2.5 cm (1 inch) thickness and 90–120cm (3–4 ft) long for making forklift crates.

ECOLOGICAL BENEFITS

Planting *Gmelina* trees on farms not only brings long-term economic benefits but also ecological benefits in non-monetary terms. For example, the majority of farmers (76%) described cooler air in the farm due to the presence of trees. This is brought about by interception of light radiation by the emergent canopies of the *Gmelina* trees. Lesser light intensity penetrating the emergent canopy results in cooler air below the canopies.

Another very important ecological benefit obtained from *Gmelina* trees is the rapid litterfall which builds up the soil organic matter. *Gmelina* leaves, being thin and broad, decompose completely within 48 weeks (Florece 1996). *Gmelina* leaves have the fastest rate of decomposition when compared with Tectona grandis, Acacia auricoliformis, Antidesma ghaesembilla, and Piliostigma malabaricum species. Decomposition rates are positively correlated with nutrient content and negatively with lignin content (Florece 1996). The N content of *Gmelina* leaves is 2.25% (Mamicpic 1997). More than half of the interviewed Claveria farmers (65%) observed beneficial effects of decomposing *Gmelina* leaves on soil fertility.

Very closely related to litterfall and the presence of tree canopies in the farm, is the control of soil erosion. Leaf litter on the ground cushions the surface soil from direct impact of falling raindrops. Emergent canopies of trees also trap, and decrease, the intensity of the falling rain. Also, *Gmelina* trees planted as hedgerows along the contours of the slope serve to break the flow of water run-off. Altogether, these different phenomena result in effective control of soil erosion by *Gmelina* trees. More than half of the farmers (53%) report soil erosion control as one of the ecological benefits gained from planting *Gmelina* trees. In the Philippines, hedgerow intercropping technology is being advocated on sloping lands as a soil erosion control measure, and to promote sustainability in permanent cropping with minimum or no fertilizer input (Mercado et al. 1996).

The presence of tall trees in the farm is a very effective way to break strong winds. About 59% of farmers report wind breaks as one of the ecological benefits from *Gmelina* trees.

REVENUE FROM PLANTING *GMELINA* TREES AND FARMERS' FUTURE PLANS

The majority of farmers (60%) say that planting *Gmelina* trees is more profitable than growing annual crops like maize or rice. However, most of the farmers (70%) said that the income they received from selling trees was somewhat below their expectations. This appears to be a result of the lower prices offered by the buyers and

the inaccuracy of the scaling method used for estimating the volume of timber (when the tree is sold by volume).

In a cost-benefit analysis of a *Gmelina* hedgerow improved fallow system in Claveria, the cumulative net present value of *Gmelina* hedgerow system was found to be double that of the open-field maize farming system after two cycles of *Gmelina* growth (Chapter 11). The higher benefits obtained from the *Gmelina* hedgerow improved fallow system include revenues from *Gmelina* fuelwood and timber, animal related benefits such as draught power and liveweight gain, and maize yield.

Forty-one percent of the farmers are planning to increase their area devoted to *Gmelina* trees, while 29% said that their area planted to *Gmelina* will remain the same. A large group (29%) are planning to plant bagras (*Eucalyptus deglupta* Blume), another tree species recently introduced in Claveria, in preference to *Gmelina*. None of the interviewed farmers intend to reduce the area planted to trees.

Most farmers also plan to continue to cultivate annual crops like maize and cassava in between the trees in the first two years of *Gmelina* regrowth.

LESSONS LEARNT BY FARMERS FROM THEIR FIRST EXPERIENCE WITH TREE PLANTING AND HARVESTING

There are several lessons that farmers learned from the first cycle of *Gmelina* tree planting. In the future they intend to harvest *Gmelina* trees during the dry season, particularly the months of November and December, when the demand for *Gmelina* as a construction material is high. Most farmers intend to cut the trees at age seven to ten years in the succeeding cycles. This is because of a greater understanding that a larger volume of logs and better quality of wood can be harvested when trees are fully mature.

Hedgerow planting of *Gmelina* trees along contours has been seen by farmers as an effective system because of its ability to control soil erosion and the alley areas can be utilised for growing cash crops during the first 2 years of *Gmelina* growth. In the above system, the recommended annuals that can be intercropped with *Gmelina* are maize and cassava. Cassava has been found to not be very susceptible to light competition.

However, farmers have noticed that hedgerow planting has some negative effects such as shading of the alley crop and the destructive effect of *Gmelina*'s rooting system on the terraces particularly in narrow alley areas. In the long run, *Gmelina* roots have a matting effect during the second cycle or when a coppiced sibling has already developed into another tree (about 14–20 years). This matting effect limits the area explored by the rooting system of the cash crop, to absorb nutrients from the soil, resulting in low crop yield.

Future planting of *Gmelina* trees with 3¥ 4 m spacing (833 trees/ha) is recommended by the majority of Claveria farmers (76%), so that the trees can grow to their optimum size. This is the same tree spacing as followed by farmers from Cikaramas, West Java (Gunawan et al. 1996a). A wider spacing of 5×5 m would be better according to some of the farmers interviewed, but this results in a much lower plant density, around 400 trees/ha .

Farmers plan to prune for the first one to two years. Farmers' main criterion for pruning is height, not age of tree, i.e. they prune trees so they reach a height of 4.2 m (14 feet). Farmers use bamboo ladders or long-stem sickles so that they can prune the *Gmelina* branches when they grow taller.

When the *Gmelina* tree canopies started to close, the farmers discovered that planting of annual crops was no longer feasible. Natural vegetation species can then be allowed to grow, in which the livestock can graze. Other farmers in the Asian region have integrated livestock into the tree/crop combination so that there is added income from the areas utilised for animal purposes (Gintings and Lai 1994).

SAWMILL OPERATOR INTERVIEWS

Some difficulty in the sawmill interviews was encountered because sawmillers thought that the members of the surveying team were part of the government's tax unit or the evaluation team of the DENR. Sawmillers were reluctant to give the survey team information regarding *Gmelina* tree production, because of the possible repercussions or tax that they would have to pay the government. This would mean possible loss of income on their part.

Most of the sawmillers located near Cagayan de Oro City are processing primarily wood fibre such as falcata, lawa'an, mahogany, acacia, etc. The primary mover of wood and its products is Asiatic Corporation, the biggest wood processing plant in Cagayan de Oro, which controls wood prices in the region. Although timber prices fluctuate, due to supply and demand, the standard price paid by Asiatic Corporation for *Gmelina* trees with a minimum diameter of 60 cm (24 in) and 2.4 m (8 ft) height is ₱ 1200/m^3 or ₱ 4/bdft. Other sawmill operators, however report a higher buying price of ₱ 1700–2000/m^3 for *Gmelina* logs.

There are three categories of wood products from *Gmelina*:

1. Primary wood which is sent to Taiwan or sold locally for furniture production or construction materials;
2. Secondary cut logs which are used for the production of forklift crates and tomato boxes; and

3. By-products, such as wood bark, which are sold to bakery owners as fuelwood, and sawdust for domestic fuel purposes.

There is some discrepancy in terms of prices paid for *Gmelina* trees sold by farmers to sawmillers. Sawmillers say they are paying ₱ 4 to 5/bdft at the farmgate while farmers claim they are only paid ₱ 3.50/bdft. If the trees are delivered to the sawmillers area of work, they will pay ₱ 8.00/bdft for the trees. The above mentioned prices are good only for trees which satisfy the required length and width 2.4 m × 0.3 m (8 × 1 ft) and have reached a minimum age of 7 years for primary processing. A lesser price is paid for smaller, younger trees. Prices for processing logs are based on the size of the tree with ₱ 0.90, 0.80, and 0.70 charged for 2.4 m, 1.8 m and 1.5 m (8, 6 and 5 foot) logs.

Taiwan is a major international market for processed *Gmelina* trees. Sawmillers are secretive about the selling price of *Gmelina* trees exported to Taiwan. The prices of processed *Gmelina* trees sold at Cagayan de Oro City for furniture-making range from ₱ 13.00–14.00/bdft. The most promising market of processed *Gmelina* trees is for the manufacture of forklift crates used by large companies such as Asia Brewery, Pepsi Cola , Coca Cola Bottling Phils. and Pilipinas Kao. These companies pay ₱ 4.62/bdft.

With the growing number of farmers planting *Gmelina* trees, there will be a need for more processing facilities which can handle larger volumes of *Gmelina* trees for local markets. There has been an increase of 2 sawmills per year in the area since 1988 but most of these sawmills have started to diversify their operations to process not just *Gmelina* but also other trees, to cater for local and international markets.

The increase in the number of sawmills processing *Gmelina* trees is beneficial to the farmers growing *Gmelina* trees. The farmers will have better opportunities to fetch a higher price for their trees because of competition between the sawmillers. Farmers can choose among prospective buyers or sawmillers to find the one who will offer them a much higher revenue for their *Gmelina* trees. This is consistent with the sawmillers' reports that there has been an increase in the price of *Gmelina* trees of about 10–20% each year for several years.

CONCLUSIONS

The first significant harvesting of *Gmelina* trees in Claveria was recent ly undertaken. Prices and revenues obtained from this initial harvest were quantified via a survey of farmers and sawmillers. Most farmers, while expressing some dissatisfaction with prices received for their tree products, plan to maintain, or increase, their tree planting in the future. Planting of *Gmelina* trees in smallholder farms brings additional income to farmers and has the potential to improve their economic situation, and environmental quality. The production and marketing system operating at Claveria was described.

An effective information dissemination system within the community would help keep farmers well informed about the current prices and demand for timber products. This seems to be a source of friction between buyers and sellers and has led to some grower dissatisfaction.

Gmelina planting density seems high, and this phenomenon of (apparently) excessive tree planting densities by smallholders has been observed elsewhere in Asia. A greater understanding of smallholders' rationale in this regard might be enlightening and valuable.

SECTION 3

MODELLING TREE-BASED AND OTHER HEDGEROW FARMING SYSTEMS

Most chapters in the remainder of this report involve modelling of smallholder upland farms on *Imperata* grasslands from a perspective of the possible introduction of trees, shrubs or grasses.

In Section 3 a range of tree-based and hedgerow interventions is examined. In subsequent sections, various extensions to these analyses are undertaken. The role of livestock in relation to tree-based and hedgerow farming systems is examined in Section 4, while fire risk and carbon sequestration in relation to tree-growing on *Imperata* grassland are analysed in Section 5.

9 *Gliricidia*, Napier and Natural Vegetation Hedgerows

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TRADITIONAL SHIFTING CULTIVATION, or slash-and-burn agriculture, is only sustainable with long fallow periods. Increased population growth in upland areas of Southeast Asia has meant that more forest land is being cleared for agriculture (Garrity 1993), and the fallow period is being shortened (Conelly 1992; Brady 1996). Shortening of the fallow period results in reduced soil fertility and increased soil erosion. This has a compounding effect — the immediate reduction in yields and economic returns causes smallholders to further intensify their cultivation (Chapter 2). Annual area cropped tends to remain relatively constant, even when total available land area decreases. With the fallow lengths prevailing in most of the uplands today, shifting cultivation is not sustainable in either economic or biological (environmental) terms (Chapter 2). This is causing policymakers and research organisations to encourage smallholders to adopt alternative farming systems which are more sustainable.

One such farming system that has received considerable attention is hedgerow intercropping. In its conventional form, this involves the cultivation of annual crops between contoured hedgerows of perennial shrub or tree species, usually legumes (Kang and Wilson 1987). Hedgerow intercropping with leguminous shrubs can significantly reduce soil loss and recycle nitrogen within annual cropping systems. Hedgerow intercropping has precursors in indigenous farming systems, and the technology does not involve concepts which are unfamiliar to upland farmers. Costs of establishment and maintenance are less than those required for structural technologies, such as bench terraces, which have a similar capacity to reduce soil loss.

Significant resources have been committed to research and extension of hedgerow intercropping in the Philippine uplands by domestic and international agencies. Many of these organisations have facilitated the adoption of hedgerow intercropping through training and subsidies, for establishment and maintenance during the life of extension projects. Despite the resources committed to research and extension, adoption of hedgerow intercropping by upland farmers has been sporadic and transient, rarely continuing once external support is withdrawn. Persistent adoption has been limited to modified versions of the technology, including natural vegetation and grass strips. By adopting natural vegetation or grass strips, farmers forego the potential nitrogen contribution of leguminous shrubs. However, these modified versions of hedgerow intercropping adopted by farmers require less labour to establish and maintain than hedgerow intercropping with shrub legumes. In this report, the word 'hedgerow' is defined broadly to include grass strips, although grass strips may not, strictly speaking, be 'hedgerows'.

The evolution of low cost farmer adaptations demonstrates that economic viability has been an important consideration in deciding whether to adopt hedgerow intercropping. Focusing on technologies that are economically viable for farmers could make research and extension of soil conservation in the Philippine uplands more effective and efficient.

Cost-benefit analysis can be used to assess whether the costs of establishing and maintaining hedgerow intercropping are offset by the returns from sustained or greater crop yields. Cost-benefit analysis is a technique for comparing the stream of net benefits produced over time by competing investment opportunities, in this case traditional methods of maize farming relative to hedgerow intercropping. In this chapter, cost-benefit analysis is used to compare the economic returns from traditional open-field maize farming with the returns from hedgerow intercropping of maize with leguminous shrub hedgerows, natural vegetation strips and grass strips. SCUAF Version 2 is used to predict the effect of erosion on maize yields.

METHODOLOGY

The overall approach of bioeconomic modelling consists of two parts: the SCUAF model, which calculates farm outputs (crop and tree yield), based on climate and site (including soil) characteristics; and, a cost-benefit analysis spreadsheet (Fig. 1.1 in the introduction). The latter takes the output from SCUAF, plus economic data on input/output levels and prices. Key informant surveys with experienced maize farmers were used to estimate the cost of maize farming (Nelson et al. 1998).

The SCUAF model is parameterised to Compact, a research station near Claveria in Mindañao, the Philippines (Nelson et al. 1998). The Compact research station is managed by the International Centre for Research into Agroforestry (ICRAF) and was established primarily to trial hedgerow intercropping regimes. Biophysical data, obtained from field trials at Compact were used in the parameterisation process (Agus 1994; Nelson et al. 1997).

The net present value was calculated as described in Chapter 1. Net returns from maize farming are expressed in Philippine Pesos (₱). A twenty-five year period was chosen for the cost-benefit analysis. Each scenario of the cost-benefit analysis is presented graphically as the net present value from each farming method. The advantage of graphing net present value is that it reveals the sensitivity of the analysis to the choice of planning horizon, and can be used to display the influence of major assumptions on the ranking of the various farming methods.

Future benefits and costs are discounted to capture the preference that individuals express for present over future consumption. To assess the economic incentives for the adoption of hedgerow intercropping, the appropriate perspective for cost-benefit analysis is that of individual upland farmers.

SCUAF simulations

Two variants of open-field farming were simulated using SCUAF Version 2 — continuous and fallow (Table 9.1). In densely populated upland areas, most arable land has been under constant use to provide crops for subsistence and sale. Simulating continuous open-field farming without fallow is, in these cases, an accurate model of farmer conditions. Continuous open-field farming also provides a useful comparison with hedgerow intercropping, because hedgerow intercropping has usually been promoted as not requiring fallow years.

In more remote communities land may be relatively abundant, and farmers are able to rotate maize cropping between two or three fields. The area cropped each year is then limited by the availability of farm family labour. For comparison with continuous cropping of a single hectare of land, it is assumed that farmers practising field rotation have two fields, each one ha in size, and that the availability of labour permits one ha to be cropped each year. Farmers are assumed to rotate the two fields alternately through two years of maize cropping and two years of fallow. The two years of fallow are assumed to be dominated by *Imperata cylindrica*, and provide no direct economic returns to the farmer. The analysis of fallow farming is therefore based on two hectares of land, rather than the single ha considered for the other farming methods.

Table 9.1. Description of farming methods simulated using SCUAF Version 2

Method of farming	Description
Continuous open-field farming	Repeated cropping of two maize crops/year in a field without hedgerows.
Fallow open-field farming	Two years of cropping two maize crops/year in a field without hedgerows, followed by two years during which the field is left to revert to shrubby grassland (*Imperata cylindrica*).
Natural vegetation strips	Repeated cropping of two maize crops/year within the alleys formed by contour strips of natural vegetation.
Grass strips	Repeated cropping of two maize crops/year within the alleys formed by contour strips of napier grass (*Pennisetum purpureum*).
Gliricidia hedgerows	Repeated cropping of two maize crops/year within the alleys formed by contour hedgerows of *Gliricidia sepium*.

Three types of hedgerow intercropping are simulated using SCUAF Version 2 over 25 years: *Gliricidia* hedgerows, natural vegetation strips and grass strips (Table 9.1). Hedgerows occupy up to 15% of the total area, i.e. for a 1 ha plot 0.85 ha is occupied by the crop and 0.15 ha by the hedgerow. Grass cuttings were assumed to be retained in the SCUAF modelling to simulate the potential of grass strips to sustain maize yields relative to *Gliricidia* hedgerows and natural vegetation strips.

Hedgerows were modelled over five years, reflecting the lifecycle observed in Claveria. Within the model, hedgerows are established in the first year of the five-year hedgerow lifecycle. In the second and later cycles, 50% infill replanting or replacement is assumed. *Gliricidia* is assumed to produce no prunings in the first year of each cycle as hedgerows establish. Natural vegetation and grass strips are assumed to produce low amounts of biomass in years of establishment. A period of vigorous growth is assumed in years two to four of each cycle, during which hedgerows produce high levels of biomass. Biomass production is assumed to fall in the fifth year of each cycle as the hedgerows senesce (Table 9.2).

Table 9.2. Rate of prunings added to hedgerow intercropping in the SCUAF model

	Year 1	Years 2–4	Year 5
		(kg/ha/year)	
Gliricidia	0	350	100
Napier grass	500	1000	500
Natural vegetation	100	200	100

Nitrogen fertilizer is applied to maize at the rate used in the Compact trials, i.e. 60 kg/ha of elemental nitrogen applied per crop, as urea. SCUAF does not model soil phosphorus or potassium balances, so phosphorus and potassium fertilizers were excluded from the simulations and economic analysis.

Economic data

Economic data to estimate the price of maize and the costs of each farming method were obtained through interviews with farmers in the community of Claveria. Six maize farmers were selected with at least ten years experience of traditional open-field maize farming. For hedgerow intercropping, groups of six farmers were selected with three to five years experience using *Gliricidia* hedgerows, natural vegetation strips or grass strips, to farm maize.

The pruning regimes adopted in the cost-benefit analysis reflect changes in biomass production over each hedgerow lifecycle. It is assumed that *Gliricidia* hedgerows require no pruning in years of establishment and re-establishment, two prunings during each maize crop in years two to four of each cycle, and one pruning per maize crop in years of hedgerow senescence. Natural vegetation strips are assumed to require two prunings per maize crop in all years. Grass strips are assumed to require two prunings in all years except years two to four, for which three prunings per maize crop are assumed.

The market wage reflects the opportunity cost of labour for adult males during seasonal periods of intense farm activity. Labour is valued at two-thirds of the market wage reported by farmers, to reflect the lower opportunity cost of labour in slack periods and for less productive family members.

Two maize price scenarios are used to assess the effect of relevant policy options on the economic viability of removing trade protection from maize imports. David (1996) demonstrated that restrictions on maize imports have caused nominal protection rates to be considerably greater than published tariff rates. The warehouse price of maize in Manila exceeded the border price by an average of 76% between 1990 and 1994. The adjusted farmgate price of maize /kg after removing trade protection, P_{F}, is given by:

$$P_{F}, = \frac{P_W}{1.76} - C_M$$

where

P_W is the warehouse price of maize in Manila, and C_M is the marketing costs.

Two discount rates were derived for this analysis. A real discount rate of 25% was derived from the opportunity cost of capital to farmers. Farmers were asked to report the known cost of capital based on recent lending, or to estimate the interest charges for borrowing a nominal amount based on their knowledge of credit markets. Traders supplying inputs to farmers on credit were asked to give details of the price premium, net of marketing costs, that they received on resale of farmers' produce. A lower discount rate of 10% was used to reflect the potential of government sponsored farmer cooperatives to reduce the cost of capital to upland farmers.

RESULTS

SCUAF simulations

Predicted maize yields decline under all five farming methods (Fig. 9.1). This occurs most rapidly under continuous and fallow open-field farming. Maize yields predicted from fallow open-field farming are only slightly greater than those from continuous open-field farming in the second year following each fallow, indicating that two year fallows dominated by *Imperata* are of little benefit for sustaining crop yields. Maize yields from fallow open-field farming are depressed in the first year of cropping following each fallow because of immobilisation of nitrogen during humification of *Imperata* residues. All three types of hedgerow intercropping sustain yields at higher levels than open-field farming in the long term. *Gliricidia* hedgerows sustain maize yields at slightly higher levels than natural vegetation strips or grass strips.

The predicted pattern of maize yields is explained by the rates of soil loss predicted under the various farming methods, and the associated decline in soil quality (Fig.9.2). Predicted erosion from continuous open-field farming averages 25.0 t/ha/year, close to the rate of 26.6 t/ha/year measured between 1991 and 1994 from continuous open-field farming at Compact. Predicted erosion from fallow open-field farming is similar during years of cropping at 22.7 t/ha/year. Fallow farming reduces erosion to low levels in the years of fallow, because of the surface cover provided by *Imperata* grass.

Hedgerow intercropping significantly reduces predicted soil loss compared to continuous open-field farming, because of the influence of the tree and grass components on surface cover (Fig. 9.2). Predicted erosion averaged 3.3, 7.0 and 6.4 t/ha/year from *Gliricidia* hedgerows, natural vegetation strips and grass strips respectively. Measured erosion from natural vegetation strips at Compact averaged 6.4 t/ha/year between 1991 and 1994.

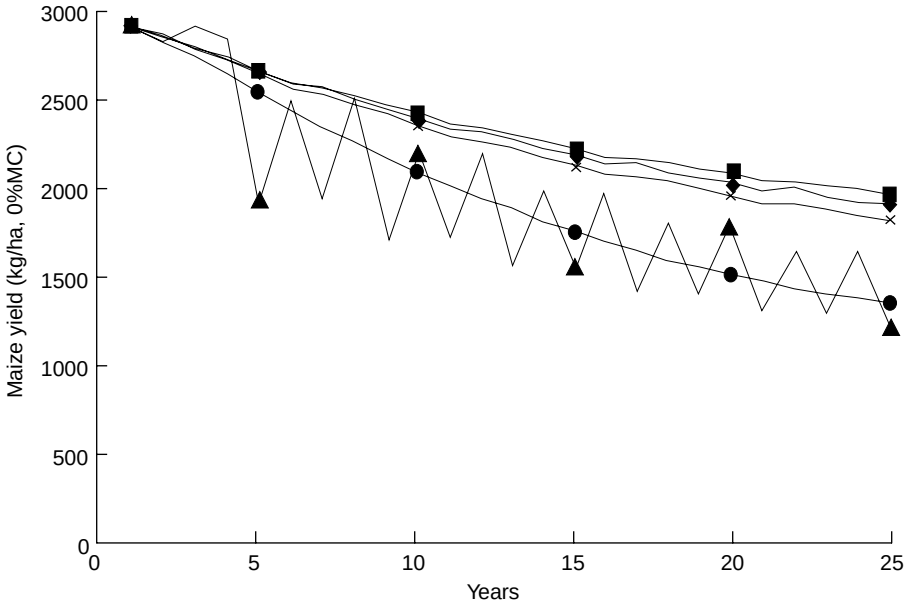

Figure 9.1. Maize yields predicted using SCUAF (The fallow rotation system refers to 2 ha of available land, with 1 ha of maize cropped annually) ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

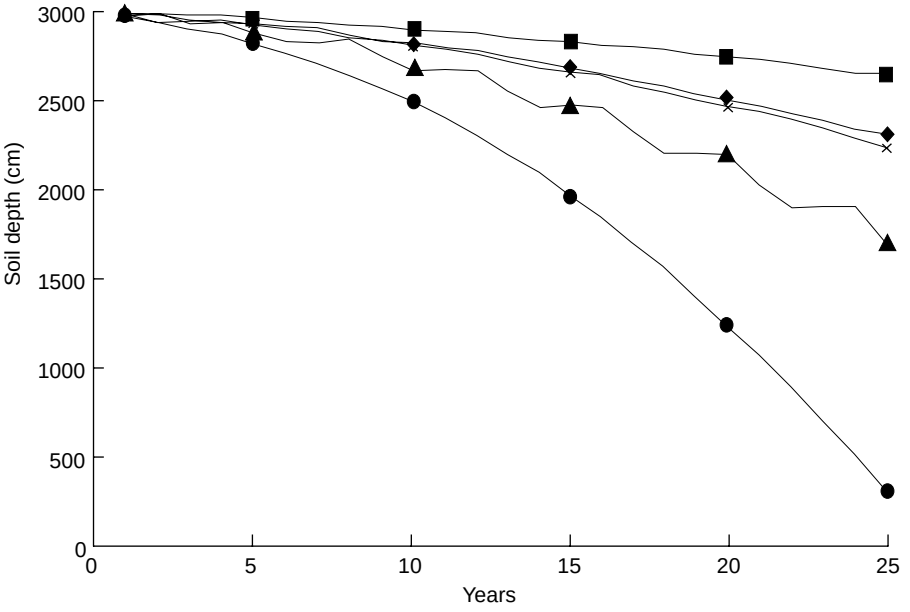

Figure 9.2. Soil depth predicted using SCUAF ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

Erosion differentially removes the finer, most fertile fractions of topsoil. Relatively rapid erosion causes predicted plant available mineral nitrogen to decline significantly under continuous and fallow open-field farming over 25 years (Fig. 9.3). The nitrogen content of organic matter contributed by *Imperata* fallows has little effect on the predicted level of soil nitrogen available to maize crops under open-field farming. Available nitrogen is predicted to be low during the *Imperata* grass fallows because no inorganic fertilizer is applied.

Predicted plant available mineral nitrogen declines more slowly under the three types of hedgerow intercropping than under continuous and fallow open-field farming (Fig. 9.3). Predicted soil nitrogen is highest for *Gliricidia* hedgerows, because of the nitrogen and organic matter cycled through hedgerow prunings. The small legume component of natural vegetation strips produces slightly higher predicted soil nitrogen levels than grass strips. The five-year hedgerow lifecycle produces a cyclical pattern in the decline of soil mineral nitrogen under the three hedgerow intercropping treatments.

Organic carbon is an indicator of soil quality, because of its correlation with soil nutrient and physical status. Predicted soil labile carbon declines significantly under continuous and fallow open-field farming. The amount of organic matter accumulating during the *Imperata* fallows is small, and has little effect on predicted soil labile carbon levels under fallow farming.

Predicted soil labile carbon levels decline slowly under hedgerow intercropping compared to open-field farming (Fig. 9.4). The predicted decline in soil labile carbon under hedgerow intercropping is influenced by an interaction of soil erosion and organic matter recycling. Soil labile carbon is sustained under *Gliricidia* hedgerows because soil loss is low while the amount of organic matter recycled is high. Soil labile carbon declines more rapidly under natural vegetation strips compared to *Gliricidia* hedgerows because of higher rates of soil loss. Grass strips sustain labile soil carbon at levels similar to those under *Gliricidia* hedgerows, because high rates of biomass production offset organic matter lost through erosion.

Economic data

The average farmgate prices of maize reported by farmers were ₱ 4.60/kg in the wet season, and ₱ 5.50/kg in the dry season. Sayre et al. (1992) reported that marketing costs to Manila for maize originating in Bukidnon, a province adjacent to Misamis Oriental where Claveria is located, were ₱ 1.60/kg in 1992, equivalent to ₱ 1.80/kg in 1994 prices. Using this marketing cost, removing trade protection from maize imports would reduce the farmgate price of maize from ₱ 4.60 to ₱ 1.80/kg in the wet season, and from ₱ 5.50 to ₱ 2.30/kg in the dry season. Improvements in transport and marketing infrastructure that halved marketing costs would increase

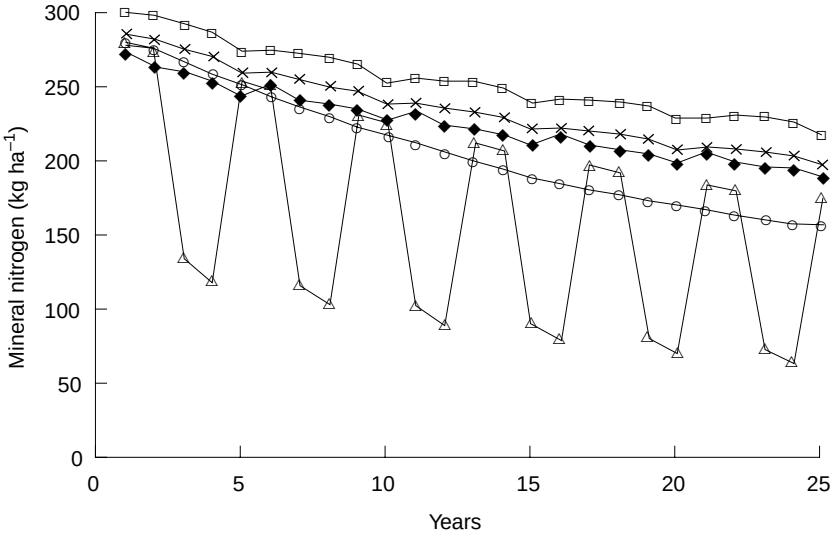

Figure 9.3. Available mineral nitrogen predicted using SCUAF. ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

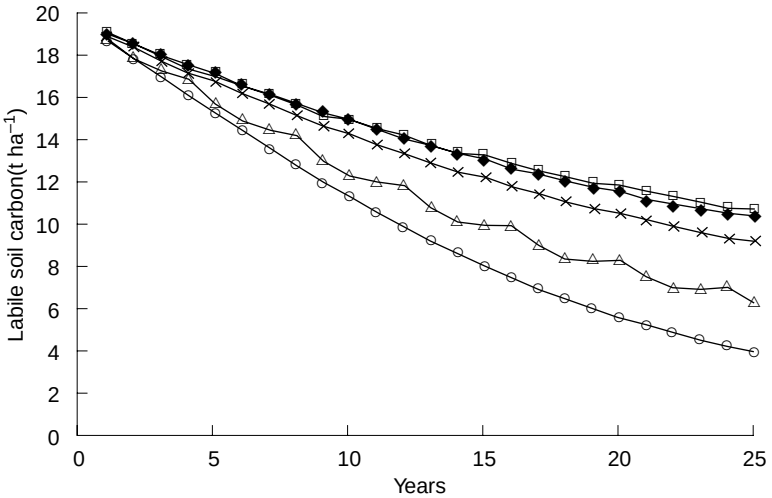

Figure 9.4. Labile soil carbon predicted using SCUAF. ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

the farmgate price of maize to ₱ 5.50/kg in the wet season and ₱ 6.40/kg in the dry season.

Labour is the most important input reported by farmers. There are significant differences in the labour required to establish the different kinds of hedgerow. Contour strips of natural vegetation are relatively easy to lay out, and no bund construction or planting of cuttings is required. Only a small amount of animal power is required to plough contour strips for *Gliricidia* hedgerows, however *Gliricidia* cuttings are woody and difficult to cut and carry from widely dispersed shrubs. Labour to lay out and construct bunds for grass strips is significant, and requires draught animal power. Grass is herbaceous and easy to cut and carry, and large numbers of cuttings can be obtained from small areas of grass in and around each farm.

Total pruning labour per maize crop is similar for the different types of hedgerow (Table 9.3). *Gliricidia* grows slowly compared to natural vegetation or grass, but can produce woody stems and be more difficult to prune. *Gliricidia* hedgerows require seven days per hectare to prune after the dry season fallow, when woody stems have developed, compared to three days for subsequent prunings. The amount of labour required to prune natural vegetation strips varies with species composition, and averages four days per hectare for each pruning. Grass strips only require three days per hectare for each pruning, but are pruned frequently during periods of rapid growth.

The median wage rate for farm labour reported by farmers in Claveria was ₱ 60 per day, including in-kind payments in the form of food. The opportunity cost of family labour was estimated, via reference to survey results (Nelson et al. 1997), to be lower than this, at around two-thirds of the market wage, or ₱ 40 per day.

The average price of seed for the local variety of maize, Tinigib, was ₱ 6.50/kg, and the seed was usually obtained from neighbouring farms, incurring negligible transport costs. Urea fertilizer was bought at an average price of ₱ 6.50/kg, with an average transport cost of ₱ 40 per crop.

Table 9.3. Median of labour estimates

Operation	Open-field farming		*Gliricidia* hedgerows		Natural vegetation strips		Grass strips	
	MD ha^{-1}	MAD ha^{-1}	MD ha^{-1}	MAD ha^{-1}	MD ha^{-1}	MAD ha^{-1}	MD ha^{-1}	MAD ha^{-1}
Hedgerow establishment								
Construct bunds/layout hedgerows	–	–	13	2	4	–	13	4
Collect and plant cuttings	–	–	35	–	–	–	14	–
Hedgerow weeding (× 5)	–	–	47	–	–	–	–	–
Hedgerow establishment (total)	–	–	95	2	4	–	27	4
Wet season								
Land preparation	–	15	–	19	–	21	–	22
Maize sowing and fertilising at planting	7	–	7	–	5	–	4	–
Replanting	2	–	2	–	2	–	2	–
Nitrogen fertilizer	8	–	6	–	6	–	4	–
Interrow weeding	–	4	–	4	–	3	–	5
Hand weeding	17	–	15	–	16	–	11	–
Hedgerow pruning[a]	–	–	10	–	8	–	9	–
Maize harvesting	8	–	9	–	11	–	5	–
Postharvest processing	12	–	16	–	19	–	17	–
West season total	54	19	66	24	68	25	52	27
Dry season								
Land preparation	–	10	–	10	–	12	–	13
Maize sowing and fertilising at planting	7	–	7	–	5	–	4	–
Replanting	2	–	2	–	2	–	2	–
Nitrogen fertilizer	8	–	6	–	6	–	4	–
Interrow weeding	–	4	–	4	–	3	–	5
Hand weeding	15	–	11	–	12	–	11	–
Hedgerow pruning[a]	–	–	7	–	8	–	9	–
Maize harvesting	6	–	5	–	11	–	4	–
Postharvest processing	11	–	12	–	12	–	11	–
Dry season total	49	13	49	14	55	15	45	18
Annual total	**103**	**32**	**210**	**39**	**127**	**40**	**125**	**49**

[a] Assumes two prunings per maize crop for *Gliricidia* hedgerows and natural vegetation strips, and three for grass strips.

Cost:benefit analysis

Predicted annual net returns from continuous and fallow open-field farming decline as erosion reduces soil productivity (Fig. 9.5). Declining maize yields under open-field farming produce negative net annual returns after 15–20 years of cropping. Net returns from all three types of hedgerow intercropping are less than those from open-field farming in the first year following establishment. As cropping proceeds, lower erosion and higher organic matter cycling under hedgerow intercropping sustains higher net returns than open-field farming. A five-year cycle in the annual net returns from *Gliricidia* hedgerows and grass strips is due to the cost of establishment and infill replanting.

With a discount rate of 25%, net present value predicted from the alternative farming methods is similar over 25 years (Fig. 9.6). Continuous and fallow open-field farming return slightly greater net present value for around seven to ten years of cropping. Over longer periods, *Gliricidia* hedgerows produce the lowest net present value because of high establishment costs. Sustained yields offset low establishment costs from natural vegetation strips, producing returns similar to fallow open-field farming in the long term. A combination of sustained maize yields and relatively low establishment costs produces higher net present value from grass strips than continuous open-field farming after 10 years of cropping.

Reducing the discount rate to 10% has little effect on the ranking of the various farming methods in the first five years of cropping (Fig. 9.7). Over longer periods, the lower discount rate increases the present value of productivity losses under open-field farming and the value of sustained future yields from hedgerow intercropping. The net present value of maize farming with *Gliricidia* hedgerows exceeds that of continuous and fallow open-field farming after thirteen and nine years of cropping. Economic returns from natural vegetation strips exceed those from continuous and fallow open-field farming after fourteen and nine years of cropping. Grass strips dominate continuous and fallow open-field farming, in terms of net present value, after seven years of cropping.

Removing trade protection from maize has a dramatic effect on maize prices and net present value from maize farming (Fig. 9.8). In this case neither open-field farming nor hedgerow intercropping return a positive net present value.

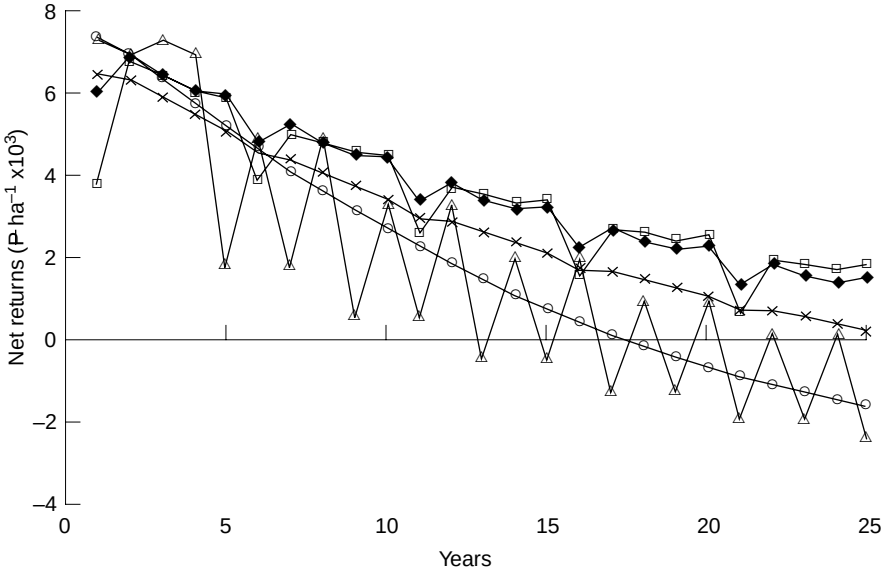

Figure 9.5. Annual net returns from maize farming. ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

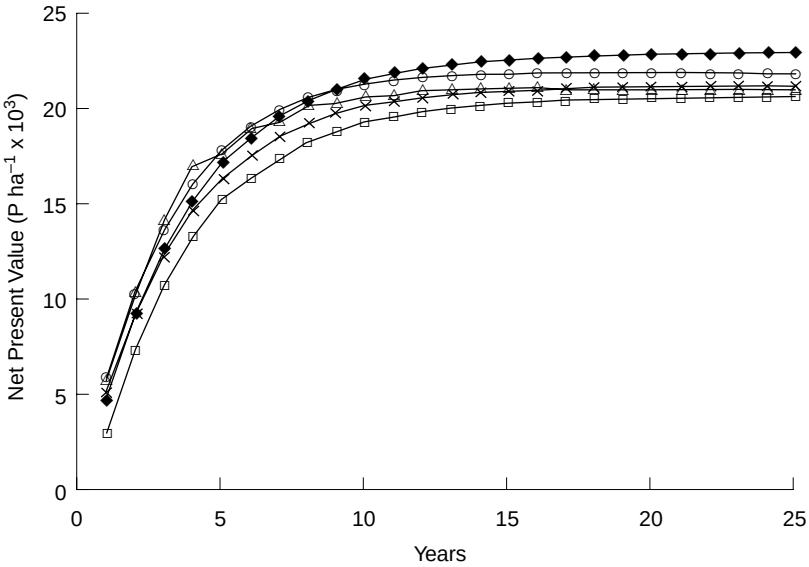

Figure 9.6. Net present value of maize farming, discount rate of 25%, 25-year time horizon. ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

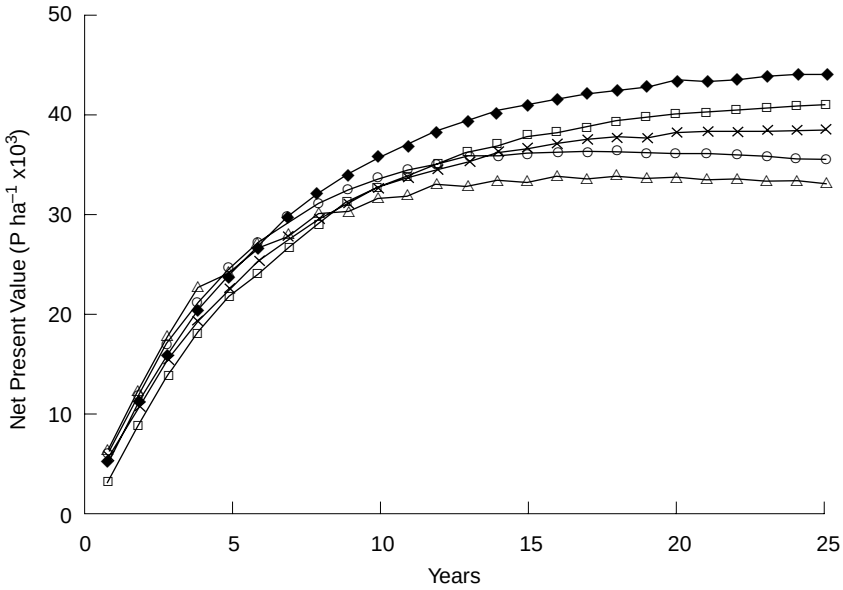

Figure 9.7. Net present value of maize farming, discount rate of 10%, 25-year time horizon. ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

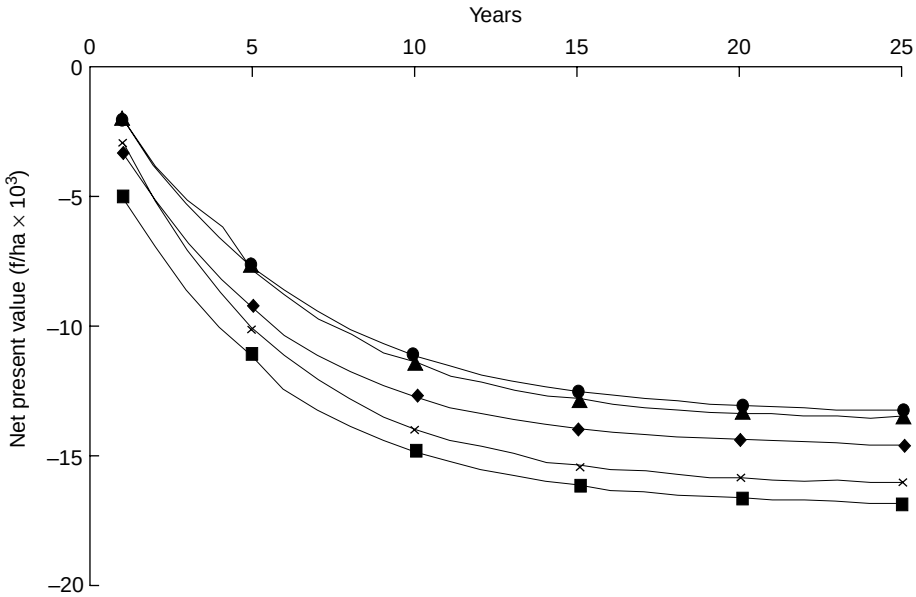

Figure 9.8. Net present value following removal of trade protection on maize imports, discount rate of 25%, 25 year time horizon ● = Open-field; ■ = *Gliricidia*; ◆ = Grass; ▲ = Fallow; X = Natural vegetation

Implications for adoption

The pattern of economic incentives revealed in the cost-benefit analysis helps to explain adoption of the various farming methods in Claveria. Continuous and fallow open-field farming are economically attractive to farmers who have limited planning horizons of 5–10 years. The planning horizons of upland farmers have been constrained by insecure land tenure, which has reduced the confidence with which farmers expect to realise long-term economic returns from land improvements. Establishment costs have been a significant disincentive for these farmers with limited planning horizons to adopt hedgerow intercropping. Natural vegetation and grass strips provide a means for farmers to reduce soil loss without the high establishment costs of leguminous shrub hedgerows.

With long planning horizons of 10 years or more, hedgerow intercropping has the potential to increase economic returns from maize farming compared to open-field farming, by reducing soil erosion and contributing nitrogen. However, the soils of Claveria are of relatively low erodability, so this potential positive impact of hedgerows is reduced. High discount rates reduce the present value to farmers of long-term productivity losses from open-field farming. The benefits from hedgerow intercropping are not sufficient to compensate farmers for establishment and maintenance costs.

Gliricidia hedgerows are the least economically attractive form of hedgerow intercropping to farmers. A small number of farmers adopted *Gliricidia* hedgerows in the late 1980s after the technology was introduced by the International Rice Research Institute. By early 1995, all but one of these farmers had abandoned their hedgerows or converted them to natural vegetation or grass strips.

A number of farmers in Claveria are using natural vegetation strips (Hafner, pers. comm.). The popularity of natural vegetation strips is due to their low cost of establishment relative to the cost of open-field farming. Farmers reduce the cost of establishing natural vegetation strips by identifying contour intervals by eye rather than using an A-frame (Nelson et al. 1996).

A small number of farmers in the community of Claveria intercrop maize between strips of various grass species, mainly napier grass. The labour involved in bund construction is a disincentive to establish grass strips compared to open-field farming. However, grass strips are attractive to farmers because of their potential to produce mulch or fodder. Of the six adopters of grass strips interviewed, three reported using grass cuttings as fodder.

Policy analysis

Direct subsidies to promote hedgerow establishment were not considered in this analysis. Once-off subsidies have universally failed to achieve lasting adoption of hedgerow intercropping in the Philippine uplands, because their incidence on farmer's economic incentives is temporary. Hedgerow intercropping is a biological soil conservation technology and requires re-establishment every few years. To achieve lasting adoption, the economic incentives to farmers need to be modified permanently so that re-establishing hedgerows continues to be economically attractive.

Government regulation of interest rates has severely restricted the supply of rural credit in the Philippines (Tolentino 1991). Upland farmers have not been able to access rationed capital in formal credit markets because their informal land tenure has not been accepted as collateral by banking institutions. Restricted supply, information asymmetries, and the high risks involved in agricultural production, have meant that upland farmers have faced very high costs of credit from money lenders. The most common type of informal cash credit in the Philippines has been the 'five/six' arrangement, with annualised interest rates of around 120%. In most upland areas, credit has been linked to crop marketing as a substitute for collateral, significantly reducing the cost of capital below the interest charges of money lenders. Farmer cooperatives have had potential to reduce the cost of capital below the cost of interlinked credit. However, the full cost of cooperative credit has been similar to the cost of interlinked credit because rationing has imposed significant transaction costs.

Improving the efficiency of rural credit markets has potential to improve the long-term economic viability of hedgerow intercropping relative to open-field farming by reducing the cost of capital and farmers' discount rates. Expansion of the existing network of farmers' cooperatives may reduce the cost of capital to farmers if transaction costs are reduced. Secure land tenure is required to encourage farmers to consider the potential of hedgerow intercropping to provide sustained economic returns in the long term.

Maize has been the only agricultural commodity in the Philippines to have received consistent trade protection in real terms since the 1970s (Intal and Power 1990). For other agricultural commodities, trade protection has been insufficient to offset negative protection brought about by consistent overvaluation of the peso. Trade protection of maize was designed to promote domestic self-sufficiency in livestock feeds for the pork and poultry industries. Trade protection has contributed to a dramatic expansion of maize production in upland areas, most of which erode rapidly under intensive agriculture. Removing trade protection could be one of the most effective soil conservation strategies available to the Philippine government, by

reducing incentives to produce maize relative to less erosive crops such as paddy rice (where feasible), coconut, fruit trees and woodlots. However, significant reductions in the domestic price of maize are likely to have drastic implications for the welfare of upland communities in the short term.

The estimated opportunity cost of labour of two-thirds of the agricultural wage reported by farmers was an approximation. Detailed data on the demand and supply of labour would be required to accurately determine the opportunity cost of farmers' labour. While macroeconomic policies favouring capital intensive manufacturing have caused considerable underemployment, rural labour markets in the Philippines have been competitive (Reyes 1991). However, the agricultural wage has been determined in seasonal periods of intense farm activity and has overstated the opportunity cost of labour in slack periods. The market wage rate has applied most directly to adult males, and may therefore overstate the opportunity cost of labour for less productive family members.

Limitations of the analysis

SCUAF Version 2 is a relatively simple model and there are some important components of the cropping system that are not considered, including soil phosphorus. Garrity (1993, 1994b) and Palm (1995) have reported that on strongly acid soils, such as those of Claveria, phosphorus may be more limiting to the sustainability of hedgerow intercropping than nitrogen. However, farmers in Claveria apply significant amounts of phosphorus to the soil, therefore this issue may not be significant.

The cost-benefit analysis presented in this paper was both static and deterministic. A stochastic version was prepared by Nelson (1996), enabling, a risk and sensitivity analysis of parameters.

CONCLUSION

Traditional methods of open-field maize farming are economically attractive to upland farmers with limited planning horizons. For farmers with longer planning horizons and moderate interest rates, hedgerow intercropping has potential to sustain maize yields by reducing soil erosion and contributing nitrogen. However, the benefits of hedgerow intercropping are often not realised rapidly enough to compensate farmers for establishment and maintenance costs. Natural vegetation and grass strips, with their lower establishment costs, are more economically attractive to farmers compared to hedgerow intercropping with shrub legumes.

High discount rates and insecure land tenure reduce the value to farmers of sustained economic returns from hedgerow intercropping. Lowering the cost of capital may reduce farmers' discount rates, improving the long-term economic viability of low cost forms of hedgerow intercropping such as natural vegetation and grass strips. However, lowering farmers' discount rates is unlikely to encourage adoption unless secure land tenure is provided to extend farmers' planning horizons.

At the time of writing the exchange rates was $A1.00 = ₱ 22.00 or US$1.00 = ₱ 34.00

10 Estimating the On-site Costs of Soil Erosion in Hedgerow Systems: The Replacement Cost Approach

CANESIO PREDO, PETER GRIST
KEN MENZ
ROBERTO RAÑOLA JR

BARBIER (1996) DISCUSSED two methods for estimating the on-site cost of soil erosion:

- the replacement cost approach, which measures the nutrients lost through erosion and calculates the equivalent value of those nutrients in fertilizer; and,
- the opportunity cost approach, which measures change in present value of net returns with and without of erosion control.

This chapter applies the replacement cost approach as a means of calculating the cost of soil erosion within a farming system. A companion document (Rañola and Predo 1997), undertakes a complementary analysis using the opportunity cost approach. The opportunity cost approach is essentially what is involved in Chapter 9, and in other chapters which compare income streams from two farming systems (with each system having a corresponding level of soil erosion.

THEORETICAL CONSIDERATIONS

In the replacement cost approach, the expenditure necessary to replace an environmental resource, service or asset lost is identified. The cost of replacing productive assets, damaged by lower environmental quality or by management practices, can be regarded as an estimate of the presumed benefits of programs for protecting or improving the asset (the environment) (Hufschmidt et al. 1983). The method is sometimes applied in resource valuations due to the relative ease of estimating replacement costs.

Within the replacement cost approach for calculating the on-site costs of soil erosion, soil nutrients are treated as inputs in crop production and are shown in Figure 10.1 to be used at the optimal level, X_1.

To evaluate the cost of soil erosion using the replacement cost approach, the value of the equivalent amount of lost nutrients $X_1 - X_0$is used to estimate the value of nutrients removed from the soil. At a unit price of fertilizer of $P_{i,}$ the equivalent value of nutrients lost via soil erosion can be measured by area *B*, or $P_i\,(X_1 - X_0)$, given an initial level of soil nutrients X_1. However the full loss of net value of output associated with this loss of soil nutrients is (*A*+*B*), if the nutrients are not replaced. In order to determine *A*, the slope of the value of marginal product line in Figure 10.1 must be known. Usually the position of the marginal product line is not known. Hence, the attraction of the replacement cost approach, where the area *B* is taken as an approximation of the total loss to the farmer (*A*+*B*) due to soil erosion.

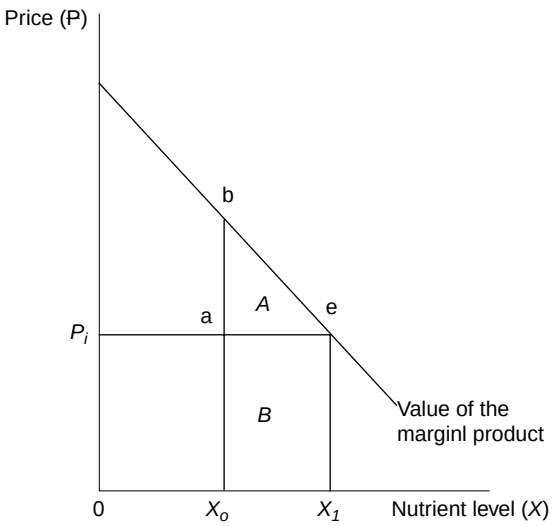

Figure 10.1.
Replacement cost approach to measuring on-site costs of soil erosion. The value of marginal product of soil nutrients changes with the level of nutrients, so the replacement cost *B*, is an approximation for the cost of soil erosion (*A*+*B*). (Adapted from Barbier 1996).

AN EMPIRICAL EXAMPLE

Compact, near Claveria in Mindanao the Philippines, was chosen for the empirical analysis. This was primarily because of the broad range of experimental data and data on farming systems available there. Details of the site and data sources are available elsewhere in this report.

Some additional data are required for this particular analysis—specifically data on prices of soil nutrients. The market price of inorganic fertilizers was obtained from a detailed economic survey of farmers in the Claveria region (Nelson et al. 1998).

Farmers reported urea to be ₱ 6.50/kg and Solophos to be ₱ 5.30/kg. The percentage of the nutrient within each fertilizer varies, with 45% nitrogen in urea and 18% phosphorus in Solophos. Organic matter *per se* is not readily sold, however some organic matter sources, such as cuttings from napier grass are traded. In local markets the price of napier grass is ₱ 1.30/kg dry weight (Magcale-Macandog et al. 1997b). This value is consistent with calculations that determines the opportunity cost of napier grass sold as fodder. (That is, when the on-farm value of napier grass retained on the field as mulch is calculated, it is found to have a similar value as the market value.)

USING SCUAF TO OVERCOME THE LACK OF LONG-TERM DATA ON SOIL EROSION

Nitrogen, phosphorous and organic matter lost via soil erosion were predicted directly by the model SCUAF, version 4 (Young et al. 1998, see Appendix). SCUAF aggregates nutrient (and organic matter) losses into categories of:

- losses in soil that is eroded;
- uptake by plants; and,
- natural processes such as leaching.

Having compartmentalised nutrient losses using SCUAF, the soil and nutrient losses in erosion are predicted using SCUAF over a twenty-five year period. The cost of the equivalent amount of nutrients in organic and inorganic fertilizer is used to value the soil nutrients lost via erosion. The annual replacement cost of soil erosion is discounted over time at a 10% discount rate, to calculate the present replacement value of soil lost. Table 10.1 outlines the characteristics of the two farming systems for which nutrient replacement costs are calculated. The napier grass strip system is oriented towards the goal of soil conservation.

Table 10.1. Two farming systems simulated using SCUAF

Farming system	Description
Without soil conservation:	
Open-field system	Annual maize-maize cropping without hedgerows
With soil conservation:	
Napier grass strip system	Annual maize-maize cropping between hedgerows of napier grass (*Pennisetum purpureum*).

For expository purposes, the first five years of the open-field case are presented in detail. SCUAF predictions of soil erosion, and nutrients lost due to soil erosion are

presented in Table 10.2. The fertilizer equivalents of these nutrients, multiplied by their corresponding prices, leads to calculation of the total replacement cost first in undiscounted, and then in discounted monetary terms.

SOIL EROSION COSTS MEASURED BY THE REPLACEMENT COST APPROACH FOR AN EROSIVE AND A CONSERVATION FARMING SYSTEM

The SCUAF-predicted annual amounts of soil erosion and soil nutrients lost over 25 years, for the two farming systems outlined in Table 10.1 are shown in Figure 10.2. For the open-field (erosive) case, annual soil erosion increases over time. Annual soil nutrient losses due to erosion show a declining trend over time, as nutrient concentration per unit of soil falls (as a result of previous erosion).

For the open-field case, average annual soil erosion over the twenty-five year period is 78.6 t/ha. Average annual soil nutrient losses are 885, 115 and 64 kg/ha of carbon, nitrogen and phosphorus respectively. To replace these lost nutrients, an average of 1770, 213 and 357 kg/ha per year of organic matter, urea and Solophos respectively, are required. Based on these quantities, the replacement cost of nutrients lost via soil erosion averages ₱ 5858 /ha/year . Discounting at a rate of 10%, the present value of the total soil nutrients lost over the period is ₱ 67 180 (Table 10.3).

The amount of soil eroded, and nutrients lost, under the napier grass strip farming system are significantly less (Figure 10.2). Predicted annual erosion over the twenty-five year period ranges from 16.2 to 2.8 t/ha per year for napier grass strips, averaging 3.9 t/ha. Erosion declines in the early years, due in part, to the formation of natural terraces around the napier grass strips. This decline in erosion contrasts with the situation of increasing soil erosion under a open-field system.

Predicted annual average nutrient loss for the napier grass system averages 113 kg/ha for carbon, 13.1 kg/ha for nitrogen and 8.4 kg/ha for phosphorous. These are only 5% to 10% of the predicted nutrient losses from an open-field system. To replace the nutrients lost via erosion in a napier grass hedgerow system, 225 kg/ha of organic matter, 29 kg/ha of urea and 47 kg/ha of Solophos is required. The predicted average annual replacement cost for nutrients lost via soil erosion over 25 years, in napier grass hedgerow systems is ₱ 729/ha (Table 10.3). The total discounted present value is ₱ 11 095.

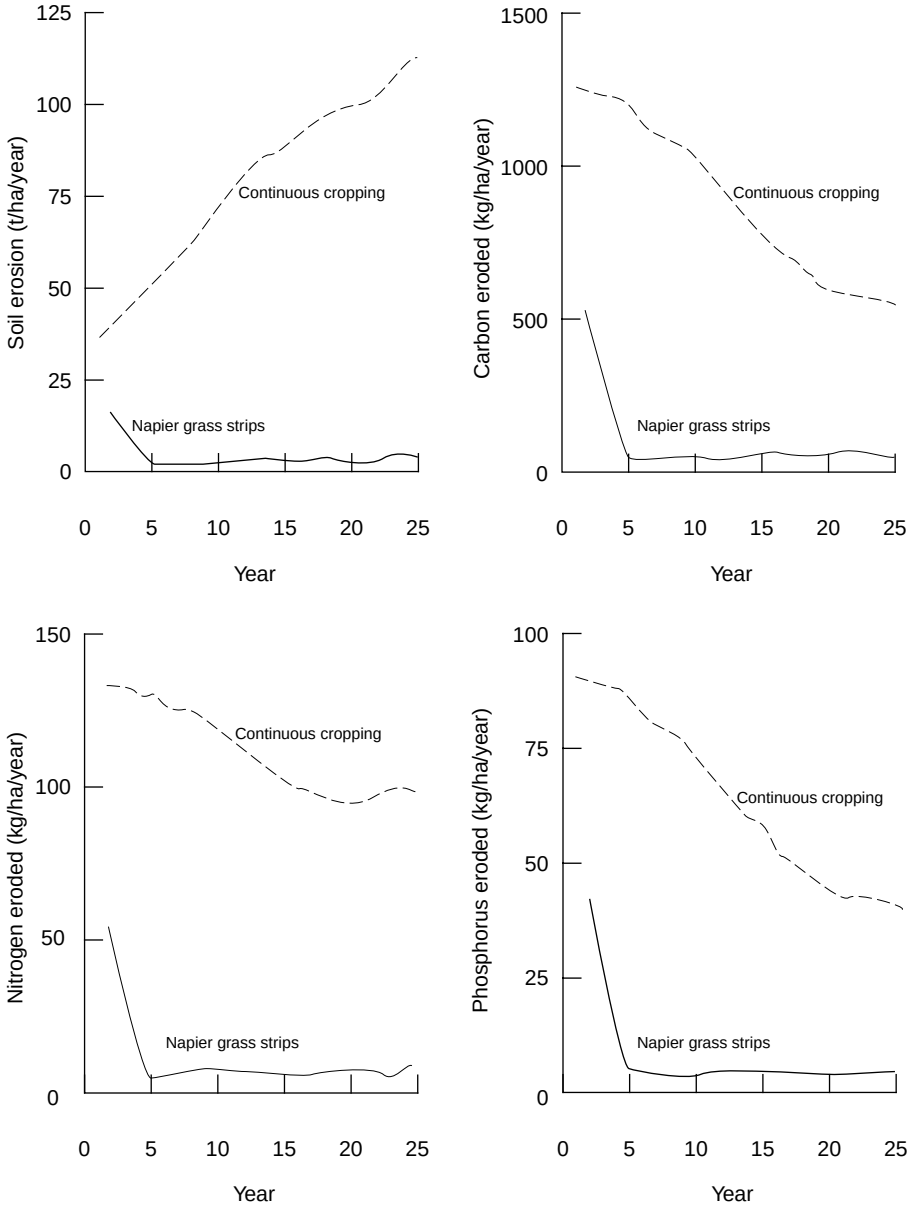

Figure 10.2. Trends in annual soil erosion and annual soil nutrients eroded from open-field and napier grass systems.

Table 10.2. Nutrients lost via soil erosion, the fertilizer equivalent of these nutrients, the total replacement cost and discounted cost at 10% over the first five years of open-field farming

Year	Soil erosion (t/ha)	Nutrients eroded (kg/ha)			Fertilizer equivalent (kg/ha)			Fertilizer costs (₱)			Replacement cost (total) (₱)	Discounted cost (₱)
		C	N	P	OM	Urea	Solophos	OM	Urea	Solophos		
1	37	1260	136	91	2520	302	506	3276	1964	2679	7920	7200
2	40	1235	135	90	2470	300	500	3211	1950	2650	7811	6455
3	44	1230	136	89	2460	302	494	3198	1964	2621	7783	5847
4	48	1212	136	88	2424	302	489	3151	1964	2591	7707	5264
5	51	1184	134	86	2368	298	478	3078	1936	2532	7546	4686
											NPV (5 years)	29 452

Table 10.3. Annual cost of replacing nutrients lost in soil erosion (₱/ha) for two maize farming methods in Claveria, calculated using the replacement cost approach, 25-year time horizon, 10% discount rate

Nutrients replaced	Continuous cropping		Napier grass strips	
	Average year (₱/ha)	Present value (₱/ha/25 yrs)	Average year (₱/ha)	Present value (₱/ha/25 yrs)
Organic matter	2302	27029	292	4525
Urea	1665	17953	189	2810
Solophos	1890	22198	247	3760
Total costs	5858	67180	729	11095

Thus the average annual cost of erosion from the napier grass strip farming system is low compared to the average annual cost in a open-field system (₱ 11095/ha vs ₱ 67180/ha) for maize farming within napier grass strips and in an open-field situation, respectively.

SCUAF predicts that maize revenues (yield) would remain relatively constant in the napier grass system, but would decline in the open-field system (Fig. 10.3). Some, but not all, of the yield decline is due to the loss of nutrients in eroded soil. (Nutrients are also lost due to leaching, plant off-take and other factors). The cost of soil erosion, calculated using the nutrient replacement cost approach, is a proxy for foregone income streams associated with soil erosion.

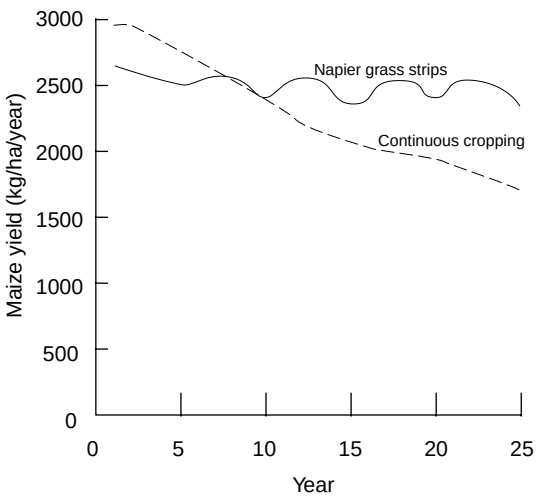

Figure 10.3.
Trends in maize yield over time in the two different farming systems

The empirical results of the modelling show soil erosion to be high in the open-field farming system, at approximately 79t/ha per year, costing an average of ₱ 5858/ha/year . This equates to ₱ 75/t.[1]

DISCUSSION

An advantage of the replacement cost approach is that it is simple to apply, especially if a time series of estimates of nutrients lost via erosion are available. When such estimates are not available, a model such as SCUAF, which predicts nutrient loss in erosion over the long term, is essential. Comparisons between farming systems, or techniques (e.g. comparing the cost of soil erosion in an erosive system versus a soil conserving system) can be made by simply subtracting the replacement cost of soil erosion in one system from the other. In practice, the replacement cost approach is able to empirically differentiate the two systems examined here, on the basis of the cost of soil erosion.

The replacement cost approach, by using a more direct, soil-based calculation, abstracts from income streams. The opportunity cost approach does take into account differential income streams associated with different systems. If data are only available on one farming system, then using the replacement cost approach may be the only feasible option for calculating the cost of erosion.

The average annual cost of soil erosion for open-field farming was calculated in this chapter to be ₱ 75/t, or an average of ₱ 5 858 /ha/year .[2]

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1. This cost per tonne of soil erosion is given in terms of annual average, i.e. annual average cost per annual average tonne of soil loss. Although it would be feasible to calculate costs of soil erosion in terms of NPV/t this appears to create some difficulties in that the numerator (NPV) is discounted, whereas the denominator (soil loss) is not. Using 'annual average cost per annual average tonne of soil loss' as a measure, alleviates this problem to a degree. It remains imprecise as a measure of the costs of soil erosion in that it does not trace accurately the costs associated with losing particular amounts of soil at different periods of time.
2. For the napier grass system the cost of soil erosion is determined as ₱186/t. Although the napier grass system has high costs/t of soil eroded, there are significantly fewer tonnes eroded.

11 *Gmelina* as Improved Fallow

DAMASA MAGCALE-MACANDOG
PATRICK ROCAMORA
CANESIO PREDO

SMALLHOLDER FARMERS IN Southeast Asia have begun farming timber trees on the frontiers of infertile grassland soils as a dominant enterprise using their own capital resources (Chapter 8; Garrity and Mercado 1994; Garrity 1994a). Farmers in Claveria, Northern Mindanao, are planting *Gmelina arborea,* initially as a hedgerow with the annual crops of maize, upland rice and cassava. The current increase in demand for fuelwood and timber is the major factor in the development of smallholder *Gmelina* timber plantations (Garrity and Mercado 1994).

The farmer surveys reported in Chapter 8 indicate that farmers believe that planting *Gmelina* trees during the fallow period is preferable to shifting cultivation maize growing. In this chapter, the economic and ecological benefits of growing *Gmelina* trees during the fallow period were quantified, via modelling.

EVOLUTION OF DIFFERENT HEDGEROW SYSTEMS AND IMPROVED *GMELINA* FALLOW SYSTEM IN CLAVERIA

In 1987, hedgerow intercropping was introduced in Claveria, through the participation of six Claveria farmers and two International Rice Research Institute (IRRI) technicians, to a World Neighbours project in Cebu, the Philippines. Farmers learnt how to establish contour lines with an A-frame, construct contour bunds and ditches, and plant hedgerows. The 'original hedgerows' were composed of one or two rows of *Gliricidia sepium* and one or two rows of *Pennisetum purpureum* (Stark 1996). The knowledge was extended to more than 200 farmers in the area through farmer-to-farmer techniques initiated by the trained farmers and adopters in Claveria from

1987 to 1991. By late 1992, more than 80 farmers in the area had adopted some form of contour hedgerow on more than 50% of their sloping lands (Fujisaka et al. 1994).

Since its introduction, farmers have tried several modifications of the 'original hedgerow' system. Some farmers started planting more fodder grasses by 1989. Others established contour strips of purely natural vegetation composed of *Pennisetum polystachium*, *Paspalum conjugatum*, *Borreira laevis*, *Ageratum conyzoides*, *Chromolaena odorata*, *Digitaria longifolia*, *Mimosa invisa*, *Rottboellia cochinchinensis*, *Hyptis suaveolens* and *Imperata cylindrica* (Fujisaka et al. 1994). By 1996 more than 200 farmers had spontaneously adopted the natural vegetation strip (NVS) or grass strip system (Stark 1996). Some farmers use the NVS as a base for establishing lines of fruit and timber trees for cash.

Gmelina arborea (Roxb.) belongs to the family Verbenaceae and is a native of Sudan, Northern Rhodesia (Lamb 1968). It was first introduced to the Philippines by the reforestation program of Minglanella, Cebu in 1956. *Gmelina* is a fast growing tree species that can attain an average height of 13.2 m, with a total clear bole of 8.22 m, in 8 years under Philippine conditions (Generalao et al. 1977).

Gmelina trees are planted in small portions of farms as block plantings, along contour strips and along farm boundaries. Alley cropping is undertaken in the areas in between contour strips, which are planted to *Gmelina* seedlings, in the first two years. Afterwards, when the tree canopy starts to close, the land is left to bush fallow. During the fallow period, *Gmelina* trees grow and natural vegetation is allowed to grow and be grazed by livestock. By the end of the fallow period, the farmer has been harvestable timber and animal gains.

METHODOLOGY

Description of farming systems under study

The study area is situated at Claveria, in the municipality of Misamis Oriental, Mindanao, 40 km northeast of Cagayan de Oro. For a detailed description of the study area see Chapter 8.

Average smallholder farm size in Claveria is 2.5 ha. Two farming systems are compared in this chapter, the conventional open-field maize farming system and the *Gmelina* improved fallow system. The conventional open-field maize farming practice involves a cycle of three years continuous maize cropping and two years fallow. During the fallow period, natural vegetation grows on the farm, upon which cattle can graze.

In the improved *Gmelina* fallow system specified here, farmers devote one hectare of their farm to a hedgerow intercropping system and 1.5 ha to the conventional open field maize system. In the one hectare hedgerow intercropping system, hedgerows are 6 m apart and *Gmelina* tree seedlings are planted along the hedgerows 1 m apart. During the first two years of *Gmelina* growth, maize is planted in the alley areas. Starting from the third year, alley areas are left to fallow and natural vegetation is allowed to grow. Cattle graze upon the natural vegetation fodder until *Gmelina* tree harvest in the seventh year. The remaining 1.5 ha of the farm has a continuous cycle of three years maize open-field farming and two years fallow, similar to the conventional open-field farming system. To obtain greater detail on cropping pattern characteristics of the open-field farming and *Gmelina* improved fallow at Claveria, see Magcale-Macandog et al. (1997b).

Interviews and data collection

Research methodologies include a combination of farmer and sawmill operator interviews, use of secondary data and simulation of predicted maize yields using SCUAF version 2. A survey was conducted in Claveria using the same farmer respondents interviewed in the study conducted by Nelson et al. (1998). With the lack of historical maize yield data and the difficulty in obtaining this type of information, which is highly variable depending on climatic conditions and fertilizer input, predicted maize yield in the successive years is simulated using SCUAF. A summary of the different information sources for the cost-benefit analysis see Magcale-Macandog et al. (1997b).

The survey respondents included 17 smallholder timber farmers from the lower Claveria zone (Patrocinio, Tunggol Estate, Ane-i-Lupok, Minsacuba, Hinaplanan, Cabacungan and Wilcom), six farmers who practice continuous open maize farming, and five sawmill operators from nearby towns of Villanueva and Jasaan who are presently buying and processing *Gmelina* trees for local and overseas markets.

A cost-benefit analysis of the two systems is undertaken based on the inputs and outputs of the two systems over 14 years, corresponding to two cycles of the *Gmelina* improved fallow system. A summary of assumptions and variables used in the computation of costs and benefits in the open field farming and *Gmelina* improved fallow systems at Claveria can be found in Magcale-Macandog et al. (1997b). Annual net returns and net present value (NPV, calculated on a discount rate of 10%) are computed to compare the *Gmelina*-improved fallow system with the traditional maize farming system.

Input requirements

Farmers at Claveria plant maize twice a year, i.e. during both the wet season and the dry season. The total annual input requirements and costs (valued in Philippine pesos, ₱) for the open-field farming system include the costs of maize seeds, fertilizer and pesticide during the three-year cropping period (Table 11.1). During the fallow period, cattle can graze on the natural vegetation, thus costs of the farming system include animal shelter establishment, maintenance and veterinary supplies (Table 11.1).

Table 11.1. Annual cost of inputs (₱) per 2.5 ha farm, for open-field farming and *Gmelina*-improved fallow at Claveria[a]

	Open-field farming						*Gmelina*-improved fallow						
Year	Maize seeds	Fertilizer	Pesticide	Animal shelter	Animal supplements	Total	*Gmelina* seedlings	Maize seeds	Fertilizer	Pesticide	Animal shelter	Animal supplements	Total
1	520	9337	2475			12332	15250	488	8777	2340			26855
2	520	9337	2475			12332		488	8777	2340			11605
3	520	9337	2475			12332		312	5602	1485	281	841	8521
4				829	2479	3308					496	2315	2811
5					2457	2457						2304	2304
6	520	9337	2475			12332		312	5602	1485	96	808	8303
7	520	9337	2475			12332		312	5602	1485		808	8207
8	520	9337	2475			12332		488	8777	2340			11605
9				745	2228	2973		176	3175	855	449	1343	5998
10					2206	2206					256	2096	2352
11	520	9337	2475			12332		312	5602	1485		753	8152
12	520	9337	2475			12332		312	5602	1485		743	8142
13	520	9337	2475			12332		312	5602	1485	88	743	8230
14				672	2009	2681					402	1933	2335

[a] Input requirements/ha and unit cost (₱); Maize seeds = 32 kg/ha, ₱ 6.50/kg; Urea = 248 kg/ha, ₱ 6.50/kg; Solophos = 264 kg/ha, ₱ 5.30/kg; Muriate of potash = 134 kg/ha, ₱ 5.40/kg; Pesticide = 2.2 L/ha, ₱ 450/L; *Gmelina* seedlings = 250 seedlings/ha, ₱ 61/seedling; Animal shelter (a) establishment ₱ 365/animal unit, (b) maintenance ₱ 130/animal unit; Animal supplts. ₱ 1092/animal unit.

In the improved *Gmelina* hedgerow system, the alley areas are planted to maize during the first two years growth of *Gmelina* seedlings. Input requirements for maize cropping within the *Gmelina* hedgerow system are similar to the open-field farming

system (Table 11.1). Inputs needed from the third year of *Gmelina* growth until harvest include establishment of animal shelter, rope and animal supplements (Table 11.1). Animal shelters have to be re-established every six years and maintained every three years. Table 11.1 presents the annual input requirements of the two farming systems for 14 years. *Gmelina* seedlings are planted in the first year of the first cycle only. In the second cycle, regrowth from *Gmelina* stumps is coppiced and only one sibling allowed to regrow.

Labour requirements

Some operations require man-labour inputs while other operations require animal labour (Table 11.2). The data presented in Table 11.2 do not refer to a specific year in the farming system, but are a presentation of all the operations needed in the whole farming cycle. For example, contour bund construction is done only in the first year while *Gmelina* trees are harvested only in the seventh year.

Table 11.2. Summarised labour requirements for each operation in an open-field farming and *Gmelina* improved fallow at Claveria.[a]

Operation	Open-field farming		*Gmelina*-improved fallow	
	MD 2.5 /ha	MAD 2.5/ha	MD 2.5 /ha	MAD 2.5/ha
Hedgerow establishment				
Construct bunds/layout hedgerows			13	2
Gmelina planting			3	
Hedgerow establishment total			16	2
Wet season				
Hedgerow weeding (ring)			16	
Land preparation		38		39
Maize sowing and fertilising at planting	18		16	
Replanting	5		5	
Nitrogen fertilizer	20		17	
Interrow weeding		10		9
Hand weeding	43		35	
Gmelina hedgerow pruning			11	
Harvesting				
1. Maize	20		19	
2. *Gmelina*				

Table 11.2. (cont'd) Summarised labour requirements for each operation in an open-field farming and *Gmelina* improved fallow at Claveria.[a]

Operation	Open-field farming		*Gmelina*-improved fallow	
	MD 2.5 /ha	MAD 2.5/ha	MD 2.5 /ha	MAD 2.5/ha
Postharvest processing				
1. Maize	30		28	
2. *Gmelina*				
Wet season total	135	48	147	48
Dry season				
Hedgerow weeding (ring)			16	
Land preparation		25		24
Maize sowing and fertilising at planting	18		16	
Replanting	5		5	
Nitrogen fertilizer	20		17	
Interrow weeding		10		9
Hand weeding	38		32	
Gmelina hedgerow pruning			11	
Harvesting				
1. Maize	15		13	
2. *Gmelina*			9	
Postharvest processing				
1. Maize	28		26	
2. *Gmelina*			11	
Dry season total	123	35	156	33
Annual total	258	83	319	83

[a]Open-field farming = maize-maize for 3 years with 2 years fallow between maize crops; improved fallow = *Gmelina*-maize-maize; MD = mandays at ₱ 50/MD, MAD = man + animal days at ₱ 100/MAD; planting of *Gmelina* seedlings = 5.51 mins/tree; pruning of *Gmelina* seedlings = 21 mins/tree; ringweeding of *Gmelina* tree = 5 mins/tree; harvesting = 18 mins/tree; postharvesting = 21 mins/tree ; animal feeding (cut and carry) = 1.5 hours/day.

RESULTS AND DISCUSSION

Gross benefits obtained from the open-field maize farming system

Maize yields during the wet season are generally higher than dry season yields. This can be attributed to the greater availability of water during the wet season, favouring higher growth rates. In the first year of maize cropping, yields are 1920 kg/ha during the wet season and 1260 kg/ha during the dry season (Nelson et al. 1998). Maize yields during the next two years are predicted using the SCUAF model. Based on the

results from the model simulation, wet season maize yields decline to 1889 kg/ha and 1846 kg/ha in the second and third years, respectively.

The dry season price of maize (₱ 5.5/kg) is higher than the wet season price (₱ 4.60/kg). The total annual benefit from maize in a 2.5 ha farm is ₱ 39405 in the initial year and declines to ₱ 38770 and ₱ 37893 in the two successive years as predicted by SCUAF (Table 11.3).

Table 11.3. Annual economic benefits per 2.5 ha farm, for open-field farming and *Gmelina*-improved fallow at Claveria.[a]

Year	Open-field farming (₱)			*Gmelina*-improved fallow (₱)				
	Maize	Animal	Total	Maize	Animal	Tree	Fuelwood	Total
1	39405		39405	37041				37041
2	38770		38770	36426			900	37326
3	37893		37893	22741	6584		4008	33333
4		19411	19411		18128		4008	22136
5		19240	19240		18043			18043
6	39405		39405	23643	6328			29971
7	38770		38770	23266	6328	98000		127594
8	37893		37893	36139				36139
9		17444	17444	13160	10518		900	24578
10		17273	17273		16418		4008	20426
11	39405		39405	23643	5900		4008	33551
12	38770		38770	23266	5815			29081
13	37893		37893	22741	5815			28556
14		15734	15734		15135	98000		113135

[a] Maize, animal and *Gmelina* tree benefits and prices (₱); maize yield (kg/ha), (a) wet season = 1920 kg sold at ₱ 4.60/kg, b) dry season = 1,260 kg sold at ₱ 5.50/kg; animal weight gain and services ₱ 8551/animal unit; *Gmelina* fuelwood (t/ha) = 1 sold at ₱ 1,200/t; *Gmelina* tree (bdft/tree) = 56 sold at ₱ 7.00/bdft.

During the fallow period, cattle graze on the growing natural vegetation. Wet season yield of the natural vegetation species in Claveria amounts to 1.26 t/ha and 1.06 t/ha during the dry season (Stark 1996). This yields an annual total of 2.32 t/ha of animal fodder. An animal with an average weight of 300 kg requires 7 kg feed per day (Kearl 1982), amounting to an annual requirement of 2.55 t/ha/au (au = animal unit). A 2.5 ha plot of natural vegetation can therefore support 2.27 au. Using SCUAF, predicted natural vegetation yields during the succeeding year decline to 2.30 t/ha. This results in a corresponding decline in the animal units which the farm can support, to 2.25 au.

Animal services on the farm include draught (ploughing, harrowing), hauling and transport. An estimate for the median total number of productive animal services is 153 days/animal/year (Magcale-Macandog et al. 1997b) and an animal day is estimated to be worth ₱ 42. Changes in animal inventory value within a year amount to ₱ 2125, and the annual gross benefits obtained from animals is ₱ 8551/au (Magcale-Macandog et al. 1997b). The annual total benefits from an open-field maize farming system are presented in Table 11.3.

Gross benefits obtained from a *Gmelina*-improved fallow farming system

In the 2.5 ha *Gmelina*-improved fallow system, 1.5 ha is devoted to open-field maize farming, with the other 1.0 ha used for the hedgerow system. In the 1.0 ha of the hedgerow system, 0.15 ha is devoted to hedgerows and the remaining 0.85 ha is used for alley cropping. During the first two years of *Gmelina* growth, maize is planted in the alley areas. This amounts to a total of 2.35 ha for maize cropping in the *Gmelina*-improved fallow farms in the first two years of the cycle. With the lack of data on maize yield in the alley areas, it is assumed in the computations for the cost-benefit analysis, that the yield in the alley areas was the same as the maize yield in the open areas.

Using the same data for initial maize yields as in the open-field farming system, maize yields in the *Gmelina* improved fallow system in succeeding years following are predicted using SCUAF. Using similar farmgate prices for maize during the wet and dry seasons (₱ 4.6 and ₱ 5.5, respectively), gross benefits obtained from maize amount to ₱ 37 041 in the first year and decline in the succeeding years (Table 11.3).

In the third year, maize may no longer be planted along the alley areas due to the shading effect of the growing *Gmelina* canopy. Instead, natural vegetation is allowed to grow in the alley areas, upon which animals can graze. Benefits obtained from the animal component include animal services and gains in weight (Table 11.3). Years 4 and 5 correspond to the fallow period of the 1.5 ha area used for open-field maize farming. During this fallow period, natural vegetation is allowed to grow for animal grazing and hence there are additional benefits from the animal component (Table 11.3).

Gmelina trees are pruned from Year 2 until Year 4. These prunings are used as fuelwood (Table 11.3). The amount of fuelwood cut from *Gmelina* is about 1.5 kg/tree/pruning in the second year of growth, and about 6.67 kg/tree/pruning in the third and fourth years. Pruning is done twice a year during these three years. Fuelwood is priced at ₱ 1200/t and the benefits obtained from fuelwood amount to ₱ 900 in Year 2 and to ₱ 4008 in Years 3 and 4 (Table 11.3). The seventh year is a cut

year and, based on farmer interviews, the average amount of timber that can be harvested from seven-year-old *Gmelina* is about 56 bdft (boardfeet)/tree.

There are two ways of harvesting and marketing *Gmelina* trees, used in the Claveria area. The first one is bulk contracting directly with the sawmill or a timber trader, wherein the contractor cuts and hauls the logs or rough-sawn timber to the mill. The second way is direct delivery by the farmer of logs or sawn lumber to the mill. The second path is usually relied upon only for small quantities (Garrity and Mercado 1994). The simplest system of marketing involves the direct sale from the producer to the consumer (Pabuayon 1989), as marketing tends to be more complex as the numbers of intermediaries and services provided increases. Timber price in Claveria fluctuates seasonally, but for this benefit analysis, an average value of ₱ 7 per bdft is used and the computed benefits from 250 *Gmelina* trees are about ₱ 98 000 (Table 11.3).

Net benefits obtained from the two farming systems

The *Gmelina* improved fallow system has a negative net income in the first year due to costs incurred in the purchase of planting materials, labour for planting tree seedlings and hedgerow establishment. During the first six years, cumulative benefits are greater in the continuous maize open-field farming (Figure 11.1) than in the *Gmelina* improved fallow system. However, after the first harvest of *Gmelina* trees in the seventh year, the improved fallow system has higher cumulative benefits than the continuous maize open-field farming in succeeding years (Figure 11.1). The benefits gained by farmers practicing the *Gmelina*-improved fallow system are spread over a longer time frame than the open-field maize farming system. The superior profitability of the *Gmelina*-improved fallow system is due to the gain in returns from harvested timber, which exceeds the value of the crop yield from the land that was lost. By year 14, the cumulative net present value of the *Gmelina* fallow system is double that of the open-field farming.

Ecological benefits obtained from *Gmelina* trees

Aside from the long-term economic benefits gained from planting *Gmelina* trees, Claveria farmers are aware of the ecological benefits. Most of the farmers (76%) observe cooler air in the farm due to the shading effect of the trees. Half of the farmers indicate beneficial effects of leaf litter in building up soil fertility and the effectiveness of the hedgerows planted to trees and natural vegetation in controlling soil erosion. Of the species examined, *Gmelina* leaves have the fastest rate of decomposition and are completely decomposed within 48 weeks (Florece 1996). It has been found that decomposition rates are positively correlated with nutrient content and negatively

with lignin content (Florece 1996). Hedgerow intercropping has been advocated in the Philippines as a technology to better sustain permanent cropping with minimum or no fertilizer input and as a soil erosion control measure for sloping lands (Mercado et al. 1996). The trees are a very good form of windbreak.

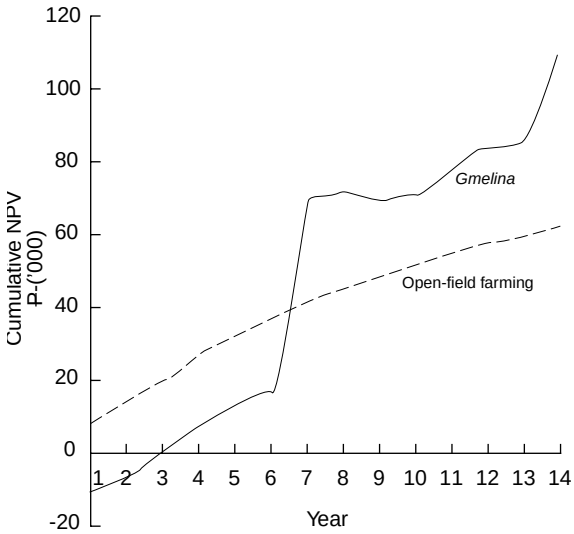

Figure 11.1.
Cumulative net present value of open-field farming and *Gmelina* improved fallow systems at Claveria, 10% discount rate, 14-year time horizon

In Southeast Asia, shifting cultivators deliberately stimulate colonisation of fallowed land with tree species to create conditions which accelerate regeneration of the land between cropping cycles (Garrity 1994a). In South Cameroon, multipurpose tree species (MPTS) are maintained on the farm to provide shade, medicinal products, timber for cash, and to ameliorate soil fertility problems (Duguma et al. 1990). Durian trees are planted in combination with timber trees in Maninjua, Indonesia, during the fallow period, to improve soil fertility, to maintain desirable species diversity and to enhance biomass accumulation. Villagers of Java, Indonesia recognise the potential of MPTS to supply fodder for livestock, fuelwood for cooking, vegetables and fruits for daily diets, building materials for houses and cash from selling the tree at harvest time (Junus 1989).

This enriched fallow area is a sustainable mode of land use following food cropping. It enables shifting cultivators to escape total dependence on annual crops for their livelihood, and evolve major parts of the landscape into perennial species. The basis for an improved fallow is that these investments pay off by increasing the efficiency of the fallow phase in building the useable nutrient reservoir, suppressing weeds, and possibly providing other economic benefits (fodder, fuel, timber, fruits) (Garrity 1994a).

Integration of an animal component is a unique element of this improved fallow system. Growing natural vegetation under the *Gmelina* trees is a source of animal fodder. Foreseen benefits from this system include cash from the main crop and timber when sold at harvest, cash from off-farm animal services, fuelwood from pruned lateral branches, animal weight gains and on-farm animal services. Pruning of lateral branches results in increased length of clear bole and veneer yield (Bhumibhamon et al. 1986) which provides higher income from the sold timber.

Adoption constraints

Hedgerow intercropping is a good technology for control of soil erosion but it has its limitations. Capital investments are necessary for seedlings and contour bund establishment during the first year of the *Gmelina* hedgerow intercropping cycle. Some farmers in Claveria who borrow capital from individual capitalists have to pay a high interest rate (25%) (Nelson et al. 1998). Labour requirements in the farm operation for this system are another major factor for the adoption of this technology (Duguma et al. 1990; Nelson et al. 1998).

Another negative aspect of this hedgerow intercropping technique is the competitive effect of trees for light, nutrients and water, with the understorey crops planted in the alley areas (Sibanda 1991; Garrity et al. 1995). The ability of the technology to conserve water remains doubtful (Lasco and Carandang 1989). Another drawback of multipurpose trees is that they are often used as indicators of soil fertility, however, for trees associated with good fertility, it is not clearly determined if they actually contribute to soil fertility or simply grow on fertile soils (Lasco and Carandang 1989).

Adoption niches where the system of fallow management makes sense

The Philippine government has set its mind to the preservation of its natural forests such that several laws like the illegal logging law and total log ban have been passed to protect and develop natural resources. Intense government campaigns to encourage farmers to plant fast-growing timber tree species include dissemination of free seedlings. In effect, industrial loggers transfer their focus of attention to other timber types like *Gmelina*. Another government law which has been passed involves the need for sawmillers/traders to get a cutting permit from the Department of Environment and Natural Resources (DENR) before they can cut trees.

The continuous increase in the price of *Gmelina* trees in the area is a result of the greater demand for timber in the local and export markets, for construction material or furniture making. The scarce availability of primary grade wood in the market due to the government's ban on hardwood logging has made marketing of secondary trees more attractive. Harvesting and marketing of *Gmelina* trees is a major determinant of

the farmers' adoption of the system. Timber prices fluctuate seasonally and vary with distance from the farm to the point of sale.

CONCLUSION

Gmelina is a timber tree that has considerable potential to provide increased economic and ecological benefits. There are numerous types of farm forestry systems that are being undertaken with *Gmelina.* The system examined here involved planting *Gmelina* with maize in between the rows of trees for two years (with and without a subsequent animal grazing component to the system). Income is obtained from timber and fuelwood; from animal weight gain and services; and from maize. Cumulative net present value in the *Gmelina*-improved fallow system is approximately double that of the open-field maize farming system by the fourteenth year, even in this case where only 40% of the farm is planted to *Gmelina.* Ecological benefits include enhanced soil fertility build-up during the fallow period, soil erosion control, windbreak and cooler air.

12 *Gliricidia* as Improved Fallow

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KEN MENZ
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A FARMING SYSTEM of planted leguminous tree fallow is modelled in this chapter. The system involves establishing a *Gliricidia* plantation in the fallow period (and hereafter is called a *Gliricidia* fallow system). It is an adaptation of the improved fallow systems conceived by Garrity (1993) and MacDickens (1990). The *Gliricidia* fallow system is compared with a traditional shifting cultivation *Imperata* fallow system.

The possibilities of an improved fallow system have been recognised within the scientific community, and there have been isolated reports of similar indigenous practices. However, there has been minimal evaluation and testing. The analysis presented in this paper can be considered to be within the framework of dynamic technology evaluation and design, outlined by Anderson and Hardaker (1979). The *Gliricidia* fallow system can be regarded as being at the initial, or 'notional', stage of development.

The analysis presented here is intended to move the technology evaluation and design from a 'notional' to a 'preliminary' (i.e. more advanced) stage (Menz and Knipscheer 1981). A computer modelling approach allows the analysis to be undertaken at minimal cost, providing a more formal evaluation of the improved leguminous tree fallow technology than has been undertaken to date. If, from this analysis, the *Gliricidia* fallow appears capable of providing environmental and economic benefits, then a more vigorous program of scientific research is warranted.

Gliricidia fallow system

The two systems considered are: a *Gliricidia* fallow system and an *Imperata* fallow (shifting cultivation) system. Both systems are specified to involve five years of fallow followed by one year of cropping. A summary of the two systems is given in Figure 12.1.

In the proposed *Gliricidia* fallow system, one-sixth of the land available is deemed to be planted as a *Gliricidia* plantation each year, and another sixth planted to maize crop. The remaining two-thirds of the farm consists of established *Gliricidia* plantation. In terms of the rotation, *Gliricidia* is planted after the maize crop, so maize is preceded by five years of *Gliricidia* plantation (fallow).

A review of the characteristics of *Gliricidia sepium* which make it suitable for use in an improved fallow system is given in Appendix 1 to Grist et al. (1997a), but in summary, *Gliricidia* :

- is a fast growing small tree capable of shading and suppressing *Imperata* and rapidly producing fuelwood and mulch;
- has a high nutrient value, capable of cycling nitrogen through mulch or green manure; and,
- is able to grow well on acid soils, which are common across Southeast Asia.

Preparing land for *Gliricidia* involves burning to remove existing vegetation (crop residues or *Imperata*). After burning, the site is ploughed, and cuttings are collected. *Gliricidia* is planted in a hedgerow pattern which in this study, consists of two rows planted 50 cm apart with 50 cm between the trees within the rows. A gap of 1.5 m is left to the next pair of rows.

Gliricidia cuttings are quick to establish, and once established require little maintenance. To maximise nutrient recycling, the *Gliricidia* plantation is pruned four times a year with the prunings being used as mulch under the plantation. During years 2 to 5, *Gliricidia* requires little labour other than pruning. At the end of the fifth year, the plantation is cleared for cropping. *Gliricidia* is cut at ground level and the stumps either hacked or poisoned to prevent coppicing. The foliage is removed from the branches and left on the site as mulch. The branches and trunks are stacked and removed to be sold as firewood.

In the sixth year, following clearing of the *Gliricidia* plantation, the site is prepared for a maize crop, by ploughing or hoeing. Maize is planted between the rows of stumps — one row between the 0.5 m spaced rows and two rows between the 1.5 m spaced rows. The *Gliricidia* plantation shades out *Imperata,* but reinfestation from

neighbouring areas necessitates some weeding during maize cropping. Following harvest, the site is ploughed in preparation for a second maize crop. Following the second maize crop, the *Gliricidia* plantation phase begins again.

Imperata fallow system

In the *Imperata* fallow system, the land is abandoned to *Imperata* during the five-year fallow. In the sixth year, *Imperata* is burnt and the land ploughed in preparation for a maize crop. Maize is then planted in rows at a 0.75 m spacing. Regular weeding of the maize crop is required due to the presence of *Imperata* propagules. Preliminary analysis with SCUAF showed that only one maize crop per year can be supported by the soil fertility following a five-year *Imperata* fallow system. This is mainly due to the low replenishment of soil nutrients during the *Imperata* fallow period. After the year of cropping, the site is again abandoned to *Imperata*.

Model calibration and economic data

The data used in the economic analysis was derived from three sources: a computer-based (biophysical) agroforestry model, SCUAF Version 4, calibrated to conditions at Claveria, N Mindanao (see Chapter 7); a literature review; and an economic survey, also in Claveria (Chapter 7). The data sources are the same as those used in previous modelling chapters based at the Claveria site (Chapters 7 and 8). However, in this chapter, a new version of SCUAF (Version 4) is used.

The labour requirements for the *Gliricidia* plantation are adapted from data obtained from a survey by Nelson et al. (1996) on *Gliricidia* hedgerow systems. The number of trees/shrubs per hectare within the *Gliricidia* plantation (20 000) is double that of the hedgerows system (10 000) surveyed by Nelson et al. (1998). The labour required for land preparation in the *Gliricidia* fallow system is deemed to be 10 days, involving a burn followed by a single ploughing. Labour for collection and planting of cuttings is estimated at 70 days/ha; pruning labour at 16 days/ha/year (Table 12.1).[1] There are no weeding requirements during the *Gliricidia* plantation phase. To cut and carry the firewood, an extra day is estimated to be required at each pruning (thus four extra days per year), and another four days for the major removal of firewood in the year of plantation harvest.

1. The plot size is only $^1/_3$ of a hectare, thus labour requirements for collecting cuttings and planting will be 23 days/year. Also, as noted earlier, the collection of cuttings can be combined with pruning or the plots under plantation, to reduce labour demand.

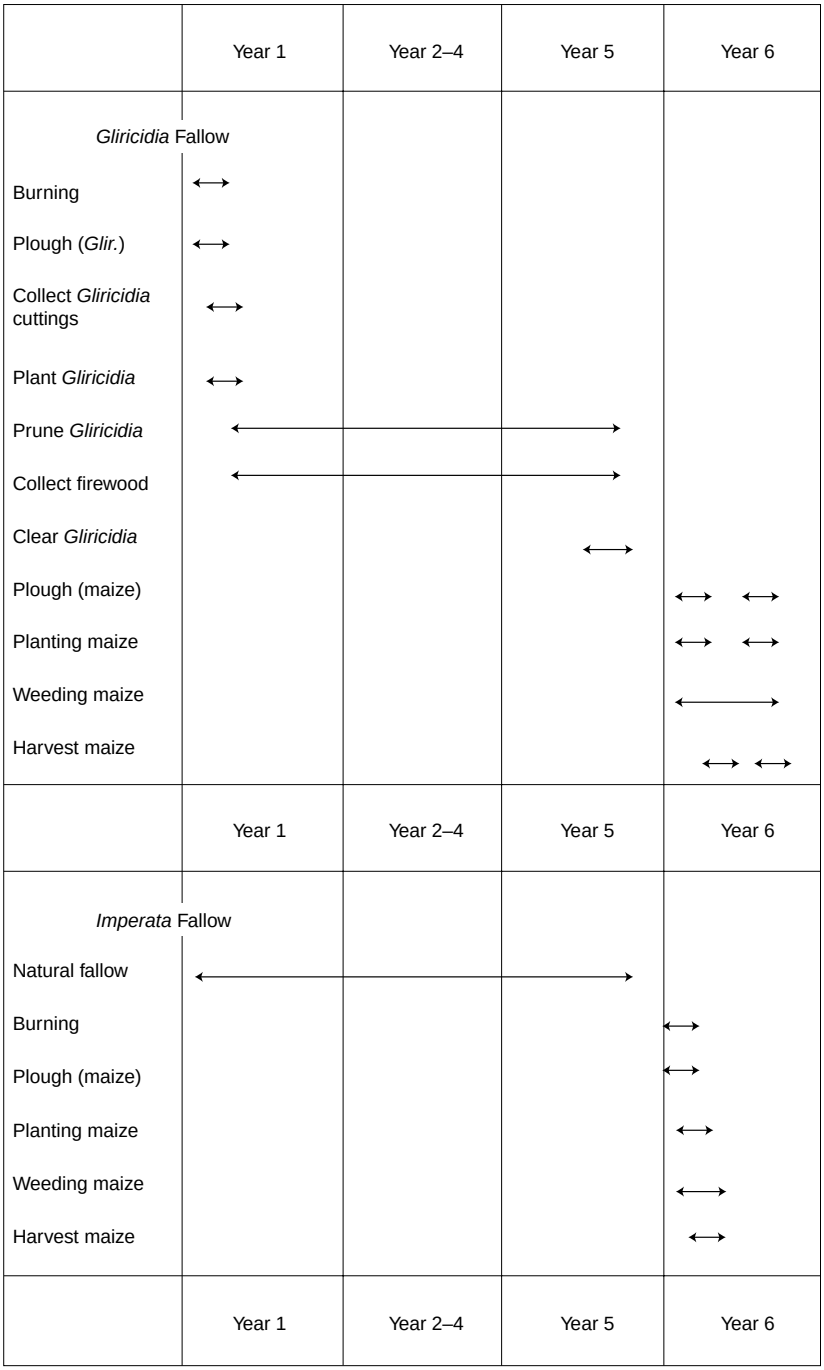

Figure 12.1. Summary of the *Gliricidia* fallow and *Imperata* fallow farming systems

Land preparation for the two maize crops planted following the *Gliricidia* harvest is estimated at 30 days/ha, and the labour required for planting maize at 25 days/ha (Nelson et al. 1996). The labour requirements for weeding maize after a *Gliricidia* fallow are estimated at 30 days for the two maize crops (Nelson et al. 1996).

A price for firewood in Claveria was obtained from a special 1996 survey of smallholders, near Compact, who had adopted a *Gliricidia* hedgerow system. The average price of firewood was ₱1000/t .

In the *Imperata* fallow system, land preparation requires approximately 30 days/ha (Conelly 1992), and planting maize requires approximately 13 days/ha (Nelson et al. 1996). During the cropping period there is a significant amount of weed competition. This is due to rhizomes and seed which remain in the soil after clearing (Eussen et al. 1976). Regular weeding during the cropping period requires approximately 30 days/ha (Conelly 1992). Note that this analysis of a shifting cultivation *Imperata* fallow system differs from that reported in Chapter 2 in two ways: SCUAF version 4 is used here, rather than version 2; and the location here is Claveria, N Mindanao, as opposed to a synthetic, 'typical' site in the Indonesian uplands.

A discount rate of 12% is used in the first instance, as it approximates the social opportunity cost of capital in the Philippine economy. Smallholders, given their lack of collateral (land tenure and other capital assets), may not always be able to borrow funds. The market borrowing rate is much higher than the social opportunity cost of capital, between 16% and 30%, with the average around 25% (Nelson et al. 1998). If farmers were to borrow most of the capital used in these systems, 25% would be the appropriate discount rate. This discount rate is used in the second instance to determine whether the systems were still profitable if most of the capital used to maintain the systems is borrowed at that rate.

Modelling

As in the previous chapters, the modelling framework used for this analysis consists of two parts, the biophysical element (SCUAF), and an economic element, which uses a computer spreadsheet.

At the time of the analysis, SCUAF Version 4 had not been published. However, with permission from the authors, Version 4 was used to access the greater power of the new version, and also as a form of model testing. Most attributes in version 2 are retained in Version 4.

SCUAF Version 4 contains several improvements. Soil nutrients are more explicitly related to plant requirements and phosphorus is now included as a factor influencing

plant growth. Nutrient flows are modelled through five soil horizons and rainfall variability is included. There are also several improvements in the way that trees and crops are handled in the model. A pruning factor allows tree foliage to be harvested, and/or to be retained on the site as mulch. An allowance is made for the nutrients left behind after burning. Two crop types and two tree types can be simulated in each period, and there is an increase in the maximum number of periods. Version 4 avoids the problem in Version 2, noted by Vermeulen et al. (1993), where application of fertilizer is not effective until the year after application. Overall these improvements provide more detail and flexibility in the use of the model. A full description of Version 4 is now available (Grist et al. 1997a).

Table 12.1. The labour requirements of the two fallow systems

Operation	*Imperata* fallow[a]	*Gliricidia* fallow[b]	
	Days/ha	Crop cycle days/ha	Tree cycle days/ha
Land preparation	30	30	10
Collect/plant cuttings			70
Maize sowing	13	25	
Weeding	30	30	
Gliricidia pruning			16
Maize harvest	9	18	
Postharvest processing	11	22	
Cut and carry of firewood			4
Additional firewood final year			4
Total crop	93	125	
Tree total (establishment year)			96
Tree total (normal year)			20
Tree total (cut year)			24
Average for whole farm			
(1/3 ha crop, 5/3 ha fallow)	31		102

[a]one maize crop during the crop year of the cycle; [b]two maize crops during the crop year of the cycle.

Economic returns from the *Gliricidia* fallow system are derived from maize and from fuelwood. Costs are incurred for tree establishment, and the cutting and carrying of prunings and fuelwood. With the *Imperata* fallow system, costs and returns are only associated with maize.

Biomass production of *Gliricidia* is specified in the model as 11.4t/ha , with leaf production at 7.7t/ha , and wood production at 3.7t/ha . These figures are derived

from measurements of biomass production of *Gliricidia* hedgerows at Compact, by Nelson et al. (1998). Similar biomass production has been observed in *Gliricidia* plantations by Ella et al. (1989), Gunasena and van der Heide (1989), Maclean et al. (1992), and Panjaitan et al. (1993). The figures used in the model are for a stand of 20 000 trees per hectare, with four prunings per year (one every 12 weeks). This high pruning intensity increases the leaf to wood ratio of *Gliricidia,* providing more foliage for mulch (Ella et al. 1989).

A five-year *Imperata* fallow system does not enrich the soil to the same extent as a *Gliricidia* fallow system, thus the productivity of maize following the *Imperata* fallow system is low. Long-term *Imperata* fallow is not actually practiced at Compact. To determine the initial yield of maize following an *Imperata* fallow, preliminary analysis was carried out using SCUAF. Based on the nutrients available in the soil (carbon, nitrogen and phosphorus), SCUAF 4 uses the law of the minimum approach to determine plant growth. The preliminary analysis with SCUAF involved reducing the initial net primary production of the crop (which is set as an input parameter) until it was approximately equal to the net primary production in the first year of cropping (an output parameter). This ensured that the initial net primary production was able to be supported by the available soil nutrients. The initial net primary production which allowed this was approximately four tonnes of biomass per hectare, which implies a maize grain yield of 1.33 t/ha. The low productivity after an *Imperata* fallow also implies that, using this system, the site is only capable of supporting one maize crop in a cropping year.

To determine the nutrient demand by plants, and the fate of soil nutrients, SCUAF equates the nutrient components of the plant parts with the rate of growth. The nutrient content of the respective crops is reported in Appendix 3 of Grist et al. (1997a).

SCUAF determines plant growth and soil changes on a per hectare basis. To translate these results onto a whole farm basis relevant to Compact, 2 ha was specified as the average available land area.

RESULTS

The *Imperata* fallow system provides a small surplus, or profit (NPV = ₱ 2000) over a fifty-year period (Table 12.2). The *Gliricidia* fallow system is far more profitable under the same circumstances (NPV = ₱ 57 549). This can be attributed to improved soil fertility (thus higher crop yields), and to the additional saleable product (firewood). Firewood production also reduces the variability of economic returns over time, through diversification.

Table 12.2. Components of net present value (NPV) for the *Gliricidia* fallow and *Imperata* fallow systems, over a period of 50 years at a 12% discount rate

	Imperata fallow ('000 ₱)	*Gliricidia* fallow ('000 ₱)
Discounted gross return — maize	21	57
Discounted gross return — firewood		47
Discounted total cost	19	47
Net present value — maize + firewood		57
Net present value — maize only	2	10

The costs associated with *Gliricidia* fallow are more than double the costs associated with traditional *Imperata* fallow (Table 12.2). However, this is countered by higher maize yield, due to improved soil fertility (Fig. 12.2), and returns from firewood. This results in the *Gliricidia* fallow system providing a significantly higher net present value. If the profitability of the *Gliricidia* fallow system is calculated based on maize production only, the resulting profit, ₱10 000, is still above the profit in the *Imperata* fallow system (Table 12.2). Firewood can return revenues almost equivalent to those from maize. Small firewood yields (approximately 400 kg/ha) are provided annually, as a by-product of mulching (branches are cut in the process of mulching the foliage). A much larger firewood yield is provided in the cut year (greater than 12t/ha).

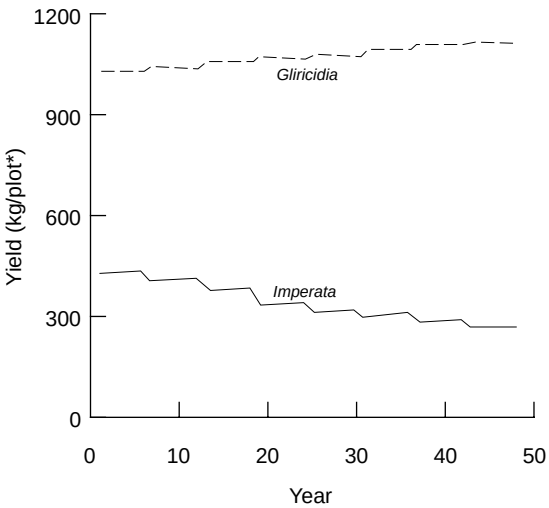

Figure 12.2.
Expected annual maize yield for the *Gliricidia* and *Imperata* fallow systems for an available land area of 2 ha

* Annual maize yield is calculated for the whole farm based on a 2 ha plot divided into six equal parcels. Each year, one parcel is cropped and the remaining five parcels are under fallow. Thus, the yield depicted here is kg/1/3 ha, assuming two maize crops in the year following *Gliricidia* fallow and one maize crop in the year following *Imperata* fallow.

Maize yield in the *Imperata* fallow system declines over time, but maize and firewood yield in the *Gliricidia* fallow system increase over time (Fig. 12.2). These changes are a result of soil fertility changes. In the *Imperata* fallow system, soil fertility is depleted over time, but in the *Gliricidia* fallow system it improves over time. This is due mainly to the effect of mulching the *Gliricidia* foliage. When used as mulch, the foliage has a half life of 20 days (Simons and Stewart 1994), which results in a rapid recycling of soil nutrients.

The changes in soil fertility can be observed via the levels of three key soil nutrients (carbon, nitrogen and phosphorus), which are predicted using SCUAF. For the *Imperata* fallow, all the nutrients show strong declining trends (Fig. 12.3). This is similar to the trends observed in previous studies of short *Imperata* fallow systems at other locations (Grist and Menz 1996b, and Menz and Grist 1996a). Nutrient levels decline during both maize and *Imperata* phases, due to erosion, leaching and uptake by plants. The level of soil nutrients in a *Gliricidia* fallow system move in the opposite direction to the level in an *Imperata* fallow. Soil nutrients steadily increase over time in the *Gliricidia* fallow (Fig. 12.3).

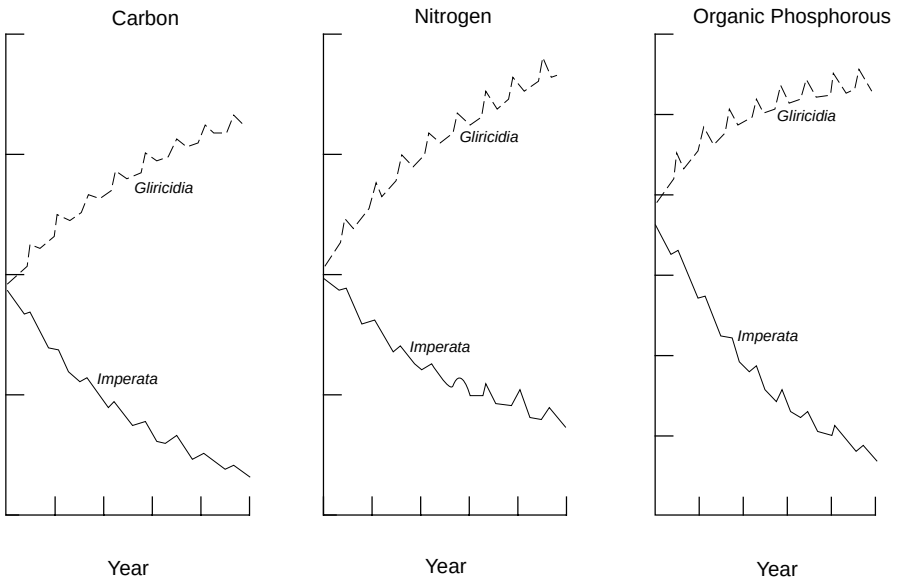

Figure 12.3. Changes in available carbon, nitrogen and phosphorus over time in the *Gliricidia* and *Imperata* fallow systems

As well as reducing erosion under the *Gliricidia* fallow system, mulching enhances soil organic matter (carbon) buildup. Soil nitrogen and phosphorus levels are improved by mulching the leaves of *Gliricidia*. Phosphorus is thought to be taken from the lower soil levels, into the *Gliricidia* leaves and ultimately to the topsoil via mulching.

In the year of maize cropping, there is a decline in soil nutrients. Overall, in the *Gliricidia* fallow, the increase in soil nutrients during the fallow period is greater than the nutrient demand by plants in the year of the maize crop.

Annual soil erosion for both *Imperata* fallow and *Gliricidia* fallow systems is presented in Figure 12.4. Most soil erosion occurs during the maize cropping years (top two lines in Figure 12.4), rather than during the years of fallow. With the *Imperata* fallow system, annual soil erosion increases over time. Although not depicted here, erosion of soil carbon, nitrogen and phosphorus follow similar trends to total soil erosion.

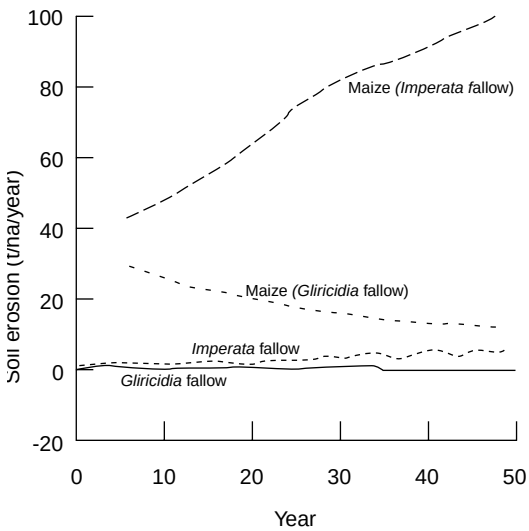

Figure 12.4.
Annual erosion over time for the *Gliricidia* and *Imperata* fallow systems

Annual soil erosion in maize plots within the *Gliricidia* fallow system decreases over time. The decrease is a result of the higher levels of soil organic matter associated with mulching. This stabilises the soil, reducing the impact of rain and surface runoff. Also, higher soil nutrient levels result in increased biomass production, protecting and stabilising the soil. Soil erosion during both types of fallow is small (bottom two lines of Figure 12.4).

Using a discount rate of 25%, i.e. assuming most capital used in production are borrowed (this includes the capital used to pay the smallholder for his own labour), the *Imperata* fallow system is no longer profitable (Table 12.3). A loss of ₱ 2880 is

incurred, which is relatively small, but signals that the *Imperata* fallow system is marginal at all discount rates. The profitability of the *Gliricidia* fallow system is reduced by over 50% when compared to the 12% discount rate, but the profit is still substantial (NPV = ₱ 25 869) (Table 12.3). The profit is again due largely to the additional returns from the sale of firewood, but the system is still profitable (NPV = ₱ 564) based on maize production alone (although marginal). This signals that in the long term, the *Gliricidia* fallow system has significant potential for adoption by smallholders in the Philippines, even with the high discount rates that are applied to smallholders.

Table 12.3. Components of net present value (NPV) for the *Gliricidia* fallow and *Imperata* fallow systems, over a period of 50 years at a 25% discount rate

	Imperata fallow ('000 ₱)	*Gliricidia* fallow ('000 ₱)
Discounted gross return — maize	12.3	30.3
Discounted gross return — firewood		25.4
Discounted total cost	15.1	29.8
Net present value — maize + firewood		25.9
Net present value — maize only	–2.8	0.5

The transition period between *Imperata* and *Gliricidia* fallow

The above economic analysis suggests that, in the long run a *Gliricidia* fallow system is quite profitable. However, the transition period is important in determining the feasibility of the system for smallholders. The transition period is the time during which *Imperata* fallow plots are converted to *Gliricidia* fallow plots. Within the system outlined here, one plot is converted each year. Thus six years are required to complete the transition for the whole farm.

During the transition period, 50% of the *Gliricidia* prunings are used as green manure for maize. The remaining 50% are placed as green manure under the *Gliricidia* plantation.[2] This improves maize productivity, although the maize plot has not been preceded by a *Gliricidia* fallow. As the number of *Gliricidia* fallow plots increase over time, the quantity of *Gliricidia* prunings available as green manure increases. Maize and firewood yields also increase over time. This situation is slightly different from the full *Gliricidia* fallow system, where 100% of the *Gliricidia* prunings are used as mulch under the *Gliricidia* plantation, and the maize does not

2. For example, given 7 t of *Gliricidia* prunings/plot/year, in the third year of the transition (and so three plots under *Gliricidia* fallow), each fallow plot will receive 3.5 t of prunings and the maize plot will receive 10.5 t (3×3.5) of prunings.

have green manure applied directly. However, transferring 50% of the *Gliricidia* prunings to the maize crop during the transition period, increases the economic return from maize (via improved soil fertility). In the absence of such a transfer, no maize yield increase would occur until year 7 of the *Gliricidia* fallow period.

The change in maize yield during the transition period, is shown in Figure 12.5. Generally, maize yield increases steadily over the first three years. By the fourth year it reaches a plateau which is approximately equivalent to the yield obtained from the full *Gliricidia* fallow system.

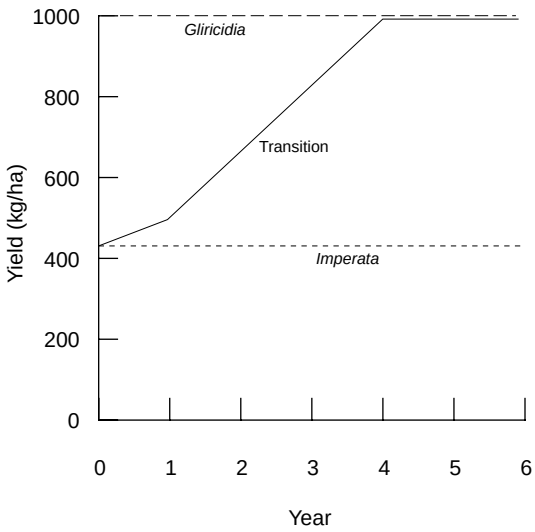

Figure 12.5.
Maize yield in the *Gliricidia* fallow system during the six-year transition period

The conversion of *Gliricidia* increases total costs relative to an *Imperata* fallow system (which involves only maize production costs). Since it takes time for the investment in *Gliricidia* to be translated into revenue increases, profitability in the early years of the transition period is not as good as for the *Imperata* fallow.

The trend observed for maize yield is reflected in the cumulative net present value of the system (dark solid line, Fig. 12.6). In the first year, the *Gliricidia* fallow system incurs a loss, and in year two, approximately breakeven. By year three, most of the first year loss is recovered. After the fourth year, the cumulative net present value of the system has recovered to a level that is greater than that of the *Imperata* fallow system.

The attractiveness of the *Gliricidia* fallow system is dependent on a smallholder's ability to absorb the loss in the first year, and to accept a lower income during the first four years of the transition period (i.e. lower than would be obtainable with an *Imperata* fallow). For subsistence farmers without savings or with limited capacity to

borrow, adoption of the *Gliricidia* fallow system would be difficult. The ability to survive the first three or four years of the transition period is critical to the adoption of the *Gliricidia* fallow system. The *Gliricidia* fallow system is clearly the logical choice beyond the fourth year.

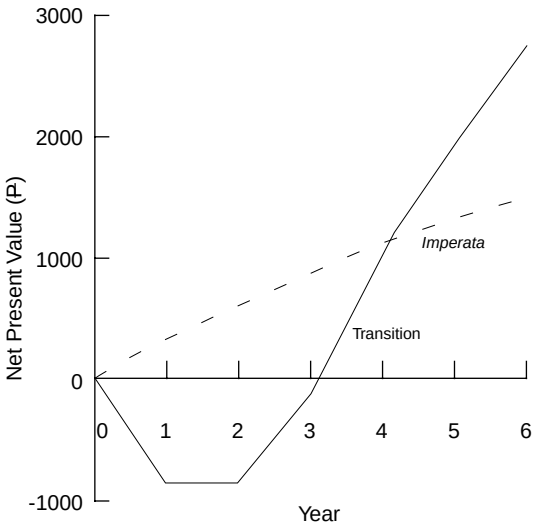

Figure 12.6.
Net present values of a *Gliricidia* fallow system during the transition period, and an *Imperata* fallow system, over a period of 6 years using a discount rate of 12%

The long-term nature of the *Gliricidia* fallow system, requiring four years to be profitable and six years to complete a fallow crop cycle, requires that land tenure be secure. In order to encourage adoption by smallholders, government policies to provide secure land tenure will be needed and credit facilitated at reasonable rates. Currently, only better off smallholders with secure tenure and with a capacity to look beyond immediate time horizons are likely to adopt a *Gliricidia* fallow system.

Labour availability within a smallholder farming system is relatively high compared to the labour requirement of either the *Gliricidia* or *Imperata* fallow systems. Menz and Grist (1995) estimated labour availability of approximately 300 workdays per year for a typical smallholder farm. Thus, although labour demand of the *Gliricidia* fallow system is triple that of the *Imperata* fallow system (102 compared to 31 respectively for a 2 ha farm), it is still well within the smallholders' capacity. Most smallholders on a 2 ha farm would be capable of adopting the *Gliricidia* fallow system without placing excessive strain on their available labour.

The role of animals in the context of a *Gliricidia* fallow is described in Chapter 17.

SENSITIVITY ANALYSIS

The wage rate and maize price used in this analysis, reflect the current market values in Claveria. A sensitivity analysis on these prices was carried out (Appendix 4, Grist et al. 1997a). Some key features of that analysis are given here.

For the *Gliricidia* fallow system, a change of 50% in the wage rate, to ₱60/day, or a 50% fall in maize price, to ₱2.6/kg, will significantly reduce profit levels. Given that the *Imperata* fallow system is only marginally profitable, any increase in system costs, or lowering of revenue will lead to the *Imperata* fallow system becoming unprofitable. However, the *Gliricidia* fallow system will still remain profitable under these substantially less favourable prices. The choice between *Gliricidia* and *Imperata* fallow systems is not affected by substantial changes in the price levels of the key inputs and outputs.

CONCLUSIONS

A *Gliricidia* fallow system can provide significant improvements to a range of soil biophysical measures. This enables higher levels of farm outputs to be achieved. So from both environmental and productivity perspectives, the *Gliricidia* fallow system is attractive.

Smallholders, however, are driven by economic imperatives. For smallholders to consider changing to a significantly different farming system, the new system must be more profitable than the existing system (perhaps considerably more so). This analysis has shown that, at the prices currently encountered, the *Gliricidia* fallow system is substantially more profitable than the *Imperata* fallow system. The value of firewood is a major contributor to this result.

The time taken for the smallholder to convert from the current system to the new system is important. In adopting the *Gliricidia* fallow system, smallholders will incur a loss in the first year, and it will take approximately four years for smallholders to begin making a profit above that achievable with the *Imperata* fallow system. Unless smallholders are capable of accepting the lower profitability in the first four years, or there is some government assistance, they are less likely to adopt the new system. Also, given the long-term nature of the investment in *Gliricidia* (requiring four years to be profitable), secure land tenure is required if smallholders are to adopt the system.

This analysis has shown that in the long term the *Gliricidia* fallow system has potential to be adopted by smallholders. Insofar as this system (and other improved fallow systems with similar characteristics) has been shown to be potentially attractive

to smallholders from economic, environmental and productivity perspectives, it gives confidence that more substantive research efforts into such systems be undertaken.

The approach to evaluation reported in this paper seems to have merit in being relatively inexpensive, yet powerful. An existing, simple biophysical model was linked with a benefit cost analysis, using data obtained from focused farm surveys. While lacking the 'sophistication' of a more process-oriented approach, the transportability of the models and their ease-of-use are attractive features. The time frame and cost of this analysis were minute in comparison to what would be involved in field experiments. Furthermore, the modelling approach allows the researcher to exert full 'control' over the relevant variables. This factor becomes more important as the number of variables of interest increases, and as the time frame of the experiment increases.

13

Flemingia Hedgerows

I WAYAN RUSASTRA
SRI HERY SUSILAWATI
GELAR BUDHI
PETER GRIST

THE WORK REPORTED in this chapter is along a similar line to that of Chapter 9. The analytical approach is the same, but the work is focused on a different location — specifically Lampung, Indonesia. The site was chosen on the basis of the quality of data available for calibrating the bioeconomic model. The need for a modelling approach was demonstrated by the review of alley cropping literature for Indonesia (Susilawati et al. 1997).

Most areas of Indonesia outside Java are dominated by Podzolic soil (Ultisols and Oxisol) with characteristics of low soil productivity, acidity associated with aluminium toxicity, and very high risk of soil erosion and degradation (Anon. 1994c). Inadequate soil management and shifting cultivation practices by the local farmers have resulted in degradation of soil, and part of these lands have been abandoned and become dominated by *Imperata cylindrica*.

Some interventions have been introduced by the government and by farmers to prevent further degradation of this land. Among the soil conservation technologies that have been introduced, hedgerow intercropping (alley cropping) is widely recommended. It has advantages, such as a low cost of construction, maintenance of soil productivity and the potential to be applied on most soil conditions (Susilawati et al. 1997). The reviewed studies indicate that the synergic effect of soil productivity increase, and soil erosion rate reduction, may increase food crop production. In addition, some hedgerow intercropping systems have shown significant reductions in farming cost per unit output *compared to mechanical soil conservation technologies*, due to decreases in labour use and other input reductions (Haryati et al. 1993).

The objectives of this study are:

1. To evaluate the long-term effects of hedgerow intercropping and two traditional farming systems (*Imperata* fallow and continuous open-field) on soil fertility, erosion and soil depth;
2. To assess the synergistic effect of changing soil characteristics and yield on food crop production over time;
3. To conduct a financial analysis by calculating the cumulative discounted net revenue of the three soil conservation technologies; and
4. To derive conclusions and policy implications.

FARMING SYSTEMS DEFINED

Three soil conservation farming systems are considered in this study. The first is hedgerow intercropping, based on the research of Adiningsih and Mulyadi (1993) in Terbanggi-Lampung, Sumatra. The other two are variants of open-field farming: a continuous cropping system; and an *Imperata* fallow farming system. In densely populated grassland areas such as Lampung, most arable land is cropped intensely to fulfil household consumption, and to provide a source of income. The *Imperata* fallow farming system commonly applied by the farmers is three years of fallow with *Imperata*, followed by one year of cropping. Due to population pressures on the land, there is a strong tendency to apply a continuous farming system.

A description of the three farming systems simulated in this study, using SCUAF, is presented in Table 13.1.

Table 13.1. Description of the three farming systems simulated using SCUAF in Terbanggi–Lampung, Sumatra

Farming system	Description
Continuous open-field farming	Repeated annual cropping of rice-maize and soybean-maize in a field without hedgerows.
Three years *Imperata* fallow followed by one year of open-field cropping.	Annual cropping of rice-maize and soybean-maize, without hedgerows, for one year, followed by 3 years of fallow, where the land reverts to *Imperata cylindrica* grassland.
Flemingia hedgerow intercropping	Repeated annual cropping of rice-maize and soybean-maize within the alleys formed by contour hedgerows of *Flemingia congesta*.

The study site was dominated by *Imperata cylindrica* before the implementation of the farming systems. *Flemingia congesta* is used as a hedgerow and a source of organic matter for the alley cropping treatment. No additional chemical fertilizer is applied in this study. *Flemingia* is periodically cut at intervals of six weeks, with the leaf material used as mulch. *Flemingia* hedgerows occupy 20% of the available land, and the remaining 80% is cultivated. Within the cultivated area, 80% is planted with rice or soybean, and 20%with maize.

PARAMETERISING SCUAF

SCUAF predicts the amount of soil erosion and the level of nitrogen and carbon in a soil profile. Changes in soil nitrogen and carbon are based on the information of climate, soil physical factors and soil chemical factors, in addition to the type of crop and farming system under consideration.

SCUAF's agroclimatic parameters were set to reflect the characteristics of the climate and soil at Terbanggi, Lampung. The climate in the study site can be categorised as lowland humid with annual rainfall of 3200 mm. The soil is imperfectly drained clay Oxisols with acid soil reaction (pH 5.2–5.3) and moderate class (slope 10–15%) (Adiningsih and Mulyadi 1993). The research findings also indicate that the initial carbon and nitrogen in the topsoil (0–20 cm) are 1.70 and 0.14% respectively, providing an initial topsoil C:N ratio of 12:1.

In the subsoil (20–40 cm depth) the initial carbon content is 0.62%. Since little information is available on the rate of carbon and nitrogen transformation and movement at this site, most of SCUAF's default parameters for carbon and nitrogen transformation in this type of environment have been accepted.

The initial net primary production (NPP) of *Flemingia* is 10 650 kg DM/ha/year (Adiningsih and Mulyadi 1993), when moisture content is taken at 30%. The proportions of *Flemingia* leaf, wood and fruit are 66%, 33% and 1.0%, respectively. The NPP of the food crop is 5555 kg DM per ha/year which consists of 67% leaf and 33% fruit. Roots as a fraction of above ground NPP for both tree and crop are 40% and 25%, respectively. The NPP of *Imperata* is 4020 kg DM/ha/year, with the roots a further 40% of above ground NPP (Soerjani 1970; Castillo and Siapno 1995). The accumulated standing biomass of *Imperata* is returned to the plant/soil system as residue following each year of fallow.

The nitrogen fraction of the dry mass of the plant parts has only been experimentally measured for the leaf of *Flemingia*, at 2.63% . The nitrogen fraction of the other plant parts was not available, so SCUAF default values of 0.50 for wood and 1.50 for root are used. For maize the N fraction of the leaf, fruit and root are taken from

Nelson et al. (1998) to be 2.00, 3.00, and 1.50% respectively. The nitrogen content of the plant parts of rice and soybean, are assumed to be similar to that of maize.

INPUTS, COSTS AND RETURNS

To assess the profitability of the three farming systems over a period of 20 years, a cost-benefit analysis is applied. Food crop production, over the twenty years considered in this analysis, is derived using the SCUAF model. Crop yield is multiplied by the market price to calculate crop revenue. As SCUAF calculates a combined, rather than an individual, crop yield it is necessary to calculate a weighted average price to apply to that yield. The weighted average price of this output is Rp 295/kg. The calculation of this figure is based on the prices of upland rice, corn, and soybean at Rp 240, Rp 260, and Rp 850/kg respectively (Anon. 1994b), and the proportion of each commodity of 55.0, 36.0, and 9.0% of total food crop yield, respectively (Adiningsih and Mulyadi 1993).

Costs vary depending on the type of farming system used. For the hedgerow conservation technology, costs comprise: labour for land clearing; labour for hedgerow planting and management; labour for food crop production; and seed costs (legume and food crops). According to Zaini and Lamid (1993), the labour requirement for manual *Imperata* land clearing in the first year is approximately 140 mandays/ha. Later years require only 40 mandays/ha. The labour requirement for hedgerow land preparation, planting and pruning, is 52 mandays (Haryati et al. 1993). For food crop production, labour used/ha is 49.2 mandays (Anon. 1994b).

Based on this information, the total labour requirements for the hedgerow intercropping system in the initial year, normal years, and in the hedgerow planting year are 241.2, 89.2, and 141.2 mandays/ha. For the continuous open-field farming system, the total labour requirement for the first year is 189.2 mandays, and 89.2 mandays/ha for the other years. Total labour used for the *Imperata* fallow system is 189.2 mandays/ha, which consists of labour for *Imperata* land clearing, food crop production and management. The labour wage rate is the same for all activities, at Rp 1700 per manday (Anon. 1994a).

Other than seed (legume and crop seed) no inputs are required. The seed requirement for legumes in hedgerow intercropping is 10 kg/ha, with total value of Rp 17500 (Haryati et al. 1993). In all systems, the seed requirement for the food crop is assumed to be the same, due to the similar cropping patterns. The quantities of seed used for upland rice, soybean, and maize are 23.7kg, 18.9kg, and 6.3kg, with market prices of Rp 445.8, Rp1230 and Rp 907.5/kg respectively (Anon. 1994b). The total seed cost for food crops therefore, is Rp 39530 /ha.

The discount rate of 12% is used for the cost-benefit analysis of the three farming systems, This rate approximates current real interest rates in Indonesia (Anon. 1996) and is chosen to represent the time value of money to society. A discount rate of 25% is also used. This represents the market interest rate and is equal to the nominal rate of interest given by the State bank.

RESULTS AND DISCUSSION

Soil quality factors

The factors of soil quality considered in this analysis are soil erosion, soil depth, labile nitrogen, and plant-available mineral carbon. Cumulative soil loss is most severe under continuous traditional open-field farming (Fig. 13.1). Total cumulative soil erosion under continuous traditional farming over twenty years is 6693 t/ha compared to 506 t/ha under *Imperata* fallow and 314 t/ha under hedgerow intercropping. Erosion in the cropping year of the *Imperata* fallow system is much lower than that for continuous open-field farming (averaging 94.2 t/ha compared to 330 t/ha), but it is still higher than for hedgerow intercropping (16 t/ha).

In general the results of this study are similar to the findings of Chapter 9 in the Philippines. The cumulative soil loss predicted from hedgerow intercropping over twenty five years is the lowest of those studied, followed by reduced fallow farming. The highest erosion is observed in the continuous open-field farming system. Nelson et al. (1998) also show that the reduced fallow farming system, in the year of cropping, produces a rate of erosion similar to continuous open-field farming. The fallow length considered in this study is three years. Menz and Grist (1996a) show that even with a ten-year *Imperata* fallow period, soil fertility is not able to recover to produce a sustainable system. They reveal that fallow lengths shorter than 20 years result in an unsustainable farming system. However, for most smallholders, it is not economically viable to reduce the cropped area to the low levels required to maintain a twenty-year fallow length.

Figure 13.2 represents the change in soil depth for the three farming systems over time. There is little significant difference between the hedgerow intercropping and *Imperata* fallow systems. After 20 years, the soil depth of both farming systems is the same, at 98 cm. For continuous open-field farming, predicted soil depth decline continuously over time. By year 20, 40% of the soil is lost, i.e. the depth of soil remaining is 60 cm.

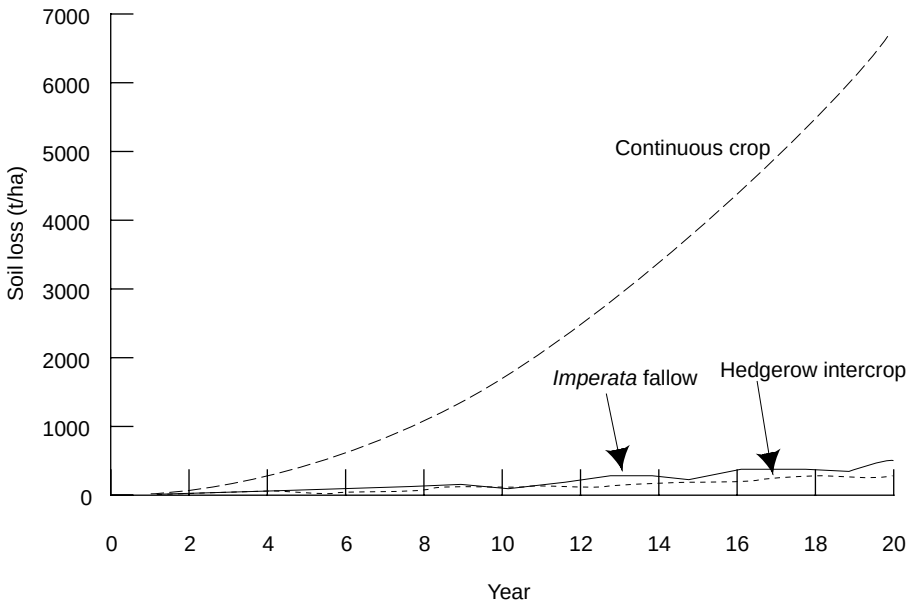

Figure 13.1. Cumulative soil erosion over time for three soil conservation technologies in Lampung, Indonesia

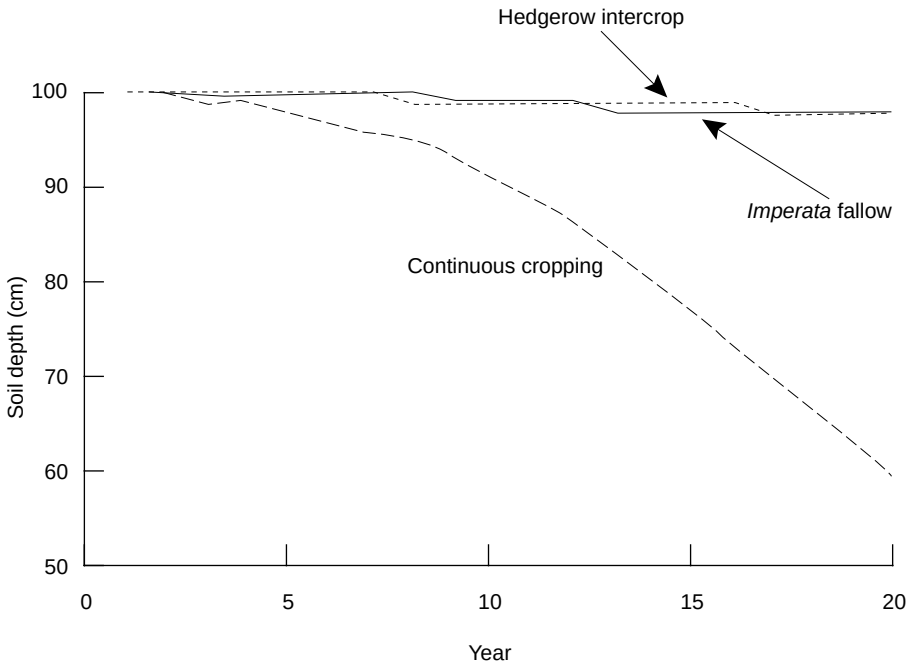

Figure 13.2. Soil depth over time for three soil conservation technologies in Lampung, Indonesia

The severe increase of cumulative soil erosion under the continuous open-field results in a sharp decline in labile nitrogen and carbon over time (Figs 13.3 and 13.4). The *Imperata* fallow system, with a moderately increasing trend of soil erosion, has a modest declining trend of both labile nitrogen and carbon over time. On the other hand, the hedgerow intercropping shows a slow-moving decline in labile nitrogen and carbon over time.

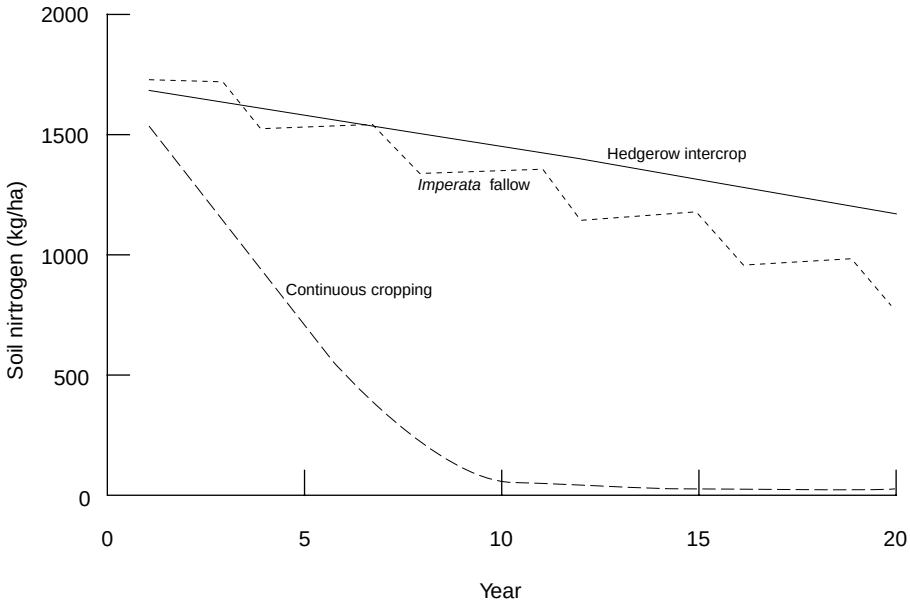

Figure 13.3. Labile nitrogen over time for three soil conservation technologies in Lampung

Predicted soil nitrogen and carbon are highest for *Flemingia* hedgerow intercropping, due to the cycling of nitrogen, carbon and organic matter through hedgerow prunings. Mulching of hedgerow prunings also shows the capability to reduce soil erosion. The organic matter contributed by the *Imperata* fallow has little impact on soil fertility, with only a minor conversion of carbon and nitrogen during the fallow period. Both elements decline significantly in the year of cropping within the *Imperata* fallow farming system (Figs 13.3 and 13.4).

Food crop production

In the first four years, crop production is highest under continuous open-field cropping. This is due to the greater proportional area under crops (100%), when compared with the hedgerow intercropping situation (80%). Under the *Imperata* fallow system, crop production only occurs on one quarter of the land so crop yield per hectare of crop planted is four times the level of crop production shown in Figure 13.5.

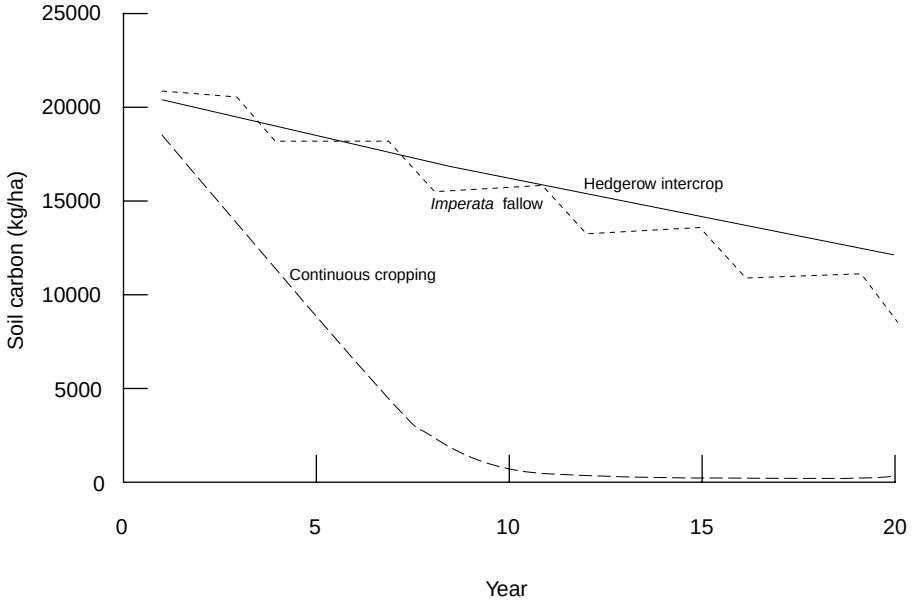

Figure 13.4. Labile carbon over time for three soil conservation technologies in Lampung, Indonesia

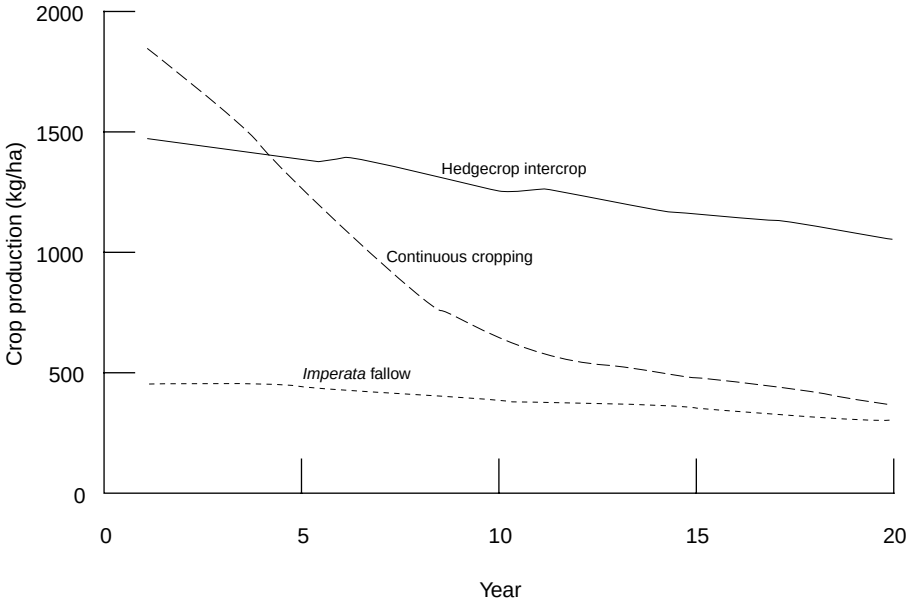

Figure 13.5. Food crop production over time for three soil conservation technologies in Lampung, Indonesia

The rate of soil loss and decline in soil quality in all three farming systems explains the predicted pattern of food crop production presented in Figure 13.5. Predicted crop production per hectare declines under all three farming systems, but declines considerably more under the continuous open-field farming system. This is associated with the sharp decline in labile nitrogen and carbon under the continuous cropping system. *Flemingia* hedgerow intercropping is able to sustain food crop production at a higher level than other two farming systems.

Under hedgerow intercropping, crop production (and yield) decreases approximately 30% over the 20-year period, from 1481 kg in the initial year to 1046 kg by year 20. For continuous open-field farming, production (and yield) decreases 81% (from 1852 kg to 352 kg), with the major part of this decline occurring in the first 10 years (from 1852 kg to 642 kg). Production (and yield) decline for *Imperata* fallow was 33%. This indicates that *Flemingia* hedgerow intercropping comes closest to maintaining sustainable food crop production in the long term.

Economic outcome

Cost-benefit analysis is applied to assess whether a higher crop yield in the future can offset the costs of establishment and maintenance of the respective systems. The result is presented in terms of cumulative discounted net revenue (NPV) at a discount rate of 12% and 25%, for each farming method over the twenty years of the analysis. The advantage of using cumulative NPV is that it reveals the sensitivity of the analysis to the choice of planning horizon, in addition to graphically displaying the influence of major assumptions on the ordering of the farming method under consideration.

Considering a wage rate of Rp 1700 per manday, and a discount factor of 12%, the continuous open-field system has a higher NPV than hedgerow intercropping for the first 8 years (Fig. 13.6). Initially, hedgerow intercropping generates lower net benefits due to the higher labor requirement for establishing hedgerows, in addition to lower food crop yields because of lower cropping area.

The hedgerow intercropping system in year 20 still has a positive annual return of Rp 18 000. The cumulative NPV of the hedgerow intercropping, continuous open-field, and *Imperata* fallow farming systems by the end of the analysis (year 20), are Rp 1.78 million, Rp 1.2 million, and Rp 1.2 million, respectively. This shows that hedgerow intercropping is more profitable over the long term.

Using the market discount rate of 25% the hedgerow intercropping system does not become more profitable than the continuous cropping system until year 17. The higher discount rate requires a longer payback time before lower returns associated with the first few years of the hedgerow intercropping system can be recovered. As a

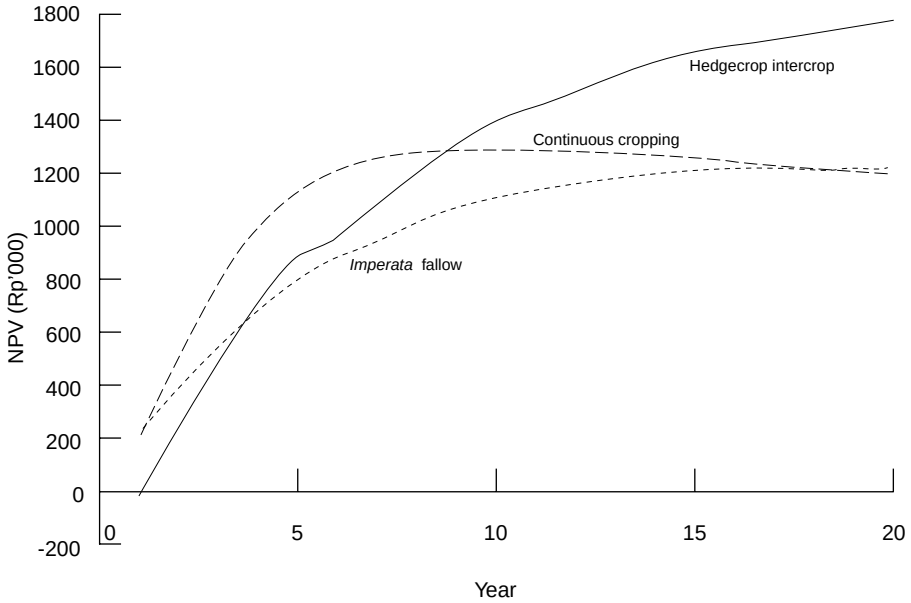

Figure 13.6. Cumulative net present value/ha over a period of 20 years using a discount rate of 12%, for three soil conservation technologies in Lampung, Indonesia (under the *Imperata* fallow system only 1/4 ha per year is cropped)

result of higher discount rate and the slower recovery of earlier losses by the hedgerow intercropping system, it is only marginally more profitable than the continuous cropping system after 20 years. The cumulative NPV of the hedgerow intercropping continuous open-field, and *Imperata* fallow farming systems, using a 25% discount rate, are Rp 1.03 million, Rp 1.01 million, and Rp 0.85 million, respectively.

CONCLUSIONS

The predicted changes in soil factors, food crop yield, and economic outcome, indicate that the *Flemingia* hedgerow intercropping produces a reasonably sustainable farming system in the long-term. The synergic effect of soil loss reduction and significant productivity improvement resulting from increased food crop production, generates higher cumulative NPV compared to the traditional farming system. After 20 years, the average food crop yield of hedgerow intercropping is over 100% higher, and its cumulative NPV by the end of the analysis is 20% higher, than that of the traditional farming system.

Hedgerow intercropping becomes an attractive option in the long-term if farmers can access credit at a rate of 18% per year. By using a discount rate of 18%, the NPV of the introduced soil conservation technology in the first year is negative, due to the significant labour requirement for hedgerow establishment. Therefore, capital is the first limiting factor for the adoption of the hedgerow farming system, in addition to land tenure status and small sizes of land ownership. The farmers need capital for salaries and in-kind payments for hired labour and collective forms of exchange labour in establishing the hedgerows, as well as for household consumption. Strategies to reduce the capital burden faced by farmers include, among other things: to develop farmer collective saving groups, to launch subsidised credit to farmers (KUT, or Kredit Usaha Tani), and to encourage farmers to organise a collective form of exchange labour for hedgerow establishment.

The limiting factor of land size must be substituted with selection of suitable planted shrubs or trees to maximise the benefits (from fuelwood or fodder) of alley cropping adoption for soil conservation purposes. By doing so, the trade-off between food crop planted area and benefits gained from legume species can be eliminated. In dealing with landholding status as one determining factor in farmers' willingness to adopt the hedgerow intercropping technology, the government must give some incentive to farmers in terms of land ownership rights. It is worthwhile to further develop these incentives, so that there is legal certainty on cultivated land.

Even though the hedgerow intercropping technology can be implemented under most soil conditions, modifications are still needed to suit the technology to specific locations. The legume species and food crop commodities must be suitable geographically and be in line with farmer interests. Therefore research and development studies need to be conducted in order to find out alley cropping farming systems suitable for each region throughout the country. The proposed soil conservation technologies should address the issues of soil fertility indicators, food crop yield, and long-term profitability, before the technology is recommended and implemented by farmers in the field, with the use of models such as SCUAF.

14 Rubber: Indonesia

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THE ECONOMICS OF the transformation of *Imperata* grassland to smallholder rubber plantations in Indonesia are examined in this chapter. Rubber, within a tree-based agroforestry system, has been successfully implemented by smallholders in that country (Chamala 1985). The regular income stream appears to be an important contributing factor. Rubber has potential for further expansion into *Imperata* areas (Bagnall-Oakeley et al. 1997) and can also serve as a model for other smallholder agroforestry systems on *Imperata* grasslands.

In this chapter, rubber production under different *Imperata* management strategies is simulated and analysed using the BEAM bioeconomic model (see Chapter 1 and Appendix for details of the BEAM model). When the timing dimension of the different management options is explicitly considered, there are a large number of possible combinations. Therefore, the scope of the analysis is restricted to options revealed as promising during exploratory analyses with the bioeconomic model. Growing rubber for direct economic return, and to shade *Imperata*, is a common thread throughout the analysis. Other aspects of smallholder rubber plantations on *Imperata* grassland (fire and carbon sequestration) are examined in Chapters 20 and 21.

IMPACT OF COMPLETE *IMPERATA* GROUNDCOVER ON RUBBER TREE GIRTH INCREMENT

There has been little effort to compile information relating to the impacts of *Imperata* groundcover within rubber plantations. Therefore the economic benefits from *Imperata* control within rubber plantations have not previously been well quantified.

In 1938, the effect of *Imperata* on the growth of rubber trees was measured (Anon. 1938) via an experiment which was conducted over five years at two sites in Malaysia (experiment stations at Klang and Serdang). After five years, trees in the *Imperata* infested plots had an average girth 0.52 times that of trees in clean-weeded plots. A continuing, unpublished, experiment at the Sembawa Research Station of the Indonesian Rubber Research Institute in South Sumatra, is assessing the impact of *Imperata* on rubber. The experiment has shown that *Imperata*-infested plots result in a rubber tree girth 0.53 times the girth of clean-weeded rubber, 30 months after planting (G. Wibawa, pers comm. 1996). A farmer survey was undertaken in 1995 and 1996 by the Natural Resources Institute (U.K.) and the Indonesian Rubber Research Institute in South Sumatra (H. Bagnall-Oakeley, pers comm. 1996). Farmers' opinion was that girths of young trees in areas dominated by *Imperata* were 0.5 times the girth of trees in areas with good weed control. *Acacia* and *Eucalyptus* trees established on *Imperata* grassland in Kalimantan, Indonesia grew at an average of 0.5 times the rate of trees growing without competition from *Imperata* (Turvey 1994). This comparison was made at a tree age of 30 months.

This brief literature review represents a consistent set of information indicating that rubber (and other) trees infested with *Imperata* show a girth increment approximately 0.5 times the increment of trees without infestation.

IMPACT OF PARTIAL INFESTATION BY *IMPERATA*

The reductions in tree growth rate reported in the previous section are for dense infestations, where the ground is totally covered by *Imperata*. Complete groundcover by *Imperata* is the norm in a treeless, fire-prone environment. However, within the shade of a rubber plantation *Imperata* groundcover is less than complete. In order to extrapolate the impact of *Imperata* groundcover for levels of groundcover between zero and 100%, a general relationship between plant growth, Y (girth increment in this case), and weed groundcover (*Imperata* in this case), W was used (Auld et al. 1987):

$$Y = a - b\sqrt{W}$$

where a is the girth increment in a weed-free situation, and b reflects the proportional change in the girth increment with respect to weed groundcover. As discussed in the previous section, the girth increment for completely *Imperata*-infested rubber (i.e. 100% groundcover) is one half that of clean weeded rubber (i.e. $b = 0.5$). With groundcover on a scale between zero and one, the relationship between tree girth increment and *Imperata* groundcover over the full range of possible groundcovers can

therefore be portrayed as in Figure 14.1. To clarify the interpretation of Figure 14.1, the vertical axis shows the tree girth increment measured as a proportion of the increment that would be obtained in the absence of *Imperata*.

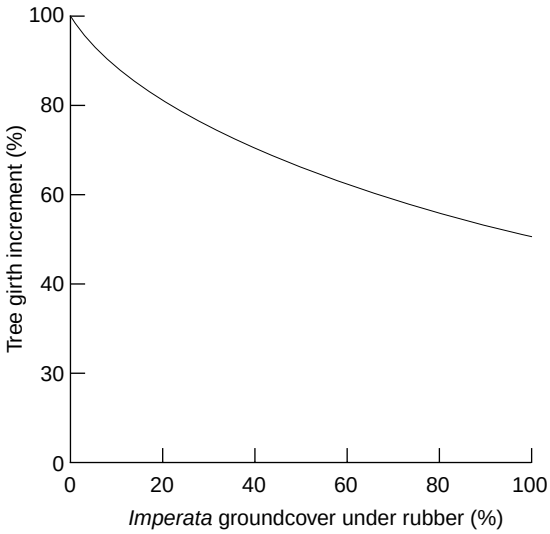

Figure 14.1.
Rubber tree girth increment as a function of *Imperata* groundcover

Only one empirical study was found in the literature indicating the impact of less than complete *Imperata* groundcover. Eussen et al. (1976) reported a negative logarithmic relationship between various levels of *Imperata* groundcover and maize yield. However, this is quite similar to the shape portrayed in Figure 14.1 which is based upon the square root function.

EFFECT OF SHADE ON *IMPERATA*

Eussen (1981) found that, for *Imperata,* relative growth rate fell as light intensity was reduced from the level normally incident in the tropics. The Eussen data related to light intensity levels between normal and 20% of normal. For light intensities below 20% of normal, a straight line relationship between relative growth rate and light intensity is assumed. Combining the Eussen data with this assumption, results in an approximately logarithmic function overall (Fig. 14.2). This is consistent with the general nature of the relationship between relative growth rate and light intensity observed for most species (Blackman and Black 1959).

Eussen found a close relationship between relative growth rate and number of *Imperata* tillers. On the basis of this, *Imperata* groundcover is assumed to be proportional to relative growth rate. This enables a link to be made between light intensity and *Imperata* groundcover, and the vertical axis of Figure 14.2 is so labelled.

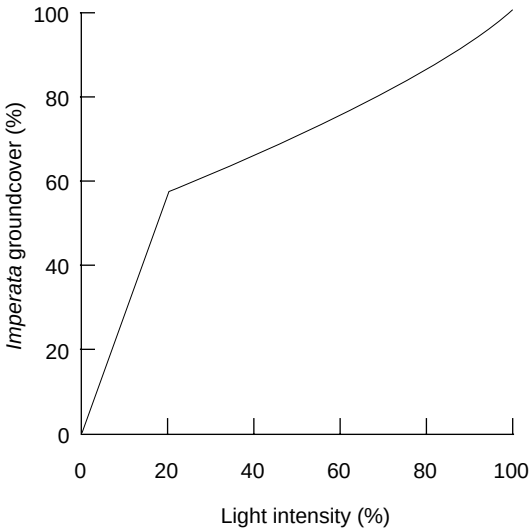

Figure 14.2. *Imperata* groundcover (relative growth rate of *Imperata*) as a function of light intensity (100% light intensity results in complete *Imperata* groundcover)

Determination of light intensity at ground level under a rubber canopy is a feature of the BEAM model. A description of the calculation of understorey light intensity is available in the original model documentation. The key variables involved in that calculation are: tree spacing, height of crown, width of crown, distance between crown base and the ground, and light permeability of the crown.

The two relationships shown in Figure 14.1 and Figure 14.2 are the key elements of new module within the BEAM model to simulate management options for *Imperata* control within smallholder rubber plantations. In summary, relative shading by rubber = f (crown height, canopy width, tree spacing) = f (tree girth) = f (*Imperata* groundcover) = f (relative shading). Light levels reaching the rubber understorey fall as trees grow. This effect flows through the equations, reducing *Imperata* groundcover (or rice yield in the case of a rice intercrop) and, in turn, increasing tree girth.

IMPERATA MANAGEMENT OPTIONS

The management options whose consequences were traced through the model in terms of their economic and physical impact on *Imperata* groundcover and rubber tree growth and output, are shown in Table 14.1.

Two types of rubber planting material are considered — unselected seedlings and clonal material (GT1). The faster-growing clones have a direct economic advantage in terms of rubber production, in addition to their effect of shading *Imperata.* But clones, at Rp 350 per seedling (or Rp 210000/ha), are more expensive and more

difficult for smallholders to obtain. The clonal adjustment factor in the tree girth equation of the model is specified to be 1.3 (based upon information from Gouyon and Nancy 1989). Unselected seedlings (or wildlings) are seedlings growing from seed dispersed from nearby trees, which are transplanted by the smallholder. Transplanting unselected seedlings is the common practice by smallholders, as there is no cost involved (other than time). Unselected seedlings are specified as having a 'clonal index' of 1.0.

Intercropping with rice can be regarded as an *Imperata* management option. Intercropping provides a direct economic return, but is competitive with rubber for soil moisture and nutrients. Only one form of intercropping is considered—rice for two years following rubber planting.

Chemical control of *Imperata* can be undertaken in lieu of intercropping, or subsequent to a period of intercropping. Three options considered in relation to chemical control are: two and five years of chemical control following tree planting, with no intercropping, and three years of chemical control following two years of intercropping (Table 14.1). Thus in the modelling, use of chemical weed control is restricted to the first five years after tree planting. Beyond that time, shading by the tree canopy reduces the need for supplementary weed control measures. Chemical control, once undertaken, is regarded as being effective for one year (Hoe 1980). This high risk of reinfestation implies that the present analysis is directed towards a situation of rubber planting in areas of intense and widespread *Imperata* infestation. Effective chemical control can be achieved with 5– 6 L of the herbicide glyphosate, costing Rp 22 000/L (Rp 110 000/ha) in the field (1US$ = approx. Rp 2900).

Table 14.1. *Imperata* management options considered

Control treatment	Options considered		
	Two years of chemical control following tree planting, with no intercropping	Five years of chemical control following tree planting, with no intercropping	Three years of chemical control following two years of intercropping
Rubber planting material	Unselected seedlings	Clone GTI	
Intercrop	Rice, 2 years	Nil	
Chemical control of *Imperata*	3 years following intercrop	5 years following tree planting	2 years following tree planting

The base case refers to a rubber plantation where no *Imperata* management is undertaken, but where there has been adequate ground preparation prior to planting the rubber. Some shading of *Imperata* is inherent in this base case.

Tree planting rate is 750 stems/ha across all treatments. The rubber and rice input/output parameters used, and their associated costs, are those pertaining to the Palembang region of South Sumatra (Grist et al. 1995). A summary of these are presented in Table 14.3 at the end of this chapter.

The economics of growing rubber on *Imperata* grassland were examined under various *Imperata* management options using the BEAM bioeconomic model. The biophysical and economic consequences over 30 years were simulated and analysed. Labour and other input costs were subtracted from revenues in the years of their incidence. Annual net revenues from latex, wood and rice were discounted back to net present values using discount rates of 10 and 25% (Chapter 1).

RESULTS AND DISCUSSION

Net present values for the various simulations with the model are presented in Table 14.2. At a 10% discount rate, the NPV of the base case, using unselected seedlings, is Rp 0.6 million.

Faster-growing rubber planting materials

The additional NPV from using clonal material over unselected seedlings in the base case was Rp 1.0 million/ha. The average increase obtained by using clones, across the range of treatments examined, is Rp 1.8 million/ha at the 10% discount rate. The *Imperata* management options giving the highest NPV are obtained from planting fast-growing clones followed by five years of *Imperata* control by chemicals. This management option represents virtually complete *Imperata* control, since, by year 5 with clonal planting material, shading by rubber is almost complete. At a 25% discount rate (not shown in Table 14.2), most of the systems examined barely returned a reasonable return to labour — the best system was the traditional one of two years of rice intercropping. The value of any investment in clones, and other forms of *Imperata* control, is questionable at a 25% discount rate.

Table 14.2. NPV/ha for various *Imperata* management options at a 10% discount rate and a 30-year time horizon

Treatment	NPV unselected	NPV clone	Absolute difference	Proportional difference
	(Rp millions)			
Base case	0.6	1.6	1.0	3.0
Intercrop 2 years	1.7	3.4	1.7	2.0
Chemical control 2 years	1.6	3.7	2.1	2.0
Intercrop 2 years				
Chemical control 3 years	1.6	3.4	1.9	2.0
Chemical control 5 years	2.1	4.4	2.3	2.0
Average	1.5	3.3	1.8	2.0

Higher NPVs are a result of reduced *Imperata* groundcover prior to tree canopy closure. For example, there are 28% fewer *Imperata* under clones compared to unselected seedlings in the fifth year (Fig. 14.3). The reduction in *Imperata* groundcover enables rubber to grow faster, providing an improvement in *Imperata* control and a threefold increase in NPV over the life of the plantation (for the base case in Table 14.2). Faster tree growth increases lifetime latex production. It also leads to an earlier commencement time for the tapping of rubber, which has a strong effect on the NPV of the plantation (Grist and Menz 1996a).

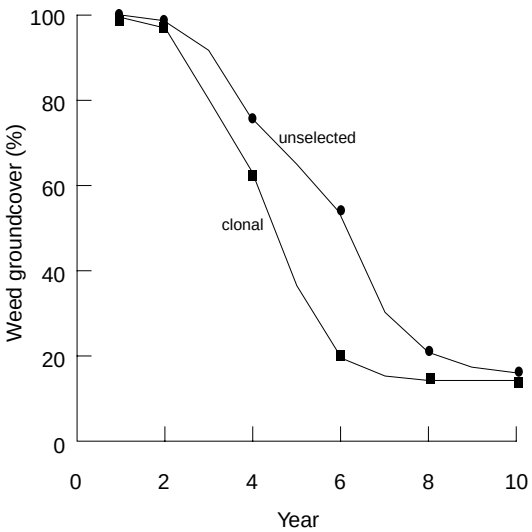

Figure 14.3. Comparison of *Imperata* groundcover under rubber for two types of rubber planting material (base case)

Intercropping and chemical control options

The period of intercropping in rubber by smallholders is normally limited to two years following tree planting, due to soil fertility decline and shading by the developing rubber plantation. The benefit of a rice intercrop, apart from controlling *Imperata*, is that it provides an economic return to smallholders in the early years of plantation development. This can strongly influence NPV in a positive direction.

Comparing the NPV's between the base case and the case of a plantation with a rice intercrop (Table 14.2) indicates a higher NPV for the rice intercrop situation.

The comparison between a two-year rice intercrop and clean-weeding with chemicals for two years is conceptually less clear. To obtain a higher NPV from rice intercropping requires that the returns from the rice harvest be greater than the costs associated with the reduced tree growth rate as a result of competition from rice. Chemical control proved to be slightly less profitable than rice intercropping when using unselected rubber trees, but slightly more profitable than intercropping when using clonal rubber trees (Table 14.2). However, for both types of rubber planting material, the difference between two years chemical control of *Imperata* and two years intercropping is small. So chemical control for two years is broadly comparable with intercropping for two years. While the net returns from an intercrop rice harvest in *Imperata* areas are usually modest, intercropping with rice does provide a method of *Imperata* control which gives a positive cash flow in the short term. For poor farmers, this may make the proposition of intercropping attractive, regardless of the effect on NPV.

However the maximum NPV is obtained with clonal planting material followed by chemical control for five years at Rp 4.4 million.

Duration of *Imperata* control following tree planting

Tree growth is influenced by the *duration* of *Imperata* control as well as by the level of control. A comparison of the NPV for treatments of different durations of chemical weed control under clonal and unselected seedlings (Table 14.2), shows an increase in NPV as the duration of weeding increases. This is portrayed in Figure 14.4, for the particular example of clones. The greatest gain in NPV is in year one. The *increment* in NPV for additional years of weeding falls thereafter.

The reason for the decline in economic returns over time from *Imperata* control is evident in Figure 14.5. The largest improvements in annual tree girth are achieved by *Imperata* control in the year immediately following planting. Subsequently, the improvement in tree growth from *Imperata* control declines, becoming stable after canopy closure. As canopy closure is approached, the level of shading of the *Imperata*

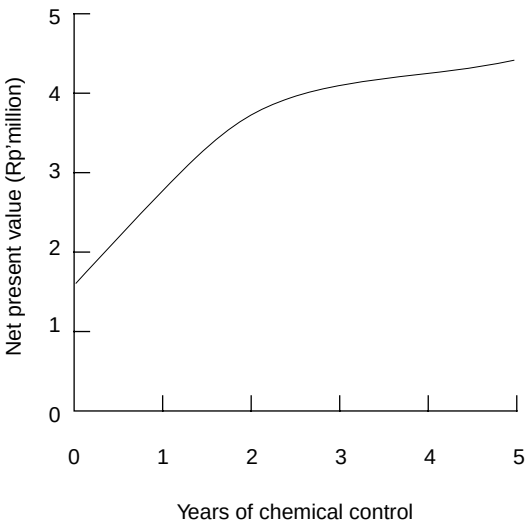

Figure 14.4.
Effect on NPV of different periods of chemical control of *Imperata* (clonal planting material, 10% discount rate, 30 years time horizon)

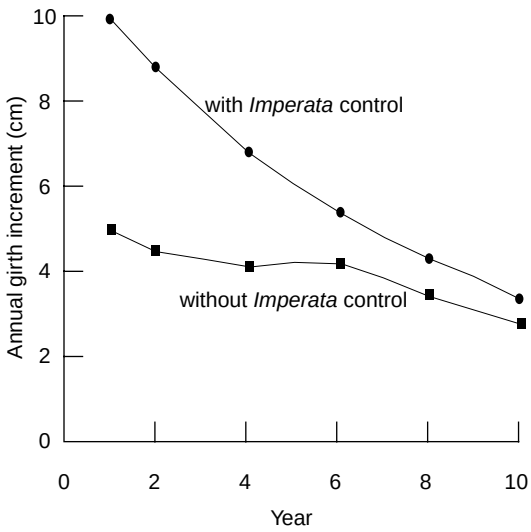

Figure 14.5.
Annual girth increment of clonal rubber with and without *Imperata* control

by rubber increases; *Imperata* groundcover falls, and the potential improvement in tree growth from *Imperata* control falls. There is also a natural decline in growth rate of the tree with time.

CONCLUSION

Rubber growing by Indonesian smallholders on *Imperata* grassland appears to be marginally profitable under the low intensity management typical of smallholders at a 10% discount rate. Profitability can be enhanced by management aimed at reducing

the competitive effect of *Imperata* on the rubber. *Imperata* control within a rubber plantation was found to be highly profitable in most circumstances, particularly, but not exclusively by using clonal planting material. Many smallholders in Indonesia do not yet use clonal planting material — unavailability and expense are cited as the main reasons. Other *Imperata* management options, such as chemical spraying, are reported to be imperfectly performed by smallholders. Given the potential economic pay-offs demonstrated here, greater extension efforts to promote these technologies would appear to be warranted.

The impacts of *Imperata* on rubber growth, and thus on the economic benefits derived from controlling *Imperata*, are highest in the first year following rubber planting. Economic benefits from reducing *Imperata* groundcover decline subsequent to year one, but remain significant up to approximately the fifth year after planting (for clones).

Other options relating to smallholder rubber plantation management, or *Imperata* control in smallholder rubber, could also be examined with the model used here.

This data relates to costs, revenues and labour requirements for the Palembang district in South Sumatra, in July 1995.

Table 14.3. Input costs, revenues and labour requirements for the RRECON model

Product prices		**(Rp '000/kg)**	
Rice crop	0.4	Processed timber	20
Latex (Grade 1)	1.2	Unprocessed timber	4
Latex (Grade 2)	0.8	Smallwood	4
Labour prices		**(Rp '000/manday)**	
Field work	3.2	Tapping	3.0
Tree harvesting	4.0	Processing	3.0
Site establishment	**Labour (manday/ha)**	**Rate (kg/ha)**	**Materials (Rp '000/ha)**
Ground clearing	42.0		
Fencing	50.0		20
Ground preparation	37.5		
Herbicide	5.0	5	110
Fertilizer	1.0	100	40
Seedlings	0.05 md/tree		Rp 350 per tree .
Material costs	**Rp '000/kg**	**Rate (kg/ha)**	
Herbicide	22.0	5	
Fertilizer	0.4	100	
Rice seed	0.3	20	
Work rates	**Rubber**	**Rice**	
Cropping		1 crop per year	
Weeding	15 md/ha	15 md/ha	
Weeding frequency	2 per year	2 per year	
Fertilizer applications	1 md/ha	1 md/ha	
Average timber transport distance to the mill (Palembang District) 50 km			

SECTION 4

INCORPORATING LIVESTOCK

In this section, a modelling analysis is undertaken of the actual and potential role of livestock in relation to a number of the tree-based and hedgerow-based systems defined in Section 3.

15 Evaluating End Uses of Napier Grass Strip Hedgerows With and Without Cattle

DAMASA MAGCALE-MACANDOG
CANESIO PREDO
KEN MENZ
ARSENIO CALUB

GRASS STRIPS AS contour vegetative cover for erosion control have gained some acceptance in Southeast Asia and other parts of the world (Lal 1990) due to their relative ease of establishment and management. Less labour is required to establish and maintain grass strip hedgerows than leguminous shrubs or trees (Nelson et al. 1998).

This study is an extension of the simulation and bioeconomic analysis described in Chapter 9, where a range of hedgerow systems were examined. Grass strips were found to be the most profitable form of hedgerow intercropping in that analysis. This result was attributed to the low establishment cost and the positive effect on soil erosion. In that chapter, the economic analysis was based on the use of napier grass cuttings for mulch.

Integration of livestock with forage grass has the potential to increase production and economic returns, as well as controlling erosion. This may therefore, enhance the longer term sustainability and productivity of a grass strip farming system.

In Southeast Asia, cattle are mainly kept for two purposes — for work and meat. Moog (1991) estimated that in the Philippines, 80% of cattle and 90% of buffalo and goats are raised by smallholders. The number of cattle per smallholding is low, with the majority of smallholders owning 1–3 head of cattle or carabao (Faylon and Magboo 1996).

Smallholder farms are typically of less than 3 ha (Alviar 1987; Limbaga 1993). Most of this land is dedicated to food crop production, such as rice or corn. Thus land available to produce feed for livestock is limited. Given the limited land availability,

and that most smallholder farming systems are focused on food crops, a cut-and-carry system of feeding cattle is more common than grazing. In the Philippines, animals are often stall-fed using a cut-and-carry system, and tethered for part of the time. However, in a cut-and-carry system, a considerable proportion of nutrients are extracted from the site of forage production. This can potentially be countered by returning manure to the field.

METHODOLOGY

The present study was conducted to assess the economic value of napier grass in alternative uses:

- as mulch; or
- as animal fodder, either by selling the grass cuttings directly for off-farm fodder; or
- by using the fodder on-farm and applying manure back into the hedgerow system (Table 15.1).

Table 15.1. Systems of napier grass cutting utilisation as simulated using SCUAF and economic models

Napier grass utilisation (System)	Description
S1	Napier grass cut and applied as mulch into the system
S2	Napier grass cut and sold off-farm as animal fodder
S3	Napier grass cut, fed to animal, manure returned to the system

The Soil Changes Under Agroforestry, or SCUAF, model is linked to spreadsheet models in order to incorporate the livestock dimension and to simulate and compare the economic benefits and long-term environmental impacts of the different uses for napier grass cuttings.

Napier grass strips and napier grass cutting usage

The hedgerow intercropping experimental trials in Claveria are described in detail by Agus (1994) and Nelson et al. (1998). Initial net primary production for napier grass is specified as 8085 kg DM/ha/year — similar to that specified by Nelson et al. (1998).[1] For the mulching treatment (S1), napier grass cuttings are not harvested in

1. As we are dealing with 0.15 ha of napier grass strips in 1 ha of a smallholder farm, the initial (Year 0) annual dry matter napier production for 1 ha of a smallholder farm is 1213 kg DM.

the SCUAF model, they are left on the site and accumulate as annual litter. This is equivalent to the napier grass hedgerow system modelled by Nelson et al. (1998). Soil parameters for systems S2 and S3 are basically the same, except for the return of manure to the soil as an organic addition in system S3. The quantity of animal manure produced from a one hectare farm using a napier grass hedgerow system is estimated at 550 kg dry manure per year. This is based upon an average digestibility of napier grass of 58% (Soewardi and Sastradipradja 1980). Analyses of cattle manure conducted by the Bureau of Soils, UPLB (unpublished data) showed a C:N ratio of 18:1.

The livestock component

A survey involving farmer interviews and farm visits was conducted in Claveria to obtain information regarding costs and returns associated with animal production. An animal component submodel was developed using a spreadsheet to complement the SCUAF model (Fig. 15.1). This was done in order to assess the potential of a napier grass hedgerow-animal system to increase productivity and economic returns, relative to hedgerow systems without a livestock component (as in Nelson et al. 1998). The napier grass cut (harvested) within the SCUAF model serves as the link to the animal component model in S3. A reverse link was made through the addition of animal manure back to the hedgerow system, also in S3. The fertilizer value of animal manure is reflected in SCUAF as an organic fertilizer addition.

There were several assumptions employed in the livestock component of the model:

1. Feeding of animals is undertaken using a combination of tethering and cut-and-carry;
2. Thirty percent of animal manure is dropped directly into the system by the animal and the other 70% of the manure is applied manually;
3. Napier grass produced in a given year is consumed by the animal within that year;
4. Animals are also fed grasses from sources other than the napier grass strips;
5. The number of animals that the system can support is proportional to the predicted annual yield of napier grass; and
6. The value of grass passing through the animal is treated as the incremental costs and benefits associated with animal production.

The labour costs associated with the animal component are presented in Table 15.2. These include cutting and carrying of napier grass to the animals; stall cleaning and maintenance costs, at 1.5 hr/au/day, where au = animal unit (Calub and Rañola 1985); and collection, carrying and spreading of manure. Other costs include establishment and maintenance of animal shelter, and the cost of veterinary drugs,

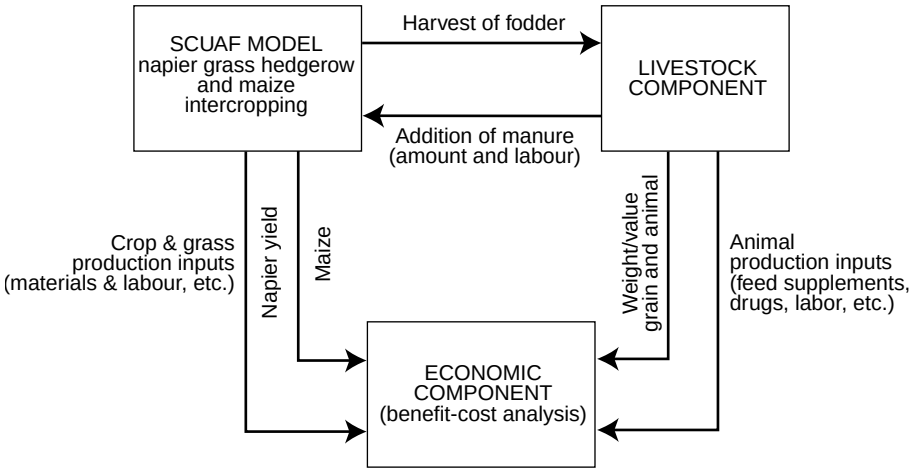

Figure 15.1. Relationship between SCUAF, economic and livestock components of the bioeconomic model used in this study

salts and rope. The average estimated cost of establishment of animal shelter in Claveria is ₱ 365 per animal unit (au) every six years, while maintenance costs amount to ₱ 130/au every three years. The annual cost of veterinary drugs, salt and rope needed in animal production is estimated, farmgate price, at ₱ 1092/au/year.

Table 15.2. Median estimates of labour requirement in animal production

Operation	Manday/animal unit/year
Cutting and carrying of napier grass, stall cleaning and maintenance	62.2
Collecting, carrying and spreading manure	23.4
Annual total	85.6

The value of grass passing through the animal is evaluated in terms of:

1. Change in animal inventory value resulting from weight gain or animal numbers;
2. Animal services such as ploughing; and
3. Fertilizer value of manure.

The first two benefits from the animal component are linked directly to the economic spreadsheet for the cost-benefits analysis. The fertilizer value of manure is reflected back within SCUAF as a subsequent increase in the productivity of grass and maize, with an associated economic benefit.

The median estimate for the change in animal inventory, valued at ₱2125/au for a period of one year, was reported in a special survey of 16 farmers in Claveria. Change in animal inventory value is derived by subtracting the beginning-year value from the end-of-year value, divided by the number of animals at the end of the year.

Based on discussions with Claveria farmers, the median total number of days of productive animal service each year is about 153 days per animal. Animal services are of two types: draught power (e.g. ploughing, harrowing etc.), and hauling and transport (Table 15.3). The total draught power of 88 days per animal per year is estimated from 16 days per month for a period of 5.5 months of the year when animals are used for draught purposes. Total hauling and transport is 65 days per animal per year based on the animal being used for 2 hours per day, throughout the period that the animals are not being used for draught power. These quantities of animal services are then multiplied by an average hiring rate per animal of ₱42/ad (animal-day —the work done by one animal in one day) in Claveria (Nelson et al. 1998), to calculate the annual gross revenue from animal services. Total annual gross benefits per animal, arising from draught services plus the change in animal inventory value, amount to ₱ 8551 (Table 15.3).

Table 15.3. Gross benefits per animal in Claveria, 1995

Type of benefit	Quantity (ad/au/year)	Value (₱/au/year)
Animal services @ ₱ 42/day		
Draught (ploughing, harrowing, etc.)	88	3696
Hauling and transport	65	2730
Change in animal value		2125
Annual total gross benefits	153	8551

The amount of napier grass harvested in the first year is 1152 kg DM/ha of the system (i.e. grass strips plus maize). Cattle with an average body weight of 300 kg require 7 kg DM each of feed daily (Kearl 1982), which gives an annual feed requirement of 2555 kg DM. The annual napier grass production in Year 1 of 1152 kg DM can therefore support 0.45 au. Thus the annual gross benefit from animal production attributable to napier grass is ₱ 8551 × 0.45, which is ₱ 3848/ha of napier grass. The number of animals that can be supported by a hectare of napier grass strips declines as soil productivity declines. This factor of 0.45, applicable to year one is correspondingly reduced for subsequent years (see Figure 15.3 and succeeding discussions).

Other data for use in the economic model

The price of maize and the costs of farming maize in a hedgerow intercropping system were derived by Nelson et al. (1998), and this analysis was used in the economic model. The data were obtained through interviews with selected farmers in the community of Claveria. These farmers have five years of experience using grass strips to farm maize. An additional survey was conducted to obtain the farmgate price of napier grass. The average farmgate price of napier grass reported by farmers in Claveria was ₱ 0.35/kg fresh weight (₱ 1.30/kg dry weight basis). This estimate is close to the price of napier grass reported by the Pioneer Development Foundation for Asia and Pacific, Inc. and PCARRD (1994).

The economic model

The economic model used to derive the NPV and profitability of the three systems is similar to the model used in previous work. For details of the model see Chapters 2 and 9.

RESULTS

The biophysical perspective

Maize yields predicted by SCUAF continually decline over the 25 years, from an initial annual yield of 2.91 t/ha, in all three systems (Fig. 15.2). Use of napier grass cuttings as mulch or fodder for animals, with manure applied back to the system, result in a smaller decline in maize yield relative to the system in which napier grass is removed directly from the system and sold.

The three systems also show variations in the annual growth of napier, similar to that seen in maize yield. Removal of napier grass from the system results in a slightly greater reduction in napier grass growth (22% reduction) than the mulching and animal manure systems (19% reduction for both systems) after 25 years.

Predicted changes to soil erosion and soil fertility were shown in Chapter 9 for farming system S1. While differences are observed between the S1, S2 and S3 treatments (Magcale-Macandog 1997b), these are generally slight (more or less as reflected in the yield changes shown in Figure 15.2).

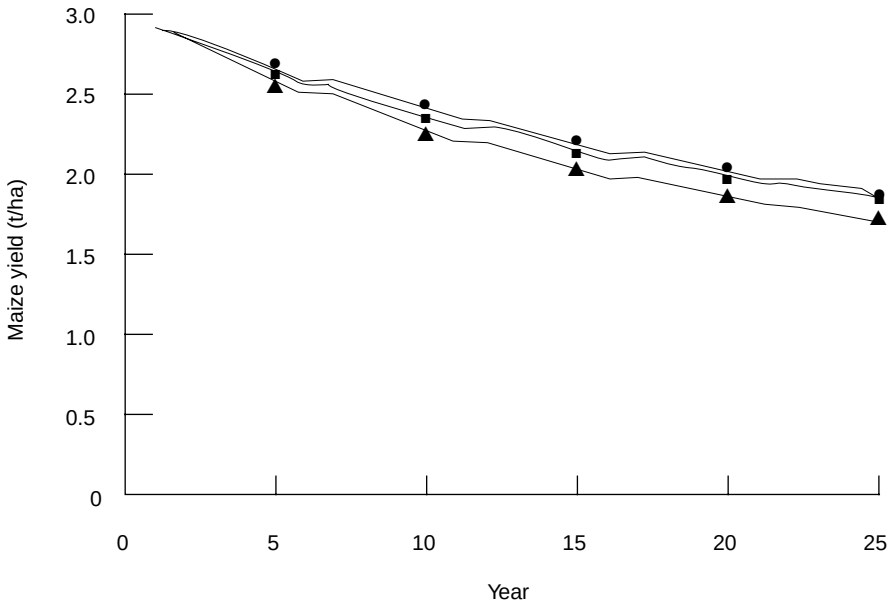

Figure 15.2. Predicted maize yield for the three farming systems
● = Mulch (S1); ▲ = Sold (S2); and ■ = Fed to animal (S3).

The economic perspective

Cost-benefit analyses are conducted on the three systems of napier grass use. Predicted annual net returns from all the alternative uses decline over time, due to reduced productivity of the systems (Fig. 15.3). The five year cycle evident in the annual net returns is due to the cost of hedgerow establishment, re-establishment and infill planting.

Throughout the period of analysis, the highest annual net returns are realised from the system where napier grass is passed through an animal (S3, Fig. 15.3). Direct selling of napier grass (S2) gives higher net economic returns than applying napier as mulch (S1) up to year 10. Between years 10–15, annual net returns are similar for systems S1 and S2. Beyond 15 years, the beneficial effects of mulching on maize yield outweigh the value of directly selling the napier (S3 > S2). After approximately 20 years, the annual profitability of all systems is marginal due to low soil quality. The lower annual net return for the first year, to following years, for all three systems, is due to costs incurred in establishment.

The predicted cumulative net present value, using a discount rate of 10% , from the various napier grass systems is significantly different over the 25 years of cropping (Fig. 15.4). Feeding the grass to animals and adding the manure back to the system results in the highest net present value ranking. Using napier grass as mulch results in the lowest net present value of the three farming systems.

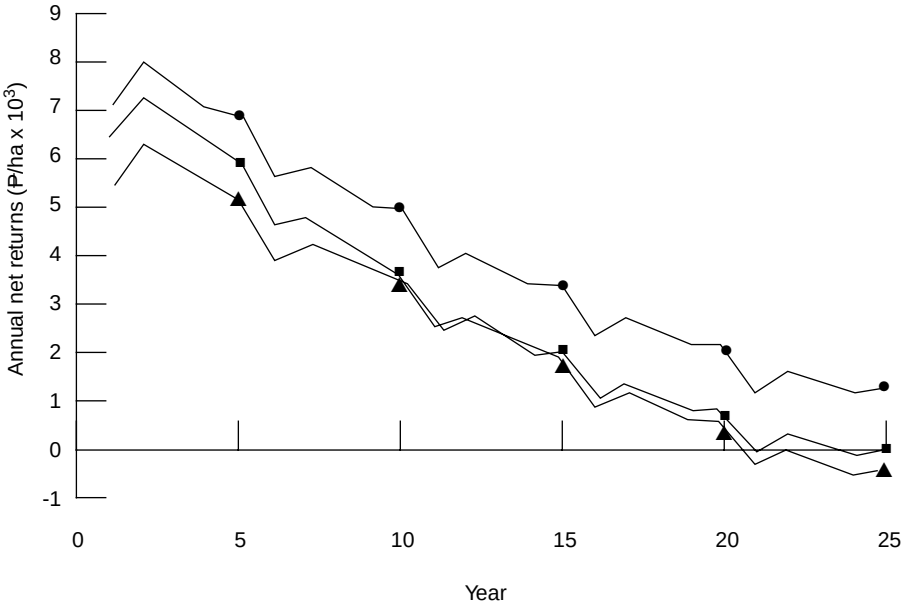

Figure 15.3. Annual net returns from the three farming systems.
▲ = Mulch (S1); ■ = Sold (S2); and ● = Fed to animal (S3)

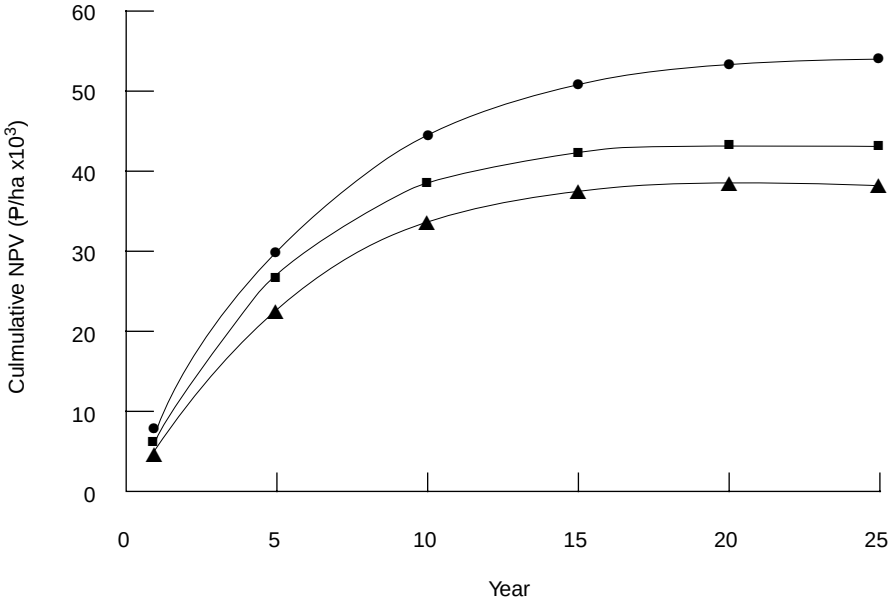

Figure 15.4. Net present value of the three farming systems with a discount rate of 10% . ▲ = Mulch (S1); ■ = Sold (S2); and ● = Fed to animal (S3).

Within system S3 (feeding napier to animals), there is the option to return animal manure from the animal stalls/shelter, to the fields. Up to this point in the paper, system S3 has been analysed on the assumption that manure is returned. The option of not returning manure is now examined (Fig. 15.5). Returning animal manure to the system is less profitable during the first six years of cropping. In subsequent years, the situation is reversed. In discounted net present value terms, the return of manure is worthwhile despite the time lag involved.

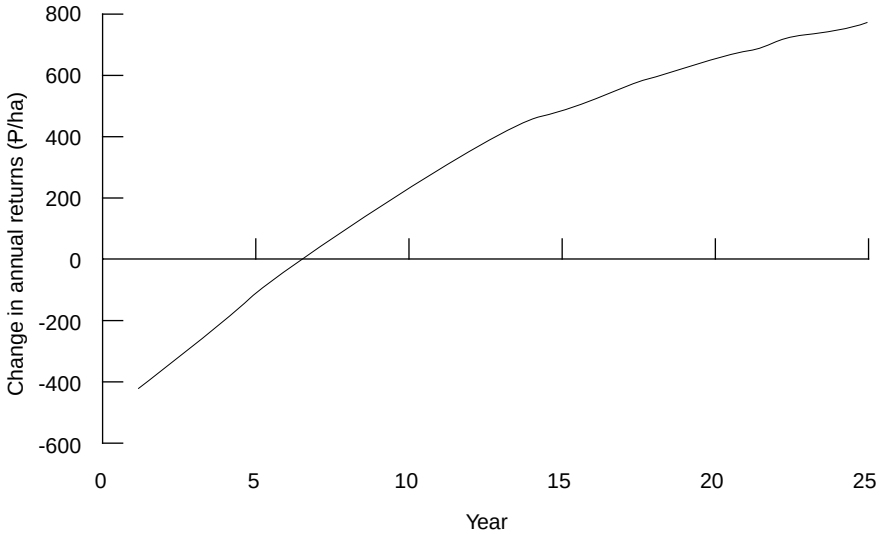

Figure 15.5. Annual net economic returns by returning animal manure to the field, compared to non-return of manure

DISCUSSION

Greater maize and napier grass yields in the systems where napier is applied as mulch (S1) or as animal manure (S3), show a positive soil nutrient effect of napier, compared with the situation where napier grass is entirely removed from the system (S2).

The amount (dry matter) of napier grass applied as mulch is 1152 kg DM/ha in the first year, declining to 985 kg DM/ha in the 25th year. With an average leaf N content of 0.88%, the equivalent amount of nitrogen added to the system is approximately 10 kg N/ha/year. The average application rate of manure is 550 kg/ha/year with manure N content of 1.77%, so the amount of nitrogen applied through manure is approximately the same, at 10 kg N/ha/year.

Decomposition of the organic materials added (mulch and manure) results in the release of nutrients from the organic biomass to become available for crop uptake. This shows the long-term beneficial effects of organic fertilizers such as green mulch and animal manure which release and build up mineralised nutrients like nitrogen and carbon in the soil through time.

Another advantage of returning organic mulch and manure is that the N and C content of the napier leaf biomass and manure will help build up the humus content of the topsoil. Spread of grass cuttings back into the cropped alley area covers and protects the soil from direct raindrop impact, such that surface soil is protected from displacement and translocation down slope by runoff water. Decomposition of mulched grass and animal manure results in organic matter and humus build up in the surface soil which improves soil structure and soil aggregation, rendering the soil less susceptible to erosion. This is supported by lower soil loss and greater soil depth in the systems where grass cuttings are applied as mulch and where animal manure is returned to the system. The total accumulated soil losses in the mulched and animal manure application systems are 16% and 13% lower, respectively, than the total soil loss from the cut-and-sell system (S2). Garrity (1994b) reported impressive control of soil loss in alley cropping areas where prunings from leguminous trees, which were planted along contour hedgerows, were applied as mulch in the alley areas.

The SCUAF–predicted decline in napier yield ranges from 18–22% of the initial yield after 25 years. Farmers at Claveria have noted a decline in napier yields over time. Vigorous growth of napier grass requires a large amount of soil nutrients, which may result in interspecific competition with the food crops planted along the alley areas for soil nutrients, water and even light (Garrity 1994b; Sanchez 1995).

Population growth and the associated intensification of agriculture has focused attention on improving upland farming practices, but one area that has been virtually overlooked as an alternative farming practice is animal production. One advantage of the maize-napier grass strip system is that the grass cuttings can be used as animal fodder. Sukmana et al. (1994) noted that the introduction of high-yielding grasses and shrub legumes to stabilise terraces improved animal carrying capacity from one animal unit to 4–6 au/ha and made farm labour more efficient. Farmers are keen to engage in livestock raising. However, current development of livestock is constrained by availability of capital.

Cattle and sheep are well suited to incorporation into most silvopastoral systems. Both species are essentially grazers and will usually consume the understorey herbaceous plants in preference to browsing trees and shrubs (Gutteridge and Shelton 1994). The daily demands of animal feed requires constant tree or grass pruning. If prunings are all given to the animal(s), the manure can be returned as fertilizer for the

crop. It is also important for farmers to include fodder species such as *Gliricidia* with timber, fruit or other species used.

Feeding napier grass to an animal gives higher economic benefits than selling napier grass directly. Livestock in most Asian countries are kept for the much needed draught power used in land preparation, and for hauling and transport activities. Some farmers use a growing animal for draught, sell it after a few years, then buy another young replacement. Others may also use a female animal, in addition to breeding the same for its calf. Extra costs associated with keeping animals were taken into account in this study.

The economic analyses showed that, both in terms of annual net returns and net present value, feeding cut napier grass to animals, with the return of animal manure to the system, gives a significantly higher value to napier grass than the alternative uses examined here. Nelson et al. (1998) found that napier grass strips used as mulch gave the highest cumulative net present value compared with other hedgerow systems. In our analysis, we found that feeding grasses to animals enhances the value of napier. These findings add weight to Nelson's conclusion that the napier grass strip system is a promising innovation for sustainable farming.

The marginal analyses show that returning animal manure to the system gives positive economic benefits in the long term. This implies that the long-term added benefits of manure application are greater than the added labour cost incurred. The short-term losses are compensated for by long-term benefits from returning manure, such as increased productivity of both maize and napier. These findings suggest that in the long run, it pays to return animal manure to the system. Feeding livestock without the return of manure to the field gives a biophysical result similar to selling napier off-farm, as animal fodder.

CONCLUSION

Results of this bioeconomic modelling study show the integration of animals into a napier grass strip system, for controlling erosion, enhances the economic attractiveness of that system. The feeding of napier grass to animals (especially when manure is returned to the field) is the most profitable end use of the napier. The results of this use are higher maize and napier yields; a lower soil erosion rate; and less of a reduction in soil mineral nitrogen and soil labile carbon content. The biophysical results were similar for using napier as direct mulch and feeding to animals with return of manure. However, economic analysis showed that higher economic returns were gained when napier grass cuttings were applied to the soil as manure after feeding to animals, rather than directly as mulch.

16 Natural Vegetation Strips (NVS) and *Gmelina* Cropping with Cattle

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RICHARD L. TINSLEY
DAMASA MAGCALE-MACANDOG

NATURAL VEGETATION STRIPS (NVS) have been promoted as a promising means of contour hedgerow cropping to help sustain crop production in the Philippine uplands. Narrow contour strips are left unploughed during land preparation for crops. Natural vegetation, mostly dominated by grass species, spontaneously develops on those unploughed strips. This system overcomes farmers' concerns about the labour required in establishing contour bunds and for planting shrub legumes and grass hedgerow species.

Another path taken by upland farmers is to farm timber trees on infertile grassland soils (Garrity and Mercado 1994). Recent rising demand for timber in Northern Mindanao, Philippines has driven smallholder farmers to plant fast-growing timber species, mostly using *Gmelina arborea*, within their farms (Chapter 8). The trees are commonly planted in portions of farms as block planting, along farm boundaries, or established along contour strips.

Much has been reported about the significant reduction in soil loss and increase in alley crop yields through the hedgerow cropping system (Garrity et al. 1993; Stark 1996). On the other hand, different tree-based farming schemes have tended to be evaluated in terms of their productive adaptability. Both hedgerow and tree cropping systems are examined here from biophysical and economic perspectives. An animal component is incorporated in the analysis since this is one area which has been virtually overlooked (Amir and Knipscheer 1989).

Livestock, particularly draught animals such as cattle and buffalo, are traditionally integrated to complement Asian agricultural and tree production. One or two

animals are kept for draught power and milk production (Ranjhan and Faylon 1987). Livestock produce organic manure for fertilizer, reduce weeds and weeding cost through controlled grazing, and increase farm production (Singh 1992). Other benefits include capital accumulation, income from rental, security and insurance, recreation and social prestige (de Guzman and Petheram 1993). The animals, on the other hand, greatly depend on natural herbage and crop residues such as rice straw and maize stover for fodder. Distinct feed patterns exist in relation to seasonal production of the crops and grasses within a particular farming scheme.

The NVS prunings can be applied as mulch on-farm, or can be used as livestock feed. However it is observed that, when used as animal fodder, the economic value of hedgerow cuttings may often exceed their value as green manure (Fernandes et al. 1992, and see also Chapters 15 and 17). In those studies, the economic benefit from the animals was attributed to the draught and transport contribution of the animals as well as in the annual change in their value.

In tree plantations, the potential for animal production depends on the amount of light transmitted through the leaf canopy of the trees (Stür 1995). Canopy closure severely restricts the amount of forage available.

Thrust of this paper

In this paper, farmer surveys are reported with the aim of determining how livestock are raised in relation to the agricultural and tree components in both NVS and *Gmelina* block planting systems. The contribution of the animals to the productivity of each cropping system is established.

Following the survey, the computer model, Soil Changes Under Agroforestry, or SCUAF, is used to predict crop and tree yields for a number of years (Young and Muraya 1990). These yields, in combination with the economic data collected, are input to a benefit-cost analysis which determined the long-term economic productivity of the cropping systems, with and without the animal component.

Relationship to other chapters

In Chapter 11 of this monograph, the *Gmelina*-based farming system at Claveria was analysed, including some elements of a livestock component. On the basis of the results emerging from that chapter, a more significant research effort was undertaken to describe and model the livestock components of the farming systems at Claveria. Also, Version 4 of SCUAF (Young et al. 1998), rather than Version 2, is used in this chapter. The role of natural vegetation strips is explicitly considered. The natural vegetation strips described in this paper are of the zero input variety (i.e. a contour

strip is left unploughed). This is in contrast to the higher input NVS referred to in Chapter 9.

Study area

The model was calibrated for Claveria, along the lines described in earlier chapters. Claveria is an upland municipality in the province of Misamis Oriental in Mindanao, Philippines. However, there were additional aspects of model calibration that needed to be undertaken for the present chapter. A total of 27 and 29 NVS and *Gmelina* farmers respectively, were interviewed. Since the crop and livestock interaction is more defined for ruminants, the study focused mainly on cattle and buffalo. The respondents were limited to smallholders raising five or less cattle or buffalo.

SURVEY RESULTS

Characteristics of farming systems

Natural Vegetation Strips Alley Cropping (NVS)

The average area of an NVS parcel is 0.78 ha/ farm. Based on actual field measurements, the area of NVS hedgerows alone occupy 15% of the contoured parcel (Nelson et al. 1998). Eight strips are commonly established enclosing seven alleys for maize cultivation. Each strip is 0.50 m wide with mean length of 80 m. Species found in the strips are naturally occurring, *in situ* grass and broadleaves. Most frequently occurring species are *Paspalum conjugatum, Chromolaena odorata, Digitaria setigera, Mimosa pudica, Bidens pilosa* and *Imperata cylindrica*. The cropping alley on the other hand is usually 7 m wide. The majority (93%) of survey respondents plant 2 crops of local white maize, producing an average of 3 tons/ha/year. Based on the predicted yields of SCUAF, an annual average of 3.1 t DM crop residues was produced by the system during the 21 years equivalent to approximately 63 kg N/ha/year when applied as mulch. Comparatively in the with-animal scenario, the available fodder was estimated at an average of 3.2 t DM yearly supporting about 1.2 animal units.

The mean quantity of manure produced annually was computed at 1.4 t DM recycling about 22 kg N/ha/year. The amount of organic matter recycled is therefore higher in the mulching scenario in the form of crop residues.

Gmelina *block planting system*

The most commonly adopted tree spacing is 2 m within rows and 3 m between rows. Though timber tree production is regarded as a high risk enterprise, the required

plantation management is minimal and casual. Pruning and ringweeding is the minimum maintenance practiced by all farmers. Both operations are done twice per year during the first two years. Timber intended for sale to traders or sawmill agents is usually harvested in the 7th year.

Maize is normally cultivated between the trees for the first two years, at 2 crops per year. Once canopy closure impedes the cultivation of annual crops, natural vegetation invades the plantation. Most commonly found species include the grasses *Paspalum conjugatum, Rottboellia exaltata, Digitaria setigera* and *Imperata cylindrica*, and the dominant broadleaf *Chromolaena odorata*. These grasses thrive initially but eventually disappear as a result of tree shading.

In the with-animal scenario, the number of animals varied depending on the available fodder. During the first 2 years, the maize crop produced sufficient stover which supported an average of 1.2 animal units. However, the biomass production under the trees during years 3–7 was inadequate supporting an average of 0.6 animal unit. This was reflected on the amount of manure and corresponding nutrient recycled.

Livestock production in NVS and *Gmelina* farming systems

The mean number of livestock per farm is two. The animals are commonly used for draught work on-farm and are seldom consumed or sold. Most animals sold are no longer serviceable in farming. The calving rate in smallholder farms is low at 50%, resulting from poor nutrition and difficulty in servicing cows due to their scattered confinement (Calub et al. 1987).

Cattle are preferred and used more compared to buffalo, as cattle are more resistant to heat and can work continuously for several hours. Female cattle predominate in both the NVS (66.7%) and *Gmelina* (69%) farms surveyed. Cows are preferred for the dual purposes of draught power and calving. A majority (> 70%) of the cattle and buffalo are owned by the respondents. These animals are normally obtained from other farmers or neighbours in the area. Meanwhile, farmers who don't have sufficient capital to procure an animal have the option to participate in a livestock rearing and sharing scheme, where an individual lends an animal to a farmer-caretaker and profits are shared. Deserving farmers can also avail livestock from the dispersal program of the Municipal Agricultural Office (MAO). Under this scheme, a cow is given over to the care of a farmer for one cycle until it produces a calf which will then be owned by the farmer.

Inputs to livestock production

Source of information

The inputs to livestock raising remain simple and traditional, since almost 60% of interviewed farmers refer to family experience as source of information on animal care. But new techniques are slowly being accepted as the MAO has been active in its livestock programs, including vaccination drives and stock dispersal.

Feeding system

There is no distinct *difference* in the livestock feeding patterns within the NVS and *Gmelina* cropping systems. Natural vegetation provides the basic livestock feed in Claveria, supplemented by corn stover following maize harvest in August–September and January–March. More than 10 species have been identified by the respondents as consumed by the animals, but the majority of feed is composed of the grasses *Paspalum conjugatum*, *Pennisetum purpureum* and *Imperata cylindrica*. Grasses are usually abundant given the relatively even distribution of rainfall in the area throughout the year, with only 1–3 dry months.

Only 23% of the farmers practiced cutting and carrying NVS prunings for livestock. *Chromolaena odorata,* comprising 20% of the hedgerow species, is not consumed by the animals due to its bitter taste. Although the remaining 80% of material is palatable, farmers still prefer to utilise other feed resources on- and off-farm.

Cattle and buffalo are customarily tethered on waste grazing areas close to or within the farm (i.e. along farm borders). Tethering is the type of confinement feeding most popular, not only in the different regions in the Philippines, but also in Southeast Asia generally (Mahavedan and Devendra 1985). The rationale is to prevent the animals from wandering into cropped areas.

Animals (e.g. cattle, buffalo, horses and goats) are tethered in the *Gmelina* stand but only after the trees reach 2 years and intercropping has stopped. A local ordinance in the village of Rizal prohibits tethering of animals in areas beyond the farm boundary of the livestock keeper. The tree growers reported an average 10% tree mortality rate during the first 3 years due to indiscreet browsing of animals within *Gmelina* stands.

Management practices

The MAO provides free vaccination against snake bites and hemorrhagic septicaemia disease twice per year. More than 75% of farmers practice deworming using commercial medicines but a few farmers rely on a local herbal species, *Panyawan*. Others give the animals a deworming mixture of coconut milk and sugar. Another common livestock parasite is the tick. The farmers spend an average of 15 minutes per day manually deticking the animal, usually before taking it to the tethering area. The use of deticking powder or other commercial medicines is not common.

Fewer than 10% of the farmers provide shelter for their animals. Cattle and buffalo are usually tied within the homeyard during nighttime. Natural mating is the only method of livestock reproduction in Claveria. Farmers with bulls are paid ₱200 per successful service to a cow. For this reason, bulls are customarily not castrated since they can be used profitably in breeding.

Labour input

All labour input in livestock raising is provided by the household. The number of days spent in rearing one animal unit per year was shown in Chapter 15. Most tasks are done by the husband. The children are not relied upon in choosing good tethering areas or even in activities such as deticking. However, 23.2% of the respondents allow their children to help in livestock rearing during weekends when they are not busy in school.

Output from livestock production

Manure

The ecological benefits of applying manure fertilizer are known to all the interviewed farmers. This high rate of knowledge on manure application can be attributed to both government research and extension activities in Claveria. But currently, there are no extension activities specific to manure recycling. Only 14.8 and 27.5% of the NVS and *Gmelina* adopters respectively, actually collect and return the manure on-field. Manure is usually applied to the homegarden where a variety of vegetables and fruit trees are cultivated. The general practice is to decompose collectively all crop residues and organic manures from the farm (e.g. maize cobs, leaflitter, cattle manure, chicken dung) and broadcast accordingly. Limited labour tops the various reasons for non-application. The respondents indicated that, since the animals are always tethered on- and off-farm, manure is scattered in different areas which makes collection time- and labour- consuming. The available farm labour is already allocated to other prioritised activities rather than for collection and spreading of manure, i.e. most activities in maize production are performed by family labour.

Draught power and transport service

The draught animal is employed in four primary field operations: ploughing, harrowing, furrowing and interrow weeding. The average total number of days worked by the animal is 93 days per year in an NVS cropping system. The work is divided into 3 areas: within the NVS parcel, in other parcels on-farm and rented to other farmers in the locality for draught work. In the case of the *Gmelina* farms surveyed, draught power is utilised within the *Gmelina* parcel only during the first 2 years, when maize is intercropped between tree rows. From the 3rd to the 7th years of the tree cycle, draught animals are employed only in other parcels on-farm and then rented off-farm.

Another major service of livestock to the farming household is the provision of transport for people as well as farm products and implements. The animal is used to haul water every day at a range of 10–30 minutes per trip. Even households residing in the village or town centre need to get water from communal water pumps. In addition, it is approximated that the animal is used 2 hours per day for general hauling and transport throughout the period that the animal is not used in field operations (Magcale-Macandog et al. 1997b). Total hauling and transport accounts for about 42% of total work rendered by the animal in a year.

The animals are customarily worked singly on-field. During transport, a sledge built of bamboo or light wood is attached and hauled. The farmers begin using the animal in field operations at 1.5 years and hauling follows 3 months later. Draught animals are worked for a span of 10–15 years. A summary of the benefits provided by animals was provided in Chapter 15.

MODELLING SCENARIOS

To examine the impact of animals on the farming systems, various scenarios are simulated as detailed in Tables 16.1 and 16.2. The net economic benefit from an animal unit were taken from Chapter 15.

Table 16.1. Modelling scenarios under the NVS cropping system

	Scenario 1—without animals	Scenario 2—with animals
System of land use	1 ha parcel is cultivated with NVS. The strips occupy 15% of the parcel area.	1 ha parcel is cultivated with NVS. The strips occupy 15% of the parcel area.
Cropping system	Maize is planted twice a year on the remaining 85% of parcel area. The NVS are cut regularly and the cuttings are applied as mulch to the parcel. The maize stover is likewise left on-field.	Maize is planted twice a year on the remaining 85% of parcel area. The NVS are cut regularly and the cuttings are fed to the livestock. But only 80% of the cuttings are fed. The unpalatable 15% is then used as mulch on the parcel while 5% remains as standing biomass. Maize stover is likewise fed to the animal. The number of animal units which can be supported by the system = (palatable NVS prunings + maize stover)/feed requirement of an animal.
Additions to the system	Inorganic fertilizer is applied to maize at a rate of 105 kg N and 59kg P/ha/year.	Inorganic fertilizer is applied to maize at a rate of 105 kg N and 59kg P/ha/year. Livestock manure is collected and recycled back to the field.

Chromolaena odorata, which comprises 20% of the species, is not consumed by the animals due to its bitter taste. Hence, maize stover and 80% of the NVS prunings are supplied as livestock feed in the system (Table 16.1). Two crops of local white maize are planted. The first crop is planted in May and harvested in August while sowing of the 2nd crop follows in October and is harvested between January and March the following year. Inorganic fertilizer is applied twice per crop, during sowing and before interrow weeding. An annual total of 105 kg N and 59 kg P fertilizer is applied/ha. Pesticide application is not practiced.

With respect to the land-use system under *Gmelina* plantations, a 2 × 3 m block spacing results in 1667 trees/ha. It is assumed that growers allocate and clear a 1 m wide row for tree planting. Given that the space between tree rows is 3 m, the area occupied by the trees is estimated at 25% of the parcel. During the first 2 years of intercropping, maize is cultivated in the remaining 75% of the area (Table 16.2). Once canopy closure impedes the cultivation of maize, natural vegetation invades the plantation. The species are mostly similar to that of the NVS hedgerow with 80% palatability. Seedlings are used in establishment of the plantation during the first cycle. In the second and third cycles, regrowth from *Gmelina* stumps is coppiced and only one sibling is allowed to regrow. Most farmers practice pruning and ringweeding for tree maintenance, with both operations done two times per year during the first two years.

Table 16.2 Modelling scenarios under the *Gmelina* cropping system

Year	Scenario 1—without animals	Scenario 2—with animals
1	2 crops of maize; maize stover applied as mulch; prune trees and sell branches as fuelwood	2 crops of maize; maize stover fed to animal; application of manure on-farm; prune trees and sell branches as fuelwood
2	2 crops of maize; maize stover applied as mulch; prune trees and sell branches as fuelwood	2 crops of maize; maize stover fed to animal; application of manure on-farm; prune trees and sell branches as fuelwood
3	Vegetation incorporated in soil	Vegetation fed to animal; application of manure
4	Vegetation incorporated in soil	Vegetation fed to animal; application of manure
5	Vegetation incorporated in soil	Vegetation fed to animal; application of manure
6	Vegetation incorporated in soil	Vegetation fed to animal; application of manure
7	Cut tree; vegetation incorporated in soil	Cut tree; vegetation fed to animal; application of manure

The modelling process for the *Gmelina* scenarios is done over 21 years corresponding to 3 cycles of tree production. Tree growers prefer to cut and sell the timber during the 7th year. For consistency, the NVS scenarios are also simulated for 21 years.

MODELLING RESULTS

Natural vegetation strips

The predicted annual soil loss in both scenarios is distinctly higher during the first 5 years (Fig. 16.1a). The decrease in the rate of soil loss after the 5th year can be attributed to the slow natural terrace formation as the soil moves downwards from the upper parts of the cropping alleys and is deposited behind the strips. The predicted soil erosion for both scenarios is more than 6 t/ha/year during the first 4 years, but stabilises at less than 4 t/ha/year for the remainder of the period. Soil loss is a little lower in the without-animal NVS because mulching of the crop residues provides surface cover.

The changes in soil erosion cause declines in soil mineral nutrient levels (Figs 16.1b, c and d). The predicted plant-available nitrogen is slightly higher in the without-animal NVS scenario because of the nitrogen and organic matter recycled through the NVS prunings and maize stover. Mulching likewise enhances soil carbon (organic matter) buildup which results in higher predicted soil labile carbon under the without-animal system. In contrast, soil mineral phosphorus is higher in the with-animal system. This could be credited to the higher phosphorus content of animal manure at 1.0% compared to the 0.96% and 0.2% P levels of NVS cuttings and maize stover, respectively. But generally, it is noted that the annual application of inorganic fertilizer and organic manure is not sufficient to compensate for the nutrient losses in the soil from plant uptake and removal of marketable crop.

The initial estimated maize yield is 2.51 t/ha/year and declines gradually over the period (Fig. 16.2). At year 21, the predicted maize production of 2.2 t/ha/year is 12% lower than the initial yield. The maize yield trend results from soil nutrient depletion due to erosion. Correspondingly, the yield is lower in the with-animal NVS situation as the result of higher erosion. The decreasing crop yield therefore indicates that both cropping scenarios are not sustainable, but are not far from it.

Gmelina cropping system

The without-animal scenario benefits from the mulching of maize stover in years 1 and 2 when maize is intercropped between tree rows, and from the bi-annual incorporation of the undergrowth from the 3rd until 7th years when canopy closure prevents further intercropping. SCUAF predicts an annual average production of 3.1

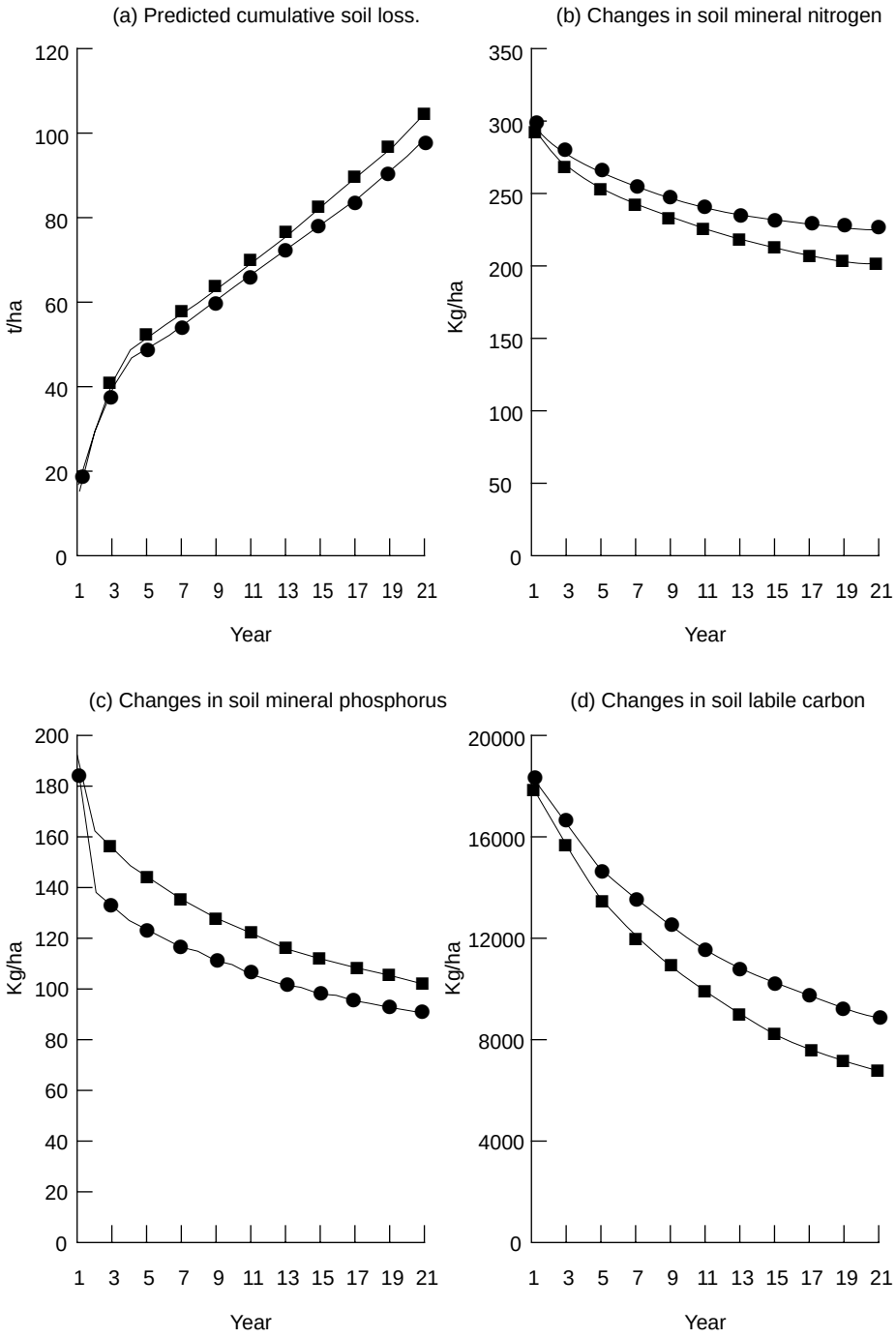

Figure 16.1. Biophysical soil changes in an NVS parcel as predicted by SCUAF
● = without animal; ■ = with animal

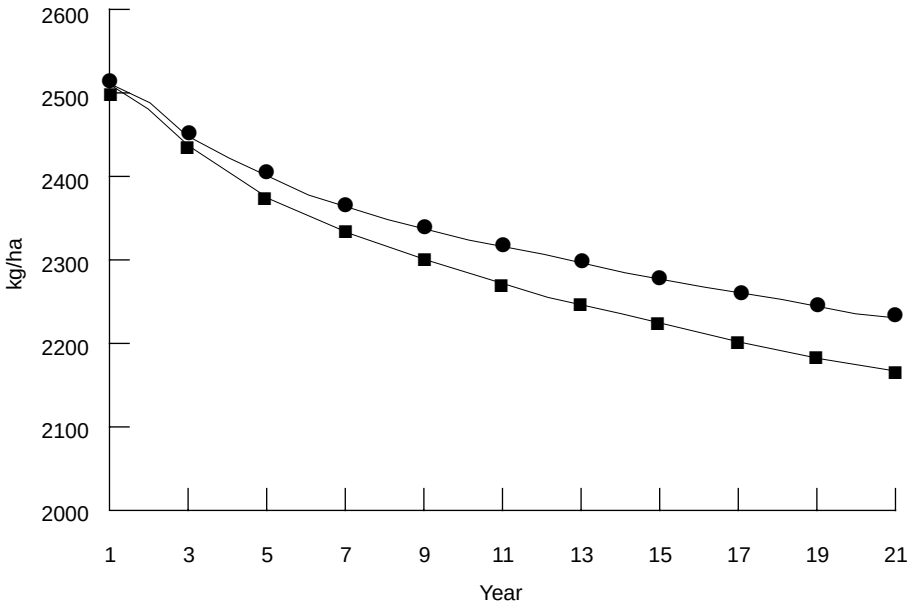

Figure 16.2. Predicted changes in maize yield in an NVS parcel as affected by soil quality ● = without animal; ■ = with animal

t/ha DM maize stover during the first 2 years of each cycle, equivalent to returning of 62 kg N/ha/year. But in the following 5 years, mulching of the undergrowth amounts to an average of 1.9 t DM yearly, translating to only about 26 kg N/ha/year.

In the with-animal scenario, the number of animals varies depending on the available fodder. During the first 2 years, the maize crop produces sufficient stover to support an average of 1.2 animal units. However, the biomass production under the trees during years 3–7 is inadequate, supporting only an average of 0.6 animal units. This is reflected in the amount of manure and corresponding nutrients recycled.

The predicted soil loss under the *Gmelina* scenarios increases over the 21 years (Fig. 16.3.a). But a distinct pattern can be recognised in all 3 cycles. During years of maize cropping, there is a higher rate of increase in soil loss because maize cropping results in more soil exposure compared to undergrowth maintenance (Fig. 16.3.a). The predicted soil loss is a little lower in the without-animal case, resulting from the additional soil cover through the mulching of maize stover.

Rapid soil nutrient depletion is highly correlated to fast growth, short rotations and whole-tree harvesting (Chijoke 1980). This is reflected in the depreciating soil quality level, based on predicted soil available nitrogen, phosphorus and carbon which all display a declining trend over the 21 years (Figs 16.3b, c and d). The predicted plant available nitrogen is significantly higher in years 1–2 of each cycle due to the inorganic fertilizer application for maize intercropping. During the 3rd to

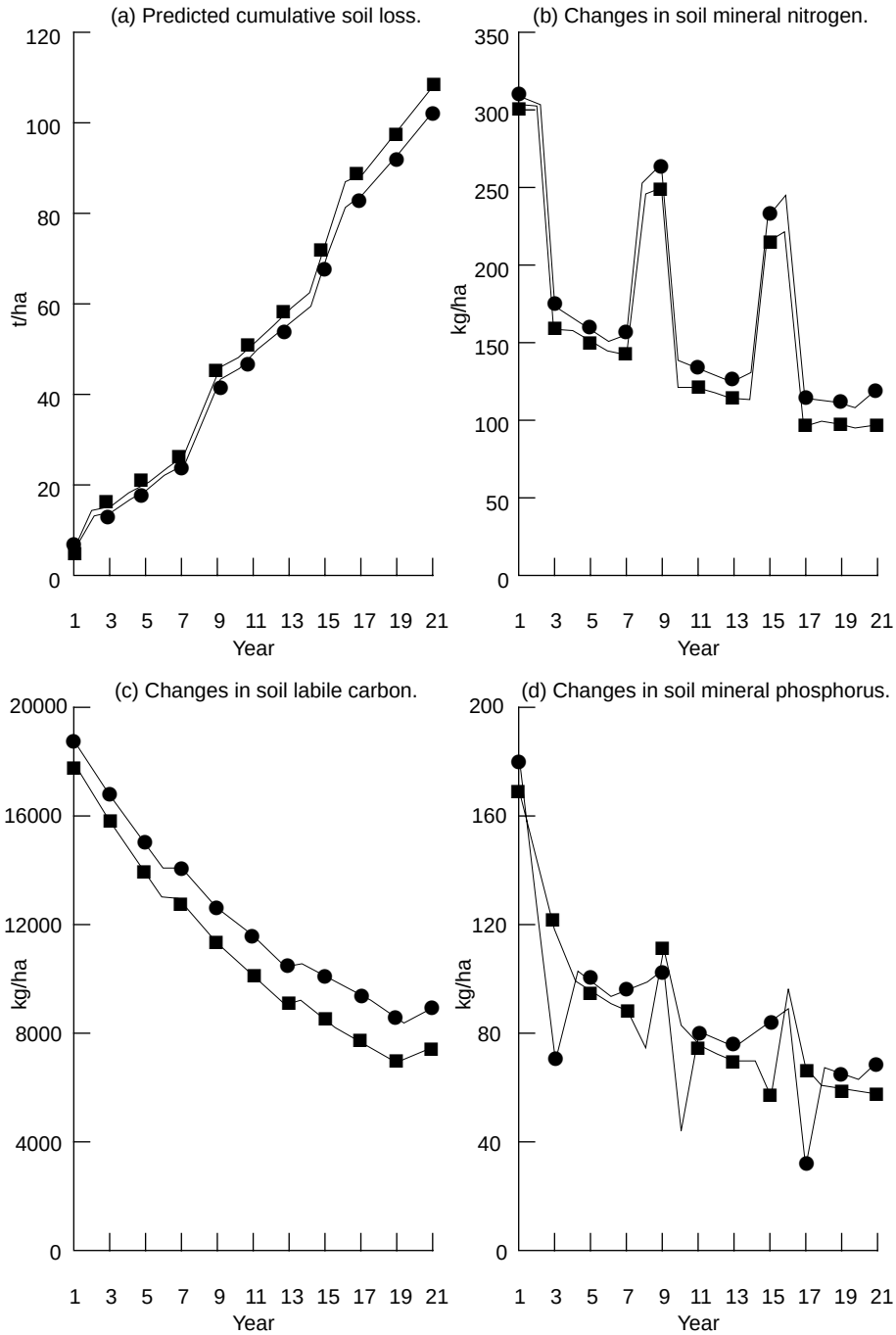

Figure 16.3. Biophysical changes in *Gmelina* parcel as predicted by SCUAF
● = without animal; ■ = with animal

the 7th years, nitrogen levels abruptly drop since no additional fertilizer is applied to the system.

Though the predicted soil labile carbon declines over the years, increases are exhibited every 7th year of all three cycles. This is brought about by the humification of the tree litter and root residues incorporated after tree harvesting.

Enterprises associated with the *Gmelina* cropping system include: (a) timber during the cutyear; (b) fuelwood from tree pruning in the first 2 years of each cycle; and (c) maize over the 2 years of intercropping. The *Gmelina* yields, both in terms of timber and fuelwood, are mostly equal for both scenarios considered. *Gmelina* timber harvested per tree is sustained at 19–20 boardfeet over the 3 cycles. The yield predicted by SCUAF is lower than the average yield per tree at 28 boardfeet, based on the surveyed growers. Pruning trees during the first 2 years produces nearly 1 ton of branchwood. Maize production is likewise not significantly different for the 2 scenarios. This predicted maize yield is on average 50 kg lower in the with-animal scenario as a consequence of the higher soil loss in that particular system.

ECONOMIC PERSPECTIVE

Natural vegetation strips

The estimated annual net returns for both without- and with-animal scenarios decline slowly over the 21 years due to the reduced yield productivity of the system (Fig. 16.4a). But the low labour cost of ₱160/ha and zero input requirement in establishing natural vegetation strips results in positive net returns in all years. The estimated cumulative net present value (NPV) from exclusive maize production in an NVS system is ₱27908. The integration of animal in an NVS cropping system results in a higher NPV ranking over 21 years compared with the without-animal scenario (Fig. 16.4b).

While the incorporation of animals clearly adds value to the NVS farming system, it should be noted that cattle are modelled as eating maize stover in addition to NVS.

Gmelina cropping system

The net returns of the *Gmelina* cropping system follow a cyclical pattern based on tree growth cycle (Fig. 16.5a). Extensive tree planting costs including seedlings and labour, are incurred in the first year. But this is compensated for by the profit realised from both maize production and tree prunings sold as fuelwood, so that net returns during the first year remain positive. Canopy development stops maize production in years 3 to 6, and thus no benefits are gained. In fact, in the without-animal scenario, financial losses are incurred during these years, with money being spent on

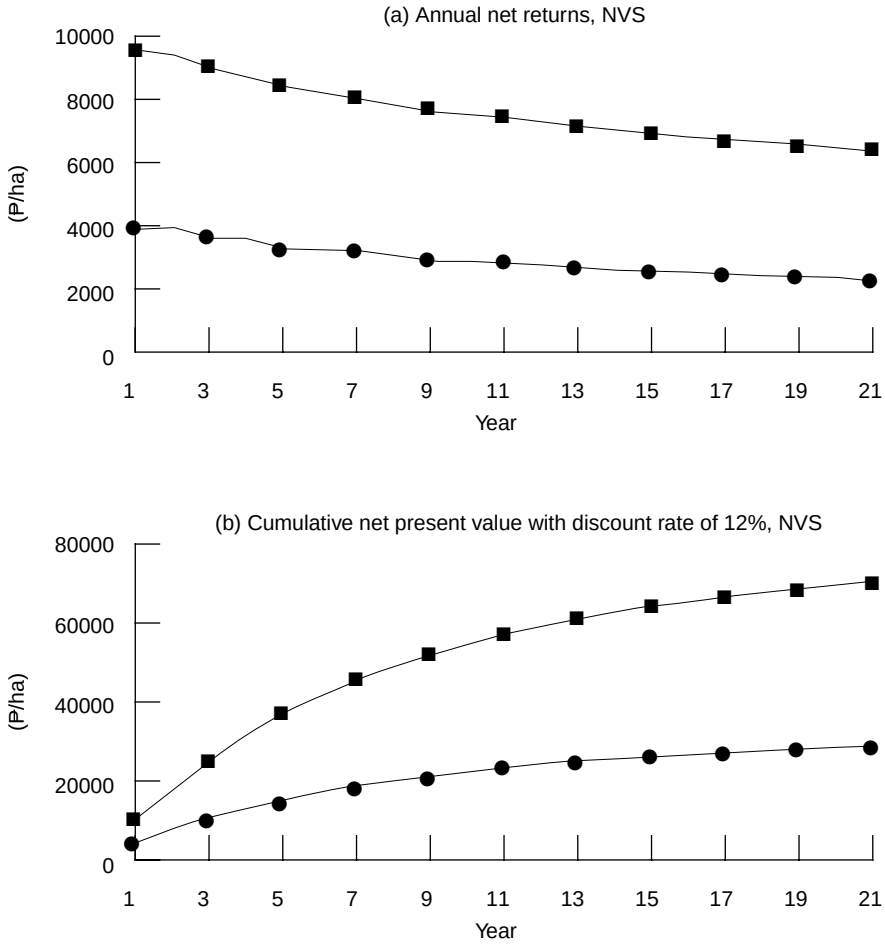

Figure 16.4. Benefit-cost analysis of the NVS cropping system scenario with and without an animal component ● = without animal; ■ = with animal

cultivation of the undergrowth. This is compensated for by the returns from the animal component in the with-animal case. Finally, the highest payoff is achieved in the 7th year of the timber production cycle when timber is harvested and sold (Fig. 16.5b). The *Gmelina*-based cropping system is a superior one, confirming the findings in Chapter 11.

The integration of animals enhances the profitability of the *Gmelina* cropping system since it provides additional income during years 3–6 of the tree cycle, when zero benefit is derived from *Gmelina*. The animals contribute both draught and transport services on- and off-farm, as well as gain in overall value.

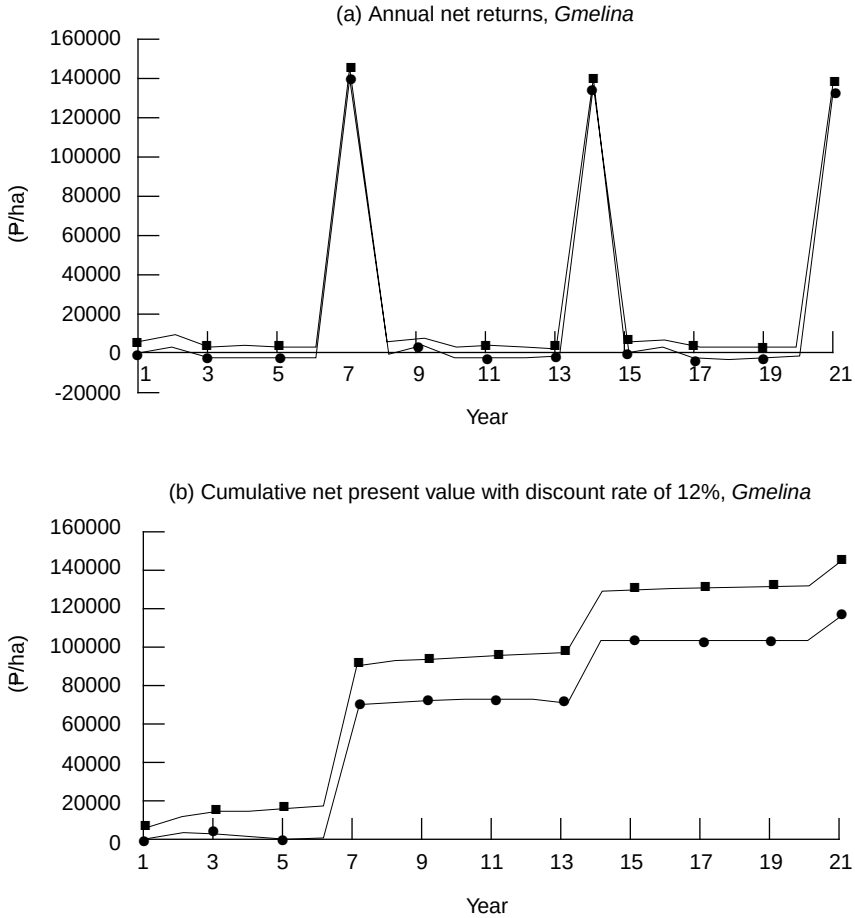

Figure 16.5. Benefit-cost analysis of the *Gmelina* cropping system scenario
● = without animal; ■ = with animal

CONCLUSIONS

The zero input NVS system, modelled and analysed in this chapter, is found to reduce soil erosion, and thus to enhance the sustainability of upland cropping. The economic return is comparable to continuous cropping (see Table in Foreword), but continuous cropping is clearly unsustainable, even with the addition of fertilizer (Chapter 9). Other hedgerows are more productive than NVS (Chapter 9), but they require fairly heavy investment, particularly of labour, and hence may be unattractive to smallholders, despite the opportunity for gain in the long term.

The analysis of the *Gmelina*-based system confirms the high economic value of that system as reported in Chapter 11. Indeed, the integration of cattle and buffalo within the farming systems enhances the profitability of both the NVS and *Gmelina* farms.

The enhancement comes primarily from the draught and transport services as well as the annual gain in value per animal unit. Again the conclusion regarding the positive economic contribution from animals confirms the results of other chapters within Section 4 of this report. The economic contribution of animals is higher in the case of NVS, but animals can also make a critical contribution to farm income during years prior to canopy closure with *Gmelina*.

More extensive reporting of this work, especially the farmer survey material, is available from the senior author.

17 *Gliricidia*-improved Fallow with Cattle

PETER GRIST
KEN MENZ
ROHAN NELSON

IN THIS CHAPTER, the *Gliricidia* fallow system described and analysed in Chapter 12 is re-examined, with the inclusion of a cattle component. *Gliricidia* foliage can be used as a feed for animals. However, there is a trade-off involved, as *Gliricidia* foliage fed to cattle will not be available as mulch. A reduction in the amount of mulch applied to the soil would be expected to affect soil fertility. The analysis is again carried out in Claveria, Mindanao, the Philippines.

THE FARMING SYSTEM DESCRIBED

The *Gliricidia* fallow system analysed in Chapter 12 was specified for a 2 ha farm, divided into six plots of one third of a hectare each, with one plot used for subsistence maize production and the remainder for a *Gliricidia* plantation. Plots were rotated annually. The same system is modelled in this analysis, with one substantive change — some of the *Gliricidia* plantation plots remain as *Imperata* grass for grazing, on the assumption of a 50–50 feed mix being fed to cattle (i.e. 50% *Imperata*, 50% *Gliricidia*). The number of plots retained as *Imperata* fallow depends upon the number of animals. One *Imperata* fallow plot supplies most of the grass feed requirement for one animal.[1]

Table 17.1 presents the land distribution (between *Imperata* fallow, *Gliricidia* fallow and maize) in order to meet the feed requirements for one, two or three animals, on a two ha farm under a *Gliricidia* fallow system, while retaining a plot of maize for human consumption. With one animal, one plot is retained as *Imperata* fallow, and four plots as *Gliricidia* fallow.

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1. The balance is met by crop residue.

Table 17.1. Partitioning of land use for a *Gliricidia* fallow system with cattle, on a 2 ha farm

Number of animals	Maize		*Imperata*		*Gliricidia*	
	Area (ha)	Plots	Area (ha)	Plots	Area (ha)	Plots
1	0.33	1	0.33	1	1.33	4
2	0.33	1	0.67	2	1.00	3
3	0.33	1	1.00	3	0.67	2

Each plot is rotated on a six-year cycle, and two (wet and dry season) maize crops are planted per maize plot per year. Figure 17.1 presents a schematic diagram of the improved fallow system. Resources flow between the three land-use types, *Imperata* fallow, *Gliricidia* fallow and maize. Three economic products are derived— cattle, firewood and grain.

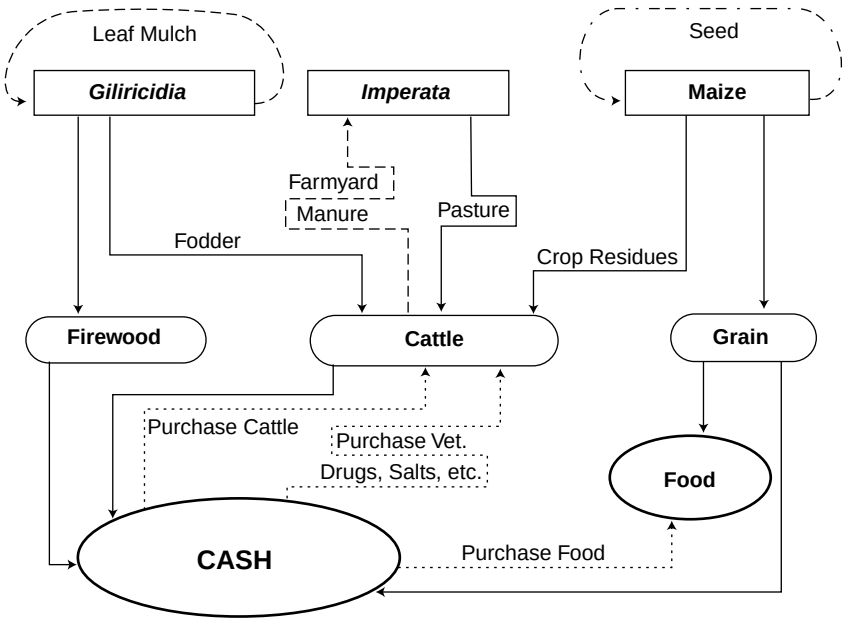

Figure 17.1. Flow of resources in the *Gliricidia* fallow system with animals

THE BIOECONOMIC MODEL

The modelling approach used in this paper is similar to the approach used in Chapters 2, 3, 9 and 12. The animal component of the farming system is treated within the spreadsheet, rather than within SCUAF. However, the implications of animals for soil, and ultimately, plant growth, are fed back into SCUAF.

Up-to-date information on labour and input demand, input costs and product returns for the Claveria region, were obtained from an economic survey (Chapter 9). This was supplemented by another survey of the Claveria region by Magcale-Macandog et al. (1997b), which focused on animals in a smallholder system. Maize yield and *Gliricidia* wood production are predicted using the SCUAF model. SCUAF is also used to predict environmental (physical) costs and benefits of the system, such as changes in soil nutrient levels (carbon, nitrogen and phosphorus) and soil erosion.

The economic spreadsheet

A cost-benefit analysis approach is used to determine profitability. Costs primarily consist of labour, as this is the sole input for the main farming activities (land preparation, planting, weeding, harvesting, and feeding animals). *Gliricidia* is established using cuttings from neighbouring plantations and requires only labour (i.e. no cash cost). A modest cash outlay is necessary for the purchase of maize seed, which is obtained from local markets. Inorganic fertilizers and herbicides are not involved in this analysis. The initial purchase cost of cattle is not included in the calculations. Instead, it is assumed that the farmer borrows the capital required to purchase the animal. Thus, the cost of the animal is calculated via an interest charge on the animal's value, at the relevant discount rate (discount rates are discussed later).

A period of fifty years (eight cycles) was chosen for this analysis, so as to be able to get a handle on long-run sustainability. Environmental factors such as soil fertility and soil erosion change relatively slowly. In economic terms 50 years is a long time, and for upland farmers, it can be argued that 50 years is an excessive time horizon. However, at a discount rate of 12%, any return beyond the fifteenth year will have little impact on the net present value of the system and profitability over 50 years will not be significantly different than the profitability over the first 15 years.

Feed mix

In traditional shifting cultivation systems, the fodder available to feed cattle consists mainly of native grasses and crop residues. These feed sources are low in digestible nutrients, and deficient in minerals. Also, the quantity of grass and crop residue consumed by animals is low, relative to other feed sources (Nitis 1985). The poor quality and low consumption of grasses and crop residues limits the number of animals that can be supported by a shifting cultivation system. Under a traditional shifting cultivation system, a smallholding of 2 ha supports only one or two animals (Franco et al. 1996). These animals are typically poorly nourished and have low productivity (Moog 1991).

Supplementing the diet of cattle with *Gliricidia* foliage has been shown to significantly improve the nutritional value of the feed (Payne 1985; Lowry et al. 1992; and Jabbar et al. 1996). Details of the nutritional value of *Gliricidia* are presented in Appendix 1 of Grist et al. (1997a). A *Gliricidia* fallow system, using *Gliricidia* foliage in combination with grasses and crop residues, can support commercially productive animals (Atta-Krah and Sumberg 1988; Moog 1991; and Gutteridge and Shelton 1993). The improved feed quality also has the potential to increase to three, the number of animals that can be supported on a 2 ha farm.

Weight gain

The quality of the feed source has a significant impact on the potential growth rate, or weight gain, of cattle (Stür et al. 1994). With a diet of mainly grasses and crop residues, Payne (1985) and Calub (1995) reported very low productivity in cattle — annual gains of around 50 kg/year, or approximately 0.15 kg/animal/day. Feeding cattle a diet of 50% *Leucaena* and 50% crop residue, Morbella et al. (1979) reported an average gain of 0.52 kg/anima/day. This is equivalent to the rate of growth expected for a 300 kg steer or heifer fed seven kg of dry matter per day (Kearl 1982). Even greater gains (between 600 g and 1 kg/ animal) have been observed by feeding higher percentages of *Leucaena* or *Gliricidia* to cattle (Moog 1991; Stür et al. 1994).

A conservative approach will be used in this analysis to calculate the annual growth rate (weight gain) of cattle. A diet providing a maximum proportion of 50% *Gliricidia* is considered. Based on a diet of 50% *Gliricidia* combined with 50% grass and/or crop residue, an average weight gain of 0.52 kg/day (or 190 kg/year) is used (Morbella et al. 1979; Kearl 1982).

Feed intake

The feed requirement of cattle is between two and three % of bodyweight. For a 300 kg animal to achieve a weight gain of approximately 0.5 kg/animal/day, Payne (1985) estimated a feed requirement of around 2.28% of bodyweight.[2] For a similar weight gain, tables by Kearl (1982) show animals requiring an average feed requirement of 2.33% of bodyweight. In this analysis, an average bodyweight of 300 kg is assumed, with an average feed requirement of 2.33% of bodyweight (seven kg of dry matter per day).

In calculating the quantity of feed required for animals, it is necessary to factor in refusals, which can be up to 25% or even 50% of feed (Ross Gutteridge, pers. comm. 1996). A conservative estimate of 15% of the feed requirement (1 kg of dry matter/day for a 300 kg animal) is added to account for refusals. Thus, approximately

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2. Eight kg of dry matter per day for a 350 kg steer or heifer.

8 kg of dry matter are required per animal per day, or approximately 3 t of dry matter/animal/year. Given a feed mix requirement of 50% *Gliricidia* and 50% *Imperata*/crop residue, approximately 1.5 t of each feed source is required per animal per year.

Manure

The quantity of manure produced by cattle is approximately 40% of the dry matter ingested by the animal. This is calculated as an average of dry matter digestibility, which is 60–65% for *Gliricidia* (Lowry et al. 1992; Norton 1994; Gutteridge and Shelton 1994), and 58% for *Imperata* (Soewardi and Sastradipradja 1980). Thus, an animal fed 3 t of dry matter per year produces approximately 1.2 t of manure.

As fodder passes through animals to become manure, there is a significant change in nutrient content. Bureau of Soils, University of the Philippines, Los Baños (unpublished data) found an 18:1 carbon to nitrogen ratio in cattle manure. The carbon content of manure is approximately 50%, so the nitrogen content of manure is 2.8% of the dry matter of the manure, or 1.1% of the dry matter fed to the animals.

It is assumed that all the animal manure is deposited on the plots used for grazing, i.e. *Imperata* fallow plots. The manure will add nutrients and organic matter, improving the soil of the *Imperata* fallow. In terms of the model, manure is added to the *Imperata* fallow plots at a rate of 3.6 t of manure/ha/year.

Modelling animals in relation to SCUAF

The *Gliricidia* fallow system is first modelled without animals, as per Grist et al. (1997a). Animals are then introduced into the system. Although, SCUAF does not directly model the animal enterprise, the biophysical effect of animals on soil and plant growth can be simulated by harvesting (removing from the system) the animal fodder requirements. The dry matter yield of *Gliricidia* is approximately 7.7 t of leaf material/ha/year and approximately 4 t/ ha/year for *Imperata* (Agus 1994; Grist et al. 1997a). The *Imperata* produced by 1/3 ha (1.33 t) plus a small allowance for feeding some crop residues, provides the 1.5 t of dry matter/year required as the grass component of the animal's diet. The *Gliricidia* component of the animal's diet is taken from the regular prunings of the plantation. The remainder of the *Gliricidia* foliage is retained in the *Gliricidia* plot as mulch. The *Imperata* and *Gliricidia* leaf material available in the system and the percentage removed to feed the animals, is presented in Table 17.2.

Table 17.2. Quantity of *Imperata* and *Gliricidia* leaf material available, and percentage of leaf material fed to animals (total farm area = 2 ha)

Number of animals	*Imperata*		*Gliricidia*	
	Quantity available (t)	Fed to animals (%)	Quantity available (t)	Fed to animals (%)
1	1.33	100	10.27	15
2	2.66	100	7.70	40
3	4.00	100	5.13	90

Each animal introduced causes a reduction in the area of *Gliricidia* fallow and thus in the amount of *Gliricidia* foliage available as mulch. Also, each additional animal requires 1.5 t of *Gliricidia* foliage as fodder, this further reduces the amount of *Gliricidia* foliage available as mulch in comparison with the no animal case.

Labour requirements of feeding animals

The only fundamental change in labour use compared to Chapter 12 is an increase in labour for the cut and carry of *Gliricidia* to cattle. To provide the full feed requirement in the form of fresh grass, via a cut and carry system, requires approximately two hours of labour/anima/day (Payne 1985; Franco et al. 1996). In the *Gliricidia* fallow system, only half of the feed requirement is obtained by cut-and-carry. Also, *Gliricidia* has a higher dry matter content and is easier to cut-and-carry than grass, so it will require less labour. The labour requirement was adjusted to half an hour/animal/day, or approximately 23 days/animal/year (based on an 8-hour workday) (Table 17.3).

Table 17.3. Labour requirements of the *Gliricidia* fallow system with one animal

Operation	Crop[a]	Tree	Cattle
		(days/ha)	
Land preparation	30	10	
Collect/plant cuttings		70	
Maize sowing	25		
Weeding	30		
Gliricidia pruning		16	
Carry of prunings to animals			23[b]
Maize harvest	18		
Postharvest processing	22		
Cut-and-carry of firewood		4	
Additional firewood final year		4	
Total crop	125		
Tree total (establishment year)		96	
Tree total (normal year)		20	
Tree total (cut year)		24	
Total animal			23
Average for whole farm, 1 animal			
(1/3 ha *Maize*; 4/3 ha *Gliricidia*; 1/3 ha *Imperata*)		118	

[a]two maize crops during the crop year of the cycle; [b]labour requirement for one animal; each additional animal requires a further 23 days.

Inventory value of cattle

Animals fed a diet supplemented with *Gliricidia* foliage have a higher average weight gain (190 kg/year), than animals fed mainly grasses and crop residues (as discussed above). Based on a beef price in Claveria of ₱ 40/ kg (Calub pers. comm. 1996) and an average weight gain of 190 kg/year, the net annual gain in inventory value of an animal (calculated in terms of weight gain per animal) in a *Gliricidia* fallow system is ₱ 7600. From a survey of smallholders in the Claveria area (Magcale-Macandog et al. 1997b), the average annual increase in inventory value of cattle in a smallholder farming system, based solely on grass feed, was specified by farmers to be ₱ 2215/year. In the smallholder farming systems surveyed by Magcale-Macandog et al., animals were fed mainly grasses and crop residues. Thus, the observed change in inventory value is consistent with the composite figures used here, of 55 kg annual weight gain, times ₱ 40/kg for a total of ₱ 2200.

Capital is a major constraint to smallholder animal production. To capture the impact of this, the costs of purchasing a young (150 kg) animal at ₱ 40/kg (₱ 6000) are incorporated into the analysis at the opportunity cost of capital to farmers (i.e. by including the interest from borrowing the capital at both the social and market discount rates).

Discount rates

Two discount rates are used in this analysis — a social opportunity cost and a market borrowing rate. An interest rate of 12% was chosen to represent the social opportunity cost of capital for the Philippine economy. This represents the reduced cost of capital that could be achieved with government-sponsored farmer cooperatives to reduce the cost of capital to upland farmers, and more truly reflects the rate of return a smallholder can expect from an investment. A higher interest rate of 25% is also used. This was chosen to represent the market borrowing rate. It is based on an estimate of the interest rate for borrowing, obtained from a survey of smallholder farmers in the Claveria area by Nelson et al. (1998). Table 17.4 presents a summary of unit costs and unit returns for the *Gliricidia* fallow system with animals.

Table 17.4. Unit costs and returns used in the analysis

Labour cost of smallholder		₱ 40/day	
Maize seed cost		₱ 6.50/kg	
Maize grain value	Wet season	₱ 5.60/kg	
	Average season	₱ 5.90/kg	
Firewood		₱ 1000/t	
Cattle	Initial purchase	₱ 6000	(150 kg @ ₱ 40/kg)
	Annual maintenance cost	₱ 1882	
	Net annual change in inventory value of cattle	₱ 7600	(190 kg @ ₱ 40/kg)
Interest rate	Social opportunity cost		12%
	Market borrowing rate		25%

RESULTS AND DISCUSSION

Biophysical aspects

The biophysical aspects of the *Gliricidia* fallow system (without animals) were described by Grist et al. (1997a). In that system, soil was enriched over time via the effect of mulching. Mulching results in a buildup of soil organic matter, which enhances fertility and helps stabilise soil, leading to higher levels of production. The

improvements in soil fertility can be observed via the levels of soil nutrients (carbon, nitrogen and phosphorus) in Figure 17.2. (The top line of each graph represents the 'without animals' scenario). The improved maize yield associated with this increase in soil fertility can be seen in the top line of Figure 17.3.

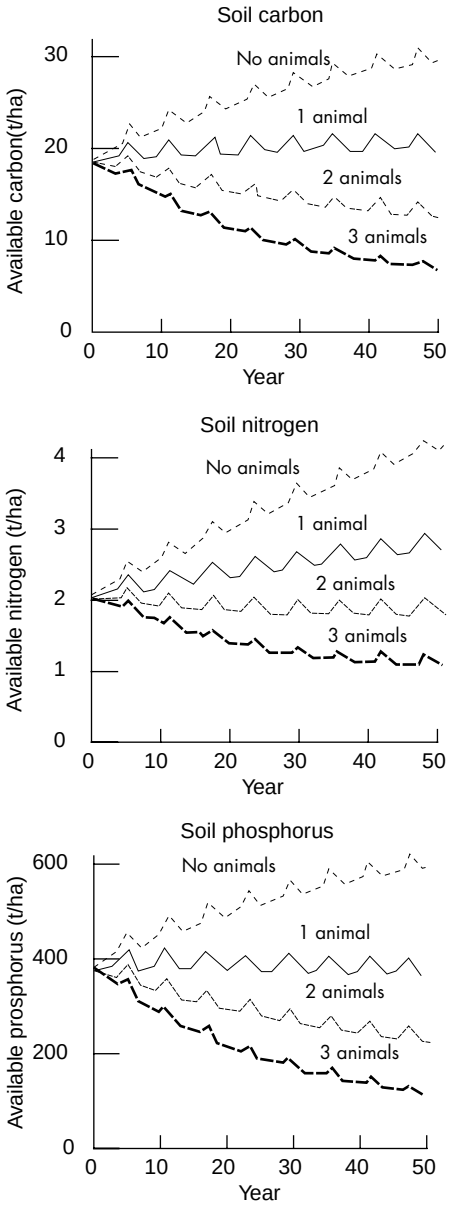

Figure 17.2. Changes in soil nutrient levels with increasing animal numbers in the *Gliricidia* fallow system

The introduction of animals into the *Gliricidia* fallow system reduces the amount of nutrients recycled. Feeding the *Gliricidia* prunings to animals, rather than using them as mulch, removes nutrients from the crop/soil system. With increased animal numbers, soil nutrient levels and crop productivity become lower. Nevertheless, with one animal, soil nutrient levels still increase above the initial level of soil fertility at Claveria (Fig. 17.2). The improved soil fertility is again reflected in an increasing maize yield (Fig. 17.3). Although the introduction of an animal into the *Gliricidia* fallow system is a drain on the level of soil fertility, improvements over time in soil fertility and yield can still be achieved.

Two animals reduce the amount of *Gliricidia* foliage available for mulching to 60% of the total produced. As a result of the reduced mulching, soil nutrients no longer increase. Over the eight cycles considered here, nutrient levels decline an average of 25% (Fig. 17.2). This is reflected in maize yield, which decreases by 5% over the eight cycles (Fig. 17.3). This decline in yield is relatively small. Thus the system is almost sustainable in the long term.

Three animals have a strong impact on the sustainability of the farming system. Ninety percent of the *Gliricidia* foliage is required as animal fodder, leaving only 10% available for mulching. Soil nutrients are predicted to fall to less than 50% of their initial levels (Fig. 17.2), and there is a 25% reduction in maize yield over the eight cycles (Fig. 17.3).

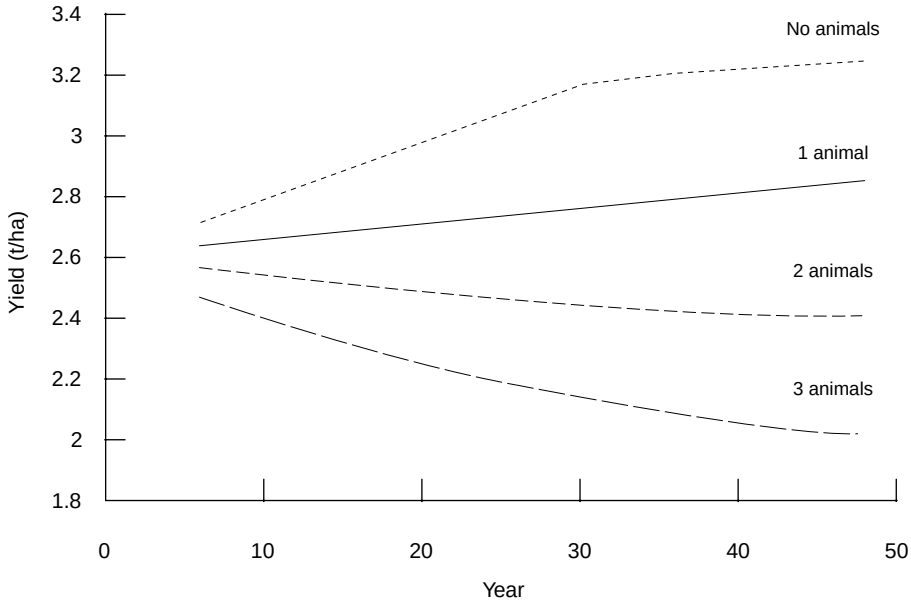

Figure 17.3. Changes in maize yield with increasing animal numbers

The erodability of the soil at Claveria is relatively low, averaging 26.6 t/ha/year for open-field maize farming (Nelson et al. 1998). This is despite high rainfall, averaging 1800 mm per year (Agus 1994), and a moderate slope of around 20% (Nelson et al. 1998). The introduction of animals requires a significant amount of biomass to be transported from the site and fed to the animals. This reduces soil cover, affecting soil erosion and crop productivity. Cumulative soil erosion, over eight cycles of a *Gliricidia* fallow system with and without animals, is shown in Figure 17.4. With no animals, the total amount of soil erosion in the *Gliricidia* fallow system is relatively low, at around 200 t/ha, over the eight cycles. The addition of each animal is predicted to increase total soil erosion by more than 75% of this for each animal.

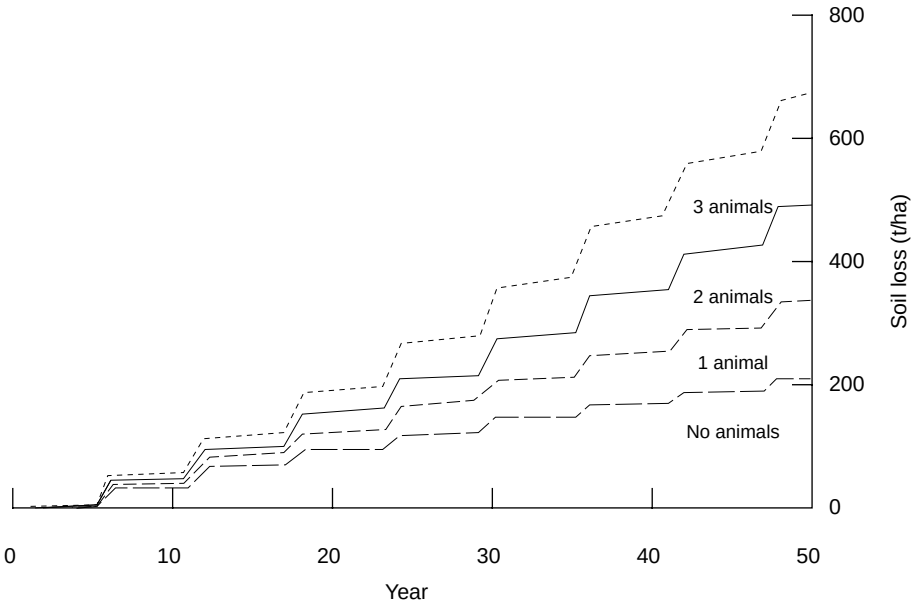

Figure 17.4. Cumulative soil erosion with increasing cattle numbers

Economic analysis

The modelling work demonstrates that a *Gliricidia* fallow system without animals is substantially more profitable than a traditional *Imperata* fallow system (Grist et al. 1997a). The increased revenue from the improved maize yield counters the increased costs associated with the establishment of the *Gliricidia* plantation. The improvements in maize yield are further complemented by returns from the sale of firewood. This result applies at prices currently perceived by smallholders in Claveria, and will still hold after a significant increase in the wage rate, or a decrease in the maize price (Grist et al. 1997a).

Table 17.5. Total revenue, total costs and net present value (₱) for the *Gliricidia* fallow system, with and without animals. Calculated at a beef price of ₱ 40/kg and using a discount rate of 12%.

	No animals	1 animal	2 animals	3 animals
		(₱ '000)		
Revenue				
Firewood	47.4	37.4	27.7	18.3
Maize	57.0	48.8	46.1	43.4
Cattle	0.0	70.6	141.3	211.9
Total revenue	104.4	156.8	215.1	273.6
Costs				
Maize/fallow system	46.9	44.4	41.9	39.4
Cattle	0.0	26.0	52.1	78.2
Total cost	46.9	70.4	94.0	117.6
Net present value	57.5	86.4	121.1	156.0

Given beef prices of ₱ 40/kg and a discount rate of 12%, the *Gliricidia* fallow system is more profitable with animals. The addition of each animal increases present value of farm costs by approximately ₱ 26000 and reduces the present value of the revenue from maize and firewood by an average of ₱ 15000. However, this is countered by a substantial increase in present value of expected revenue from the sale of animals, approximately ₱ 70000/animal (Table 17.6). Thus, for up to three animals (the maximum number of animals considered here), the addition of animals increases profit. When compared to a *Gliricidia* fallow without animals, the net present value increases by 50% with one animal, 110% with two animals, and 170% with three animals.

Table 17.6. Total revenue, total cost and net present value for the *Gliricidia* system, calculated at a beef price of ₱40/kg and using a discount rate of 25%.

	No animals	1 animal	2 animals	3 animals
		(₱ '000)		
Revenue				
Firewood	25.4	20.1	15.0	10.0
Maize	30.4	26.0	25.0	23.9
Cattle	0.0	38.0	76.0	114.0
Total revenue	55.8	84.1	116.0	147.9
Costs				
Maize/fallow system	25.2	23.9	22.6	21.2
Cattle	0.0	17.9	35.8	53.7
Total cost	25.2	41.8	58.4	75.0
Net present value	30.6	42.3	57.6	72.9

An increase in cattle numbers in the region is likely to lead to a lowering of beef prices. Beef prices in the Philippines are currently buoyed by import protection (Franco et al. 1996). If cattle numbers increase, and/or the protection is reduced, beef price will fall (Fig. 17.5). While beef prices are above ₱ 30/kg, it is profitable to include animals in the *Gliricidia* fallow system. Profitability increases with each additional animal. At beef prices below ₱ 30/kg, the additional revenue obtained from the sale of an animal is less than the corresponding cost of animal maintenance plus foregone firewood and maize revenues.

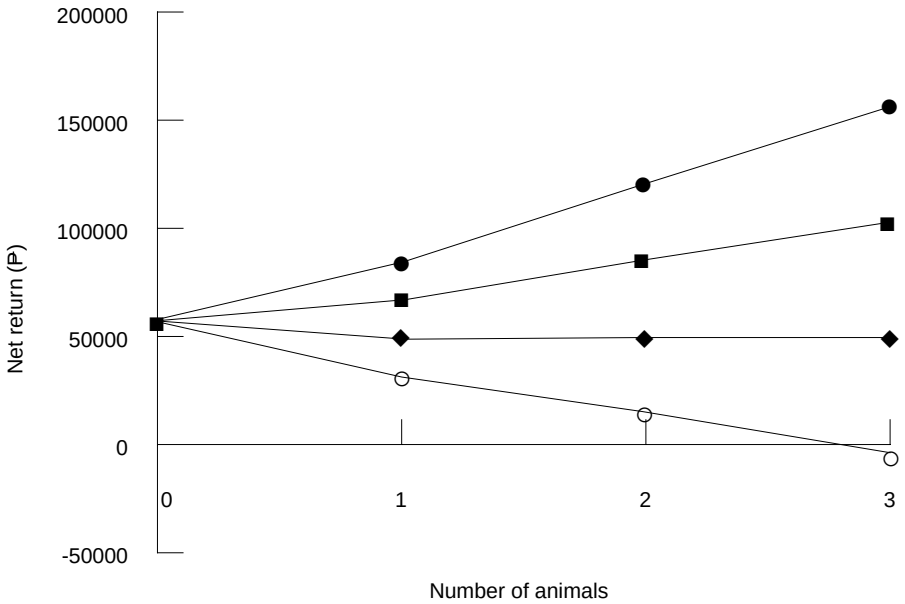

Figure 17.5. The effect of a change in beef prices on net returns (calculated using the social opportunity cost of capital, 12%). ○ = ₱10/kg; ◆ = ₱20/kg; ■ = ₱30/kg; ● = ₱40/kg

The above calculations are based on a discount rate of 12% representing the potential lower discount rates if government-sponsored farmer cooperatives are introduced. This discount rate is considered to closer reflect the social opportunity cost of capital to farmers. Actual interest rates facing farmers in Claveria are between 16% and 30%, with 25% seen as the most representative interest rate for borrowing (Nelson et al. 1998). At this discount rate, the overall profitability of introducing animals into the system is reduced, but the general trends noted above are maintained. There is an almost linear increase in profitability with the addition of animals, but the size of the increase is less at the higher discount rate. The net present value of the system increases 40% with the addition of one animal, 90% with two animals and 140% with three animals (Table 17.6).

The effect of changing beef prices at the 25% discount rate is shown in Figure 17.6. The same general trends observed with the lower discount rate apply. Below ₱ 30/kg, the addition of animals to the system is no longer profitable.

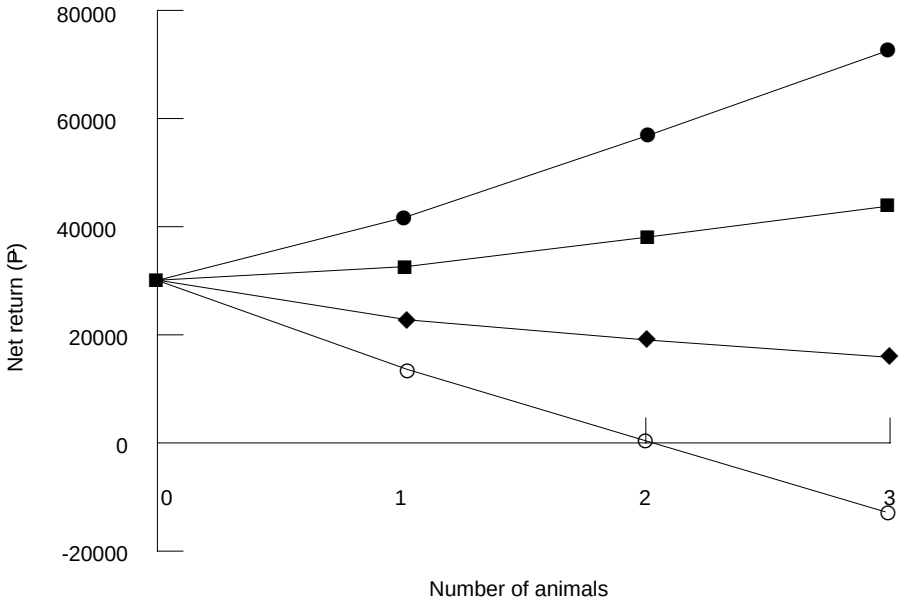

Figure 17.6. Graph of changing net present value of system with a change in beef prices, calculated at a discount rate of 25%. ○ = ₱10/kg; ◆ = ₱20/kg; ■ = ₱30/kg; ● = ₱40/kg

The analysis so far has focused on an established system, showing that with and without animals the *Gliricidia* fallow system is profitable. However, for farmers not already practicing a *Gliricidia* fallow system, there are other considerations. A significant barrier to the adoption of the *Gliricidia* fallow system could be the initial economic losses during the transition period. Analysis by Grist et al. (1997a) indicates a loss of approximately ₱ 850 in the first year of the transition period between an *Imperata* fallow system and a *Gliricidia* fallow system (without animals). It would take four years for smallholders to recover this initial loss, and for cumulative profitability to become higher than with an *Imperata* fallow system (Grist et al. 1997a).

The addition of cattle to the *Gliricidia* fallow system further increases these initial transition costs. Unless upland farmers can bear initial losses during the transition period, via savings or their ability to borrow money at reasonable rates, adoption of the *Gliricidia* fallow system (with or without animals) will be difficult.

This analysis has shown that for farmers using a *Gliricidia* fallow system with animals, the potential long-term benefits are likely to be large. However, the transition period, for conversion from existing systems to a *Gliricidia* fallow system, is likely to be a barrier for adoption by farmers. Government policies could consider methods of encouraging adoption, through options such as reduced interest rates and access to long-term loans.

CONCLUSIONS

The introduction of cattle into a *Gliricidia* fallow system involves a trade-off between the amount of *Gliricidia* foliage used as mulch, and the amount fed to animals. Reducing mulch decreases soil fertility levels, resulting in an increase in the level of soil erosion and lower plant yields. The rate of increase in erosion is approximately proportional to the number of animals. Although at this study site in Claveria, erosion is low relative to other sites in the Philippines, maize and firewood yields are still affected by erosion. In other locations, where soils are more erodable, adding animals is expected to have more serious consequences for soil erosion and maize yields.

At current beef prices in the Philippines of around ₱ 40/kg, significant economic benefits can be derived from the introduction of animals into a *Gliricidia* fallow system. The modelling exercise indicates that up to three cattle per 2 ha farm could profitably be carried on a diet of one half *Imperata*, one half *Gliricidia*. A three-animal system is preferred in terms of profitability. However, biophysical analysis of a three-animal system, indicates that it is not biologically sustainable (i.e. soil nutrient and crop yields maintained at a constant level over time). Two animals are likely to be more sustainable. The profitability of a two-animal system is predicted to be relatively high, more than twice that of a *Gliricidia* fallow system without animals.

At lower beef prices, the introduction of cattle into the *Gliricidia* fallow system becomes less economically attractive. Beef prices around ₱ 30/kg provide only marginal improvements in farm profitability. Below ₱ 30/kg for beef, there is no gain from the inclusion of animals. At ₱ 40/kg, beef prices in the Philippines are higher than international levels, due to import restrictions.

Limited availability of savings or restricted access to capital makes adoption of the system difficult. To encourage upland farmers to adopt these more sustainable, and more profitable systems, governments could consider policies that facilitate long-term loans, and lower the cost of credit to upland farmers to a level approaching the opportunity cost of capital to society. However, even at interest rates as high as 25 %, the *Gliricidia* fallow system with cattle appears to be superior to traditional shifting cultivation systems in *Imperata* areas.

SECTION 5

FIRE MANAGEMENT AND CARBON SEQUESTRATION

In Chapter 3, fire was examined in the context of a shifting cultivation system on *Imperata* grassland. Using fire as a means of clearing *Imperata* was shown to have negative biophysical effects approximately equal to a reduction in fallow length of one year. The *economic* implications of using fire vis-a-vis other *Imperata* control techniques were large. The work in Chapter 3 referred only to the on-site effects of fire.

In this section, other issues relating to fire are examined:

- A report on a survey of farmers' attitudes to fire in Isabela, Luzon, Philippines is presented.
- An experiment to test the effect of shading by *Gliricidia* combined with deliberate burning of *Imperata* is reported.
- A 'fire damage' component is incorporated into the rubber modelling work, and is used to assess both the on-site and one component of off-site fire damage costs.
- The economic disincentives caused by fire are quantified for two types of rubber planting material.
- The consequences of the type of rubber planting material for *Imperata* and fire control, and carbon sequestration, are examined.

18 Fire Occurrence in Grassland-based Smallholdings

DAMASA MAGCALE-MACANDOG
WILMER GALINADA

Grasslands in the Philippines cover 6.5 million ha, approximately 22% of the country's total land area (Concepcion and Samar 1995). They are widely distributed in all regions of the country. There are two distinct sets of grass types that represent pedo-ecological zones in the Philippines. The first one is *Imperata cylindrica* (cogon) which generally represents degraded, acidic, low organic matter and dry soil areas susceptible to erosion. *Themeda triandra* (bagokbok) and *Chromolaena odorata* (hagonoy) also grow in these areas (Padilla 1995). The second occurs in areas where there is adequate moisture, *Saccharum spontaneum* (talahib) dominates and the ecosystem becomes more stable with ferns and shrubs starting to appear (Concepcion and Samar 1995).

The topography of grasslands varies at different localities but is generally undulating to moderately steep. Grasslands have expanded rapidly and encroached indiscriminately, in terrain from rolling to ruggedly steep which was previously covered with a diversity of forest or herbaceous species, because of slash-and-burn farming systems (Marchand 1987; Bandy et al. 1993; Sangalang 1995). A great majority of grasslands are underutilised and dominated by *Imperata* (Sangalang 1995). There are about 400 000 ha which are actively used for pasture, generally for cattle grazing. These areas are currently suffering from severe soil erosion due to inadequate management and overgrazing (Concepcion and Samar 1995). Conversion of grassland into upland crop farms is likewise proliferating at a fast rate. This is triggered by the interacting factors of rapidly increasing population, the system of landholding, difficulty in finding a job and declining area of arable land per farmer in the lowlands (Marchand 1987).

A small portion of the grassland area may have resulted from natural disturbances, but the majority has occurred due to the repeated occurrence of fire (Barlett 1956). Fire has been used as a cheap management tool in shifting cultivation since early civilisation. The slash-and-burn method of farming in the country (*kaingin system*) has been considered one of the primary causes in the transformation of an original tropical rainforest, or second-growth forest ecosystem, into grassland.

Grasslands are prone to fire occurrences, be it natural, accidental, intentional or conducted as a management tool. There are a variety of reasons for the origin of fires in Philippine grasslands, among them are:

1. Clearing of upland farms by kaingineros (farmers practicing the slash-and-burn system);
2. Management of pasture areas;
3. Negligence e.g. live cigarette butts thrown into dry grassland areas or campers leaving live fires at camp sites;
4. Hunters burning grasslands to attract wildlife species which feed on ashes and new growth from burned grasslands;
5. Firewood gatherers;
6. Timber poachers or loggers;
7. Fishermen fishing along riverbanks and creeks/streams adjacent to grassland areas;
8. Reforestation contractors intentionally burning their contracted areas to deceive evaluators and investigators for low seedling survival rate;
9. Fires lit by unpaid labourers and other alienated individuals involved with reforestation projects;
10. Natural phenomenon like lightning; and
11. Use of fire by ant and honey bee collectors.

Fires have both beneficial and detrimental effects on the ecosystem. Among the beneficial effects are

1. Control of pests and diseases (Bandy et al. 1993);
2. Manipulation of plant succession through controlled burning (Anderson 1979);
3. Removal of old cogon and inducing new growth which is palatable to livestock;
4. Attract wildlife species to eat ashes and new grass regrowth; and
5. Immediate release of nutrients from the burnt biomass into the soil which will be available for plant uptake in the next two years (Seubert et al. 1977).

Detrimental effects include susceptibility of burned and exposed sloping areas to erosion (Lal et al. 1986). More than 50% of grasslands in the Philippines have been severely eroded (Concepcion and Samar 1995). Moreover, nutrients in the soils may be lost by leaching and through water and wind erosion.

Revegetation of *Imperata* grasslands is quite difficult due to its resistance to pests, disease, competition and burning (Mendoza 1978). *Imperata* requires full light for growth and dies with shading, therefore biological control requires quick establishment of trees capable of shading *Imperata* (van So 1995). Exclusion of fire is therefore essential to make possible the establishment and development of tree and shrub seedlings (van So 1995). Thus, it is important that grassland fires be properly studied and understood.

This study aims to understand and explain factors affecting the occurrence of grassland fires in Isabela, characterise grass fires in the area, and determine factors influencing successful control of fire.

METHODOLOGY

The grassland study area was located in the province of Isabela in the Cagayan Valley Region (Region II) in Luzon. Region II has the second highest level of grasslands in the Philippines, and Isabela has the largest share of agricultural land areas for potential expansion in crop production of all the regions in Luzon (Bureau of Soils and Water Management 1993).

Three barangays (villages) were considered as study sites in the province of Isabela. These were Salindingan in Ilagan, and Masipi West and Masipi East in Cabagan. A summary of the cropping systems practiced in the barangays is shown in Table 18.1 The sites were selected after a reconnaissance survey was conducted in the region. The survey was done so as to find representative samples of *Imperata* areas that are highly-developed (Salindingan), moderately-developed (Masipi West) and less-developed (Masipi East), where development is related to a declining proportion of grassland under cultivation. Each area was documented using a structured interview questionnaire consisting of biophysical, fire and socioeconomic characteristic components. Thirty farmer-respondents were randomly interviewed from each site. Farmers typically occupy two to three parcels of land, so that the total number of sample parcels of land was approximately 75 per site. Field photo-documentation was collected from the study sites. Secondary data were collected from government and non-government institutions within the municipalities.

Table 18.1. Present cropping systems practised by farmers (%)

Cropping system	Salindingan	Masipi West	Masipi East
Corn-based	67	89	51
Corn-upland rice	8	0	1
Upland rice-based	12	4	4
Lowland rice	3	5	36
Tree-based	6	1	5
Other	4	1	3

LAND OWNERSHIP

Farmers are either owners/heirs, squatters, tenants or stewards of their present farmlots. Landowners have land titles of their own while the land stewards have certificates which they have acquired from the government. These are the Certificate of Land Transfer (CLT) and the Certificate of Stewardship Contract (CSC). CLT's are issued by the Department of Agrarian Reform (DAR) to farmers who are original tillers or tenants of a land. They are required to pay, in a lump sum or by instalment, the monetary value of the land before a land title is given under their names. On the other hand, CSC's are under the auspices of the Department of Environment and Natural Resources (DENR). These certificates are given to farmer-participants of the Integrated Social Forestry program in the area, for a tenure of 25 years and renewable for another 25 years. Some farmers have combinations of farmlot ownership, with either CLT or CSC, or both.

Most of the farmers in Salindingan own their farms, having certificates of land transfer (92%). In Masipi West and Masipi East, the majority of farmers are land squatters (46% and 39% respectively) and tenants (26% and 22% respectively). Some of the farmers in the area own their land, these account for about 16% in Masipi West and 21% in Masipi East. Only about 10% of farmers in the latter two areas are holders of CSC's which are valid for 25 years.

Ordinances on stray animals and damaging fires are strictly implemented by the barangay council of Salindingan. These ordinances cover penalties to the offenders such as fines in cases of light violation, or imprisonment to some extent.

GRASSLAND FIRES IN ISABELA

The majority of fires in the study area are intentionally lit. The intention is to clear the area in preparation for the next cropping season. Generally, farmers manually cut the standing biomass of crop residues and grasses, and let them dry in the field, before

setting them on fire. Fuel moisture content, along with other fuel characteristics, such as quantity, height and arrangement in the field, greatly affect fire behaviour (Brown and Davis 1973; McArthur 1973). Dry *Imperata* biomass is highly combustible.

When biomass is cut and laid on the ground, the height of fuel available for burning is quite low, maybe up to 0.5 m high. This has a direct bearing on the height of flames during burning. The height of flames is often twice the height of the fuel, therefore the flames would have a height of a metre or less. This flame height is relatively easy to control.

Weather is one of the most important factors affecting the ignition and spread of fires. The most important weather-related element which affects fire behaviour is wind. Wind speed is important not only for the rate of spread, but also because of its effect on ignition probability and combustion rate. Except for low and very high wind speeds, the rate of spread of a fire is approximately proportional to the square of the wind speed (Luke and McArthur 1978; Lorimer 1982). Wind velocity dictates the rate of spread and uniformity of burning. Wind velocities of about 15 m/second result in slower spread of fire but uniform burning (Atabay 1978), while stronger wind, velocities of about 40 m/second, result in faster spread of fire but less uniform burning.

Most of the burning done in the three sites occurs when wind speeds are much lower than 15 m/second, thus the rate of spread of fire is slow but uniform. Farmers in Masipi West do not supervise their fires, probably because most of them conduct fires during low wind velocities (0– 2 m/second) such that they don't think it is necessary to closely supervise the burning dry biomass. In Salindingan and Masipi East, farmers supervise their fires and establish fire breaks or fire lines because there are instances when they conduct burning during moderate and strong wind velocities.

As a consequence of the above practices, fires in the three areas generally remain under control. No sweeping fires have been reported recently. This can be attributed to successful management practices and existing ordinances in the barangay. In Salindingan, there is an ordinance that if a farmer's fire jumps to neighbouring farms, they must pay a fine. This may be a reason why farmers in this area establish fire breaks or fire lines and supervise their fires.

The inherent poor fertility and acidic conditions of *Imperata* areas make it difficult for the introduced tree species to establish and grow as fast as they need to in the initial stages (Sangalang 1995). Besides, *Imperata* is quite difficult to eradicate and thus is a very tough competitor for nutrients and water. *Imperata* is intolerant to shading, so planting of tree species that will outshade *Imperata* and suppress its growth is a good alternative biological control. Important characteristics of the selected species are: deep rooting capacities, fire resistance, a widespread dense crown,

resistance of roots to penetration by rhizomes of *Imperata,* fast growth and of course, economic value (van So 1995). Fast growing reforestation tree species such as *Gmelina* sp. and *Leucaena leucocephala* have been planted and are successfully growing along the borders and as hedgerows in all three sites.

A very important factor to be considered in the introduction of perennial species to the farms is security of land tenure or land ownership. In Salindingan where almost all of the farmers have tenurial security over their farms, planting of perennial tree species is highly feasible. In fact, there is one model farm in the area, which was initiated by the Department of Environment and Natural Resources, where perennial tree species were introduced and the farm has been economically and environmentally successful. This may set a trend and influence other farmers in the area to introduce reforestation and fruit tree crops, not only as hedgerows or boundaries, but to allot a certain proportion of their farm for tree farming. Another dominant factor that may influence them in their decision to plant trees in the near future, particularly for pulping, is the establishment of paper mill plant in the area. When this plant becomes operational, there will be a market for paper and pulp trees. In Masipi West and Masipi East where the farmers are just squatting in the area, they might not have the motivation to plant perennial trees and improve the area.

CONCLUSION

Generally, fire is used as a management tool in the three sites to clear the land of vegetation debris in preparation for cultivation and planting activities. However, there are a significant number of unintentional fires. The frequency of fires is high (more than two per year). Farmers generally cut the standing vegetation and dry it on the ground before setting it on fire. The height of fuel and flame of most of these grass fires are therefore low and very close to the ground. Farmers light fires during slow to moderate wind velocities. Farmers in the more developed sites of Salindingan and Masipi East supervise their fires and establish fire breaks or fire lines to control the spread of fire to neighbouring farms. Barangay ordinance also exists in Salindingan which successfully controls fire in the area.

Introduction of forest and fruit trees may improve the productivity of *Imperata* based upland farms. Shade will suppress the growth of *Imperata* and improve the microclimate and soil characteristics in the area. Fire is not an insurmountable constraint to tree establishment on lands occupied by smallholders in the Isabela region as evidenced by the number of trees growing in Salindingan, but fire is less under control in the less developed area of Masipi East. The more important socioeconomic factors that affect the decision process of the individual farmers to plant trees are land tenurial security and economic benefits. With the knowledge that

they will not be pushed away from their lands, farmers may be motivated to plant perennial species and have more motivation to control fires. This can be seen in the survey data. The establishment of a paper mill plant would ensure a ready market for pulp products and the high market value of quality wood would make the enterprise more attractive.

19 *Gliricidia* as a Fire-tolerant Reforestation Species

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DEGRADED GRASSLAND IN the Philippines today is the outcome of various forms of forest utilisation processes such as logging, repeated shifting cultivation, fuelwood and charcoal production, grazing and fire. It is an important ecosystem which requires rehabilitation for productive and ecological reasons.

Grasslands cover an estimated 6.5million ha of the country (Conception and Samar 1995) with varying composition, structural and physical characteristics. They are distributed nationwide, but two distinct pedo-ecological zones in the Philippines can be identified (Magcale-Macandog and Galinada 1996): (i) degraded, acidic, low organic matter and dry soil areas susceptible to erosion, which are dominated by *Imperata cylindrica*, *Themeda triandra* and *Chromolaena odorata*; and (ii) areas with adequate moisture, becoming more stable, which are dominated by *Saccharum spontaneum*, with some invading fern and shrub species (Concepcion and Samar 1995; Padilla 1995).

Efforts toward rehabilitation of degraded grasslands started many years back. However, the pace of reforestation often lags behind the rate of forest destruction. Of the various approaches already tried, notable strategies include the Family Approach to Reforestation (FAR), the Communal Tree Farm (CTF), Forest Occupancy Management (FOM), Integrated Social Forestry (ISF), and the Contract Reforestation Scheme that provided opportunities to all sectors of society as partners of reforestation initiatives. Substantial experiences and lessons have already been generated, but reforestation is still confronted with problems.

Specifically, one of the major drawbacks of reforestation is the low survival rate of outplanted seedlings, brought about by grass competition and the regular occurrence of fire. Grasslands are prone to fire, and because people live on grasslands adjacent to reforestation areas, fire in reforestation areas cannot be avoided. Some wildfires are lit intentionally while some are accidental, but records show that most originate from various sources such as (Espaldon 1995; Florece 1996; Magcale-Macandog and Galinada 1996): (i) incendiarism, (ii) escape of fire from swidden farming practices, (iii) negligence, (iv) hunters, (v) fuelwood gatherers, and (vi) timber poachers or loggers. Controlling the spread of fire appears to be difficult in local situations because of limited manpower, accessibility and topographical impediments. Fire incidence in reforestation projects has become phenomenal since the early 1970s. Since then, a tremendous amount of money and resources have been wasted which could have been used for other purposes. In 1993 for instance, 595 fire cases were reported, and these were estimated to have burned tree plantations worth ₱ 165 m.

In situations where fire is prevalent, fire exclusion appears to be unachievable and counterproductive. However, identification of tree species which can withstand repeated fire, or can readily regenerate after fire, is seen to be one viable fire management option left for farmers. Studies in the past decades have dealt more on growth and development performance of trees affected by fertilizer treatments, species trials, and nursery and planting techniques. There are insufficient studies in the Philippines on fire tolerance attributes, or survival monitoring, of tree species on fire-prone grasslands. Tupas (1976) has pointed out the importance of *Piliostigma malabaricum* and *Antidesma ghaesembilla* clumps in savannah grasslands as 'nurse trees' for introduced species, but the successional dynamics and fire intervals within these biomes are poorly understood.

Many species deserve consideration as reforestation material for degraded grasslands, Perino (1979) for instance, found that *Gliricidia sepium* cuttings can be used. This species has an advantage over other species in that it is found in most latitudes throughout the country and thrives in most soil and vegetation types, except at altitudes beyond 900m (Perino 1979). Furthermore, *Gliricidia* stem cuttings have the following advantages as reforestation material:

(i) socially acceptable especially among farmers,

(ii) use of cuttings eliminates nursery operation, therefore reduces reforestation cost,

(iii) the species has already adapted to local conditions, and

(iv) it is a multipurpose tree species.

It is a very popular tree crop in fallow *kaingins* (shifting cultivation farms) because of the high nitrogen content in leaf litter. *Gliricidia* is difficult to eliminate once established, due to its excellent coppicing ability. This species thrives in marginal areas and even in road cuttings however, its ability to tolerate fire and to suppress grasses has not yet been fully elucidated. It is in such a context that this study was undertaken. The study had the following objectives:

i) to quantify survival responses of *Gliricidia* cuttings after planting and subsequent fire; and

ii) examine the micro-biophysical changes under the established stand of *Gliricidia* stem cuttings some years after the burn.

MATERIALS AND METHODS

The study site

The study was conducted in Mt. Makiling, Puting Lupa, Calamba, Laguna at an elevation of 390–400 m. The site is approximately 65 km from Manila. The area was a dipterocarp forest which has been subjected to repeated shifting cultivation since World War II. When this study commenced, the site has been an abandoned field for almost 20 years, primarily because of soil acidity, low soil fertility and the invasion of *Saccharum spontaneum* (talahib) and *Imperata cylindrica* (cogon). Regular occurrence of anthropogenic fire maintained the dominance of these grasses, which is the reason why it became the site for fire ecology studies of the Upland Hydroecology Program (UHP) of the University of the Philippines in 1979. During that year, the area was surrounded by a secondary forest dominated by *Ficus* spp., and *Arenga pinnata* while the grassland area was dominated by *Imperata* and *Saccharum*.

Other grass species present were *Apluda mutica*, *Mikania cordata*, *Blumea* sp., *Elephantopus tomentosus, Grassocephalum crepidioides, Spathoglottis* sp., *Habenaria malintana, Derris eliptica, Desmodium triflorum, Cayratia trifolia, Mussaenda phillipica, Ophioglossum* sp., *Centilla asiatica, Polyscias nodosa*, and *Dioscorea bulbifera* (UHP 1980). The grassland area is approximately 0.3ha.

The soil in the area is Macolod Clay Loam (UHP 1980). It is under the Type 1 climate, based on the Corona system of classification, with almost 94% of the total annual rainfall occurring during the months of May to October.

The following studies have been conducted by UHP in the area:

(i) effect of fire on soil temperature at two depths (2.5 and 6cm);

(ii) effect of fire on soil moisture;

(iii) effects of fire on some soil chemical properties;

(iv) effects of fire on the Acarine fauna of grassland;

(v) influence of fire on soil fungal populations in grassland;

(vi) effects of fire on grassland vegetation;

(vii) effects of grass management on the bacterial and actinomycete populations and on the nitrogen availability;

(viii) runoff and sediment load; and

(ix) chemical composition of the runoff water from grass-covered plots subjected to different types of grass management and times of burning.

Below the study site are fallow kaingins randomly planted with perennial fruit trees at low density. The most common fruit trees include oranges (*Citrus* sp.), avocado (*Persea americana*), jackfruit (*Artocarpus hetyrophylla*), mango (*Mangifera indica*), coconut (*Cocus nucifera*), coffee (*Coffea* sp.), guava (*Psidium guajava*), santol (*Sandoricum coetjape*), guyabano (*Annona muricata*), etc.

Vegetation and soil sampling

Initial vegetation composition was determined by the harvest method in a $1m^2$ quadrat in April 1989. Twelve $1m^2$ quadrats were randomly located along the ridge and another twelve below the ridge. The harvested above-ground biomass was placed in plastic bags and brought to the laboratory for segregation by species, then placed in paper bags and oven dried for 48 hours at 105°C. Twelve composite soil samples were taken randomly in the area for soil pH, nitrogen, phosphorus, potassium and organic matter determination. In August 1996, or seven years after planting, the above mentioned sampling was repeated.

Land preparation and planting

Prescribed fire was used as the site preparation method. The area was burned in April 1989, after the initial vegetation sampling was completed. Prior to burning, the grasses were lodged to achieve a good burn or complete removal of above-ground biomass. Stems of *Saccharum* constituted the majority of the unburned material because of its high moisture content.

Planting was done in May 1989 at a spacing of 1 × 1m. A pole with 5 cm diameter was used as a priming material to make holes where cuttings were planted. Planting was made vertically at a depth of 25 cm, or half the length of the cuttings.

Experimental design and treatments

The study occupied a total area of 2500m^2. The experiment was laid out in a completely randomised design with diameter class as the main plots and length of cutting storage as sub-plots. The following treatments were imposed:

T_1 or 2A	1.5–2.99 cm diameter class, cuttings stored for 1 week, and burned;
T_2 or 2B	1.5–2.99 cm diameter class, cuttings stored for 2 weeks, and burned;
T_3 or control$_2$	1.5–2.99 cm diameter class, not stored, and not burned;
T_4 or 4A	3.0–4.99 cm diameter class, cuttings stored for 1 week, and burned;
T_5 or 4B	3.0–4.99 cm diameter class, cuttings stored for 2 weeks, and burned;
T_6 or control$_4$	3.0–4.99 cm diameter class, not stored, and not burned.

The cuttings were sharpened at the base at the time of collection, then were immediately stored in the shade. These cuttings were gathered for one day only. The experiment had six replicates. Twenty sample plants/cuttings represented the various treatments giving a total of 720 plants.

One year after planting, the area was burnt (grasses were lodged to achieve a good burn). There was no subsequent intervention made except for monitoring of the survival of *Gliricidia*, and bi-monthly lodging/pressing of grass regrowth until the third year.

Percentage survival of cuttings was monitored every month. However, the initial or reference survival used in the analysis was the data gathered in November 1989 (six months after planting). Final determination of tree survival was done in August 1996.

Data analyses

A multi-factor ANOVA was used to determine the effects of fire treatment, diameter size, and length of storage on survival of cuttings. A multiple range test (Tukey test) was subsequently performed when the ANOVA showed significant differences. A one-factor ANOVA was used to analyse the initial and final sampling of soil variables.

Survival of stem cuttings

The initial mean survival of *Gliricidia* stem cuttings six months after planting (November 1989) was 64% (Table 19.1). This may be low because planting was delayed for two weeks. Although there is no available study which emphasises the best time to plant cuttings of this species, field observations and experiences of farmers reveal that it should be before the beginning of the rainy season. There were no statistically different treatments during the initial sampling, but the cuttings with the largest diameter size (4 cm), stored for two weeks, had the highest survival rate at 78%, while the cuttings with 2 cm diameter, stored for two weeks, had the lowest survival rate at 48%. This simply means that either size cutting can be utilised as planting material, and that planting of stem cuttings may be delayed for two weeks as long as they are stored under shade and abrasions on the stems are avoided.

The final mean survival rate (August 1996) was 37% (Table 19.1), which is significantly different ($p < 0.05$) from that of the initial survival rate. The difference in survival rates of the two sampling periods could be attributed to the fire imposed in April 1990 (i.e. one year after planting). Survival rate, however, in the final sampling was only significant between the control treatment of the biggest diameter size and the smallest size class cuttings which were stored for one week. The relatively higher survival rates in the final sampling show that diameter size is an important fire tolerance attribute. However, despite the imposition of fire, the plantation was able to generate a 37% survival rate. It could be deduced from the results that plantation maintenance should continue until the trees reach a diameter of 4 cm, so as to achieve a good survival rate in case of an accidental fire. This situation is only true to species that are fire tolerant. In the study by Florece (1996) fire-intolerant species easily succumb to high intensity fire, even at diameter sizes beyond 10 cm dbh. Fire resistance should therefore be an important consideration in the selection of species for fire-prone grasslands.

Table 19.1. Mean survival (%) of *Gliricidia sepium* stem cuttings during initial (1989) and final (1996) sampling

Treatment		1989	1996
2A		48.33 [a]	18.33 [a]
2B		63.33 [a]	33.33 [ab]
Control2		56.67 [a]	38.33 [ab]
4A		65.00 [a]	40.83 [ab]
4B		78.33 [a]	41.67 [ab]
Control4		71.67 [a]	50.00 [b]
	Mean	64 [a]	37 [b]

Note:The numbers in the treatment (e.g. 2 & 4) represent diameter sizes in cm, while the letters (e.g. A & B) represent the length of storage of cuttings prior to planting; A for 1 week; B for 2 weeks.
Superscripted values with different letters are significantly different at a 5% level of significance (Tukey test.)

Micro-biophysical changes under the stand of *Gliricidia*

Initial vegetation sampling in April 1989, showed 16 plant species, where *Saccharum* and *Imperata* were the dominant grasses (Table 19.2). Seven out of 16 species present during the Fire Ecology study by the Upland Hydroecology Program (UHP) in 1979 were encountered in 1989, ten years after the project was abandoned. The results also showed the absence of tree species in the early sampling. This simply means that succession was relatively slow despite the proximity of seed sources. Fire may have influenced the rate of succession in the area from the time it was abandoned by UHP in 1979.

The result of the final sampling, in August 1996, showed a shift in vegetation composition after a lapse of seven years under a *Gliricidia* plantation (Table 19.2). It is interesting to note the total elimination of *Saccharum* and *Imperata*, and the dominance of shade-tolerant species like *P. conjugatum* and *C. patens*. Five species in the initial 1989 sampling were still present in the final sampling. These were *M. cordata*, *E. tomentosus*, *P. conjugatum*, *C. patens*, and *C. acrescens*. New species such as *S. nodiflora*, Ferns, *L. camara*, *C. odorata*, *C. asiatica*, and *A. conizoides* were also encountered on the site. A complete survey of tree species found in the site showed the presence of 14 tree species (Table 19.3). It may be safe to assume that *Gliricidia* plantation provided a conducive microclimate for the entry of other pioneering species and it can initiate vegetation change over a period of seven years. Also, the secondary forest near the site may have played an important role in providing seeds of the pioneer species.

Table 19.2. Vegetation composition during the initial and final sampling

Initial Species	Oven dried wt. (g)	Initial veg. (%)	**Final** Species	Oven dried wt. (g)	Initial veg. (%)
*Saccharum spontaneum**	1472	47.1			
Oxalis corniculata	0.4	0.01			
*Desmodium triflorum**	15.4	0.49			
*Apluda mutica**	39.6	1.267			
Cyperus sp.	1.2	0.038			
*Imperata cylindrica**	1296	41.48			
*Dioscorea bulbifera**	0.2	0.006			
Echinochloa oryzoides	100.8	3.23			
Centrosema pubescens	0.4	0.01			
*Lygodium circinatum**	5.2	0.17			
Ipomoea sp.	9.6	0.31			
*Mikania cordata**	18.7	0.59	*M. cordata*	29.6	4.82
*Elephantopus tomentosus**	3.1	0.09	*E. tomentosus*	13.2	2.15
Paspalum conjugatum	150.8	4.83	*P. conjugatum*	225.5	36.7
Cyrtococcum patens	9.2	0.294	*C. patens*	206.7	33.64
Cyrtococcum acrescens	1.8	0.058	*C. acrescens*	4.1	0.67
			Synedrella nodiflora	2.1	0.34
			Nephrolepis cordifolia	32.6	5.3
			Lantana camara	7.5	1.22
			Chromolaena odorata	56.1	9.13
			Centilla asiatica	0.1	0.02
			Ageratum conizoides	0.5	0.08
			Trees		
			Leucaena leucocephala	19.8	3.22
			Ficus hauili	4.3	0.7
			Ficus ulmifolia	11	1.79
			Celtis philippensis	0.2	0.03
			Biscofia javanica	1.2	0.19

* Species present during the FIre Ecology Study by UHP in 1979.

Table 19.3. Other tree species present in the area but not found in the sampling quadrat

Local name	Scientific name	Family
Paguringon	*Cratoxylum celebicum* (Blume)	Guttiferae
Tibig	*Ficus nota* (Blanco) Merr.	Moraceae
Banaba	*Lagerstroemia speciosa* (l.) Pers.	Lythraceae
Salago	*Phaleria capitata* Jack	Thymelaeaceae
Matang-araw	*Melicope triphylla* (Lam.) Merr.	Rutaceae
Mamalis	*Pittosporum pentandrum* (Blanco) Merr.	Pittosporaceae
Hamindang	*Macaranga bicolor* Muell-Arg.	Euphorbiaceae
Bogus	*Acalypha stipulacea* Klotz.	Euphorbiaceae
Kalingag	*Cinnamomum mercadoi* Vid.	Lauraceae
Tangisang bayawak	*Ficus variegata* Blume	Moraceae
Bignay-pogo	*Antidesma pentandrum* (Blanco) Merr.	Euphorbiaceae
Tirukan	*Beilschmiedia glomerata* Merr.	Lauraceae
Matang-hipon	*Breynia rhamnoides* (Retz.) Muell-Arg.	Euphorbiaceae
Putat	*Barringtonia racemosa* (L.) Blume ex DC	Lecythidaceae

Soil chemical analyses during the final sampling showed higher values than initially for all variables, but significant differences occurred in pH, phosphorus and potassium (Table 19.4). This trend is an indication that *Gliricidia* can be a good fallow crop for marginal grasslands or abandoned shifting cultivation fields.

Table 19.4. Initial and final soil chemical analyses of the experimental site

Variables	Initial (1989)	Final (1996)
pH	5.34^a	5.86^b
% Organic matter	5.72^a	5.93^a
Nitrogen	0.243^a	0.276^a
Phosphorus	0.219^a	1.311^b
Potassium	1.78^a	2.86^b

Superscripted values with different letters are significantly different at a 5% level of significance (Tukey test).

CONCLUSION AND RECOMMENDATIONS

Grasslands dominated by *Imperata* and *Saccharum* can be rehabilitated using *Gliricidia* stem cuttings. *Gliricidia's* potential for shading out grasses which supply a substantial amount of combustible fuel during the fire season was found to be effective. This reforestation technique is easy to adopt and entails lower inputs than

conventional reforestation methods. Dense planting is recommended to promote the shading capacity of *Gliricidia.* The survival percentage will be lower, so a spacing of around 1 × 1 m is recommended. Neither the size of the cuttings, nor the length of time the cuttings are stored affects the rate of survival in the first year. With the imposition of fire at the end of the first year, a *Gliricidia* survival rate of 37% provided sufficient trees to suppress the grasses over a 6–7 year period.

Wildfires have become a major constraint to tree establishment in public lands. The strategy of using fire early in the life of the plantation can reduce fuel load and fire risk. No wildfire entered the experimental plantation subsequent to the deliberate burn. Fire risk was substantially reduced by burning the grasses at the end of the first year followed by shading from the surviving *Gliricidia.* If local communities are given the chance to implement this approach, rehabilitation of grasslands of this type, under the public domain or in pasture areas, can be facilitated.

20 Fire as an Economic Disincentive to Smallholder Rubber Planting

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CZECH CONROY
ANANG GUNAWAN
KATIE ELLIS

RUBBER IS ONE tree that is successfully grown in *Imperata* areas by smallholders, despite being routinely threatened by fires. Fires were especially prevalent in 1994 and 1997 in South Kalimantan and South Sumatra — two islands with heavy concentrations of *Imperata*. In this paper, the physical impacts and financial effects of fire risk in relation to smallholder rubber plantations in *Imperata* areas are examined.

The geographical focus of the study is South Sumatra, Indonesia. Survey work was carried out in 1995 and 1996 in order to gain an increased understanding of the nature and importance of fires in *Imperata* for smallholder rubber producers. Semi-structured group interviews were used to get farmers to describe and discuss the fire problem. This was followed by participatory mapping (i.e. by the farmers) of the local area showing where and when fires had occurred, including the areas of immature rubber destroyed or damaged by fires.

Based upon this and other information, a simple conceptual model of fire in relation to rubber in *Imperata* areas was developed. This 'fire model' was then incorporated within an existing bioeconomic model (BEAM) of a smallholder rubber agroforestry system involving *Imperata* (Menz and Grist 1996b). In the model, rice is initially the understorey to rubber followed after two years by *Imperata* as the understorey. The economic disincentives caused by fire risk and fire spread are calculated. An analysis of these costs facilitates judgement as to whether community or government-sponsored efforts to control fire are warranted.

Imperata is a fire climax vegetation type. The subsoil rhizomes of *Imperata* are stimulated by fire to grow rapidly, so fires perpetuate *Imperata*. Mature *Imperata* has been found to burn in the dry season, if there is no rain for a week (Wibowo et al. 1997), and so is extremely hazardous in dry periods. *Imperata* may be cleared from an immature rubber plantation, but this is a very labour intensive (and therefore costly) process, and the weed will quickly re-establish (Gunawan et al. 1997). Gunawan et al. (1997) also found that some farmers consider the fire hazard posed by *Imperata* to be as serious a threat to their immature rubber as the direct competitive effect of *Imperata* on rubber growth. This dual impact of *Imperata* on tree growth is shown in Figure 20.1. The circularity of competition between *Imperata* and rubber is also shown — increased *Imperata* groundcover provides more competition for the tree, which reduces the rate of growth in the tree's shading capacity, which leads back to the level of *Imperata* groundcover.

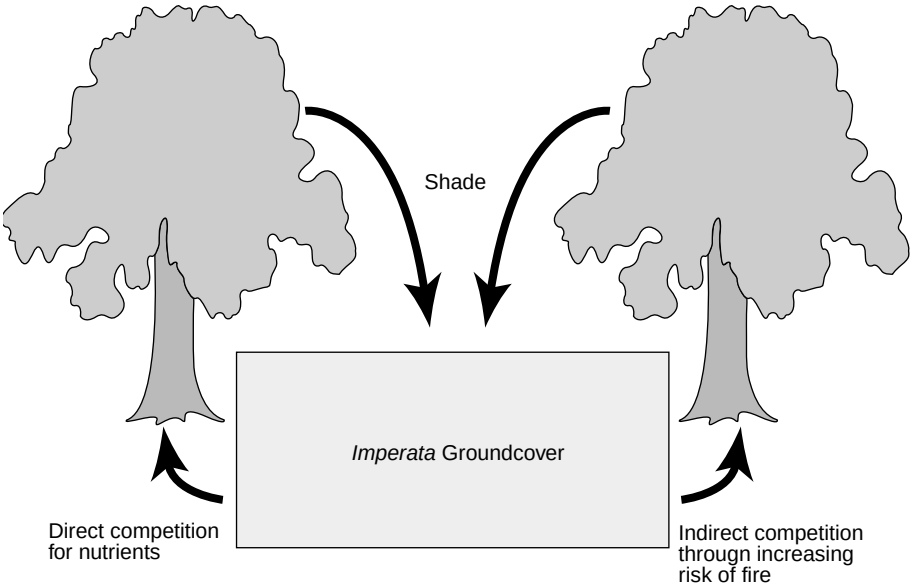

Figure 20.1. The dual competitive effect of *Imperata* and the circularity of competition between *Imperata* and rubber

The risk of fire is deemed to be most significant following the period of intercropping rice (usually the first two years after planting). This risk remains, but diminishes up to the time of canopy closure. For smallholders, this is usually between years 8–10 years after planting (Bagnall-Oakeley et al. 1997), as portrayed in Figure 20.2. Susceptibility in this period of immature rubber relates to the presence of highly flammable *Imperata* growing as the understorey (Pickford et al. 1992).

A more economically meaningful interpretation of Figure 20.2 was constructed after consultation with staff at the Indonesian Rubber Research Institute (IRRI) at Sembawa, near Palembang, South Sumatra. This interpretation is portrayed in Figure 20.3, as a '**fire damage function**', showing damage caused by a fire *within a rubber plantation* for various levels of *Imperata* groundcover *within the plantation*. The function is based upon the accumulated experience and perceptions of IRRI staff.

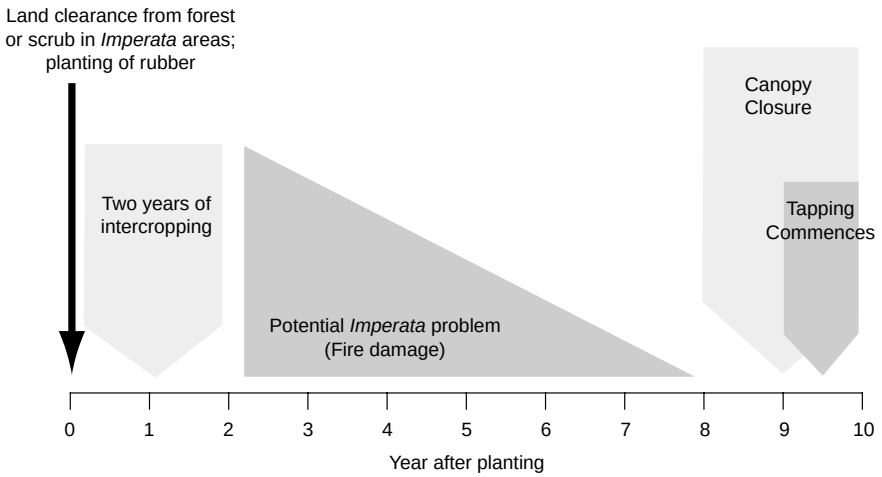

Figure 20.2. Period between planting seedling rubber and canopy closure, when *Imperata* is likely to be a fire hazard

During the first two years after planting rubber, farmers usually intercrop with annual crops. *Imperata* groundcover is normally kept at low levels, minimising any threat posed by fires. After canopy closure, with *Imperata* groundcover at 25% or less, fire is not expected to result in significant damage to rubber trees, since fires in mature rubber are relatively uncommon (Gunawan et al. 1997). Thus, it is in the intervening years, between the conclusion of intercropping and canopy closure that the fire risk from *Imperata* is a major concern, and the 'probability of having immature rubber damaged or destroyed by fire is worryingly high' (Gunawan et al. 1997). In terms of Figure 20.2, this is between the end of year 2 and canopy closure. In Figure 20.3, it is at *Imperata* groundcover levels above 25%. All trees are assumed to be destroyed by fire at levels of *Imperata* groundcover greater than 75%. For *Imperata* groundcover levels less than 75%, there is a proportionate reduction in stem damage as *Imperata* groundcover falls (Fig. 20.3). This assumption gains some support from the smallholder farm interviews carried out in South Sumatra. Fires were found to destroy immature rubber when *Imperata* groundcover was high but less than 100% (Gunawan et al. 1997).

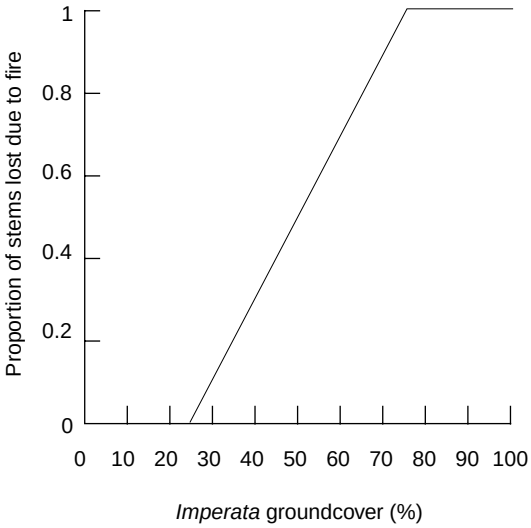

Figure 20.3.
Fire damage function: proportion of rubber stems lost in a dry season fire, in relation to the level of *Imperata* groundcover *within* the plantation

The nature of the surrounding vegetation will influence the risk of fire entering a plantation. In this paper, the risk of fire entering a plantation ('fire risk') is taken to be the product of the probability of fire ignition and proportion of *Imperata* groundcover *in the surrounding areas*. Smallholders sometimes use firebreaks to reduce this risk (Gunawan et al. 1997), so the fire risk should be regarded as being measured in the light of any such ameliorating actions.

Probability of fire entering a plantation (fire risk) =
(probability of fire ignition) × (proportion *Imperata* groundcover in areas surrounding the plantation) **Equation 1**

An average annual probability of fire ignition was used for the expository purposes of this paper. The probability of ignition was set at 0.1 (10%) per year. So, with an *Imperata* groundcover of one (100%) surrounding a plantation, fire risk would be $0.1 \times 1 = 0.1$, or 10% per year. This average-year approach avoids the complexities involved with a stochastic model. In South Sumatra, frequent small fires affecting 20 to 250 ha appear to be the norm rather than occasional large fires (Gunawan et al. 1997).

The number of rubber stems lost to fire per year can thus be calculated from the risk of fire entering a plantation (from Equation 1) times the prevailing *Imperata* groundcover *within* the plantation (from Fig. 20.3). The *Imperata* groundcover *within* the plantation is derived from the shading function in a rubber plantation simulation model. That model is also used to trace through the long run consequences of fire damage on the plantation, as indicated in the following section.

THE RUBBER PLANTATION MODEL AND KEY ASSUMPTIONS IN THE ANALYSIS

The BEAM bioeconomic rubber agroforestry model, RRYIELD, is outlined in the appendix to this paper. The focus of the model is on smallholders, rather than estates. The RRYIELD model includes a section dealing with the competitive effect of *Imperata* on rubber tree growth (Chapter 14). *Imperata* groundcover is the key variable in both the fire risk and fire damage calculations. In the work to be reported in this chapter, 'fire damage' and 'fire risk' parameters were calculated and incorporated within the RRYIELD model, based upon the logic outlined in the previous section. For determining the risk of fire entering a plantation ('fire risk'), the relevant *Imperata* groundcover is that on *surrounding* farms or plantations (equation 1). For determining 'fire damage', it is the *Imperata* groundcover *within* the plantation being examined.

Wibowo et al. (1997) specified fire risk to be a function of various factors, including fuel load and ignition probability. The latter two factors are considered to be incorporated within the 'fire risk' parameter of equation 1. The probability of ignition (0.1 per year in the example) is input directly into the model by the user. *Imperata* groundcover *within* the plantation is calculated in the model annually, based upon light intensity passing through the rubber canopy. The *Imperata* groundcover *surrounding* the plantation can either be specified by the user, or it can be simulated by RRYIELD, where the *surrounding* areas contain rubber plantations of comparable age.

Fire damage has been assumed to be evenly distributed throughout the rubber plot. Trees destroyed by fire are deemed not to be replaced. *Imperata* groundcover is not affected by fire for a significant length of time, since the rhizomes ensure fast recovery of *Imperata* after fire (Pickford et al. 1992). Therefore fire does not *directly* alter the competitive effect of *Imperata* on rubber tree growth. However it does so *indirectly* by killing rubber trees, which allows more light to reach the *Imperata* understorey (aiding subsequent *Imperata* growth).

After the two-year period of intercropping with rice, no further *Imperata* control is specified in the example. *Imperata* groundcover then becomes a function of light penetration through the rubber tree canopy.

The planting material most commonly used by smallholders is unselected seedlings (wildlings). The model parameters in this example are based upon growth rates from unselected seedlings. Seedlings are usually transplanted using seed dispersed from nearby trees (Grist and Menz 1995), and the material is often of relatively poor quality.

All output from the RRYIELD model is determined on an annual basis. For this analysis, the rubber seedlings are planted at a density of 750 stems per ha. This was the average planting density found by Gouyon and Nancy (1989) in a survey of Indonesian smallholders. It also coincides with the economically optimal rubber planting density (in *Imperata* grassland areas) found by Menz and Grist (1997b).

The physical outputs (latex and wood) obtained from the RRYIELD model are translated into economic terms via a companion economic model, RRECON, which calculates net present value (NPV) from the annual cash flows of alternative scenarios. Discount rates of 10% and 25% are used. Price and cost data were obtained for the Palembang region in South Sumatra (Chapter 14). Where fire reduces the number of trees to be tapped, a corresponding reduction in tapping cost is made within the model. This corresponding reduction is also applied to other tree-related costs such as harvesting and processing.

The model was initially run three times:

1. with the probability of fire ignition set at 10% per year and the surrounding *Imperata* groundcover at 100% (the '$fire_{100}$' scenario)
2. with the probability of fire ignition set at 10% per year and the surrounding *Imperata* groundcover at 50% (the '$fire_{50}$' scenario)
3. with the probability of fire ignition set at 0% per year (the 'no fire' scenario)

The first two situations represent an individual planting rubber in a plantation surrounded by high and moderately *Imperata*-infested areas.

THE ECONOMIC COSTS OF FIRE IN RUBBER

The results of the modelling exercise, in terms of net present value (NPV, as determined using a discount rate of 10%) and total latex production, are shown in Table 20.1. Inclusion of fire risk (in the '$fire_{100}$' scenario) caused a reduction in latex yield over the life of the plantation of 2.8 t/ha which led to a reduction in NPV of Rp 0.3m (One U.S. dollar equals Rp 2900). The '$fire_{50}$' scenario, as expected, caused lower damage. These figures are indicative of the cost of fire for these circumstances, or alternatively, of the value of eliminating the risk of fire. NPV is calculated after allowing for payment to labour (i.e. NPV is net of labour costs). At a 25% discount rate (not shown in the Table), all NPV's are close to zero, but still positive in the 'no fire' risk case.

Table 20.1. NPV and total latex production /ha over 30-year life of a smallholder rubber plantation for the one 'no fire' and two 'fire' scenarios, using unselected rubber seedlings as planting material, discount rate of 10%

	Net Present Value r =10%* (Rp mill)	Difference due to fire	Latex production (t)	Difference due to fire
No fire	1.7	–	15.8	–
$Fire_{50}$	1.6	0.1	14.8	1.0
$Fire_{100}$	1.4	0.3	13.0	2.8

* r represents the discount rate.

The underlying reasons for these differences in net present value and in latex production can be seen in Table 20.2. Fire in a plantation surrounded by sheet (100% groundcover) *Imperata* causes stem damage, reducing the number of trees reaching tappable age by 26%, and delaying the commencement of tapping by one year. *Imperata* groundcover within the plantation is higher under the '$fire_{100}$' scenario than the 'no fire' scenario (Fig. 20.4). The shaded area provides an indication of the additional competition from *Imperata* as a result of fire. This is due to the increased light penetration through the canopy, as the density of trees is reduced by fire. The extra *Imperata* groundcover reduces tree growth rate for a given tree planting density. It also increases fire risk in subsequent years. There is an economic cost associated with both of these effects.

Table 20.2. *Imperata* groundcover and the number of tappable trees /ha, at the time of tapping commencement

	No fire	$Fire_{100}$
Number of trees reaching tappable size	750	552
Reduction in number of trees reaching tappable size, due to fire	–	26%
Year of tapping commencement	10	11

Individual trees in the '$fire_{100}$' scenario grew at a slightly faster rate than the trees unaffected by fire, due to the reduced tree density. The additional competition from a higher *Imperata* groundcover was approximately equal to the competitive effect of the trees in the 'no fire' scenario. As a result, tapping commencement time was approximately the same in the '$fire_{100}$' and 'no fire' scenarios. Since fire did not significantly reduce tree girth increment or tapping commencement time, the net negative effect of fire was mostly to reduce tree numbers. The difference in total latex production was largely due to the greater number of stems in the 'no fire' scenario. Since costs were approximately equal in all scenarios, (with the exception of lower

tapping and harvesting costs /ha following fire), if a 10% discount rate is used the NPV is lower with 'fire$_{100}$' by Rp 0.3 million (18%). So a smallholder could spend up to Rp 0.3 million in achieving fire control, where a smallholder is planting rubber in an area surrounded by 100% *Imperata*. With surrounding *Imperata* groundcover at 50%, up to Rp 0.1 million could be spent (Table 20.1).

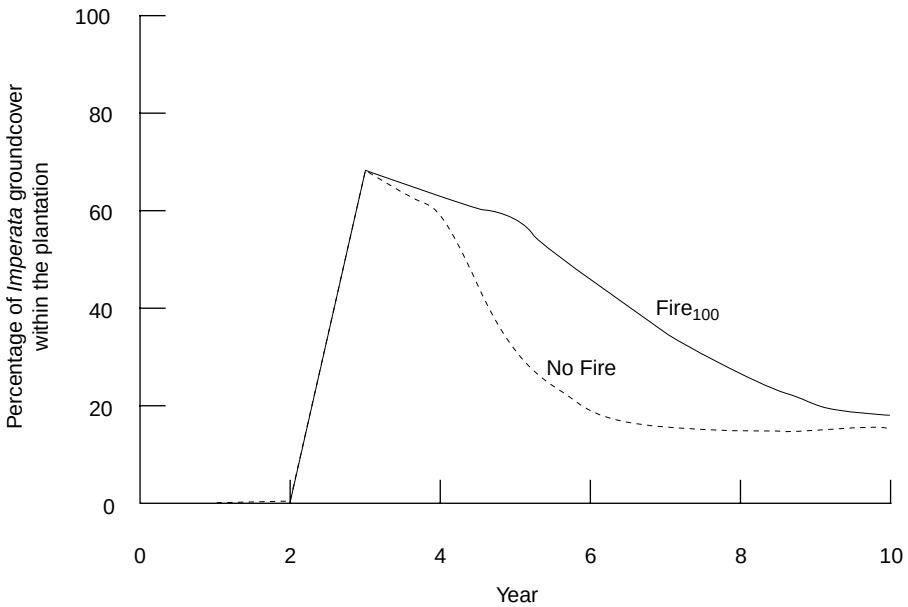

Figure 20.4. *Imperata* groundcover within the plantation up to the time of tapping commencement

SENSITIVITY ANALYSIS

The effects of fire risk levels greater than 10% per annum were assessed. Fire risk is calculated as the product of ignition probability and surrounding *Imperata* density, so for this analysis it was not important which of the latter two factors was manipulated. Only the product (fire risk) was altered. The 'break-even' point, where NPV approaches zero, was found to be where fire risk was 13% per annum. For fire risk values above 25% per annum, fire damage in seedling rubber was extensive. Canopy closure was not achieved, and tree establishment costs were not recouped. Under these conditions, rubber growing is not economically viable.

FIRE CONTROL VIA A COORDINATED APPROACH TO TREE PLANTING

Fire spreading across farm boundaries can be regarded as an 'economic externality' in a similar manner to herbicide drift, or a weed spreading, from farm to farm (Menz et al. 1984). The value of fire control consists not only of the private benefits from control (Table 20.1) but also of the 'social' benefits stemming from a reduction in fire risk to neighbouring farmers. This occurs through a reduction in *Imperata* groundcover. If one farmer reduces understorey fuel load of *Imperata* (e.g. via tree planting), then the fire risk is reduced *for all neighbouring farmers*.

This implies that some of the responsibility for fire control appropriately rests with communities, or governments as their representatives, rather than solely with individuals. Tree planting can be regarded as a form of fire control, since the risk of fire entering a farm is conditioned by the fuel load on neighbouring farms (refer Figs 20.1 and 20.2). A relatively simple, and low cost, approach for reducing fire risk would be for groups of smallholders with land containing *Imperata* to *simultaneously* undertake rubber planting.

This approach was examined with the aid of the models. The previous results for the '$fire_{100}$' and the '$fire_{50}$' scenarios (shown in Table 20.1), showed latex yield and net present value on the assumption that no *Imperata* control was undertaken on surrounding farms. Where a farmer and his/her neighbours undertake simultaneous, or coordinated, rubber planting, fire risk is lowered *for all farmers* because the *Imperata* density of surrounding farms is reduced. Such coordinated planting has been noted in farm interviews in South Sumatra (Gunawan et al. 1997).

The economic effect of fire control via the coordinated planting of smallholder rubber at a 10% discount rate is shown in Table 20.3. The analysis was not carried out at a 25% discount rate as the net benefits from rubber production were previously shown to be marginal at this discount rate. The benefit from fire control through a coordinated approach to planting was Rp 0.2 million (/ha in NPV terms) for the '$fire_{100}$' scenario and negligible for the $fire_{50}$ scenario (not shown in Table 20.3). This compares with a saving of Rp 0.3 million /ha achieved by the complete elimination of fire (Table 20.1 for the '$fire_{100}$' scenario). For coordinated planting, there was a corresponding increase in latex yield of 1.4 t/ha over the life of the plantation. Tree loss and competition from *Imperata* was reduced with the coordinated approaches to tree planting.

Table 20.3. NPV and total latex production with and without fire control /ha over the 30-year life of a smallholder rubber plantation using a 10% discount rate. Partial fire control achieved via coordinated planting of rubber.

	NPV (Rp mill.)	Latex production (t)
No fire control	1.4	13.0
Fire control	1.6	14.4
Benefit gained	0.2 (+14%)	1.4 (+11%)

These benefits from a coordinated approach to planting (via a reduction in fire risk) are necessarily less than the benefits of total fire control (for the latter see Tables 20.1 and 20.2). The benefits from coordinated planting may be obtained at lower costs than the benefits from more conventional fire-fighting techniques. The only cost is that of the coordination itself.

A coordinated approach to planting rubber would have added advantages (not taken account of here) in terms of the cost of constructing fire breaks. Fire breaks in South Sumatra are generally made by slashing the vegetation and then turning over the land with a *cangkul* (a mattock-like agricultural implement) and are 3 m wide or greater (Gunawan et al. 1997). This, therefore represents a cost in terms of labour usage. However, fire breaks are not fully effective. When farmers plant their immature rubber plots adjacent to each other, the cost of surrounding the plots with a fire break, and maintaining it, would be shared by the farmers involved. Costs per farm would be reduced due to the reduction in perimeter size per unit area planted.

CONCLUSIONS

The risk of fire was demonstrated to be an economic disincentive to tree growing. Even a modest fire risk of 10% per year was shown to considerably reduce expected profit from rubber growing. A fire risk greater than 13% resulted in economic non-viability of rubber growing under the specified conditions. Total control of fire, in a plantation surrounded by 100% *Imperata* and with a 10% fire risk, would return an additional Rp 0.3 million /ha in terms of NPV.

A simple, low cost, fire risk reduction technique in highly *Imperata*-infested areas, would be for all smallholders to *simultaneously* plant rubber. This policy would provide, at minimal cost, approximately two thirds of the benefits obtained by complete elimination of fire. Other forms of fire risk reduction such as fire breaks and care with lighting fires in windy conditions are also feasible.

The direct economic impact of fire risk on the profitability of farms (including neighbours), was the subject of this chapter. In addition, there are other costs

associated with fire (land degradation, health and other problems from smoke haze, reduction in carbon sequestration by trees) which were not included in the analysis. For example, in Indonesia in 1994 and 1997, smoke haze from agricultural and forest fires caused airline flight disruptions in the area, and the pollution which spread to Singapore and Malaysia caused respiratory difficulties and became a major diplomatic issue with these neighbouring countries. The issue of carbon sequestration is addressed in Chapter 21.

The fire damage function used in the empirical models is admittedly somewhat speculative. Yet it is in accordance with observed general relationships between fire and *Imperata* groundcover, and with tree losses over time. The fire ignition probability is genuinely speculative, but at 0.1 per year is thought to be conservative.

Precision in estimation was not the objective of the modelling. Rather it was to demonstrate a framework for conceptualising fire risk and damage in relation to tree growing in *Imperata* areas and to make some 'best bet' judgements about their magnitude. The social costs of fire, in terms of the economic disincentive to neighbouring farms, were demonstrated as was the promise of a coordinated community approach to fire control. Smoke haze, global warming (through emissions of carbon and reductions in tree planting) and land degradation are other social costs emanating from fire. If account were taken of the impacts of fire control with respect to these issues, total social benefits from fire control would be higher than indicated here.

In general fire risk becomes less as grassland areas become more developed (Magcale-Macandog and Galinada 1996). The issue of fire risk is most pertinent in the less densely populated, *Imperata*-dominated areas. The calculations here were for non-clonal rubber planting material typically used in these areas.

Some of the responsibility for fire control in these areas appropriately rests with communities, or governments as their representatives, rather than solely with individuals. Government intervention may well be justified in promoting fire control techniques.

21 Private and Social Benefits from the Use of Clonal Rubber

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KEN MENZ
ANURA KUMARA AMARASINGHE

RUBBER TREE GROWING has been shown to be a profitable alternative to food crops in *Imperata*-infested areas (Gouyon 1992, also Chapters 14 and 20). Rubber can out-compete *Imperata* via shading. For smallholders, who occupy most of these upland areas, rubber has the potential to provide reasonable returns, even under conditions of low quality planting material and low maintenance (Gouyon et al. 1990).

The profitability of growing rubber trees in areas affected by *Imperata* was assessed in Chapters 14 and 20. The potential of rubber is indicated by the three million ha currently planted in Indonesia, of which most (80%) are managed by smallholders on upland sites (Gouyon 1992).

Clonal rubber trees are considered to have several advantages over the unselected rubber trees that are commonly used by smallholders. The former provide direct economic advantages in terms of higher latex yields and an earlier tapping commencement time, as well as the indirect advantage, of faster growth and thus an ability to compete with *Imperata* (Chapter 14). This also reduces the risk of fire entering a rubber plantation and so provides a larger store of carbon sequestered from the atmosphere by rubber trees (Tomich et al. 1997). The main disadvantage of clones is the initial capital cost, at Rp 350 per seedling. For a plantation of 750 stems per ha, this amounts to Rp 0.26 million per ha. Furthermore, for smallholders in Indonesia, good quality clones are relatively difficult to obtain (Barlow 1997).

In this chapter, three dimensions of benefits obtainable by using clonal rubber trees in smallholder plantations are defined and quantified:

- Private benefits to smallholders derived from faster growth, more effective *Imperata* control, and higher latex yields;
- Private benefits to smallholders derived from a reduction in the risk of fire (resulting from more effective *Imperata* control); and,
- Social benefits associated with an increased level of carbon sequestration, thus reduced the environmental impacts from high atmospheric carbon dioxide levels, and assisting Indonesia to reach its net carbon dioxide emissions targets.

These benefits are then compared with those obtainable from unselected seedlings.

Previous research has assessed the *private benefits* (*growth and yield*) from using clonal rubber in the absence of fire risk (Chapter 14 and Grist and Menz 1996c). Most emphasis in this chapter will be placed on the *benefits from clones associated with fire risk reduction and the benefits from enhanced carbon sequestration*.[1]

THE BEAM RUBBER MODEL

For this analysis the BEAM rubber agroforestry model is used to predict the growth and yield of rubber and to observe the influence of fire on rubber and the levels of carbon sequestration from using clones and unselected planting material. For information on the workings of the BEAM rubber models see the Appendix.

The simulations carried out in this analysis are based on one ha, with a planting density of 750 stems. Smallholder rubber plantations typically have low capital input, without fertilizer added, or herbicide used for weed control (Barlow and Muharminto 1982; Gouyon and Nancy 1989). An agroforestry rubber/rice farming system is taken to represent current smallholder practice — with rice intercropping in the first two years after tree establishment. During the intercropping period, *Imperata* is controlled, so fire risk is minimal. There is competition between rice and the rubber trees but it is less than that between *Imperata* and rubber (Grist and Menz 1996c). While the net economic return from an intercrop rice harvest is modest, it does provide a method of *Imperata* control which gives a positive cashflow in the short term. For poor farmers, this makes intercropping attractive.

After the period of intercropping there is not considered to be any further *Imperata* control. *Imperata* groundcover is calculated as a function of light penetration

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1. A reduction in fire risk on farm A also provides a social benefit by reducing fire risk on neighbouring farm B. This latter effect is not included in the current analysis, but was addressed in Chapter 20 (for the example of unselected planting material). Insofar as the social benefit from fire control would be expected to be higher with clones than with unselected planting material, the economic advantage of clones is underestimated in the current chapter.

through the tree canopy, with *Imperata* groundcover decreasing as the trees mature. Competition from *Imperata* becomes minimal after tree canopy closure.

In plantations of unselected rubber trees, smallholders typically tap once the tree reaches a girth of 35 cm. The slow growth of unselected rubber trees, particularly if *Imperata* control is not practiced, leads smallholder farmers to tap prior to the recommended girth of 45 cm (Grist and Menz 1996a). With clonal rubber trees smallholders are modelled to commence tapping at a girth of 45 cm.

The private financial benefits from *Imperata* control by shading with rubber, and the associated benefits from reducing fire risk, were reported in Chapters 14 and 20.

Here the model is determined for three dimensions of benefits, for both clones and unselected seedlings:

- Private benefits, given a zero fire risk and no carbon sequestration;
- Private benefits given two levels of fire risk — 5% per annum and 10% per annum; and,
- The benefits as in 2 above, plus the social benefits from carbon sequestration. The imputed value of carbon sequestration is calculated at three rates — $US5/t, $US10/t and $US20/t. The imputed value of carbon sequestration is then added to private financial profitability, to derive the net private plus social benefits from using clones verses unselected rubber trees.

RESULTS OF SIMULATIONS OF BENEFITS FROM PLANTING CLONAL RUBBER VS UNSELECTED SEEDLINGS

Zero fire risk and zero carbon sequestration

The fast rate of growth of clonal rubber enables it to better compete with *Imperata*. This was highlighted in Figure 14.3 of Chapter 14, where *Imperata* groundcover under clones was shown to decrease at a faster rate than under unselected rubber trees. This allows rubber tapping to commence earlier and gives a higher latex yield. Both have a strong positive effect on the NPV of a plantation.

When using a discount rate of 10%, the expected NPV of unselected rubber trees was found to be Rp 1.68 million/ha. For clonal rubber trees, the expected NPV at 10% was Rp 3.66 million/ha. Using the market discount rate of 25%, both unselected and clonal rubber provide only marginally positive returns — Rp 0.03 million for unselected rubber trees and Rp 0.29 million for clonal rubber. However, the fact that unselected rubber and clones are profitable at a 25% discount rate, is impressive, as few alternative land-use (farming) systems are likely to provide a positive return at this rate.

Five and ten percent per annum fire risk

The faster growth of clones, and the corresponding earlier shading effect on *Imperata* helps reduce fire risk.

The approach used here is similar to that reported in Chapter 20. However, in Chapter 20 only the situation of unselected rubber trees was addressed. Here clonal rubber is also considered. The model was run for both unselected rubber trees and clonal rubber for: zero fire risk; 5% p.a. fire risk; and, 10% p.a. fire risk.

The net present value of investment in a rubber plantation for both unselected rubber trees and clonal rubber trees are presented in Table 21.1 for the three fire risk scenarios.

Table 21.1. Net present value at 10% and 25% discount rates (*r*) and latex yield/ ha (clonal and unselected seedlings) at each of 3 fire risk levels, 30-year time horizon

	Unselected rubber trees			Clonal rubber trees		
	NPV (Rp million)		Latex yield	NPV (Rp million)		Latex yield
	r = 10%	*r* = 25%	(t/ha/25 yrs)	*r* = 10%	*r* = 25%	(t/ha/25 yrs)
Zero fire risk	1.68	0.03	15.8	3.66	0.29	25.8
5% p.a. fire risk	1.60	0.02	14.8	3.62	0.28	25.4
10% p.a. fire risk	1.38	–0.04	13.0	3.56	0.27	24.9

At a 10% discount rate, the use of clonal, rather than unselected rubber seedlings provides a 120% improvement in NPV when fire risk is zero. The improvement in NPV from using clones increases as the level of fire risk increases. That improvement becomes 125% with a 5% fire risk and 160% with a 10% fire risk.

At a 25% discount rate, the proportional improvements are much higher, but the trends are generally the same. The general conclusion is that the higher level of fire risk results in a greater financial advantage for clonal rubber in comparison to unselected rubber trees.

Fire risk and carbon sequestration

Perennial grasses, such as *Imperata*, have relatively low potential to sequester and store carbon. Furthermore, the lifecycle of *Imperata* plant parts is relatively short, thus carbon is stored for only a short period.

Trees, such as rubber can sequester and store carbon. Much of the carbon sequestered by rubber trees is stored in the form of wood or latex. Some carbon is retained in the wood or latex until well after tree harvest. The change in land use from *Imperata*

grassland to a rubber plantation significantly increases the volume of carbon stored and the length of time the carbon is stored (Tomich et al. 1997). Large-scale transformation of *Imperata* grassland to rubber, or other tree plantations, will have an impact on atmospheric carbon levels. The benefits of this are not captured in the private benefits obtained by smallholders from their rubber plantations.

The output of the BEAM rubber models provides information on annual wood growth and latex yields. Carbon sequestration for the six scenarios represented in Table 21.1 was calculated. Average annual rubber wood and latex production is given in Table 21.2. The carbon content of both rubber wood and latex are estimated to be 50% by weight, with the basic density of the wood being 0.5437 tonnes per cubic metre.

Table 21.2. Average annual wood and latex yield of clonal and unselected rubber trees at three levels of fire risk

	Clonal rubber trees		Unselected rubber trees	
	Wood volume (m^3/ha)	Latex yield (kg/ha)	Wood volume (m^3/ha)	Latex yield (kg/ha)
Zero fire risk	7.7	860	3.3	527
5% p.a. fire risk	7.6	847	3.1	493
10% p.a. fire risk	7.5	830	2.9	433

Source: BEAM rubber agroforestry model.

The marginal cost of carbon emissions is estimated to be between $US5 (or Rp 14500) and $US20 (Rp 58000)/t (Nordhaus 1993, quoted by Tomich et al. 1997). The value of the carbon sequestered is calculated using each of these two price levels, as well as an intermediate level of $US10 (Rp 29000)/t of carbon.

Carbon sequestered by rubber trees is not removed from the atmosphere indefinitely. The non-timber rubber wood (approximately 60% of the total) is assumed to be burnt in the year of cutting (year 30). Carbon in timber wood and latex is assumed to be released back into the atmosphere based on a half-life (after tree harvest) of 10 years. Although much of the carbon is returned to the atmosphere in the 40-year time horizon considered for this part of the analysis, discounting the value of the carbon stored still results in a substantial benefit from carbon sequestration.

Table 21.3 presents the financial profitability of the plantation, the imputed value of the carbon sequestered, and the net of private and social benefits of the plantation, for each of the three fire risk scenarios, at the 10% discount rate (a higher market-oriented discount was not considered in the carbon sequestration analysis).

Table 21.3. Private financial profitability (30-year time horizon), plus imputed value of carbon sequestration (40-year time horizon), per ha of clonal and unselected rubber trees at a 10% discount rate, 3 levels of fire risk

Discount rate 10%		Clonal rubber trees			Unselected rubber trees		
	Fire risk	Zero	5%	10%	Zero	5%	10%
		(Rp million)			(Rp million)		
Private financial profitability		3.66	3.62	3.56	1.68	1.60	1.38
Imputed value of carbon sequestered with C value at:							
$US5/t	Tree biomass	0.29	0.28	0.28	0.12	0.11	0.11
(Rp 14500)	Latex yield	0.06	0.06	0.06	0.04	0.04	0.03
	Total	0.35	0.35	0.34	0.16	0.15	0.14
$US10/t	Tree biomass	0.57	0.57	0.56	0.25	0.23	0.21
(Rp 29000)	Latex yield	0.13	0.12	0.12	0.08	0.07	0.06
	Total	0.70	0.69	0.68	0.32	0.30	0.28
$US20/t	Tree biomass	1.14	1.13	1.12	0.49	0.46	0.43
(Rp 58000)	Latex yield	0.25	0.25	0.24	0.15	0.14	0.13
	Total	1.40	1.38	1.36	0.64	0.60	0.55
Financial profitability plus imputed value of carbon sequestration with C value at:							
$US5/t		4.01	3.97	3.90	1.84	1.75	1.52
$US10/t		4.36	4.31	4.25	2.00	1.90	1.65
$US20/t		5.06	5.00	4.93	2.32	2.20	1.93

Exchange rate; Approximately Rp 2900 =$US1.00

The imputed value of the carbon sequestered is substantially higher in clonal rubber plantations than in plantations of unselected rubber trees. This is expected, given the higher levels of wood and latex production from clonal rubber trees. Most carbon is sequestered in wood, rather than latex. At an imputed value of carbon sequestered of $US5/t, clones provide an increase in net present value of carbon sequestered of Rp 0.19 million, Rp 0.20 million and Rp 0.20 million, for zero, 5% and 10% fire risk respectively. In percentage terms, the improvement in NPV for clones, in terms of carbon sequestration, are broadly comparable to the percentage improvement in terms of private financial profitability.

So when the private financial profitability plus the social benefits from using clones over unselected seedlings are added together (bottom section of Table 21.3), the total (private plus social) advantages of clones are enhanced. The improvement in NPV

when using clones, at each of the carbon sequestration values, is summarised in Table 21.4.

Table 21.4. The improvement in total (private plus social) NPV/ha, in changing from unselected trees to clonal trees, at four values of carbon and three levels of fire risk, 40-year time horizon

Value of carbon sequestered	Improvement in NPV (Rp millions)		
	Zero fire risk	5% p.a. fire risk	10% p.a. fire risk
Rp 0/t ($US 0/t)	1.95	2.02	2.19
Rp 14500/t ($US 5/t)	2.18	2.22	2.39
Rp 29000/t ($US 10/t)	2.36	2.41	2.59
Rp 58000/t ($US 20/t)	2.74	2.80	3.00

Note: The social benefits from reducing the risk of fire spread to neighbouring farms, as a result of planting clones, are not included in the calculations (see Chapter 20 for a discussion of this concept).

When only the private economic advantage is considered, there is a Rp 1.95 million improvement in NPV from using clones rather than unselected seedlings when there is no risk of fire. When the fire risk is 5%, the private economic advantage increases to Rp 2.02 million. The advantage associated with fire control by planting clones increases further when the fire risk increases, i.e. to Rp 2.19 million at a 10% fire risk. Consideration of the social benefits from carbon sequestration at the lowest imputed value, increases the advantage provided by clones to Rp 2.39 million.

Of course, higher monetary values per unit of carbon sequestration further increase the advantages of clones over unselected seedlings. At the highest value per tonne of carbon considered (US$20), carbon sequestration accounts for approximately 40% of the economic advantage provided by clonal rubber (compare top and bottom rows in Table 21.4)

CONCLUSION

The primary aim of this chapter was to compare the benefits obtainable from clonal and unselected rubber trees. However, there are other pertinent results worth highlighting again:

- Rubber growing appears profitable, even under low intensity smallholder management;
- An increase in fire risk reduces the expected economic payoff from rubber;
- Carbon sequestration benefits are significant vis-a-vis the private benefits obtained from latex and rubber wood.

A switch from planting unselected seedlings to planting clonal material provides substantial private benefits to individual smallholders. Some of these benefits are a result of improved fire control emanating from *Imperata* suppression. Clones also provide social benefits to neighbours by reducing fire spread (not addressed in this chapter) as well as to society as a whole through carbon sequestration.

Given the strong private benefits, there exists an economic incentive for smallholders to plant clonal trees. However, lack of information on the comparative advantages of clones, physical unavailability, and the cash constraints of smallholders have been cited as reasons for non-adoption (Barlow 1997). Given this lack of adoption, and the significant social benefits (fire control and carbon sequestration) that are derived if smallholders use clonal trees, there is a case for government intervention to encourage smallholders to plant clonal rubber trees. Governments in many countries with smallholder tree crops have set up extension and credit services to make information and new technologies available. Such services are not prominent in Indonesia (Barlow 1997).

The subsidisation, or provision, of rubber clonal planting material may be a win-win situation in terms of the reduction of atmospheric carbon, while also alleviating poverty and perhaps arresting soil erosion. If developing country governments are unwilling to pick up on these ideas, they may be attractive as development assistance from richer countries. The global benefits should be appealing.

Appendix
The SCUAF and BEAM Models

GENERAL DESCRIPTION OF THE SCUAF MODEL.

SCUAF (Soil Changes Under AgroForestry) is a computer model which predicts the effects upon soils of specific land-use systems under given environmental conditions. It is designed to include the distinctive features of agroforestry, that is, land-use systems which include both trees and crops. However, it can also be used to compare agroforestry systems with land use under agriculture or forestry.

SCUAF is a process-response model. The user specifies:

- the physical environment;
- the land-use system;
- the initial soil conditions;
- the initial rates of plant growth;
- the rates of operation of soil–plant processes;

The land-use system is based on two plant components, trees and crops. The primary basis for description of this system is the proportion of trees and crops in each successive year. Other elements of the land-use system are additions (organic additions, fertilizers), removals (harvest, losses), prunings (of the trees) and transfers (e.g. transfer of tree prunings to soil under crops). As well as the above-ground parts of the plants (leaf, fruit, wood), the effects of roots are modelled.

The model simulates, on an annual basis:

- changes in soil conditions;
- the effects of soil changes upon plant growth and harvest.

SCUAF is not a plant growth simulation model. The user enters the initial rates of plant growth (trees, crops, and their component parts) as biomass increases per year.

The model then estimates the effects of changes in soil properties upon subsequent rates of plant growth.

The soil conditions and processes covered are:

- soil erosion: its rate and effects;
- soil organic matter, represented as carbon;
- plant nutrients: nitrogen and phosphorus;
- tree/crop competition for nutrients.

Besides conventional crop harvest, the harvest may include crop residues, and harvests of fruit, fodder, or wood, from trees.

The values employed in the model, parameters and variables, are accessible to the user. There is a set of default values, varying according to the physical environment: climate, soil, slope, etc. This set provides reasonable estimates for variables whose values are unknown for a particular site.

SCUAF is primarily intended for simulation over periods of the order of 20 years.

The major advantage of SCUAF is its ease of operation. To anyone familiar with basic soil–plant relationships, including nutrient cycling, the processes involved are largely self-explanatory from their descriptions in the inputs section. It is, however, less complex in its simulation of processes than some comparable models.

SCUAF AS THE BASIS FOR ECONOMIC ANALYSIS

Whilst it does not directly include an economic component, SCUAF can be employed to provide input and output values for economic analysis. For example, by showing the trends in soil fertility and their consequences for plant growth over periods of the order of 20 years, it provides a basis for analysis of the economic aspects of sustainable land-use systems.

The types of data directly relevant to economic analysis are, for each year of the land-use system:

Economic inputs:

- land areas under trees and crops, as a basis for assessing inputs of seed, labour, etc.;
- fertilizer inputs;
- pruning practices, as a basis for their labour requirements.

Economic outputs:

- harvest, from trees and crops, including crop yield, fodder, fruit, and timber or fuelwood;
- soil properties at the end of the model run, as a basis for assessing change in the capital value of land.

SCUAF can be applied to the economic analysis of soil conservation measures, showing:

- consequences of land-use systems without conservation (other than that which is intrinsic to the system);
- effects, on the soil and thereby on plant growth, of reducing rates of erosion by adding conservation works.

Bioeconomic modelling

Data from research trials provide the basis for calibration of SCUAF to local conditions. The SCUAF model then simulates two sets of outputs: changes, over time, in soil properties (including erosion and fertility) and in plant growth (trees and crops). The trends in soil properties form a basis for assessment of environmental costs or benefits.

Parallel with the above, farm surveys provide the costs of inputs and the prices of outputs. These are linked with the land-use systems represented in the model, which may include both actual land use and proposed improvements. The resulting data can be input to an economic model to give net present value or other measures of economic success.

AGROFORESTRY-SPECIFIC FEATURES

A number of SCUAF elements are designed to permit modelling of agroforestry systems. These all stem from the presence of trees and crops on the same land management unit, in a spatial arrangement or a rotation. In modelling agriculture or forestry, with 100% crops or trees, these elements become non-functional.

The agroforestry-specific features are:

- input of the relative areas under trees and under crops;
- separate modelling of soil changes for soil-under-trees and soil-under-crops;
- an adjustment to the rate of erosion to take account of the specific effects of trees, the tree proportionality factor;

- an input which permits above-ground biomass transfer from the trees to the soil under crops — litter by wind, prunings by human agency;
- an input which permits a proportion of the roots of trees to grow into the soil under crops, and abstract nutrients from it;
- provision for additions (manure, fertilizer) to be applied differentially to soil under trees and under crops (normally, all will be given to the crops);
- the existence of a cutyear, in which the trees are felled or coppiced, etc., and there is an additional harvest.

THE SYSTEM OF DEFAULT VALUES

The construction of SCUAF was based upon a wide range of studies of soil carbon dynamics and nutrient cycling; some of the sources used are listed in the References to Version 2. Default values for variables were obtained on the following basis:

1. Three studies of natural ecosystems were taken, in the forest, savannah and semi-arid zones, and the model adjusted until trees-only gave a steady state soil.
2. A range of published experimental studies of agroforestry systems were taken, including rotational systems such as shifting cultivation, spatial zoned systems such as hedgerow intercropping, and spatial mixed systems such as perennial crops with shade trees. The model was checked to ensure that the observed results could be simulated, with or without adjustments to the values for processes.
3. Hypothetical situations were taken and the model checked to confirm that, on changing the value of a variable (e.g. rate of plant growth, root fraction), the results for soil changes were in the direction expected.

All variables in SCUAF are given default values. These are set by the environmental conditions: climate, soil and slope. Examples are:

- the default rates of leaching are higher for humid climates than for dry, and higher for sandy soils than clayey;
- the slope factor for erosion varies with slope class, and becomes zero if the slope class is 'flat';
- phosphorus immobilisation onto clay minerals becomes higher in strongly acid soils.

The default values are intended to prevent malfunctioning of the model through missing values, and to fill in missing values where field observations have not been taken.

MODEL VALIDATION

Two previous applications of SCUAF give confidence in the model. Vermeulen et al. (1993) used SCUAF to simulate soil nutrient dynamics and plant productivity for the Miombo woodlands and adjacent maize crops in Zimbabwe. Over the fifteen-year period considered in their analysis, Vermeulen et al. (1993), judged SCUAF that provided reasonable predictions for maize and tree growth.

In the second case, Nelson et al. (1996) compared the results from calibrated runs of SCUAF with another more detailed model, APSIM. APSIM is a complex dynamic process model, that simulates the physical processes involved in a cropping system, considering fluctuations in crop yields due to seasonal weather. Nelson et al. (1996) found that SCUAF predicted similar trends in maize yields to APSIM in the medium term, but is unable to capture the seasonal variation due to climate (Figure A.1).

The utility of modelling stems from simplification that enables the essential features of a system to be studied. There is a trade-off between the precision with which biophysical processes can be represented mathematically and the complexity of building and using models. One of the most attractive features of SCUAF is the ease with which it can be applied. SCUAF avoids the demanding data requirements that can make complex process models difficult to apply. However, some degree of physical realism is lost.

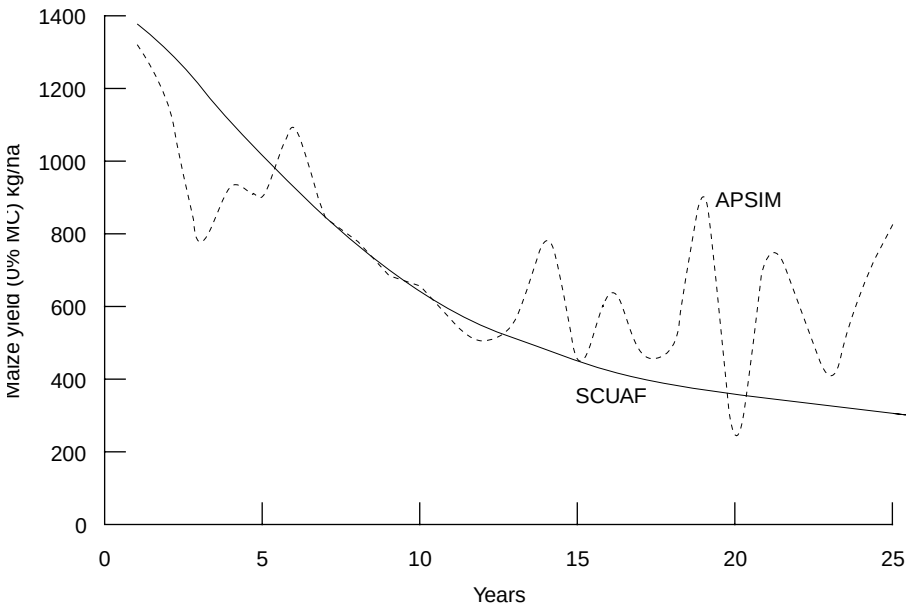

Figure A.1. A comparison of wet season maize yields for continuous open-field farming predicted using the APSIM and SCUAF models

DIFFERENCES BETWEEN SCUAF VERSION 2 AND VERSION 4

In addition to the features of Version 2, Version 4 covers:

- phosphorus cycling;
- consequences for plant growth of changes in the levels of soil nitrogen and phosphorus, modelled on the basis of nutrient requirements, availability, deficiencies, and the limiting nutrient.

Other improvements in Version 4 as compared with Version 2 are:

Inputs

- provision for transfers of litter or prunings from trees to soil under crops;
- provision for the growth of tree roots into soil under crops;
- a more flexible method for specification of land-use systems, allowing for combinations of rotational and spatial agroforestry systems;
- provision to select two crops, or two trees, with different rates of growth;
- the addition of a temperate climate;
- provision to select three initial levels of soil organic matter, corresponding to soils in relatively good, intermediate, and poor condition;
- the default values for the slope and crop cover factors of erosion have been substantially reduced, on the grounds that values taken directly from the Universal Soil Loss Equation give unrealistically high rates of erosion for tropical conditions on moderate to steep slopes.

Additional Outputs

- differential changes in soil under trees and under crops;
- nutrient requirements, availability, deficiencies, and recycling percentages;
- graphical outputs of flows of carbon, nitrogen and phosphorus within the plant–soil system, and for the external balance of the system.

Two features found in Version 2 have been omitted from Version 4. These are:

- the optional consideration of the effects of rainfall variability (based on the decision that it was not practicable to include a water module);
- the facility for automatic generation of line graphs of soil changes over time (consequent to the large numbers of graphics packages and software platforms, e.g. versions of Windows, that are now available).

AVAILABILITY OF THE MODEL

Computer discs, as well as detailed model descriptions and instructions are available from:

ACIAR
GPO BOX 1571
Canberra ACT 2601
Australia

or the computer program and associated documentation can be downloaded directly from the *Imperata* Home Page at:

http://cres.anu.edu.au/imperata/imperat1.htm

General description of the BEAM rubber model

The BEAM models, RRYIELD and RRECON, are two of a series of bioeconomic models developed by the Bio-Economic Agroforestry Modelling (BEAM) project, which is based at the School of Agriculture at the University of Wales. The RRYIELD model deals with the biophysical components of a rubber-based agroforestry system. It focuses on the changes in output (latex, wood and intercropped annual and perennial crops) to a number of bioclimatic, topographic and silvicultural variables (Thomas et al. 1993). Outputs are measured annually over the life of the plantation. The RRYIELD model is linked to an economic model RRECON (Willis et al. 1993), which is used to determine the economic returns from a rubber plantation. The two models are designed to be used together as an extension and research tool to supply farmers or researchers with information on the viability of alternative rubber intercropping systems.

The two models were originally developed for large estates and government plantations. Thus the models represented a situation of a high level of management including weed control, fertilizer and the use of clonal planting material. Tree growth (thus wood production) and latex yield are determined as a function of site and climatic variables (measured by the site index), age of the tree, and planting density. The understorey crop is restricted to upland rice, which is commonly used as an intercrop in most areas of Southeast Asia. Interactions between the tree and the understorey crop are represented in terms of the above-ground competition for light, i.e. rice production is inversely related to the canopy density. However, there is not a reciprocal restriction on tree growth due to competition with rice for soil moisture and soil nutrients.

Subsequent modifications to the model by the current authors were aimed specifically at making it relevant to Indonesian smallholder plantations. These modifications included a level of weed competition, an option to control weeds and to use fertilizer, an option to use either wildlings (unselected planting material) or clones, and the introduction of fire risk. For details on the basic set up of the model and background to both the original and modified RRYIELD and RRECON models, Thomas et al. (1993) and Grist et al. (1998) could be consulted.

The following briefly details some of the main features of the BEAM model.

TREE GIRTH

The girth function is the building block for many of the other functions in the model; equations for height, canopy width, wood volumes, etc., all include girth as a variable. The modified version of the model also calculates latex yield as a function of girth. In the original BEAM model, girth is a function of tree age, density and site index. Tree age and density provide the general shape of the function, while the site index shifts the function vertically though space (Thomas et al. 1993).

The girth function is compatible with graphs of the girth increment produced by DeJonge (1961) and Westgrath and Buttery (1965). The equation in the original BEAM model was unsuitable when factors that shift the equation vary on a short-term (e.g. annual) basis. The modifications to the model included changing the girth function to calculate annual girth increment. The girth equation was then modified further to allow for a reduction in girth increment due to early tapping or due to competition from ground cover.

A clonal index is included as part of the rubber tree girth increment function. This index allows the effect of improved planting material to be manifest in tree girth. Another addition was a fertilizer effect, which provides the option for potential improvements in tree growth with fertilizers.

LATEX YIELD

The BEAM model calculates a 'natural' decline in latex yield after the ninth year of tapping. The general shape of the decline function is close to that provided by Gouyon (1992). Research by Gouyon (1992) indicates that the latex yield will rise over the first few years after tapping begins, then reach a plateau, before it begins to decline. The BEAM model specifies the length of this plateau as approximately five years.

THE EFFECT OF FIRE

In smallholder rubber plantations, *Imperata cylindrica* is a major weed. *Imperata* also creates a high level of fire risk.

Fire risk is especially important for perennial crops, such as rubber. The high initial cost and the long-term exposure to the fire risk for a single tree crop, adds further weight to the importance of considering fire when establishing rubber plantations.

In adjusting the BEAM RRYIELD model to include the effects of fire, two main assumptions were made: that the risk of fire reaching a plantation is dependent on the density of the *Imperata* present in surrounding plantations; and, that the effect of fire within the plantation will be in terms of a reduction in the proportion of stems present on a site, this reduction being calculated according to the amount of *Imperata* present.

The effect of fire is calculated on a straight line basis, averaging the effect of fire over the life of the plantation, rather than providing a random event plantation destruction.

In the original BEAM model, the stand density was calculated only once, at the beginning of the model, and was held constant every year the model is run. The introduction of fire makes the stand density calculation more dynamic. The stand density per hectare is reduced annually, as a result of fire.

SITE INDEX

The site index factor captures the variability in site conditions in terms of the soil quality and climate. It is used in many of the calculations in the model, including tree girth, latex yield and ground cover (rice and *Imperata*) productivity / density. In the original BEAM model the site index is a multiplicative function of fourteen climatic and soil variables. The climatic variables considered are: rainfall, dry season period, water deficit, tapping days lost, vapour pressure deficit, temperature and windspeed. The soil variables considered are: slope drainage, duration of flooding, texture, soil depth, organic matter, CEC and base saturation. Each of these variables is assigned a value between 0 and 1, relative to the optimal condition for the variable. The variables are then multiplied to provide the site index.

This was seen to be a relatively weak procedure as the product of 14 fractions is invariably a very small number. Thus, it is likely that this calculation will not be representative of the true site index.

In the more recently modified version of the BEAM model, the site index was replaced with a new site index that is more representative of rubber growing areas of

Indonesia. Three climatic factors (i.e. rainfall, air temperature and light intensity) are used to create moisture, thermal and light indices. These indices are then combined to form an overall climatic index, similar to the GROWEST approach developed by Fitzpatrick and Nix (1970), and tailored specifically to rubber in Indonesia. Each of the three indices ranges from 0 to 1, where an index of 1 means that there is no constraint to growth. The indices are then multiplied to form the climatic index. This will again be between 0 to 1.

The soil index in the modified version of the model is based on the soil index derived by Sugianto (1987). It utilises seven soil parameters (soil depth, slope, texture, drainage, percentage of rock, soil nutrient levels and pH), and rates them as good, moderate or bad. Each rating (good, moderate and bad) is then assigned a value which is weighted so that, when added, the values provide a soil index between 0 and 100.

The soil index is then multiplied by the climate index to provide the site index. The site index is calculated as a number between 0 and 100.

Despite these improvements, use of the site index remains problematical. Further research is needed to improve the site index. Meanwhile, the site index override function can be used to calibrate the model to prevailing yield and growth conditions.

RRECON

The RRECON model is a simple cost-benefit analysis of the rubber plantation. Productivity factors of rice yield, wood volume and latex yield are linked between the RRYIELD and RRECON models. The productivity factors are then multiplied by the factor prices, which the user adds to the model, to determine revenue. Labour requirements, labour costs and factor costs for establishment, maintenance, tapping and harvesting of the rice crop and rubber plantation, are used by the model to determine annual costs. Again these requirements and costs are input to the model by the user, and are specific to the region being observed by the model. From the costs and returns, the net present value of the system is determined, using the appropriate discount rate (input by user).

The modified version of RRECON incorporates factors related to the changes made to the RRYIELD model. The inclusion of fire risk in RRYIELD, as detailed above, reduces the number of trees (stand density) over time, which will affect tapping costs and wood harvesting costs. Thus, the modified version of BEAM, links stand density between the two models.

AVAILABILITY OF THE MODEL

Computer discs, as well as more detailed model descriptions and instructions are available from:

ACIAR GPO BOX 1571 Canberra ACT 2601 Australia	*OR*: BEAM Project School of Agricultural and Forest Sciences University of Wales Bangor, Wales LL57 2UW U.K.

or the computer program and associated documentation can be downloaded directly from the *Imperata* Home Page at:

http://cres.anu.edu.au/imperata/imperat1.htm

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