Sustainability of Upland Agriculture in the Philippines: Evaluating the Potential of a Tree Fallow System

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Declaration

I, Peter Gerard Grist, hereby declare that this thesis is the result of my own independent research and that all references and sources that have been used are duly acknowledged.

Peter Gerard Grist

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Abstract

Smallholder farmers in the uplands of Southeast Asia practice a form of short fallow shifting cultivation that has been shown to be unsustainable in the long term. This study examines the potential of an improved fallow system that can improve soil fertility, crop yield and the farmer's economic situation. The improved fallow system involves the establishment of a nitrogen fixing multipurpose tree plantation during a short fallow period. The tree foliage is used as green manure, maintaining soil fertility and providing improved crop yields.

A bioeconomic model is used to compare the improved fallow system with a traditional short fallow shifting cultivation system. The model is a combination of cost benefit analysis and the SCUAF model (Soil Changes Under Agriculture, Agroforestry and Forestry). Cost benefit analysis is used to identify the most economically efficient system. The SCUAF model is integrated within the cost benefit analysis framework, and is used to observe changes in crop productivity over time. It is a relatively simple deterministic model designed to predict the effect of various tree and crop combinations on soils and commodity outputs.

From a biophysical perspective, soil nutrient levels (Carbon, Nitrogen and Phosphorus) improved by up to 80 per cent, soil erosion decreased and crop yield was found to be sustainable, under the *Gliricidia* fallow system. In comparison, soil nutrients fell to approximately 30 per cent their initial levels, soil erosion increased and crop yield declined, under an *Imperata* fallow system.

Economically, from both social and private perspectives, the *Gliricidia* fallow system was shown to be quite profitable when a market for firewood is available, but showed a small loss based on revenue from maize only. The *Imperata* fallow system, in comparison, was only marginally profitable from a private perspective, and quite unprofitable from a social perspective.

In the transition between an *Imperata* fallow and a *Gliricidia* fallow system, it takes four years for crop yields to rise from the low levels obtained from an *Imperata* fallow system to the higher levels obtained from a *Gliricidia* fallow system. Economically, the system incurs a loss in the first two years of the transition period, and it is not until after the sixth year that these initial losses are recovered. Thus, unless farmers are able to absorb these initial losses, they will be unlikely to adopt the *Gliricidia* fallow system, even though it is more profitable over the long term.

Introducing cattle in the *Gliricidia* fallow system, while involving a trade-off between the use of *Gliricidia* for cattle fodder and for green manure, can significantly improve the profitability of the system. A system with two cows, two *Imperata* fallow plots, three *Gliricidia* fallow plots and one maize crop plot, will maximise both economic and environmental benefits. This provides a sustainable maize crop and a high return to farmers from cattle, maize and firewood.

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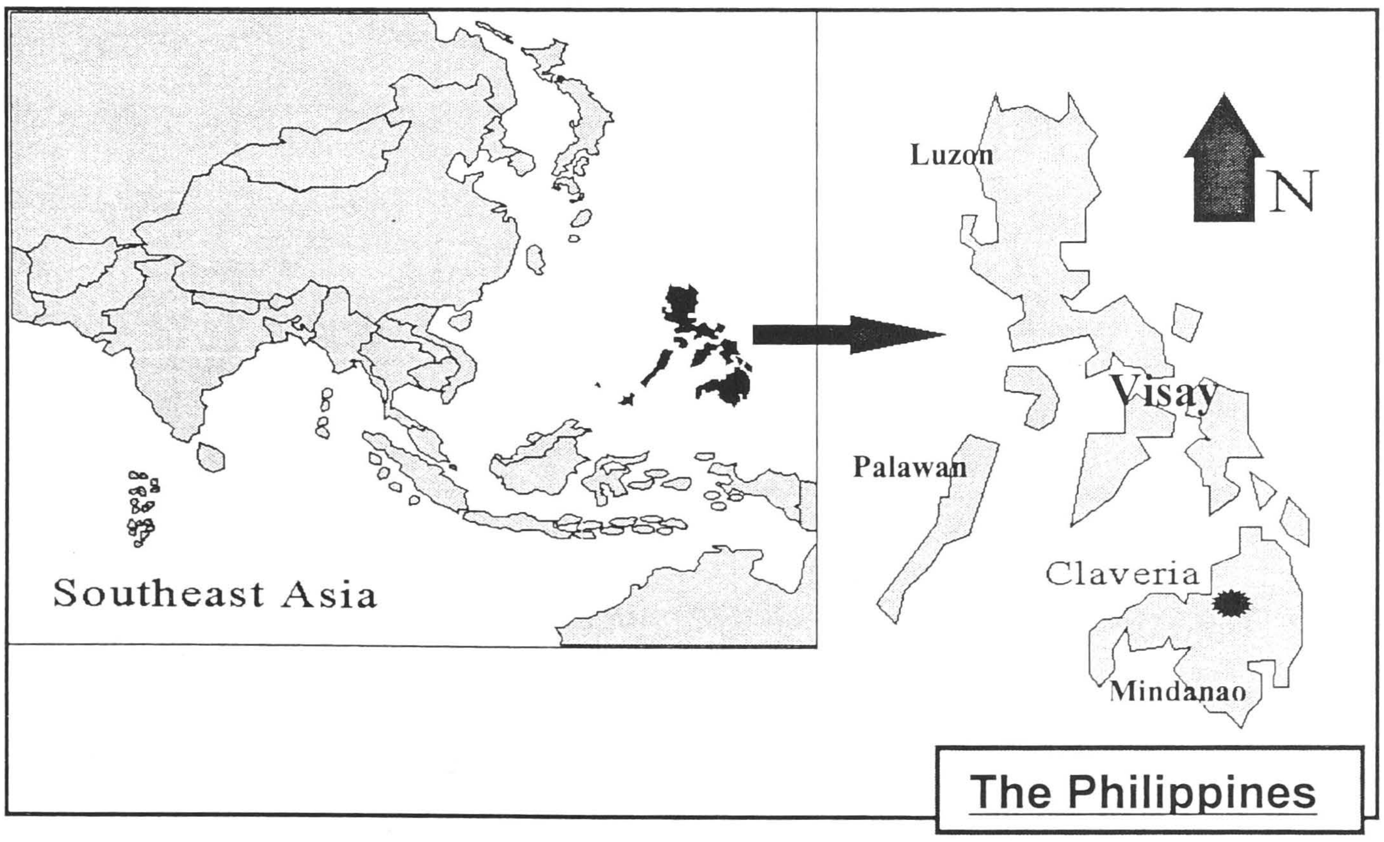
Chapter 1. Introduction

1.1 Background

This study is concerned with the bioeconomics of smallholder farming in the uplands of Southeast Asia, and in particular the Philippines. Typically, the uplands are weed infested and the productivity of the land is declining. Farmers in this region traditionally practice a form of short-fallow shifting cultivation. An alternative fallow system, which could potentially improve the fertility of the soil, increase crop yield and improve the farmer's economic situation, is evaluated in this study.

The farmers considered in this study are located in Claveria in the northeast of the Island of Mindanao. Mindanao is the second largest of the 7,107 islands that make up the archipelago of the Philippines (Figure 1.1). The society is patrilocal in residence, with males remaining in the village and females leaving the village to marry men in nearby villages. Most of the males in the village are related, being either brothers, first or second cousins. A patrilineal inheritance is prevalent in land ownership. When the sons reach marrying age, the father typically divides the land between his sons, thus maintaining familial association with the land.

Figure 1.1 **Geographic location of Claveria, Mindanao, Philippines.**



A typical farming family in this region has five children. The family maintains a near subsistence existence. The main crop is maize, which is grown to obtain cash in the local markets. Maize is cultivated with minimum inputs in a shifting cultivation system. Seed is purchased from local sellers, while the only other input in the cropping system is the labour of the farmer and his family. Typically, a family cultivates a small parcel of approximately two hectares. The land is typically divided into six parcels or plots, that are cropped on a six year rotation. The average area cropped in each year is approximately one third of a hectare. Plots not under cultivation are left fallow to maintain soil fertility for cropping in the future.

The low fertility of the soil allows only one crop to be planted each year. This crop is planted in the wet season between April and June and harvested between October and December. Before the maize crop can be planted, a dense mass of *Imperata*, which invades during the fallow period, must be cleared. The presence of stored seed and rhizomes in the soil require regular weeding during the cropping period. Harvesting the maize cobs is labour-intensive, requiring the labour of all available family members to recover the crop. The crop, sold in the local markets or to the local agent, is the chief source of cash income for food, education for the children and farming implements. Following the harvest, the plot is simply abandoned, with the subsequent year's crop planted on the next plot in the cycle, a plot that had been left fallow for several years. The abandoned plot is soon invaded by grasses, especially *Imperata cylindrica.* The *Imperata* grass stabilises the soil, which is prone to erosion, but provides hardly any other benefits.

A small garden plot is maintained near the farmer's house, in which vegetables for household consumption are grown. The home garden is typically maintained by the farmer's wife. A few chickens are kept, also for household consumption.

Some relatively rich farmers in the region own cattle, typically a cow and graze on their fallow plots. Cattle are a form of savings and are sold when the farmer is in need of money for major expenses, such as the children's education or at times of illness or death in the family.

1.2 Shifting Cultivation

Shifting cultivation, or slash and burn farming, is one of the most basic forms of agriculture. Although of primitive origin, shifting cultivation is still practiced in parts of Africa and South America, and is common in many upland areas of Southeast Asia. It is estimated that shifting cultivation provides a subsistence existence to almost 300 million of the world's poorest people, 50 million of which are in Southeast Asia (Nye and Greenland, 1960).

Traditional shifting cultivation practices involve the clearing of virgin or secondary forest to establish a crop. The forest or secondary re-growth vegetation is slashed and burnt. Forest cover provides an organic topsoil and the use of fire in clearing releases nutrients from the above ground biomass, some of which are incorporated into the soil (Nye and Greenland, 1960). This provides, for a short time, a relatively fertile seed bed for the establishment of crops. After one or two crops much of the organic matter and nutrients released by the burning of the forest residues are depleted and weeds become a problem. In the traditional shifting cultivation system, the land is then abandoned and left to recover over a period of fallow (Vasey, 1979). Smallholders move to a neighbouring area of virgin forest, secondary forest or grassland, to continue cropping.

In the revegetation sequence, grasses such as *Imperata cylindrica* initially take over and dominate the abandoned site. If left undisturbed by fire for a reasonable length of time, trees and shrubs establish on the site. Eventually, the trees and shrubs will form a secondary forest cover that suppresses the grasses. Over time, the soil recovers its fertility and the organic matter in the topsoil is restored through litter fall and decay. After the secondary forest has re-established and the soil has renewed its fertility, cropping is undertaken and another cycle begins.

This form of slash and burn agriculture is sustainable only with long fallow period. However, increased population growth in upland areas of Southeast Asia is placing heavy pressure on the availability of land. The land area available to individual upland farmers is shrinking, causing more forest to be cleared for agriculture and a shortening of the fallow period (Garrity, 1993; Brady, 1996; Conelly, 1992). The shortening of the fallow period results in increased weed competition, reduced soil fertility and increased soil erosion. This has a compounding effect, with reduced yields and economic returns causing smallholders to further intensify their practices (Boserup, 1965). With the short fallow lengths prevailing in most parts of the uplands today, slash and burn agriculture cannot be sustained, either economically or biologically. Such considerations are leading policy makers and research organisations to encourage upland smallholders to adopt alternative forms of agriculture that are more sustainable.

1.3 The Improved Fallow System

There has been significant research undertaken on improved farming systems, such as hedgerow intercropping, in upland areas of Southeast Asia. However, the long term financial viability of such systems, which require a significant amount of capital and labour for establishment, above smallholders current means, is questionable.

Other research has considered subsidisation of inputs, such as fertiliser and capital investments, to encourage smallholders to adopt technological improvements (Huszar and Cochrane, 1990; Huszar et al., 1993). However, these usually provide only a short term promotion of the new technology. Farmers often revert to previous techniques after the subsidies cease (Huszar et al., 1993). Price subsidies can also create incentives for excessive and ecologically destructive conversion of land from practices using unsubsidised goods to practices using subsidised goods (Templeton and Scherr 1996).

It may be argued that improved farming systems that require a significant change from traditional farming systems are inappropriate for subsistence farmers. To be adopted by poor upland farmers the system should demand only an increase in labour, with little capital input. They must be able to limit erosion and soil degradation, maintain soil fertility and sustain relatively high crop yields. The improved fallow considered in this study seems to have these characteristics.

The improved fallow system involves the establishment of a nitrogen fixing multi-purpose tree plantation during a short fallow period, of up to five years, between the cropping periods. The tree foliage is used as green manure, a form of organic fertiliser. This is a form of biological technology aimed at maintaining fertility and providing improved crop yields.

While leguminous plants are widespread, a leguminous tree plantation fallow is not commonly practiced by smallholders in Southeast Asia, therefore farm level data is not available. Information on the tree component is derived from experimental results of density and growth trials of *Gliricidia sepium* conducted mostly outside of Asia. This information is supplemented with data extrapolated from hedgerow farming systems currently being practiced in Southeast Asia. The improved fallow system analysed here could be regarded as a variant of the hedgerow system. The improved fallow system separates the tree and crop components in time, avoiding the direct competitive effects between the two, for soil nutrient, soil water and light. It also avoids the need for precise management of the tree, with its attendant high labour costs.

1.4 Context of Technological Development

The improved fallow is examined here using a modelling approach. The modelling is intended to provide a preliminary analysis of the potential of the system in terms of biophysical and economic benefits for upland farmers. It will be compared with an *Imperata* fallow system, a short fallow shifting cultivation system, that is used as a baseline for comparison.

The improved fallow system described here is an adaptation of the improved fallows discussed by Garrity (1993) and MacDickens (1990). This study of the improved fallow system should be considered within the framework of dynamic technology development and design, outlined in Anderson and Hardaker (1979) and Menz and Knipscher (1980). Three stages were identified to describe the process of technology development, namely, notional, preliminary and developed. Notional new technologies range from intuition to preliminary analysis, with analytical appraisal limited to models rather than real systems. Preliminary new technologies are unrefined research with neither testing nor evaluation adequately completed. Developed new technologies are those that have survived careful and thorough evaluation and are awaiting communication to, and adoption by, farmers (Anderson and Hardaker, 1979). The improved fallow system could be considered to be at the first, or 'notional', stage of technology design. There has been minimal testing and evaluation of this technology. Extensive and expensive field experiments cannot be justified until a more formal evaluation of the technology is undertaken.

This study may be regarded as moving the technology design and evaluation from the notional to a preliminary stage (Menz and Knipscher, 1980). If the analysis shows that an improved fallow is capable of providing environmental and economic improvements, then a more vigorous program of scientific research is warranted. The results of this analysis will provide a better indication of the potential of the improved fallow system than has been available to date.

1.5 Thesis Outline

The purpose of this study is to evaluate within a modelling and simulation framework, the potential of an improved fallow system from both biophysical and economic perspectives. The improved fallow system involves a nitrogen fixing, multi-purpose tree plantation (*Gliricidia sepium*) as the fallow crop. Hereafter, the system will be called a *Gliricidia* fallow system. Nitrogen fixing trees have been shown to improve soil fertility in relatively infertile soils (Panjaitan et al., 1993). They also have the potential to reduce soil erosion and to provide an alternative source of income through fuelwood and animal fodder (Jabbar et al., 1996; and Larbi et al., 1993).

A review of current literature, highlighting the situation facing upland farmers in Southeast Asia, is carried out in Chapter 2. This focuses on the high population growth occurring in many areas and its subsequent contribution to high levels of land degradation. The effect of land degradation on both environmental and economic sustainability is explored from both private and social perspectives. Attention then turns to hedgerow intercropping systems, which were developed to address this problem. The advantages and disadvantages of hedgerow intercropping systems are discussed. This is the base from which the *Gliricidia* fallow system is developed.

The biophysical characteristics of both *Imperata* and *Gliricidia* are examined in Chapter 3. These are considered in terms of their use in the *Imperata* fallow system and the *Gliricidia* fallow system. *Imperata* is not cultured or managed, thus only the biological features of *Imperata* and means of *Imperata* control are discussed. *Gliricidia* is cultured and managed, thus this section will consider its establishment from cuttings, density for weed control, nutrient recycling and use as animal fodder.

A bioeconomic model is developed to analyse the proposed new system, a *Gliricidia* fallow system. The framework of the model, which uses a detailed biophysical model in combination with cost benefit analysis, is outlined in Chapter 4. A cost benefit analysis approach is central to this study. The economic data, such as labour requirements, input costs and output prices, are obtained from field surveys (Nelson et al., 1996b). Tree and crop productivities are derived using an existing biophysical model known as SCUAF (Soil Changes Under Agroforestry [Young et al., 1998]). As the SCUAF model also provides information on soil fertility and soil erosion, it is also used for the biophysical analysis of the system.

The analysis per se begins in Chapter 5 with a comparison of the biophysical characteristics of the *Imperata* fallow system and the *Gliricidia* fallow system. Soil erosion and the recovery of soil nutrients within the system form the main focus of this analysis. The economic features of the systems are then compared in Chapter 6.

They are considered from two perspectives, that of the farmer and that of society. A farmer takes into consideration only factors that impact upon him directly, such as the prices he pays for goods on the one hand and the prices he receives for his goods on the other. However, the social welfare can be affected by external factors such as market distortions and pollution, the cost of which are not borne directly by the farmer. The farmer's view-point is referred to as the private perspective, while the social welfare view is referred to as the social perspective.

The analyses in chapters 5 and 6 consider the systems over the long term. Chapter 7 considers short term impacts, observing the transition period between an *Imperata* fallow system and the *Gliricidia* fallow system. The transition period is the key to adoption, as farmers currently practicing shifting cultivation are subsistence farmers, and thus have very little capital or access to loans. They cannot afford a high initial start up cost or bear any loss of income with the adoption of a new system.

The scope of the *Gliricidia* fallow system is expanded in Chapter 8 to include beef cattle. Cattle feed can be supplemented with *Gliricidia* foliage to improve meat productivity. However, a substantial portion of cattle feed is grass, so not all fallow plots can be converted to *Gliricidia* fallow. Some plots must remain *Imperata* fallow to allow grazing. *Gliricidia* foliage has two competing alternative uses, as fodder and as soil mulch. This analysis focuses mainly on the trade-off between the two uses of *Gliricidia* foliage. It includes an estimate of the optimum number of animals that can be included in the system, from both an economic and a biophysical perspective.

The final chapter summarises the results of this analysis and considers options for further research.

Chapter 2. A Review of the Literature

2.1 Introduction.

Land degradation is a major problem in many parts of the humid tropics. Nowhere is this more evident than in the uplands of Southeast Asia, the focus of this study. Shifting cultivation is still the main agricultural practice in most upland areas, but in many cases it is no longer the most appropriate practice. Increasing populations and decreasing availability of land for individual farmers has led to an increase in the intensity of agriculture in upland areas. This, in turn, has contributed to an increasing rate of land degradation. Farmers are adopting shorter fallows to provide subsistence food requirements for their families on the shrinking land area available to them. The shorter fallows reduce the recovery time of the land and increase the frequency of periods where there is minimal protection of the soil through vegetative cover. Increasing crop intensity is also increasing the amount of soil nutrients removed from the site via the consumption of crop fruits, etc. On the steep slopes, which are the main feature of upland areas, the shorter fallows eventually lead to an acceleration of land degradation. This can be observed via high rates of soil erosion, shallow soils, and falling productivity due to falling soil nutrients levels.

The cause of land degradation in upland areas of Southeast Asia was described by Blaikie and Brookfield (1987) as a social problem. The physical aspects of land degradation, such as leaching of soil nutrients and soil erosion, occur naturally and are part of the process of soil formation. It is only when soil erosion and nutrient leaching occur on a large and accelerated scale that it is defined as land degradation. It is the human influence that accelerates erosion processes and magnifies the scale of the area influenced by these effects. This human influence defines land degradation as a social problem. To understand the physical aspects of land degradation, in an effort to consider potential remedial action, it is also important to identify the socioeconomic factors leading to the land use.

This chapter initially focuses on socioeconomic factors driving the misuse of land, such as population growth and poverty. Particular attention is given to population growth and economic theories related to it. The biophysical factors of land degradation, are then considered. This discussion centres mainly around soil erosion, but some consideration is given to other forms of land degradation. Soil conservation, in both physical and economic terms, is then discussed as a means of maintaining the productivity of this land. The introduction of hedgerow inter-cropping in the Philippines, is examined as an example of a soil conservation technique applied to upland farming in Southeast Asia. The final section of this chapter focuses on the potential of an alternative system, an improved fallow system, and features of it, which are likely to lead to successful adoption.

2.2 Population Growth

Much of the land degradation occurring in upland areas of Southeast Asia is the result of intensification of agriculture associated with population growth. Increasing populations are leading to less land and capital available to individual farmers, thus increased poverty of the individual farmer (Boserup, 1965). As populations increase, lowland farmers are migrating into the more marginal upland areas. This is further compounding the steady increase in the numbers of the upland populations. More productive areas are also being divided into smaller and smaller parcels, as the farmer passes the land down to the next generation. With decreasing land availability, the use of more marginal land and more intense farming systems, smallholders need to work more in order to obtain the same amount of food per family as before. The decreasing productivity of the land which is reducing the socioeconomic status of the farmer, acts as a deterrent to the introduction of less degrading, but more labour and / or capital demanding systems of agriculture. As long as smallholders can gain yields sufficient to feed their family in the following year, they will continue using their existing farming practices. This is done regardless of the long term degrading impact on the land.

Many areas of the developing world suffer under the strain of growing populations, with the outward signs in the environment, such as land degradation, political and economic peripheralization, stagnant production, outmigration and poverty, common in many upland areas (Blaikie and Brookfield, 1987). The future of upland agriculture and the people of these areas are being questioned, as populations expand and land degradation becomes more severe.

2.2.1 Malthus's Theory of Population Growth

Early theories of population growth suggest a boom and bust situation. Malthus (1798) (in Boserup, 1965) proposed that increases in population to a level beyond the current carrying capacity of land, leads to an elimination of the surplus population. This occurs either through direct starvation or by other positive checks, such as disease, which can be traced back to insufficiency of food supplies as the basic cause. Malthus's theory can be interpreted as a prediction that as the population grows and land use intensifies (the fallow length shortens), land will become more and more degraded. This will lead to declines in crop yields such that smallholders would no longer be able to maintain their subsistence existence. Starvation, disease, infertility and infant mortality would occur such that the population would decline back to a level that can be sustained by the land.

This theory was later revised (Neo-Malthusian theory), to a prediction that increases in population eventually lead to the destruction of the land followed by migration. In order to avoid starvation, people move to land in neighbouring areas. These neighbouring lands are, in time, also destroyed, and followed by further migration (Boserup, 1965). This practice has been common in the past, given sparse populations, and what seemed to be an infinite land resource. However, this situation is changing. Population densities have increased to high levels across much of Southeast Asia. Land has become increasingly scarce and the ability to migrate to new undisturbed areas is limited. Farmers are becoming more sedentary, restricted to a small, fixed area of land. As land is handed down from generation to generation it is divided into smaller and smaller lots. Increased poverty, as a result of less land and capital available to the individual farmer, has reduced the options available to the farmers. Farming practices are not changing in response to these changing conditions, and as a result the food production potential of the land, is gradually reduced.

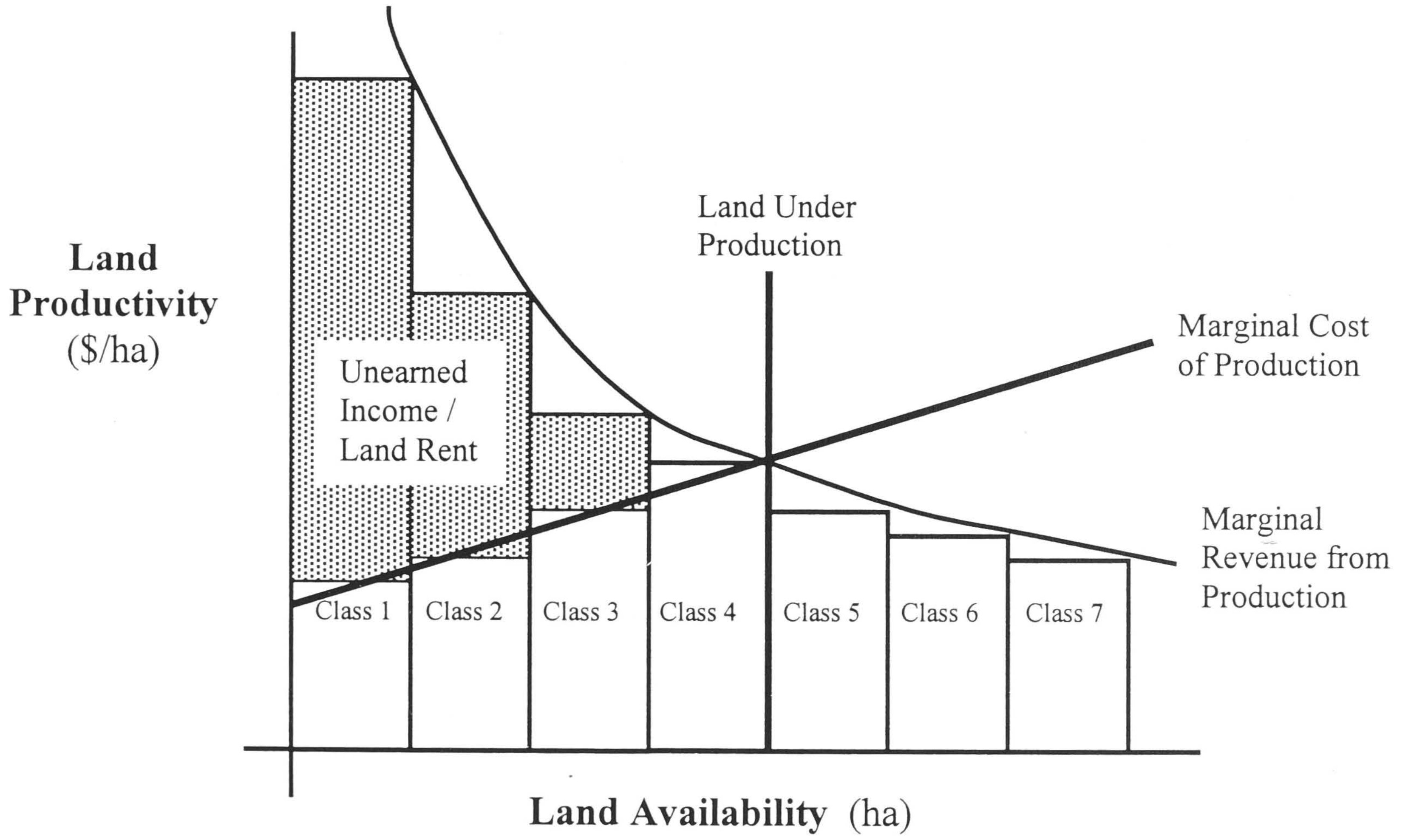
2.2.2 Ricardian Theory of Land Rents

As growth of population presses hard on limited resources under constant technology, cultivation frontiers move to more marginal land, and increased labour is applied per unit of cultivated land. This results in an increase in the cost of food production, and a rise in food prices. In the end, labour income decreases to a subsistence minimum, barely sufficient to maintain a stationary population (Kikuchi et al., 1980, in Blaikie and Brookfield, 1987). This is the basis on which Ricardo (1851) (as quoted in Blaikie and Brookfield, 1987) developed the theory of land rents.

Ricardo suggested that a rational farmer will identify the areas of highest productivity on which to base agricultural activity. When all land of the first, and by definition uniform quality, has been brought into production, the land of the second quality is engaged. The cost of production on land of the second quality will be higher than that of the first. For this to be possible the price of land must rise, and so all land of the first quality will receive an unearned income in consequence of incorporation of the second, as illustrated in Figure 2.1. The unearned income of labour inputs on this land is rent. If this land is more intensely cultivated the law of diminishing returns will apply. The schedule of production will form a parabola, so that the optimum ratio of both land and labour will be fully utilised, and beyond this point there is a shortage of natural growth relative to the input of labour. Further increases in growth will make it necessary to bring in new and inferior land, and the last land to be brought into production or intensified will just repay the cost of production and no more. This is the margin. When areas of land classes are sufficiently small, the land rent is the area bounded by the Marginal Cost curve and Marginal Revenue curve in Figure 2.1.

Signs of both Malthusian and Ricardian theory are evident in many parts of the Southeast Asian uplands. The population is increasing, land is degrading, and the population is becoming poorer. Where possible farmers are migrating to neighbouring, usually more marginal, land. However, opportunities to migrate, due to limited availability of land in neighbouring areas, are limited. The increasing demand for land as populations grow, is forcing farmers onto even steeper slopes, slopes unfit for sustained farming (Eckholm, 1976). Without a change in farming practices, large scale famine and disease may be inevitable in the future in these upland areas.

Figure 2.1 **The unearned income or land rent achieved by the first three land quality classes when the fourth land class comes into production.**



2.2.3 Boserup's Theory of Technical Progress

Although examples of Malthus and neo-Malthus theory can be found, like many other theories, these theories of population growth should be regarded as a conditional hypothesis (Glass, 1953). Land degradation followed by famine and/or migration, is only likely under a given set of circumstances. Under other circumstances, population growth can be followed by economic growth and changing technology.

Boserup (1965) argues that these theories are unrealistic as they overlook the potential of technical progress to improve the production of land via the invention of new methods and tools. Boserup does not deny that the food potential of the world is being reduced by a population that does not know how to match their growing numbers by more intensive land use without spoiling the land for a time or forever. However, she points to the fact that regions previously under forest fallow supporting only a couple of families per square kilometer, today support hundreds of families by means of intensive cultivation.

Boserup's theories (1965) are supported by theories on induced technical change (Ruttan, 1982). Induced technical change asserts that constraints on the supply of land and labour are offset by new technologies. The constraints serving as catalysts, facilitating the substitution of relatively abundant factors for relatively scarce factors. Where labour is scarce, mechanical technology is introduced and where land is scarce, biological technology is introduced. For upland farmers, as the cost of land increases, demand for land will induce changes in technology that can provide greater productivity on a given area of land. Ruttan (1982) points to increased recycling of soil fertility by more labour intensive conservation systems, and the use of fertilisers as evidence of changes in methods of production to preserve and improve fertility of land.

Both Boserup (1965) and Ruttan (1982) have shown that increases in population growth can induce changes in farming systems. Changes such as investment in landscape improvements and the choice crops and production techniques that are more ecologically viable. Production systems that are relatively protective of watersheds and are labour intensive, typically occur at high population densities. Increases in population are seen to create economic incentives for people not only to increase cropping but to choose products and production techniques that are more environmentally benign (Boserup, 1965).

Technological improvements in agriculture could raise the productivity of land and labour, thus making it possible to feed a larger population. However, unless the technological change in agriculture was rapid, as occurred in industrial societies, the escape was assumed to be only temporary (Templeton and Sherr, 1996). The surplus created by technological progress is eaten up by further population increases associated with the improved nutrition.

Production systems that utilise advancements in technology typically require additional labour and / or are capital intensive. Under long fallow systems, smallholders can produce sufficient yields with a small input of labour per family, a very large land area (including fallow), and with virtually no capital. As they change to more intensive use of land, they have much less land per family, and need to invest considerably in land improvements, such as additional implements, fertilisers, improved cultivars, etc., to maintain productivity in the wake of increased land degradation.

Boserup's theory (1965) and those of induced technical change (Ruttan, 1982) assume that smallholder farmers have at their disposal the resources and capital to adopt improvements. However, as mentioned earlier, population growth exacerbates poverty by reducing the land and capital available per capita. As land availability decreases and farming systems intensify, smallholders need to work more hours per year in order to obtain the same amount of food per family as before. This acts as a deterrent to the introduction of more intensive, labour and / or capital demanding, systems of agriculture. As long as smallholders can gain yields sufficient to feed their family in the following year, they will continue using their existing farming practices. This is done regardless of the long term degrading impact on the land. Short term necessity dominates.

Unless there is continued economic development with population growth, technical innovation to improve productivity and support the growing demand for food is unlikely to keep pace with the growing populations (Boserup 1965). Typically, farmers are risk averse, thus poor farmers lacking the resources to weather failure, suffer greater risk and are more inclined to behave in a risk averting manner than wealthier farmers (Blaikie and Brookfield 1987). Innovative behaviour, such as the introduction of soil conservation technology into the farm, involves risk and uncertainty. Rich farmers are better able to bear risks and thus stand to gain greater benefits. Technical innovations, such as the introduction of soil conservation practices which would affect short term returns but will lead to long term profitability of the farm, requires a high level of risk. Unless the farmers are wealthy enough to bear high levels of risk, the technical innovation described by Boserup is unlikely to proceed.

If technology change in upland agriculture can be achieved by the application of labour alone, a resource in abundance in upland areas of Southeast Asia, population growth may run the course outlined by Boserup (1965). However, if it requires significant capital (cash) input, a scarce resource for poor upland farmers, the potential for technological change is limited. As identified above, population growth must be paralleled by economic growth if technical innovation is to occur. Evidence of diminishing returns, stagnation in rural wages and increased hours of work in Boserup's writings, suggest that Malthusian factors dominate as Boserup's theory advances.

As Cassen (1976) notes "while Boserup's theory may have some validity in the broad sweep of history ……. There is no reason to believe the argument is of general validity in developing countries today. Cases of the opposite effect are not hard to find such as over-exploitation of land, man made erosion, etc."

To avoid the boom and bust of population growth predicted by Malthus, and in its place to see the technological innovation predicted by Boserup and Ruttan, there is a need to focus the attention of research organisations on technology appropriate for upland farmers. What is needed is the development of systems that are capable of improving the productivity of land and reducing land degradation, with only minor modifications to the current systems and minimal increases in capital costs.

2.3 Land Degradation.

Before proceeding to discuss changes in technology, likely to limit the spread of land degradation across upland areas of Southeast Asia, this section will consider the physical aspects of land degradation. These physical aspects are the outward signs of the stress placed on the environment by population growth.

Degradation can simply be defined as a lowering of quality or other measurable property (Shorter Oxford English Dictionary, 1995). From this it can be implied that land degradation involves a lowering of the quality of land, or a reduction in land productivity (Blaikie and Brookfield, 1987). Alternatively, land degradation can be described as a change in the nature of the land, via increasing soil erosion or decreased soil nutrient levels, which reduce the productive capacity (or quality) of land (Thampapillai and Anderson, 1993). Land degradation can be the result of many factors, acidification, salination, leaching of soil nutrients a breakdown of soil structure, etc. This discussion will focus mainly on soil erosion as the main cause of land degradation in upland areas of Southeast Asia. Soil erosion is likely to influence the occurrence of many of these other factors.

2.3.1 Causes of Soil Erosion

Soil is a natural body, evolving slowly under the influence of many factors of the environment. The processes of soil formation include the processes of soil erosion, thus by itself soil erosion is not a significant problem (Thampapillai and Anderson, 1993). Rainfall and wind are the main environmental factors initiating soil erosion. The impact of rain on the soil surface loosen soil particles, and the surface flow of the water carries the soil particles away from the site to be deposited elsewhere. Wind has an abrasive effect, which also removes and redistributes soil particles.

The potential for erosion is extremely variable, dependent on time, climatic conditions and steepness of slope. Most erosion occurs during short intervals of high energy availability (ie. high rainfall, high winds, etc) (Larson et al., 1987). Steepness of slope is a major factor contributing to high levels of erosion in some upland areas.

The greater the slope, the higher the rate of surface water flow, and thus the greater the energy to carry soil particles.

As well as the physical loss of soil (ie a reduction in soil depth), erosion also involves changes in soil structure (reducing soil pedality and aeration), loss of soil nutrients, and an increase in acid and salt levels in the soil. These changes can have a significant impact on plant growth, by restricting the growth of roots, reducing the availability of water and oxygen to the roots, reducing the availability and concentration of plant nutrients, and increasing soil toxicity (Magrath, 1990).

2.3.2 Influence of Land Use on Soil Erosion

In a natural environment of a forest or grassland, soil erosion processes are typically very slow, occurring over very long periods of time. Soil is protected by vegetative cover, which reduces the impact of rainfall and the effects of wind. Organic matter (leaf litter, etc) forms a layer which protects the soil from erosion, and roots hold the soil together, requiring greater force to remove the soil particles. In a natural situation soil erosion is likely to be balanced by soil production.

Changing land use will influence the rate at which soil erosion occurs. Dense forest cover, with a deep organic layer and at thick mesh of integrated roots, typically has the least soil erosion. Grasslands have a slightly higher level of erosion, although the thick mesh of grass blades and adventitious roots strongly bind and protect the soil. Agricultural activity typically has a large impact on soil erosion, given the disturbance associated with land preparation and establishment of crops. However, the level of erosion varies widely dependent on the type of agricultural activity. Integrated agroforestry and multi-tiered crops are the least erosive agricultural practices, while mono-crops, particularly row crops lead to the greatest erosion. Row crops typically induce a high level of erosion because they require clearing and ploughing, thus exposing the soil to the effect of wind and rain for a long period of time.

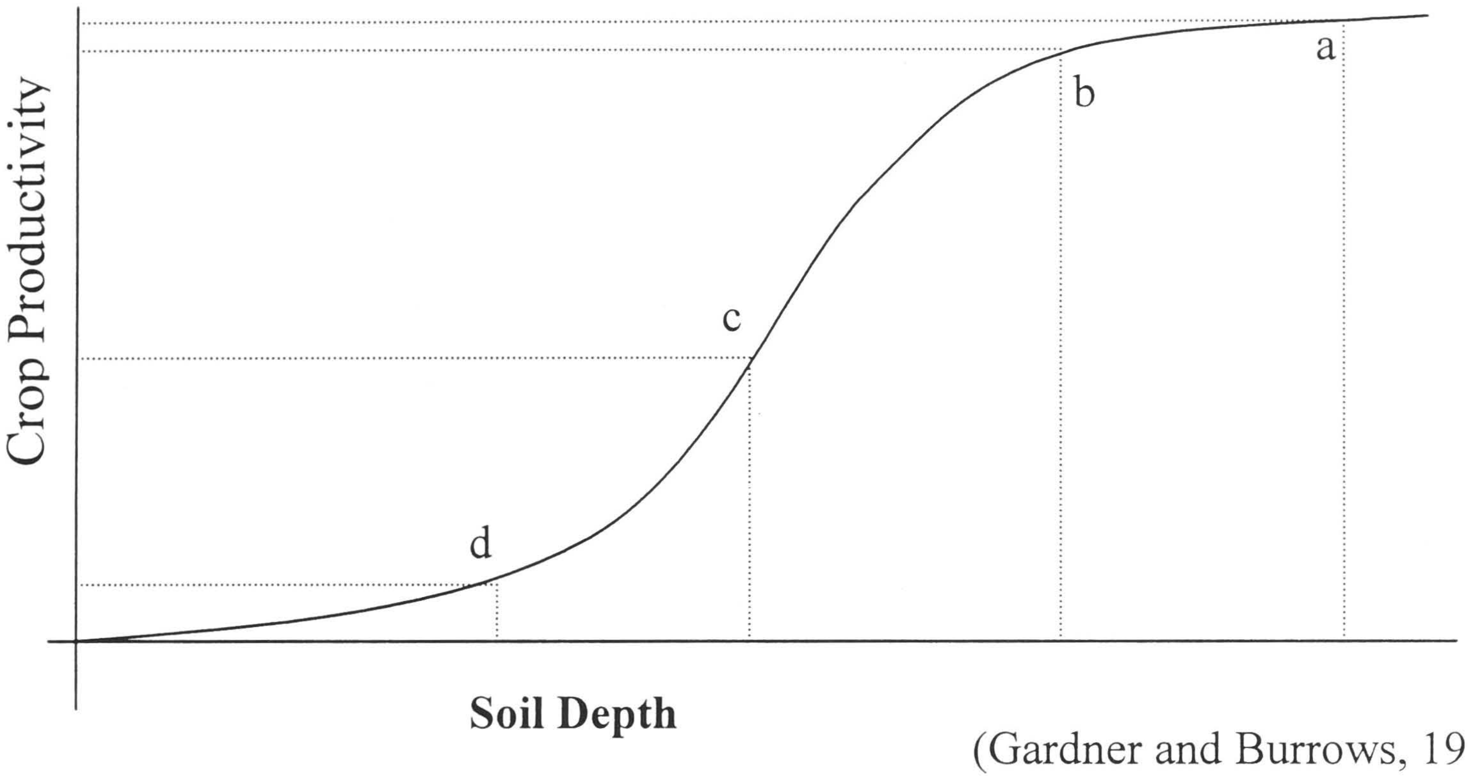
Transforming land from forests or grasslands, to agriculture is likely to lead to a substantial change in the level of soil erosion. Further changes, from multi-cropping to mono-cropping are likely to further accelerate the process of soil erosion.

2.3.3 Soil Depth and Crop Growth

The initial depth of soil is the main factor determining the impact of soil erosion on crop productivity. If the soil is initially very deep, soils such as deep loess, a high rate of soil erosion may not greatly affect soil productivity. As long as soil depth remains adequate for the plants rooting zone the impact of soil erosion on crop productivity is likely to be small (Gardner and Burrows, 1985). However, if soils are initially relatively shallow, which are common for soils in upland areas of Southeast Asia, a small amount of soil erosion is likely to have a substantial impact on crop productivity (Stocking, 1987).

The relationship between soil depth and crop productivity can be seen in Figure 2.2 below (derived from Gardner and Burrows, 1985). Moving from point a on this graph to point b, the soil remains relatively deep and crop productivity will not change significantly, even with high rates of soil erosion. However, once the soil depth threshold has been reached, and soil depth falls below the depth adequate for the plants rooting zone (ie moving from point b to point c on the graph), a similar rate of soil erosion will lead to a substantial decrease in crop productivity.

Figure 2.2 **Relationship between soil depth and crop productivity**



(Gardner and Burrows, 1985).

2.3.4 Soil Erosion on Tropical Upland Soils

The impact of soil erosion on crop growth is more dramatic in the tropics than in temperate conditions. Tropical soils are generally relatively fragile and the tropics tend to provide more extreme climatic conditions (ie high rainfall, etc) (Lal, 1987; Stocking, 1984). The exposure of these fragile soils to extreme climatic conditions leads to relatively high levels of soil erosion and sharp reductions in crop production. Upland soils are also relatively shallow, so a small decrease in soil depth is expected to have a substantial impact on crop productivity. The high erosion levels associated with short fallow systems common in upland areas, is likely to lead to a sharp reduction in soil productivity and rapid degradation of land. To maintain the productivity of this land, either longer fallow must be reintroduced or new more soil conserving farming systems must be adopted.

2.3.5 The Use of Additional Inputs and Improved Technology.

Technology can play a role in masking the impacts of soil erosion, such as declining productivity. Improved cultivars and the use of fertilisers and herbicides can increase crop productivity, at a time when there is high soil erosion (Stocking, 1987). Farmers are typically not very concerned about soil loss, as they can substitute other inputs for soil depth (Burt, 1981).

It is helpful to think of soil simply as another input into the farming system, similar to labour and capital. Soil should be considered interchangeable with labour and capital in determining the optimum system. A farmer can choose to allow a higher level of soil loss in the current crop cycle and use more fertiliser in following cycles. Alternatively, the farmer can choose to adopt practices, which limit soil loss in this period so as to maintain productivity, and use less fertiliser, in the following crop cycle. As Barbier (1996) suggests, farmers should treat soil erosion as just one income producing asset among many.

Although farmers can substitute other inputs for soil, these inputs do have a cost. By allowing a high level of soil erosion in the current period farmers are likely to be increasing the cost of the farming system in terms of fertiliser input, etc. in future periods. Increased costs with similar returns leads to decreasing net revenues for the farming enterprise. Upland farmers need to optimise their usage of soil (allowance of soil erosion) and other inputs into the system to provide the greatest returns for now and in the future.

Although this discussion of the physical aspects of land degradation has focussed mainly on soil erosion, it should be noted that productivity and erosion do not change discretely in isolation of other factors (Stocking, 1987). Other factors are responsible for yield decline and productivity losses, and although these factors are related to soil erosion, they are distinctly separate processes. Erosion rates by themselves are poor indicators of loss in productivity.

2.4 Soil Conservation

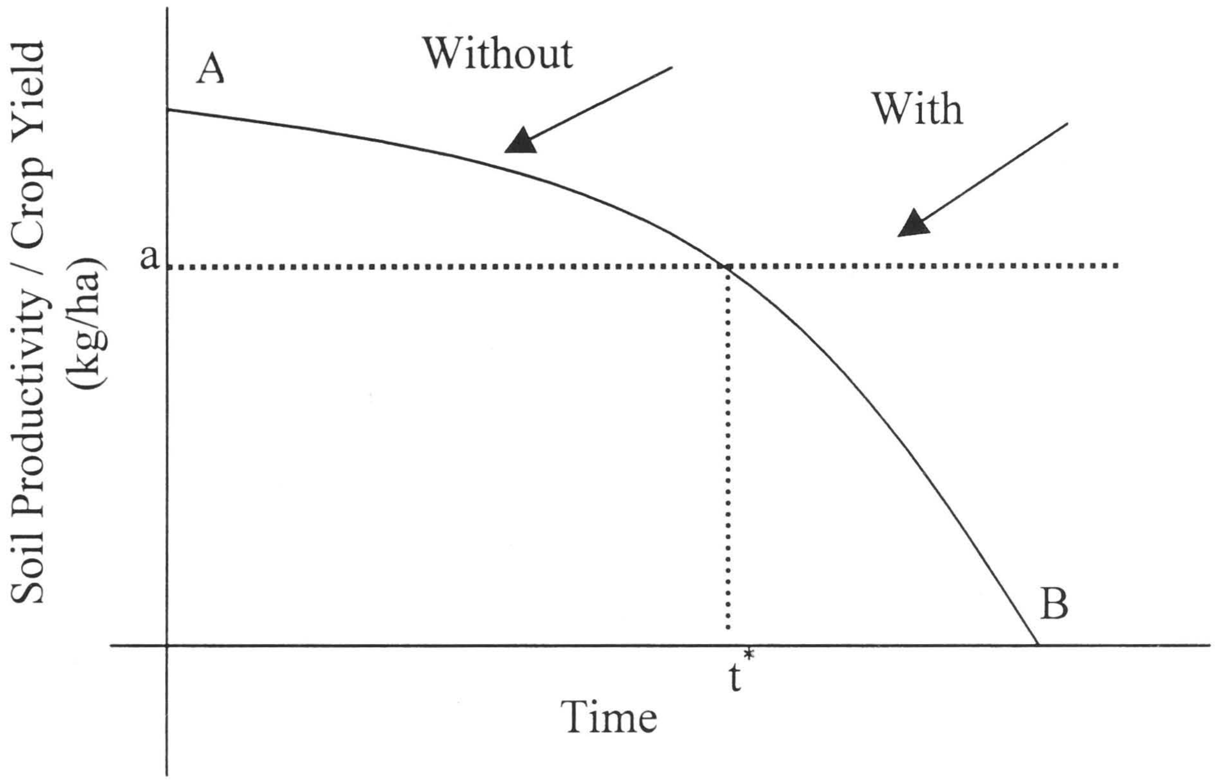
The cost of soil erosion should be seen by the farmer in terms of the foregone future productivity (ie. the potential loss of income to the farmer) and the related reduction in future resale value of the land (Gaffney, 1965, Seckler, 1987). From an economic perspective, a rational farmer should allow soil erosion only to the point that the marginal benefits derived from the farming activity compensate for the marginal loss of future productivity and the reduction in future resale value of the land. Short rotation shifting cultivation systems, that cause high levels of soil erosion, are only justified if productivity is high and the value of the soil is low. If the current returns do not justify the cost, then the farmer should consider changing to an alternative farming system that incurs less soil erosion, ie. adopt a more soil conserving farming system (Bunce, 1950).

2.4.1 Soil Conservation within Agricultural Systems

One of the difficulties in dealing with agricultural land and soil erosion lies in the fact that soil is partly a fund resource and partly a flow resource (Bunce, 1950). Soil is a fund resource in that it is limited in supply and can be exhausted, while it is also a flow resource as it slowly replenishes itself over time through the weathering of rock and transport via erosion of neighbouring areas. Agricultural production may exploit the stored fertility of thousands of years or it may utilize the fertility that is annually renewed through the flow of resources. Conservation of agricultural land usually involves maintaining the fund resource and the present level of productivity of the soil. Whereas exploitation or land degradation, is usually associated with using up this fund resource.

Under an exploitative land degrading farming system, for a period of time the costs of production are lower than they would be if fertility was maintained and little or no land degradation was taking place (Bunce, 1950). This provides higher returns to the farmer during the period that exploitation is economic. However, after a period of continued exploitation, the productivity of the land is reduced to the point where it is no longer profitable to continue cropping. Soil conserving practices, on the other hand, can be seen as a means of maintaining the productivity of soil in the long term. Soil conservation practices may involve high initial costs or reduce the maximum productivity in any given year due to a restriction on the total land used. However, the long term productivity of the soil is maximised by limiting land degradation, and thus the decline of soil productivity over time. Figure 2.3 illustrates this situation. The without soil conservation strategy by maximising the land under crop in the current period allows a higher level of productivity in the short term. However by exploiting the soil, productivity steadily declines to the point that it is no longer profitable to continue cropping. The soil conserving system, although it restricts the area under crop, thus reducing the productivity relative to the maximum yield, is able to maintain the level of productivity in the long term.

Figure 2.3 **Soil productivity with and without soil conservation**



(Bunce, 1950)

In general, soil conserving farming systems are aimed explicitly at reducing soil loss by:

- reducing the rate of surface water flow, via barriers such as hedgerows and contour bunds;
- reducing the slope via terracing; or,
- increases in vegetative cover via intercropping or agroforestry (Sanchez, 1976).

These have negative impacts in that they can increase costs and reduce the land available to be cropped, but they can also induce other positive reactions, such as an increase in soil organic matter, that directly improve conditions for crop growth (Magrath, 1990).

2.4.2 Investment in Soil Conservation

The introduction of many soil conservation techniques to upland farms usually requires a substantial investment of farmers labour and capital (Barbier, 1990). The adoption of soil conserving systems, such as agroforestry, can also require additional waiting time between establishment and harvest. This waiting time can reduce the area available for cropping. As a result, the net returns with conservation may be much lower than those without.

The economic attractiveness of soil conserving systems, in terms of net revenue, are affected by the length of the planning period and discount rate applied (Thampapillai and Anderson, 1994). Farmers behave rationally, and will only adopt a soil conserving farming system if the improved revenue expected from reducing soil erosion outweigh the increase in costs associated with changing from the existing system. Farmers who expect net returns with soil conservation to be lower than without conservation are certainly likely to postpone adoption of soil conservation (Thampapillai and Anderson, 1994).

2.4.3 Factors Limiting Adoption of Soil Conservation Practices

Wade and Heady (1979) suggest that, generally soil conserving farming practices are not adopted because “even though the practices may provide higher long run profits....the savings are simply not worth the change....”. This is especially so for upland smallholders, given their near subsistence existence (Barbier, 1996). Short term needs dominate, encouraging farmers to maximise short term returns. Lack of or limited access to credit, lack of information and the farmers attitude to risk are major factors limiting the adoption of soil conservation systems in upland areas.

The lack of an effective rural credit market distorts farmers investment decision. Individuals discount future benefits excessively due to their limited access to credit and the high interest rates applied to them when credit is available (Barbier, 1996; Thampapillai and Anderson, 1994). This does not favour soil conservation systems, which usually require an increased level of input and an increased waiting period.

The lack of adoption of soil conserving practices can also be attributed to lack of information. Upland farmers have little understanding of how their agricultural practices impact on erosion and very limited knowledge about methods for protecting soil (Veloz et al., 1985). Imperfect information leads to investment in conservation not being capitalised into the land value of the farm. Land values cannot accurately be estimated, as it is very difficult for buyers to determine how much erosion has occurred previously on the land parcel (Gardner and Burrows, 1985). Thus a lack of understanding of the impacts of erosion on crop productivity and difficulty in translating the amount of soil erosion into the land values, results in a lack of recognition of the cost of soil erosion to the farmer.

Farmers attitude to risk limits the adoption of soil conservation practices, especially if adoption alters the perception of risk (Thampapillai and Anderson, 1994). Most farmers are risk averse whether in developing or developed countries. Conservation practices while reducing the risk to the soil resource, generally lead to modifications of existing farm operations and increased uncertainty (Thampapillai and Anderson, 1994). Risk aversion by farmers encourages farming practices with high short-term income and high soil erosion, such as an *Imperata* fallow system. (Thampapillai and Anderson, 1994)

Compounding the problems associated with the lack of information and risk in the adoption of soil conservation systems, is the fact that many upland smallholders cultivate public land or rent their land. Thus, they retain no security of tenure and are not likely to benefit from improvements made to the land in the long term (Thampapillai and Anderson, 1994). This reduces their incentive to adopt improvements such as soil conservation, which often require long term planning. For farmers without secure land tenure, the user cost of soil is irrelevant and farm resale value is unimportant. These farmers are only likely to conserve soil if it improves the short term productive capacity of the land and involves little or no cost (McConnell, 1983).

In summary, change to a soil conserving farming system that reduces productivity in the short term, requires cash or capital investment, increases the level of risk, or decreases the area available to be cropped, will be less attractive to the farmer. Given, the very high interest rates applied to upland farmers and lack of secure tenure of the land, practices which maximise short term benefits but induce rapid soil loss, are expected (McConnell, 1983). To encourage smallholders to adopt soil conserving farming systems, it is necessary to develop and encourage farmers to adopt systems, which have limited capital investment, and do not require significant changes to the farming system.

Since the early 1980's, hedgerow intercrops were identified by many research organisations as a system with potential to reduce soil erosion and provide long term productivity benefits to upland farmers. The next section outlines the experience with hedgerow intercropping in Southeast Asia.

2.5 Experience with Hedgerow Intercropping

In tropical regions, hedgerow intercropping emerged as the focus for soil conservation research in the 1970's. Planting leguminous trees (particularly Leucaena spp.) along contours to provide a vegetative barrier to the surface flow of water while contributing green leaf manure to cereal crops (rice or maize) grown in alleys was seen to have potential to reduce soil erosion in upland areas (Garrity, 1993). By early 1980's, hedgerow intercropping was widely advocated as a technology to better sustain permanent cereal cropping with minimal or no fertiliser input, and as a soil erosion control measure for sloping lands.

2.5.1 Characteristics of Hedgerow Intercropping

Hedgerow intercropping is a spatially zoned agroforestry practice, using the contoured hedgerows to control soil loss and sustain yields. Contour hedgerows are seen to be as effective as structural barriers, and are appropriate for low-input upland farming systems. Leguminous shrubs, such as *Leucaena leucocephala* and *Gliricidia sepium*, are commonly used as a hedgerow intercrop as they supply large quantities of nitrogen and organic matter to companion food crops.

Hedgerows provide a physical barrier to overland water flows, reducing the velocity of rainfall runoff and enhancing infiltration. The use of prunings as mulch in the cropping rows increases the organic matter content of the soil, and also reduces the velocity of water runoff and enhances infiltration (Lal, 1988; Young, 1989).

The barrier effect of the hedgerows also induces rapid terrace formation. Maclean et al. (1992), found contour hedgerows of *Leucaena* formed a terrace within 18 months. Once established hedgerow terraces operate in a similar manner to mechanically formed terraces, reducing slope length and gradient, thus reducing the velocity of runoff.

Regular mulching of hedgerow prunings in the crop rows, especially with leguminous trees such as *Leucaena* and *Gliricidia*, generally leads to increased crop productivity compared to monocultures. Consistent yield benefits were observed in upland rice and maize using *Gliricidia* hedgerows and napier grass strips along contours (Garrity, 1993).

Variations on hedgerow systems include the use of natural vegetation strips and grass strips (Garrity, 1993). These have been observed to be as effective as tree based systems in controlling erosion and the formation of terraces. However, they lack the potential to improve nurtient recycling, that is achieved with leguminous tree based systems. Thus, leguminous tree based systems have dominated international research and extension efforts (Nelson, 1996b). Regardless of the species, the effect of vegetative barriers in reducing soil loss is significant, when compared with open field systems (Garrity, 1993).

2.5.2 Problems with Hedgerow Intercropping

Although, there are significant beneficial effects of hedgerows, they are often off-set by the negative competitive interactions between hedges and the alley crops. Hedgerows reduce the area available for cropping by up to 25 per cent when compared with open-field systems (Young, 1989). Hedgerow - crop competition, such as shading, unless the hedges are well maintained and regularly pruned, may reduce yields in the crop rows closest to the hedges. Also, root competition for soil moisture and soil nutrients, especially in times of drought, can also lead to reduced yields (Lal, 1989a).

The labour requirements of the hedgerow system is an important economic consideration for farmers. The high labour demands of hedgerow establishment and maintenance (pruning), and its cost, may also off-set the potential benefits of higher yields and long term sustainability. Labour required to manage the hedges (3 to 10 prunings per year) adsorb a large proportion of the households labour and compete with other income generating tasks. This will also limit the size of land that can be farmed to less than 0.5 ha per adult male (Garrity, 1993).

2.5.3 Adoption of Hedgerow Intercropping

Adoption of hedgerow systems is generally limited to high intensity extension projects. There is little evidence of spontaneous farmer interest (Nelson, 1996). The main constraint to adoption of hedgerow intercropping systems is a lack of resources. Shortages of labour for establishment and pruning, and limited availability of planting material and tools are seen as a significant factors inhibiting adoption (Fujisaka, 1993; Garrity, 1991). The large initial labour investment and ongoing drain on labour resources to maintain an effective pruning regime reduce the attractiveness of hedgerow systems (Garrity et al., 1993; Kent, 1985). Difficulties in obtaining planting materials and the degree of technical backup have also limited the adoption of hedgerow intercropping (Garrity et al., 1993; Londhe et al., 1989). In seeking a better system for upland farming, problems with labour availability and availability of materials must be considered.

An improved fallow system is seen to have potential as an alternative to hedgerow intercropping systems. The timing of establishment is of less importance as it does not need to be integrated with crop establishment, thus reducing the demand for labour at peak times in the cropping season. The establishment of the plantation can be organised for times when labour demand is low. The competition between the tree and crop is eliminated, reducing the importance of regular pruning and thus the labour requirement of regular prunings. Reducing labour costs and the demand for labour at peak times of the crop season is likely to make the improved fallow system more attractive to farmers hesitant to adopt a hedgerow intercropping system.

2.6 An Improved Fallow System

The improved fallow system is seen to have the potential to reduce soil erosion in upland farming areas. Other attractive features of the improved fallow system, are the enhanced rate of nutrient buildup, and the potential to provide alternative forms of income. It is expected that the establishment of the improved fallow system will be achieved with little additional capital cost to the farmer, other than an increase in the farmer's own labour input.

2.6.1 Characteristics of the Improved Fallow System

The improved fallow system considered in this study, involves the establishment of a plantation of leguminous shrubs over the fallow period. During the fallow period the foliage of the shrub legume are pruned regularly and dropped on the site as leaf mulch. This enhances organic matter buildup and protects the soil from rain and wind, limiting soil erosion. After a short fallow the plantation is cleared, providing an additional source of income in the form of firewood and a fresh batch of prunings to protect the soil during crop establishment. A short cropping period follows, and then the leguminous shrub plantation is re-established.

The use of leguminous trees in the plantation has the potential to increase the efficiency of the fallow period compared with natural fallows. Regular pruning, two to three times a year, of leguminous trees accelerates the nutrient buildup in the soil through nitrogen fixing and nutrient pumping (Sanchez, 1976). Leguminous trees have a symbiotic relationship with root fungi, which fix nitrogen in nodules on the roots, thus improving soil nitrogen concentrations. The relatively deep roots of the shrubs are able to access nutrients from deeper in the soil profile. Regular shedding of leaves, redistributes these nutrients to the upper layers of the soil profile. Lal (1975) has shown that mulching further enhances the buildup of nutrients, above the rate of regular shedding of the trees' leaves. Mulching, by providing a thick leaf litter and humus layer, also improves soil recovery by reducing soil temperatures, conserving moisture, and protecting the soil from wind and rain impact (Sanchez, 1976).

2.6.2 Examples of Improved Fallow Systems

Examples of indigenous improved fallow systems are rare. Although Sanchez (1976) found an example in some forest areas where tree species were planted in the field following the crop cycle. The tree species were selected for their ability to accumulate certain nutrients at a faster rate than occurs in mixed secondary forest fallows. The trees were also used for building materials and firewood (Sanchez, 1976).

On-farm trials of an improved fallow of Sesbania in western Kenya, show that an improved fallow appears to be a promising option to restore depleted lands (Swinkles et al., 1996). In densely populated areas of Benin with degraded soils, similar positive evaluations of improved fallows were made using *Mucuna pruriens* (Vesteeg and Kodoukpon, 1993).

2.6.3 Design of Improved Fallow Systems

The challenge in designing improved fallow systems, is to find a design that can be easily incorporated into the local cropping system. It is necessary that the system does not require significant labour for mulching, or the addition of costly inputs (Balasubramanian and Blaise, 1993).

Sanchez (1982) noted that legume - cereal intercropping is extremely site specific, thus the different management aspects of the fallow-food crop system should be validated locally in each agroclimatic zone (Balasubramanian and Blaise, 1993).

If farmers intend to raise cattle, grass fallows may be more appropriate (Sanchez, 1976). As with tree fallows, the selection of grass types, such as leguminous grasses, can improve the rate of nutrient buildup in the soil. The cattle manure is also likely to increase the rate of nutrient buildup.

2.6.4 Adopting Improved Fallow Systems

Improved fallow need not threaten food self-sufficiency of the household in any given season as a farmer would only have a portion of land under fallow at any one time. The fallow will rotate within the farm, alternating with the staple food crops (Swinkles et al., 1996). Although labour demands and land use has increased, improved fallow will not substantially increase food production of the farm. That is, unless yield responses of the improved fallow are much larger than the yields from natural fallows on the degraded land (Swinkles et al., 1996).

Improved fallow systems do require a waiting time of at least one fallow crop rotation period before improvements in yield can be observed. Thus, as with most soil conserving farming systems, the increased cost of the improved fallow, in terms of increased labour, will not be recovered in the short term. However, sustainability is a long term consideration and will involve some sacrifices in the short-term. Access to off-farm income may increase the farmers ability to practice improved fallows, depending on the reliability of the food market (Swinkles et al., 1996).

In high population areas where land is depleted, a yield increasing technology that reduces land degradation, such as improved fallow, seems promising. The improved fallow system may qualify as a form of induced innovation, ie. an innovation that reflects farmers' changing resource scarcities and sparing use of resources that have become scarcer such as land, and the use of more plentiful resources such as labour (Hayami and Ruttan, 1985; Swinkles et al., 1996)

Chapter 3. Biophysical characteristics of *Imperata* and *Gliricidia* Species

3.1 Introduction

Imperata is a troublesome weed, which competes vigorously with other vegetation for moisture and nutrients. In a typical *Imperata* fallow system the site is abandoned following the crop and *Imperata* will take over the site, establishing from windblown seed and stored rhizomes and seed. As a fallow, while not optimal, *Imperata* stabilises the soil and provides a low level of nutrient buildup. However, the difficulty in removing *Imperata* following the fallow period and its likely regeneration during the fallow period, from stored seeds and rhizomes, result in high labour demand for establishment and weeding during the cropping period.

As an improved fallow, *Gliricidia* offers significant potential to out-compete *Imperata*, and over a short period (five years) removes its potential to regenerate from stored seed and rhizomes. It also offers the potential for fast recovery of the soil following cropping, through a combination of nutrient cycling and nitrogen fixing. Regular pruning and mulching of the leaves will enhance the rate of soil recovery. Other advantages of *Gliricidia* as a fallow crop include the provision of additional products, such as firewood and animal fodder, which can provide an income to offset for the increased costs associated with establishing and maintaining the *Gliricidia* fallow.

In order to model and analyze the potential of the *Imperata* and *Gliricidia* fallow systems, a better understanding of the characteristics of these species is necessary. This chapter will focus on the biophysical characteristics of *Imperata* and *Gliricidia*, providing a background for the modelling of the *Imperata* and *Gliricidia* fallow systems. It will begin by considering the biophysical characteristics of *Imperata* and potential control methods. It will then discuss the characteristics of *Gliricidia* that make it a suitable fallow species in terms of nutrient recycling, weed control and additional products.

3.2 Characteristics of Imperata

Imperata is regarded as a noxious weed in deforested areas, because of its high competitiveness and high reproductive capacity, by way of buds present on the rhizomes. Once established it tends to dominate a site and can form pure single species stands when managed by fire, due to its ability to resprout quickly from rhizomes stored below the soil surface. If regeneration of woody species is not inhibited by fire, woody species will eventually recolonise a site, given there is sufficient seed left in the soil or the forest margin is in close proximity. One of the most important factors governing this vegetative succession is competition for sunlight. *Imperata* is regarded as being shade intolerant. Shading, by the introduction of soil covering plants, is therefore included as a preventive or control measure against this weed.

3.2.1 Biological Features of Imperata

Imperata is of pandemic genus, found throughout the tropics. It is a rhizomatous perennial grass, with a spreading habit, dispersing locally through the rhizome system and more widely through wind dispersed seeds. In the Philippines, degraded grasslands including *Imperata* and other species cover more then 5 million hectares (de la Cruz, 1993). Much forested land has been converted to *Imperata* grassland through the processes of logging, shifting cultivation and burning (eg 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, especially 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). It is often associated with low soil fertility, but this does not imply that *Imperata* is restricted to, or grows better, on poor soils. Low fertility soils dominated by *Imperata* are more likely the end product of shifting cultivation cropping systems where there is a high human population density.

The biological features of *Imperata* have been documented quite extensively, including a number of BIOTROP publications (eg Soerjani, 1970; BIOTROP, 1980; Eussen, 1981; Brook, 1989; Sabarnurdin et al., 1991; Turvey, 1994). Hence, only a short summary is presented here.

Imperata is spread both by seeds and vegetatively through rhizomes. It is a prolific seed producer, with seed dispersed widely by the wind. Seeds can remain viable in the soil for long periods of time, but are quick to germinate when conditions are right. This makes it a very opportunistic pioneer species, quickly taking advantage of areas that have been disturbed and asserting its dominance. Seed production is also encouraged by disturbance, enabling it to quickly reestablish when cut or cleared.

Imperata produces an extensive net of rhizomes concentrated in the upper 20 cm of soil (Soerjani, 1970). This allows *Imperata* to sprout quickly after a fire or other disturbance, giving it a significant advantage over naturally growing trees and shrubs. Repeated burning favours grasses over woody species in general and *Imperata cylindrica* in particular (Turvey, 1994). The drying of the *Imperata* foliage in the dry season leads to high risk of fire. The overwhelming majority of grasslands in Southeast Asia, owe their existence to the removal of the forest for crops, followed by regular uncontrolled fires (Dove, 1986). Other disturbance such as cultivation also stimulate rhizome bud growth.

Imperata competes vigorously with other species, due to its fast growth rate, large biomass production and strong ability to extract nutrients and moisture from the soil. Its high flammability and ability to sprout quickly following fire also provide it with a significant advantage over other species. This makes cropping difficult unless *Imperata* is controlled prior to establishment.

3.2.2 Imperata control

From an economic perspective *Imperata* has few real benefits, being considered a noxious weed. Farmers usually control *Imperata* by checking its growth, rather than eradicating it completely. However, given its ability to spread vegetatively quite rapidly, it can quickly dominate a site. Once established it is difficult to remove it, therefore it is desirable to eradicate it completely where possible. Several methods are available to control *Imperata*, the main ones being physical, chemical, shading or a combination of these.

Physical methods of *Imperata* control include manual cultivation with a hoe and cultivation using animal traction. This cultivation technique is very labour intensive, requiring the soil to be turned several times to bring the rhizomes to the soil surface to dry (Menz and Wibawa, 1995). Slashing and burning are other options for physical attacks. Slashing may exhaust the rhizome reserves, but this will require repeated application and will not be fully effective in totally removing *Imperata* (Soerjani, 1970). Burning will clear the area of surface *Imperata*, but there will be rapid regeneration from the underground rhizomes, so is of little value in controlling *Imperata*.

The most effective chemical control of *Imperata* is the use of glyphosate. 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 litres of glyphosate per hectare, followed up by a one litre correction spray (Menz and Wibawa, 1995). The effectiveness of the herbicide is greater if applied to new shoots after slashing or burning. Following herbicide spraying *Imperata* will typically reinvade after 6 to 12 months. Glyphosate is not likely to be commonly used by upland farmers in the Philippines. It is relatively expensive and given their subsistence existence, upland farmers are unlikely to be able to afford to maintain a regular spraying regime to control *Imperata*.

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. *Imperata* is known to be susceptible to shading from trees, so the establishment of a tree plantation that can form a dense canopy to shade *Imperata*, is desirable. Shading offers the only long term solution for *Imperata* control, while physical and chemical methods offer short term control, and present an opportunity for tree or crop establishment. Thus, a combination of either physical or chemical clearing of *Imperata* followed by the establishment of trees, will enable long term control of *Imperata*.

3.3 Characteristics of *Gliricidia*.

Gliricidia has the potential to compete with *Imperata* and quickly overcome its dominance of a site. Its main advantage lies in its fast growth of up to six metres in a year, ability to resprout vigorously after lopping or pollarding and the ability to establish from cuttings. This potential for fast growth enables *Gliricidia* to overcome competition with *Imperata* at ground level and then develop a canopy to shade out *Imperata*. Propogation of *Gliricidia* from cuttings enable the tree to establish quickly, thus giving a further competitive edge over the *Imperata*.

Unlike *Leucaena,* which has been the main tree used in agroforestry to date, *Gliricidia* is free of pest problems. The psyllid, *Heteropsylla cubana*, has had a significant impact on *Leucaena* in many parts of Southeast Asia. Given most *Gliricidia* is established by vegetative propagation, care must be taken to maintain the genetic diversity of *Gliricidia*, to reduce the risk of a similar occurrence. Other qualities of *Gliricidia* offer the potential to improve site quality and conditions, making a *Gliricidia* plantation an effective improved fallow for a shifting cultivation system. This section will detail the characteristics of *Gliricidia,* which enable it to suppress *Imperata* and make it an effective species for improved fallow.

A plantation of *Gliricidia* forms the basis of the improved fallow system considered in this study. As this system is not yet commonly practiced in the field, the specifications of a *Gliricidia* plantation, to provide effective *Imperata* control and an effective intensively managed, soil enriching fallow, have not been defined. This section will discuss the characteristics of *Gliricidia*. Included in this discussion will be the specifications of a *Gliricidia* plantations for the improved (*Gliricidia*) fallow system.

3.3.1 Gliricidia planting density and weed control

In trials, *Gliricidia* has been shown to grow successfully at high densities (between 5,000 and 40,000 stems per hectare) and also under regular pruning regimes, such as every 6-12 weeks (Ella et al., 1989).[1] On a per hectare basis, *Gliricidia* is highly productive, in terms of the foliage and wood yield, at higher densities. However, a high tree mortality rate was observed at 40,000 stems per hectare. A planting density of 20,000 stems per hectare is optimal for the *Gliricidia* fallow system, as it will reduce the inter-tree competition. Ella et al. (1991) showed that *Gliricidia* plantations of this density were successful in suppressing weeds. Similar studies in Africa by Anoka et al. (1991) showed a significant decrease in *Imperata* density and rhizome biomass, under a *Gliricidia* plantation. In rubber plantations, Menz and Grist (1995) demonstrated that increasing tree densities shortened the time to canopy closure and had a significant impact on the rate at which the *Imperata* density was reduced.

A *Gliricidia* plantation should be designed to enable a smallholder to move freely through it, while maintaining a high level of shade to control *Imperata*. The *Gliricidia* fallow system in this study is based on a tree density of 20,000 stems per hectare, with rows running along the contour, the intra-row spacing is 0.5 metres, with two lines of trees per row, also spaced at 0.5 metres. Rows are spaced at 1.5 metres to enable smallholders to move within the plantation to prune regularly for mulch and for firewood collection. Although this design may slightly reduce the

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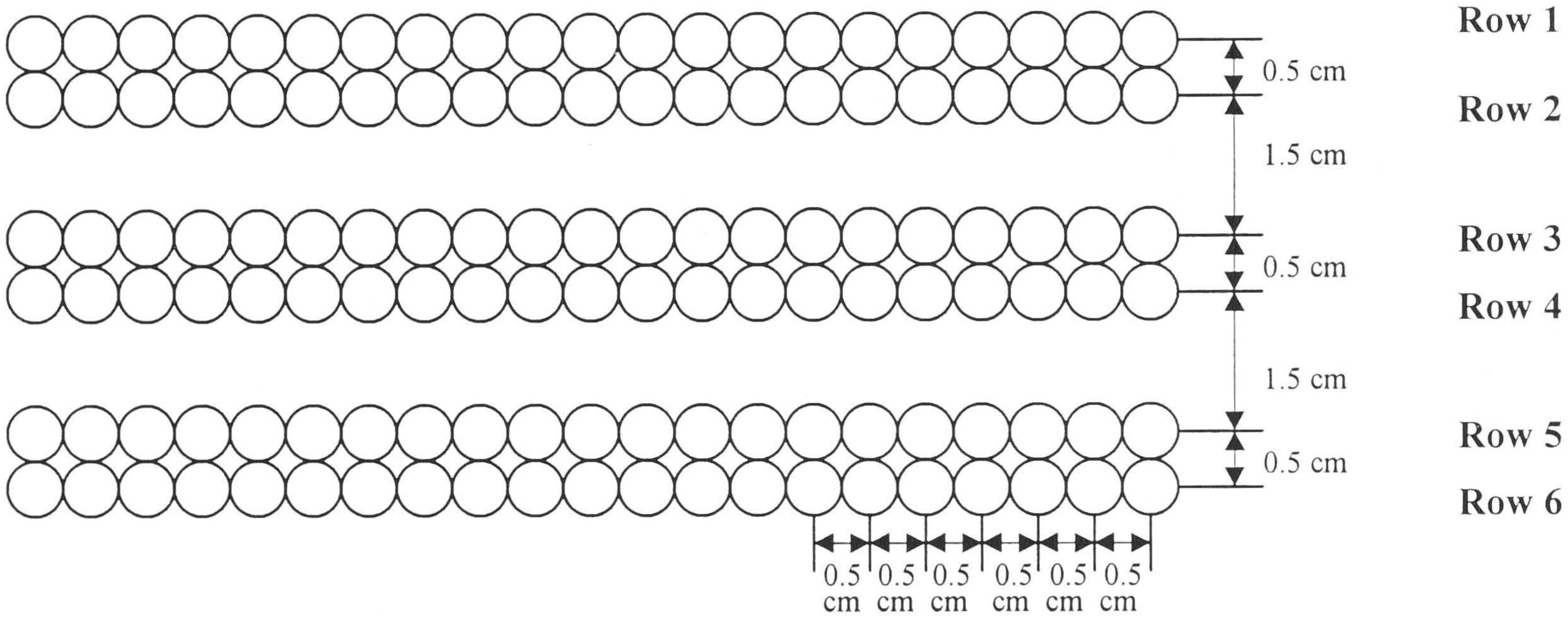
[1] Much of the data for the improved fallow is based on research in planting density trials for Gliricidia in Africa (Panjaitan et al. 1993; Anoka et al. 1991; and Ella et al. 1991 and 1989), and hedgerow intercropping trials with *Gliricidia* at the Claveria site in the Philippines (Nelson et al. 1996a and 1996b).

amount of shade at ground level, compared to a regularly spaced design, it is not expected to be significant.

Figure 3.1 **Planting pattern of trees in a *Gliricidia* fallow system.**



3.3.2 Establishment with the cuttings

There would normally be no cash costs associated with the establishment of a *Gliricidia* plantation. It establishes well from cuttings, which can be collected from existing trees (Ella et al., 1989; Panjaitan et al., 1993). The only cost of establishing *Gliricidia* relates to the labour requirement for collecting and planting the cuttings.

Using cuttings to establish the plantation provides an improvement in the trees' ability to control *Imperata*. *Gliricidia* will quickly sprout from cuttings, and thus will be able to compete with *Imperata* at an early stage in development. This reduces the need to undertake an intense weeding program before establishing the plantation. The site can simply be burnt to remove the *Imperata*, and the *Gliricidia* cuttings planted soon after the burn. Using large cuttings, of 0.5 metres, gives *Gliricidia* a significant early advantage over the re-emerging *Imperata*. It soon establishes a cover that provides shade at ground level, thus restricting *Imperata* growth. Timing of establishment is very important. An effective burn should be undertaken at the end of the dry season, but effective establishment of *Gliricidia* requires rain. Thus, the smallholder needs to choose the establishment time carefully.

Although they establish quickly, cuttings do not have the same hardiness as seedlings. Cuttings do not develop a tap root, as they produce only adventitious roots. This means they are more susceptible to drought conditions and to uprooting in strong winds. The use of cuttings also increases the risk of pests and disease, although there are no significant problems with this species at present, due to the lack of genetic diversity that is associated with the use of cuttings in plantations.

3.3.3 Nutrient recycling

As *Gliricidia* is a legume, it has the potential to improve soil fertility. It has a high decomposition rate, and thus is capable of recycling nutrients back into the soil relatively quickly (Maclean, 1991; Palm, 1995). Nutrient recycling is enhanced by regular pruning and mulching. Ella et al. (1989) found that a short pruning cycle, at six weekly intervals, provided the greatest amount of foliage for nutrient cycling. However, if firewood is also a valuable product of the *Gliricidia* fallow system, a longer pruning cycle (twelve weeks) should be used to obtain a saleable amount of wood. The longer pruning cycle also has advantages in reduced labour requirements, thus lowering costs.

In a study of the effect of two tonnes per hectare of *Gliricidia* residue as green mulch on a maize crop, Almendras and Serohijos (1994) found an improvement in maize yield of 30 - 35 per cent, compared with no green mulch application. Rodriguez et al. (1988) found that a plantation of *Gliricidia*, with cuttings regularly used as mulch, has the potential to improve soil nitrogen and phosphorus, equivalent to an application of 100 kg of nitrogen and 40 kg of phosphorus fertiliser per hectare. This is supported by data from Sanchez (1995) who estimated the nitrogen content in four tonnes of mulch from a nitrogen fixing tree to be around 100 kg. This level also equals the expected nitrogen content of the four tonnes of mulch, based on the N content of 2.5 per cent in the leaves [4,000 * 0.025 = 100] (Nelson et al., 1996b).

Palm (1995) found that the nitrogen content of 4 tonnes per hectare of leaf material is sufficient to meet the requirements of two tonnes of maize grain and three tonnes of crop residue. However, Palm (1995) also found that the percentage of nitrogen in the leaf material does not serve as a good index of nitrogen release. Although Palm (1995) found that *Gliricidia* consistently releases a higher percentage of nitrogen than other materials, only 30 - 70 per cent of the nitrogen actually present was found to be released. At the Claveria site, Maclean et al. (1992) calculated the nitrogen released from 10 tonnes of mulch to be 106 kg per hectare. This is equivalent to approximately 40 per cent of the nitrogen content in the leaves as found by Sanchez (1995) and Nelson et al. (1996b), well within the range found by Palm (1995). Therefore, in calculating the release of nitrogen, research findings by Maclean et al. (1992) were used.

3.3.4 Gliricidia as animal fodder.

As well as being valuable as a green manure, *Gliricidia* foliage can also be used as fodder for animals. The nutritional value of *Gliricidia* is high when compared to *Imperata* and maize crop residue. *Gliricidia* contains between 20 and 28 per cent of crude protein, 20 K Cal/g of gross energy and approximately 60 per cent dry matter digestibility (Lowry et al., 1992; Nitis and Lana, 1984; Gutteridge and Shelton, 1994). The crude protein, gross energy and dry matter digestibility of *Imperata* and crop residue are significantly lower, approximately 9 per cent, 18.0 K Cal/g and 58 per cent respectively (Lowry et al., 1992; Soewardi and Sastradipradja, 1980).

Gliricidia has no apparent toxicity to animals (Atta-Krah and Sumberg, 1988). Thus, it is highly valuable as feed for cattle. Some animals may initially refuse to eat *Gliricidia* when it is first introduced to their diet (Atta-Krah and Sumberg, 1988). This is thought to be related to the release of an odour by freshly cut material (Simons and Stewart, 1994). Refusal is more common in older animals, which are less likely to accept changes in their diet. Younger animals are more likely to accept fresh *Gliricidia*. If *Gliricidia* is introduced into an animal's diet at a young age, there are unlikely to be any problems.

In cases where there is initial refusal, several methods have been attempted to overcome the problem. The most common involves wilting the *Gliricidia* foliage before providing it to the animals (Lowry et al., 1992; Jabbar et al., 1996). This usually involves cutting the material in the morning, allowing it to wilt during the day, and then feeding it to the animals in the evening. By evening it appears that the strength of the odour has diminished and it will be more acceptable to the animal. Alternatively, Atta-Krah and Sumberg (1988) have suggested a weaning approach, whereby over a three to seven days period, *Gliricidia* is included in the animals feed source, forcing them to keep smelling and nibbling it. After an initial conditioning period, the aversion is broken, and the animals will accept Gliricidia as part of their feed source, often in preference to other feed sources.

3.4 Concluding Comment

The advantage of an *Imperata* fallow is that it involves a low cost, with the site simply abandoned following the period of cropping. *Imperata* will quickly dominate the abandoned land and stabilise the soil. Woody species, which can potentially grow above the dense mat of *Imperata*, will be slow to establish in competition with *Imperata*. The occurrence of fire early in the fallow period will further enhance the dominance of *Imperata*. A five year fallow period is unlikely to enable other species to establish and begin to outcompete *Imperata*. As a result, a five year fallow is effectively an *Imperata* fallow. Allowing *Imperata* to dominate the site during the fallow period provides problems later for removal after the period of fallow, so that a crop can be reestablished on the site. Physical and chemical methods of control, although effective initially, are only short term solutions to *Imperata* control. They are also quite costly, in terms of labour requirements for the physical method and the purchase of the herbicide for the chemical control method. Cropping following an

Imperata fallow will require regular follow up weeding, as *Imperata* will continually re-invade from seed stored in the soil and rhizomes, which could not be removed. Poor soil recovery and competition from the persistent re-invading *Imperata* will produce relatively low crop yields following the *Imperata* fallow. Thus, although the *Imperata* fallow is low cost (or zero cost), its impact on the cost of crop establishment and maintenance, and crop yield, are substantial and should not be overlooked.

A *Gliricidia* fallow is potentially far more effective than an *Imperata* fallow. Gliricidia will be quick to establish and will quickly outcompete re-emerging *Imperata*. Closely spaced *Gliricidia* will quickly form a dense canopy, which can shade *Imperata*. Shading provides the only long term solution to controlling *Imperata*. After a period of shading, three to five years, *Imperata* rhizomes and stored seeds will no longer be viable. Thus, *Gliricidia* offers significant potential to control *Imperata* by shading. During the cropping period following a *Gliricidia* fallow, *Imperata* can only reestablish from wind blown seeds. This will be more widely dispersed and slower to establish. As a result, *Imperata* weed problems in a crop following a *Gliricidia* fallow period will be less.

The use of *Gliricidia* as the fallow crop offers the added advantage of significant soil enrichment. Nitrogen fixation by the *Gliricidia* and cycling of nutrients deep in the soil profile, will improve soil nutrient levels and provide a fertile bed for the crop following the fallow period. Regular mulching of the *Gliricidia* leaves also provides a thick humus layer, which protects the soil from erosion and maintains soil moisture.

A *Gliricidia* fallow provides other benefits, such as firewood and nutrient enriched fodder for animals. These further enhance the advantages of the *Gliricidia* fallow system, providing alternative sources of income to supplement the income available from cropping.

Having discussed the biophysical characteristics of *Imperata* and *Gliricidia,* the next chapter will outline the model used to analyse the potential of the *Imperata* and *Gliricidia* fallow systems.

Chapter 4. The Bioeconomic Model

4.1 Introduction

Few attempts have been made to quantify the long term consequences of shifting cultivation and to project the potential advantages of alternative systems. While numerous descriptions of current shifting cultivation practices are available, from both socio-economic and biophysical perspectives, the long term consequences have remained somewhat intractable. This is mainly due to a lack of comprehensive and consistent data. To overcome the lack of data, it is necessary to employ a modelling approach in order to understand the impact of shifting cultivation and other farming systems on environmental factors.

The are few previous attempts at modelling shifting cultivation systems. Dvorak (1992) presented a theoretical model of a shifting cultivation system, but the detail of the data required to run the model is overwhelming. Trenbath (1984) constructed a much simpler operational model of shifting cultivation, capable of capturing some of the essential biological and economic elements. The conclusions drawn by Trenbath (1984), regarding biological and economic sustainability, however, were limited by the lack of explicit consideration of soil parameters and the relatively short time frame considered.

SCUAF, Soil Changes Under Agro-Forestry (Young et al., 1998), provides a good compromise to the complex theoretical model and the simple operational model. It is a relatively simple deterministic model designed to predict the effect of various tree and crop combinations on soils and commodity outputs (Young et al., 1998). Yet SCUAF has considerably greater biological sophistication than the Trenbath (1984) model. It can support long run analysis, specifically including soil parameters relevant to upland agriculture. Tree and crop combinations can be handled either simultaneously or sequentially. Previous research has shown SCUAF to have the capacity to model the broader features of farming systems in a manner comparable with more complex process models (Nelson et al., 1996).

A bioeconomic modelling approach is used in this study to compare and contrast both the economic viability and the environmental impacts of a short fallow shifting cultivation system and an improved fallow system. The model is based on a spreadsheet version of cost benefit analysis. Cost benefit analysis is used to identify the economically efficient, or optimal, system. The SCUAF model is integrated within the cost benefit analysis framework. SCUAF is used to observe changes in productivity over time. Labour and capital input costs are derived from an economic survey of smallholder farmers. The survey also provides the market prices of farm output that, when used in combination with the changes in productivity calculated by SCUAF, provides the total benefits derived from the farm. SCUAF is also used to observe the physical changes in the farming system over time. Environmental impacts, such as the rate of soil erosion, changes in soil nutrient levels and annual plant biomass production, are provided by SCUAF.

This chapter defines the bioeconomic model that is used in this study. The next section outlines cost benefit analysis and details how it is to be used in this analysis. Section three outlines the SCUAF model and explains how it is integrated in the cost benefit analysis. As this is a site specific model, the model is calibrated to a specific site, Compact in Clavaria, Mindanao, the southern Philippines. However, the results should be considered generally applicable to Southeast Asia. The final section describes the Compact site, providing site details that are relevant to the model.

4.2 Cost Benefit Analysis

4.2.1 Theory of Cost Benefit Analysis.

Cost benefit analysis offers a method for assessing the relative desirability of competing options when deciding the best use for limited resources (Sinden and Thampapillai, 1995). It enables the decision-maker to choose the option that maximises the net benefits received from use of the resource. All advantages and disadvantages, in terms of the costs and benefits associated with the use of the resource, are considered in the cost benefit approach. By including both direct and indirect impacts within the analysis, cost benefit analysis aims to maximise the net social benefit.

Cost benefit analysis involves a systematic categorisation of impacts as costs and benefits. By valuing these impacts in monetary terms, they can easily be compared in terms of the net benefit each proposal provides. The net benefit is a measure of the allocative efficiency of resource use in each option. Determining the net benefit enables the decision-maker to rank competing options on the criterion of economic worth (Boardman et al., 1995). The decision-maker is then in a position to deploy limited resources, such as land, labour and capital, at their highest values, in terms of the goods and services they create. The main advantage of cost benefit analysis is that all costs and benefits are converted to a single denominator, the local currency (pesos[2] in this case), which significantly reduces the complexity of an analysis when comparing very different factors, such as environmental costs and commercial benefits. With all factors scaled into a single unit, the trade-off between the real benefits provided by a given option and the real resources (or costs) that must be given up to receive these benefits can be captured (Sinden and Thampapillai, 1995).

Intertemporal analysis of competing projects can be achieved using discounting within the cost benefit analysis framework. Summation of the discounted stream of costs and benefits provides the net present value of each resource use option. Once the net present value of each project is derived, the decision-maker can rank the alternative projects in order to determine the best use of resources over time. Using this approach the decision-maker can compare the use of resources, or investment opportunities, with different time horizons, and different rates of return.

4.2.2 Pareto Efficiency and the Kaldor-Hicks Compensation Principle

Cost benefit analysis applies the concept of Pareto efficiency to identify the optimal allocation of resources (Sinden and Thampapillai, 1995). An allocation of goods is

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[2] In June 1997 the exchange rate was approximately ₱17:US$1.

Pareto efficient if the resources are allocated such that a re-allocation of the resources cannot make one person better off without making someone else worse off (Sinden and Thampapillai, 1995). Kaldor and Hicks have further refined the concept of Pareto efficiency as it relates to cost benefit analysis, through the Kaldor-Hicks compensation principle. The principle states that an activity or policy "... should be adopted only if those who gain can fully compensate those who lose and still be better off" (Perkins, 1994).

The Kaldor-Hicks compensation principle can be used to define the criteria of a cost benefit analysis. Thus, any increase in costs associated with a new activity, a new farming system in this instance, must be compensated by a greater increase in benefits. Alternatively, an activity (or farming system) is more desirable than the current practice, only if the net benefit that it provides is greater than the net benefit derived from the current practice. In the scenarios considered in this study, if the improved fallow system provides a greater net present value than shifting cultivation, it will be the preferred system. In most applications of cost benefit analysis, if the net benefits to the individual are greater than the costs to society, such that the individual can compensate society for the costs it imposes, then the alternative project should be undertaken.

4.2.3 Social vs Private Objectives.

When calculating the net benefit of an activity, such as a new farming system, an individual will only consider direct costs and benefits, calculating costs and benefits at current market prices. Society, on the other hand, will also consider indirect costs and benefits, including external (off-site) impacts and market distortions, when calculating the net benefit. External impacts include externalities, such as pollution and public good benefits, while market distortions include transfers, such as taxes and subsidies, and trade barriers, such as quota restrictions. The net benefit to an individual can be calculated using financial analysis, which is an accounting method. Calculation of the net benefit to society requires cost benefit analysis, which is much broader in scope.

Financial analysis calculates the net benefit of a project for an investor using current market prices of inputs and outputs. The net benefit is simply an accounting measure of revenue minus costs. No attempt is made to correct the prices of inputs and outputs for market distortion (Perkins, 1994). The firm pays and receives market prices, thus it is only concerned with choosing the project with the largest excess of revenue over receipts, after taxes and interest payments on loans, etc. (Perkins, 1994). Similarly, no attempt is made to include external costs and benefits conferred on other people in the community or imposed on the environment.

Cost benefit analysis is broader than financial analysis as it aims to optimise economic welfare rather than simply maximising profits (Perkins, 1994). In contrast to financial analysis, cost benefit analysis includes all costs and benefits, direct and indirect. These costs and benefits are included irrespective of whether they are incurred or received by the firm, individual or institution undertaking the project. A similar result can be achieved using financial analysis, only if there is compensation for market distortions, and there are no external impacts associated with the project (Perkins, 1994).

4.2.4 Market Distortions in Developing Countries

Many developing countries have quite serious distortions due to the absence of perfect knowledge, government intervention and market failure. As a result, market prices often fail to reflect the true economic value of scarce resources to society.

Imperfect information or knowledge exists in markets of many developing countries due to poor transport and communication infrastructure and low education levels (Perkins, 1994). People are unaware of the true market price of goods and have limited options to access alternative buyers or sellers of the good. This is mainly a result of inadequate integration of markets and the existence of local monopolies or monopsonies. As a result, many goods markets are distorted. This is particularly so in rural areas of developing countries, where isolation leads to limited access to other markets and encourages local monopolies and monopsonies.

Governments in developing countries frequently intervene in import markets by imposing quotas and tariffs to protect activities that are not internationally competitive. The Philippines has a high level of protection of domestic markets. Tariffs and quotas cause a divergence between local market prices and world prices of internationally traded goods. This results in the price of the protected good in the local market exceeding world prices by the amount of tariff protection. However, the tariff protection is not a benefit of production, but a tax on local consumers.

Labour markets are frequently regulated in both developed and developing countries, with fixed minimum wage rates for the formal sector jobs (Perkins, 1994). Unemployment will occur, if the fixed minimum wage rate is set above the market clearing wage rate. This is the case in rural areas of the Philippines, where the hired labour rate is relatively high at ₱60 per day, but the availability of work is infrequent. Unemployment is high and the wage rate does not reflect the true price of labour.

Cost benefit analysis attempts to correct for distortions in market prices by calculating shadow prices of the inputs and outputs of an activity. In the absence of any qualifying factors, the shadow price reflects the marginal cost of any final output. In a perfectly competitive economy, market price will equal marginal cost, so that the market prices are themselves adequate shadow prices. However, if there are market distortions, the market prices will be higher than the marginal cost. By adjusting the price of inputs and outputs to reflect the marginal cost, the shadow price implicit in the Pareto optimality conditions, will maximise net willingness to pay for inputs and outputs (Dasgupta and Pearce, 1972). Thus, cost benefit analysis using shadow prices will provide a more precise calculation of the true economic value of an activity.

4.2.5 Social Discount Rate

The social discount rate should reflect the social opportunity cost of capital funds used by the country as a whole. This will be the opportunity cost of the marginal unit of investable funds to both savers and investors. However, capital markets, like goods markets, are often distorted, by taxes and subsidies, imperfect knowledge, etc, making the social discount rate difficult to determine. There are two main approaches to determining the social discount rate, the shadow price of investment and the weighted average approach. Both approaches will be discussed below.

The shadow price of investment is a conversion factor, rather than a shadow price. It simply determines the social value of investment relative to the social value of consumption. The shadow price of investment in a distorted capital market, is measured by comparing the effect of the distortions in the capital market on savings and investment behaviour, providing a ratio of savings to investment (Marglin, 1963a, 1963b, 1967; UNIDO Guidelines, 1972; Feldstein, 1964). This is then used to calculate a shadow price for all changes in investment, such that all flows of funds are expressed in terms of consumption flows. The consumption flows are then discounted with the social discount rate to determine the Social Rate of Time Preference. If there are distortions in the capital market causing a premium to be placed on investment, then savings and investment will not have an equal economic value to society, and the shadow price of investment will be greater than 1. This is the case for upland farmers in the Philippines, where given their subsistence existence, the social value of consumption is far greater than the social value of savings. The Philippine government has intervened in the capital market, placing a premium on increasing investment by offering subsidies. Here the shadow price of investment will be greater than 1, reflecting the fact that the value of investment exceeds savings. The subsidies have resulted in recipients treating the government credit as grants that do not need to be repaid, and has resulted in many banks becoming insolvent. This has forced interest rates on investment up. Thus, government intervention has resulted in the social discount rate being higher than it would normally be.

The weighted average approach offers an alternative way to calculate the social discount rate for small investments. In distorted capital markets, the social discount rate can be calculated as the weighted average of the supply and demand price for investable funds (Sandmo and Dreze, 1971; Harberger, 1972a, 1972b; Dreze, 1974).

The appropriate weights are then determined by the proportion of the investable funds drawn from consumption and investment, respectively. This provides a social discount rate equal to the opportunity cost of investable funds used in the public sector. The weighted average cost of capital was proven effective in the case where the investment generates a perpetuity (Sjaatad and Wisecarver, 1977). However, if the investment does not generate a perpetuity this approach can distort the social discount rate due to the way funds are reinvested.

In a special case of the weighted average approach, the social discount rate in a competitive international market where capital is a traded good, will be the interest rate at which the country can borrow on the international capital market. A country not heavily indebted, can draw freely from borrowings from foreign capital markets. In this situation the supply curve for investable funds is the elastic international supply curve for capital. The interest rate in the international capital market varies at different times, but averages 4 to 5 per cent in real terms in the long term (Perkins, 1994). In this situation, after account is taken for exchange rate movements, the social discount rate is simply the real international borrowing rate.

However, if a country is heavily indebted and investors cannot draw freely on international capital markets, capital will essentially be a non-traded good. This situation may arise either because of domestic restrictions on overseas borrowing by individuals or problems in obtaining access to foreign capital due to heavy indebtedness of the country and resulting debt service problem. This is the case in the Philippines where credit markets are controlled by financial policies administered by the central bank. As a result of government intervention in the Philippine credit markets the supply curve for investable funds is less than completely elastic. Policies aimed at subsidizing rural credit, have had the opposite effect, with the total interest rate on loans increasing three fold (Lambert and Lim, 1987).

4.2.6 Cost Benefit Analysis to Assess the Potential of an Improved Fallow System.

Cost benefit analysis is used in this application as a means of comparing the economic returns of shifting cultivation (the status quo), and an improved fallow system over time. These systems have different implications for soil quality and production over time, which make it difficult for farmers and/or governments to compare directly. In this instance, cost benefit analysis offers a technique for comparing the different farming systems over time. This approach does not necessarily identify the optimal soil use over time, but it does provide an economic ranking of the systems under consideration, thus enabling the user to identify the system offering the highest net benefit.

The improved fallow system has higher costs than shifting cultivation, due to the higher labour and capital demands associated with the establishment of the plantation fallow. However, the long term benefits are also expected to be higher, due to improved crop productivity, the sale of firewood and reduced land degradation. If the higher returns from the improved fallow system offset the additional costs, then the improved fallow system should be developed further. Using the cost benefit approach the farming system with the highest net present value over the given time horizon, will provide the most efficient use of resources.

This study will initially calculate the net benefits of shifting cultivation and the improved fallow system using financial analysis. It will then attempt to correct for market distortions caused by import restriction, limited opportunities for off farm employment and restricted access to capital. The corrections involve substituting the market price for maize with the world price, using an own labour wage rate instead of the hired labour wage rate and introducing a social discount rate. The results of this analysis will help determine whether it is socially desirable to adopt improved fallow system in regions where shifting cultivation is currently practiced. This will assist decision-makers, such as governments and research organisations, to decide whether expenditure on further research and development of the improved fallow system is justified.

4.3 The SCUAF model

4.3.1 General Description of SCUAF Version 4.

SCUAF is a simple model that can be used to predict the effect of agroforestry systems on soil (Young et al., 1998). It represents the outcomes of years of agroforesty and soil conservation research (Young, 1989). Erosion is predicted in SCUAF using the modified universal soil loss equation (MUSLE) (FAO, 1979) based on average year climate and soil characteristics. Through a calculation of the rate of soil erosion, the rate of nutrient uptake by plants, nutrient cycling and nutrient additions, the levels of carbon, nitrogen and phosphorus in the soil profile are adjusted. From this, changes in crop yield and tree biomass are calculated.

SCUAF 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. The primary basis for description of the land use system is the proportion of trees and crops in each successive year (Young et al., 1998). Other elements of the land use system are additions (organic additions or inorganic fertilizers), removals (harvest and other losses), tree leaf prunings 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.

SCUAF is a process-response model, not a plant growth simulation model (Young et al., 1998). The user enters the initial rates of plant growth for each of the components of the system (trees and crops), in terms of biomass production per year. The model then estimates the effects of changes in soil properties on subsequent rates of plant growth.

If all site information required by the model cannot be obtained, a set of default values is available. These vary according to the physical environment specified by the user, in terms of climate, soil, slope, etc. The default values provide reasonable estimates for variables that have not been measured (Young et al., 1998).

SCUAF is primarily intended for simulation over periods of the order of 10-20 years, i.e. for the assessment of land use sustainability within the medium term (Young et al., 1998). It can also be applied to long-term simulation, provided the user is aware of the pitfalls inherent in long-term extrapolation.

4.3.2 Bioeconomic Modelling Using SCUAF

Data from research trials provide the basis for calibration of SCUAF to local conditions. From this the SCUAF model simulates two sets of outputs: changes in soil properties over time, including erosion and fertility; and, changes in plant growth (trees and crops) over time (Young et al., 1998). The trends in soil properties form a basis for assessment of environmental costs or benefits.

Parallel with the above, farm surveys undertaken by Nelson et al. (1996) 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.

4.3.3 Agroforestry-specific features of SCUAF

A number of SCUAF elements are designed to permit modelling of agroforestry systems. All this stems 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 per cent 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.

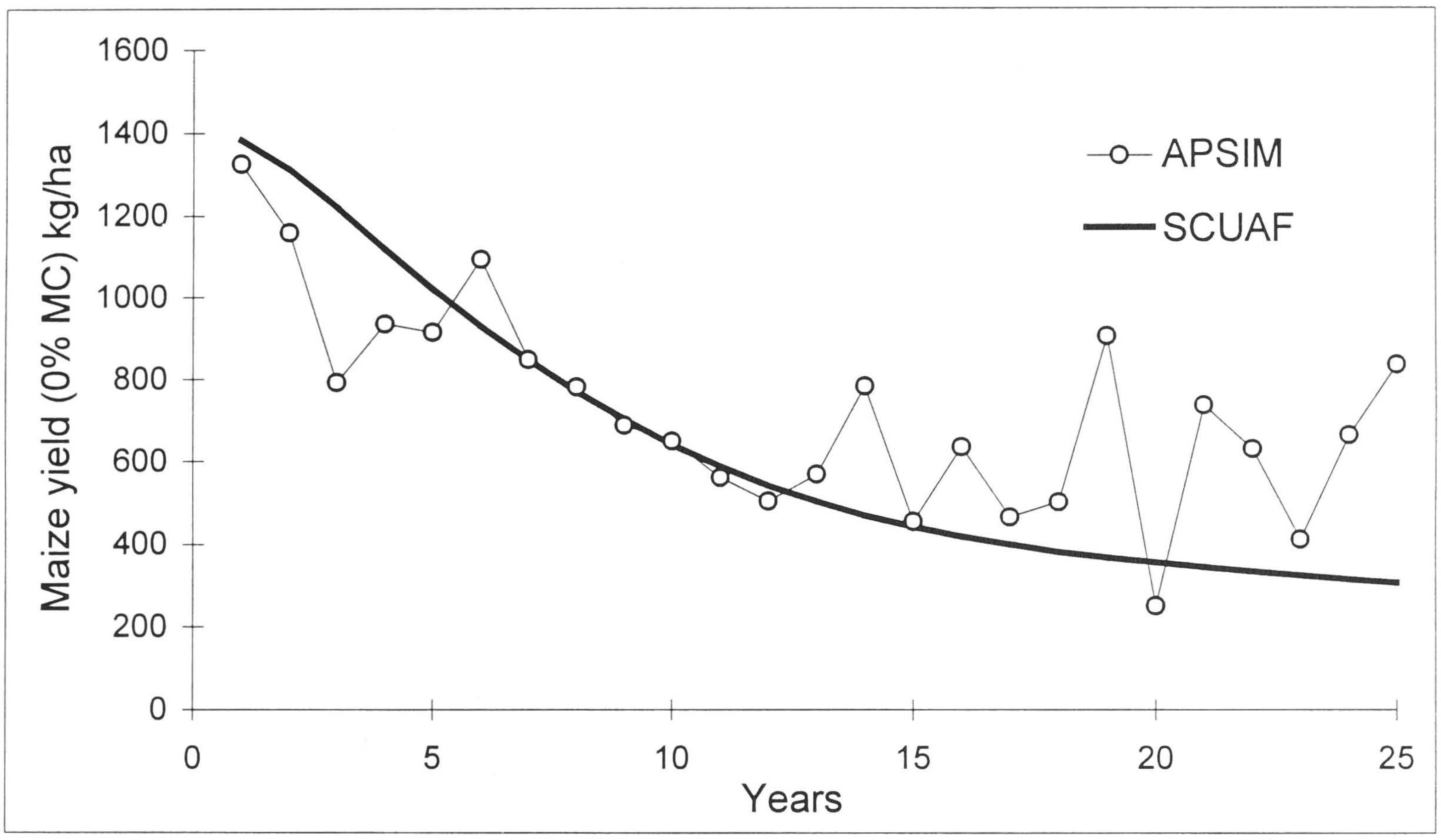
(Young et al., 1998)

4.3.4 Model validation

Two previous applications of SCUAF lend confidence to 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 that SCUAF provided reasonable predictions for maize and tree growth.

In the second case, Nelson et al (1996a) compared the results from 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. (1996a) 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 4.1).

Figure 4.1 **A comparison of wet season maize yields for continuous open-field farming predicted using the APSIM and SCUAF models.**



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 (Young et al., 1998). 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, inevitably some degree of physical realism is lost.

4.4 The Compact Site

The SCUAF model is a site specific model, requiring detailed data from an actual site (Young et al., 1998). If more general conclusions are to be drawn they can be inferred from the results of the specific site. For this application, SCUAF was calibrated based on the Compact site near Claveria, in the Philippines. Compact is a research station established primarily to trial hedgerow intercropping regimes. It was originally developed by the International Rice Research Institute (IRRI) in the mid-1980's, but responsibility has since been transferred to the International Centre for Research into Agroforestry (ICRAF) (Nelson et al., 1996b). This site was chosen due to the availability of large detailed data sets from previous research at the site. It was also chosen in order to allow comparison with data resulting from similar modelling carried out there by Nelson et al (1996b). A further advantage is the availability of recent, detailed economic data for the Claveria area (Nelson et al., 1996b).

Details of biophysical research trials carried out at the Compact site can be found in Agus (1994), Nelson et al (1996b) and ICRAF (undated). Although the trials at Compact were for hedgerow intercropping, the information will be extrapolated and combined with other research data to apply to the improved plantation fallow scenario. The data from the Compact site includes the basic soil and climate data necessary to run SCUAF. Furthermore the experimental yield data for both crop (maize) and tree legume (*Gliricidia*) can be used as a yardstick to ensure the results obtained from the model are reasonable.

4.4.1 Biophysical Features of Compact

The Compact site, as outlined by Nelson et al (1996b), falls within the lowland humid class used in SCUAF (Young et al., 1998)[3]. Rainfall is typically greater than 1,800 mm per year, with four dry months. The Compact site has a moderate slope of approximately twenty per cent and a relatively low elevation of 200 metres above sea level.

The soil at Compact is a well drained oxisol; acidic (pH between 4.5 and 5.0), deep and highly weathered. The soil has good structure and drainage and there are no significant changes in clay content with depth. Table 4.1, derived from research by Agus (1994), presents the soil profile characteristics for the Compact site, including the depth of the first five profile layers, carbon and nitrogen content of each layer and the bulk density at each level.

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[3] SCUAF uses a Koppen climate classification.

Table 4.1 **Soil profile characteristics at Compact.**

Soil Profile Layer	Depth (cm)	Carbon (%)	Nitrogen (%)	Bulk Density (g cm^{-1})
1	0-14	1.30	0.13	1.09
2	14-31	0.50	0.06	1.05
3	31-59	0.40	0.05	1.00
4	59-85	0.40	0.04	0.95
5	85-111	0.40	0.04	0.90
Avarage 2-5		0.43	0.05	0.98

(Agus, 1994)

Previous research trials had shown erodability at the Compact site to be relatively low, averaging 26.6 tonnes per hectare per year in the first five years of the trials for open field farming (Nelson et al., 1996b). When initialising SCUAF, the MUSLE (Modified Universal Soil Loss Equation) factors were conservative relative to the default factors for a similar environment to capture the low erodability (Young et al., 1998). The MUSLE factors were:

- rainfall factor - 900, based on the average rainfall at the Compact site over four years (1989-92) of approximately 1,800 mm per year (Agus, 1994);
- slope factor - 1.5, based on the moderately steep slope in experimental plots (Nelson et al., 1996b);
- soil erodability factor - 0.09 (Limbaga, 1993, and Nelson et al., 1996).
- tree (and *Imperata*) cover factor - 0.006 (SCUAF default value, Young et al., 1998); and,
- crop cover factor - 0.3 (SCUAF default value, Young et al., 1998).

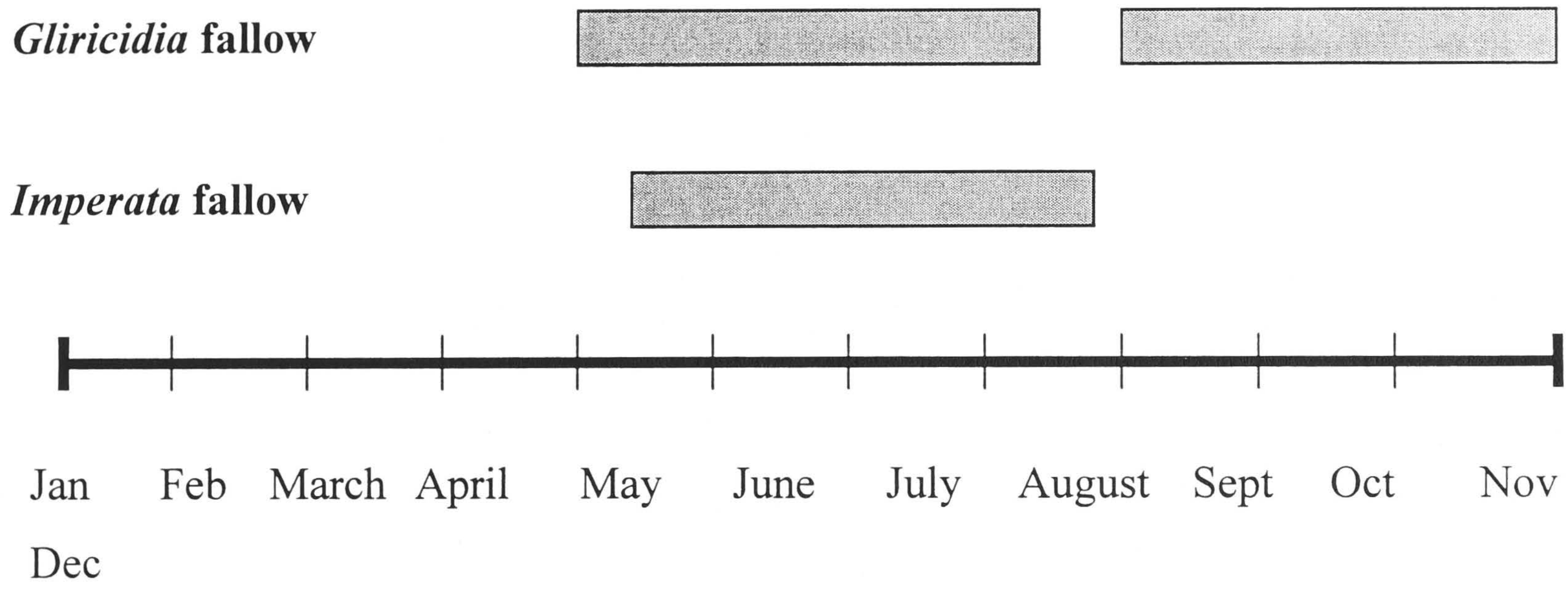
Using these factors an initial rate of erosion for open field cropping of 35 tonnes per hectare per year was predicted by SCUAF. Thus, by calibrating SCUAF to the conditions prevailing at Compact, a reasonable prediction of average historical soil erosion was obtained. These parameters are similar, but not identical to those used by Nelson et al. (1996b).

4.4.2 Soil and plant growth characteristics at Compact for the calibration of SCUAF.

The *Gliricidia* fallow system produces a high level of soil fertility, enabling the planting of two maize crops in the wet season and dry season. The wet season crop is planted between May and June and harvested in August, while the dry season crop is planted between September and October and harvested between December and January (see figure 4.2). In research station trials of *Gliricidia* hedgerows, maize net primary production averaged 7.2 tonnes per hectare (including stover) in the wet season, and 2.5 tonnes per hectare in the dry season. Consequently, the initial (first year of cropping) wet season maize grain yield in SCUAF was specified to be 2.2 tonnes per hectare, and the dry season maize grain yield to be 0.8 tonnes per hectare (Nelson et al., 1996b). Biomass production of *Gliricidia* was specified in the model as 11.4 tonnes per hectare, with leaf production at 7.7 tonnes per hectare, and wood production at 3.7 tonnes per hectare. These figures are derived from measurements of biomass production of *Gliricidia* hedgerows at Compact, by Nelson et al. (1996b). 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 within the *Imperata* fallow system is low. Only a wet season crop can be established, due to a lack of soil nutrients and soil moisture, which does not allow a dry season crop (see figure 4.2).

Figure 4.2 **Comparison of the cropping cycle of the *Gliricidia* fallow and *Imperata* fallow systems.**



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, such as carbon, nitrogen and phosphorus, SCUAF uses the law of the minimum approach to determine the 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 tonnes per hectare. Biomass production of the *Imperata* is modelled as being approximately four tonnes per hectare per year (from Castillo and Siapno, 1995 and Sajise, 1980).

To determine 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 nitrogen content of *Gliricidia* at Compact was 2.5 per cent for foliage and 0.5 per cent for wood (Agus, 1994). The nitrogen content of *Imperata* was measured by Sajise (1980) to be 0.94 per cent. For maize the SCUAF default values of 2.0 per cent nitrogen crop residues (leaf) and 3.0 per cent for maize grain, were accepted. The phosphorus content of both *Imperata* and maize was calculated by Lowry et al. (1992) to be 0.2 per cent. Maclean et al. (1992) calculated the phosphorus content of the *Gliricidia* leaf to be 0.27 per cent, and Agus (1994) calculated that the average phosphorus content of all plant parts to be 0.2 per cent. This implies that the phosphorus content of the wood is 0.065 per cent. Agus (1994) and Nelson et al (1996b) provide a detailed description of the site conditions at Compact.

SCUAF determines plant growth and soil changes on a per hectare basis. To translate these results onto a whole farm basis, the economic model takes account of the average area available to upland smallholders. For this analysis, two hectares was chosen to represent this average available land area (van Noordwijk et al., 1995; Menz et al., 1995; RePPProT, 1989).

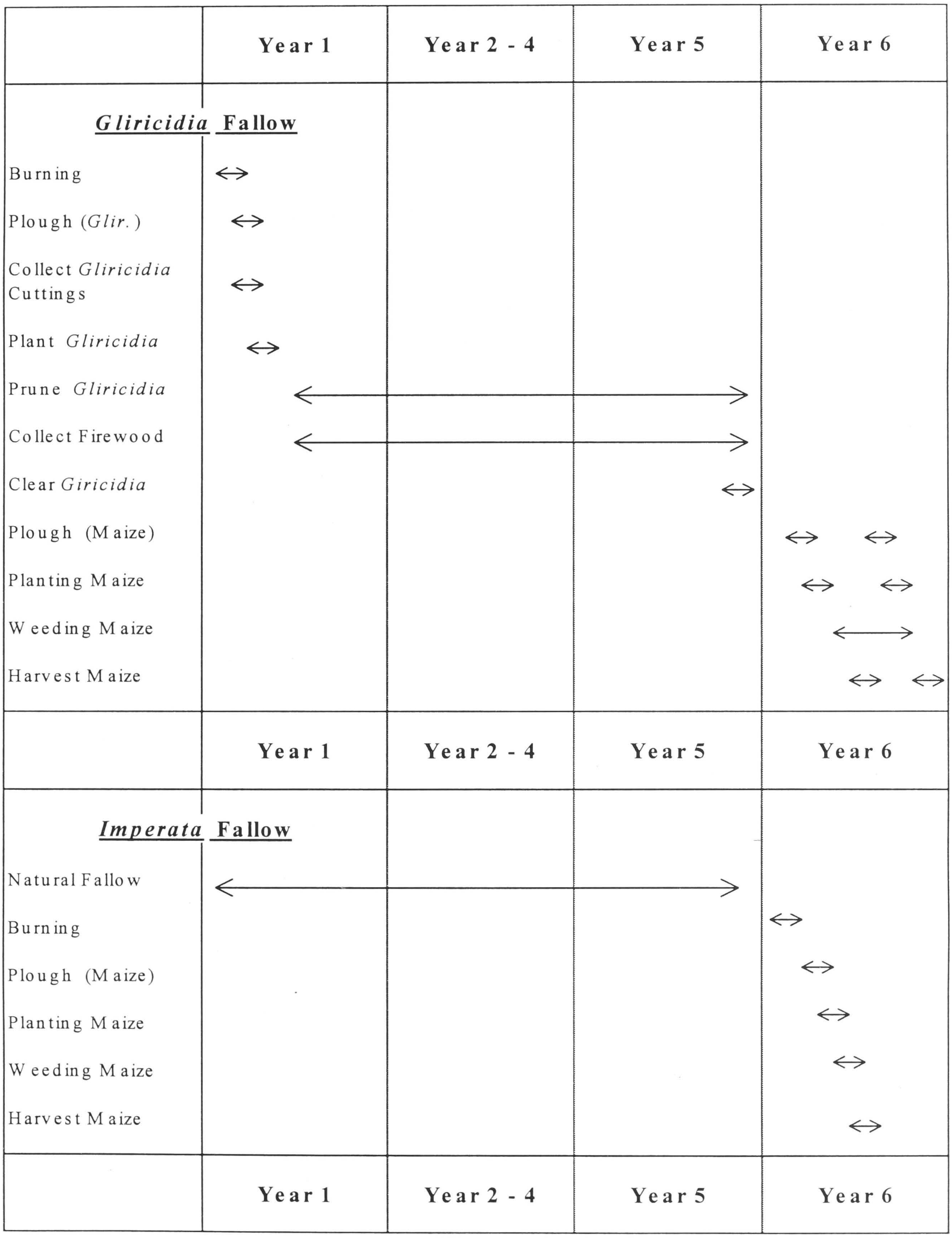
Chapter 5. A Biophysical Assessment of the Improved Fallow System.

5.1 Introduction

The effect of rapid population growth and shrinking fallow periods on the sustainability of traditional shifting cultivation systems, and the associated land degradation resulting from continued use of shifting cultivation, were considered in Chapters 1 and 2. Details of a potentially more sustainable, and less land degrading system, an improved fallow system, was also considered in these chapters. The improved (or *Gliricidia*) fallow system, which involves establishing a *Gliricidia* plantation in the fallow period, is an adaptation of the improved fallow systems conceived by Garrity (1993) and MacDickens (1990). This chapter will present an experimental analysis of the biophysical characteristics of the *Gliricidia* fallow system. The biophysical potential of the *Gliricidia* fallow system and an *Imperata* fallow system are analysed using a computer simulation model, SCUAF, which is detailed in Chapter 4. The model is calibrated using data from field trials at Compact, Mindanao, the Philippines.

This chapter focuses on the biophysical characteristics of the systems, with the following chapter concerned with the economic analysis of the systems. The main biophysical features that are considered in this analysis are crop productivity or yield, soil nutrient levels and soil erosion. Using SCUAF, the changes in productivity, soil nutrient levels and rates of soil erosion are observed over time. This provides an indication of the long term sustainability of the systems.

Figure 5.1 **Summary of the *Gliricidia* fallow and *Imperata* fallow farming systems.**



5.2 Outline of the two fallow systems

The two systems considered are: an improved fallow system, based on a *Gliricidia* plantation; and, an *Imperata* fallow system, which is common in the more remote upland areas of Southeast Asia. Both systems involve five years of fallow followed by one year of cropping. The following description outlines each system. A summary of the two systems is given in Figure 5.1.

In the proposed *Gliricidia* fallow system, one sixth of the land available is planted as a *Gliricidia* plantation each year, and another sixth is 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, and maize is preceded by five years of *Gliricidia* plantation (fallow). Figure 5.2 illustrates the crop rotation over the six years of the crop cycle.

Figure 5.2 **Crop rotation in each year of the *Imperata* and *Gliricidia* fallow systems.**

Crop	Fallow
Fallow	Fallow
Fallow	Fallow

Year 1

Fallow	**Crop**
Fallow	Fallow
Fallow	Fallow

Year 2

Fallow	Fallow
Crop	Fallow
Fallow	Fallow

Year 3

Fallow	Fallow
Fallow	**Crop**
Fallow	Fallow

Year 4

Fallow	Fallow
Fallow	Fallow
Crop	Fallow

Year 5

Fallow	Fallow
Fallow	Fallow
Fallow	**Crop**

Year 6

Preparing land for *Gliricidia* requires 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, with two rows planted 50 cm apart and with 50 cm between the trees within the rows. A gap of 1.5 m is left to the next pair of rows.

Imperata is stimulated by burning and ploughing, so it is important to co-ordinate burning of the existing vegetation at the end of the dry season, and planting of the *Gliricidia* cuttings at the beginning of the rains. *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.[4] 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 the 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 provides a dense cover shading the *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.

An illustration of the flow of resources in the *Gliricidia* fallow system can be seen in Figure 5.3. The improved fallow is self-sustaining with cuttings for reestablishment of the *Gliricidia* plantation taken from adjacent *Gliricidia* plots. *Gliricidia* prunings are left under the *Gliricidia* plantation as mulch to improve soil fertility and to assist in suppressing *Imperata.*

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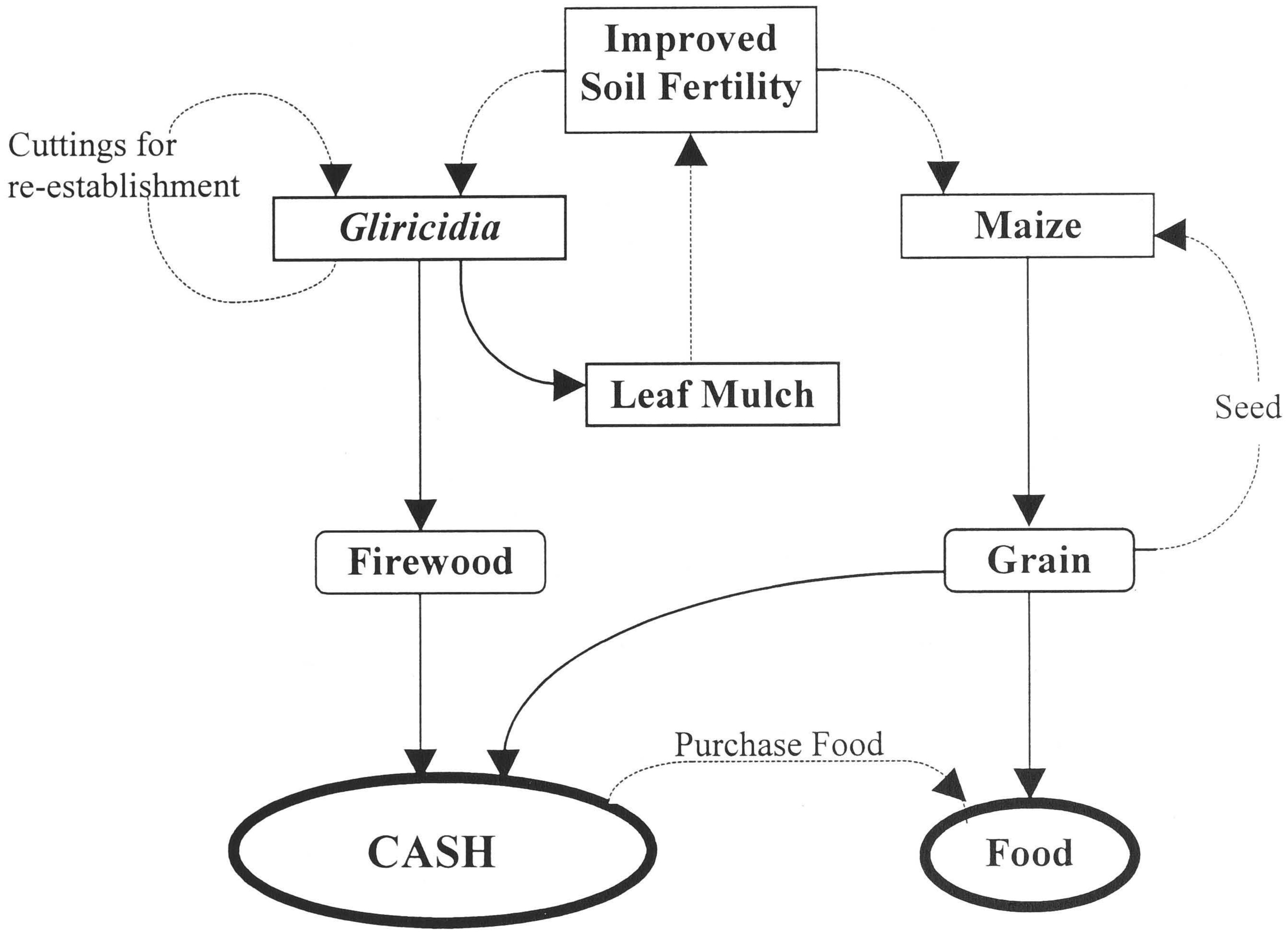
[4] Pruning is also an opportune time to collect cuttings for the establishment of *Gliricidia* on other plots.

Figure 5.3 **The flow of resources in the *Gliricidia* Fallow system.**



In the *Imperata* fallow system, the land is abandoned 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 has shown that only one maize crop per year can be supported by the level of soil fertility following a five year *Imperata* fallow system. This is mainly due to the poor replenishment of soil nutrients during the *Imperata* fallow period. After the year of cropping the site is again abandoned to *Imperata*.

5.2.1 The site used for model calibration.

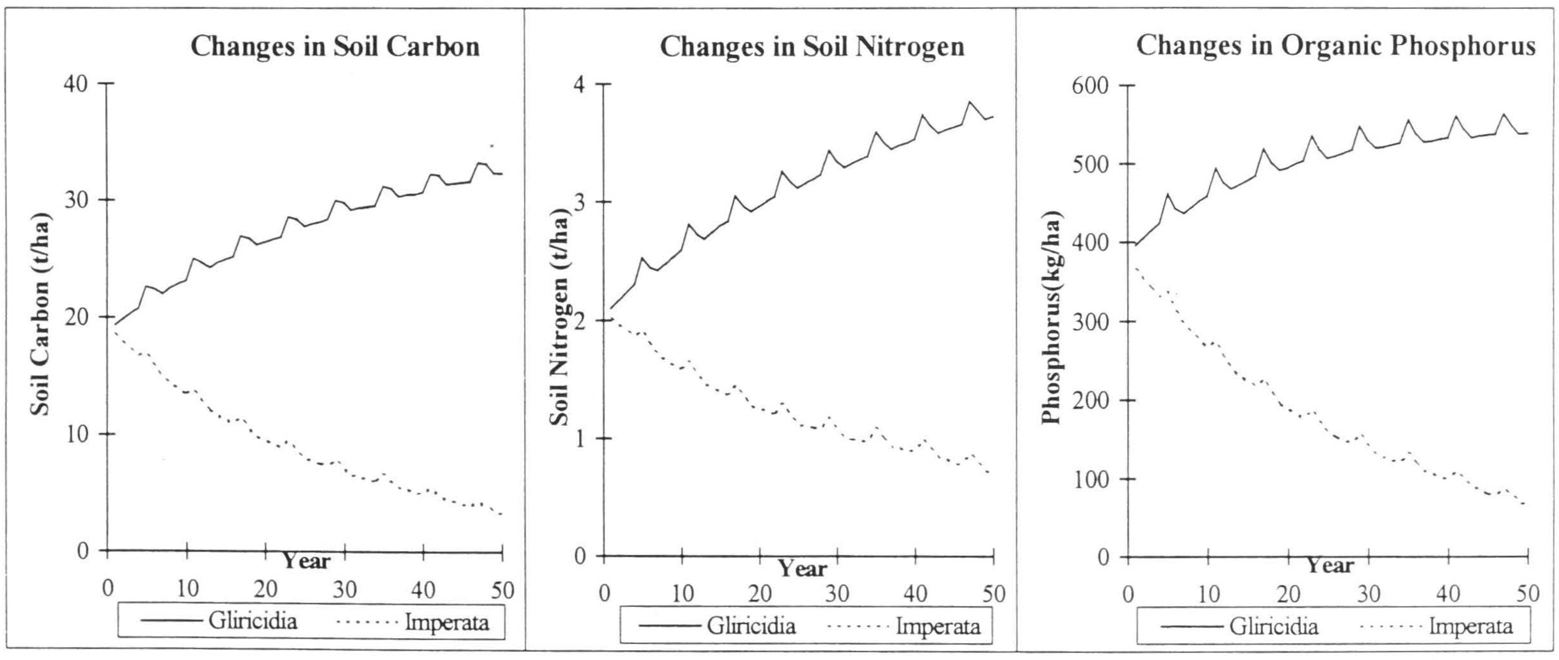
Although the model is intended to be generally applicable to upland areas of Southeast Asia, for validation purposes, the model is calibrated to a specific site. Compact, a research station near Claveria in Mindanao, the Philippines was chosen for this purpose. A detailed site description of Compact and a description of the model (SCUAF) used in this analysis, are presented earlier in Chapter 4.

5.3 Results and Discussion

5.3.1 Soil Nutrients

Changes in soil nutrients over time for traditional *Imperata* fallow and *Gliricidia* fallow systems are shown in Figure 5.4. For the *Imperata* fallow, the three nutrients (Carbon, Nitrogen and Phosphorus) show declining trends similar to those found in previous studies (Grist and Menz, 1996; Menz and Grist, 1996). Through erosion and through uptake by plants, nutrient levels decline during both crop and fallow.

Figure 5.4 **Changes in available Carbon, Nitrogen and Phosphorus over time in the improved and *Imperata* fallow systems.**



The final year of *Imperata* fallow involves burning to remove *Imperata* biomass in preparation for cropping. Associated with this burn, there is a consequent release of nutrients. Previous research of slash and burn agriculture has shown that more than 90 per cent of carbon, 60 per cent of nitrogen and a small amount of phosphorus from the plant biomass is lost in a burn (Andriesse and Koopmans, 1984). However, the nutrients from the stored biomass that are not lost in the burn, ie 40 per cent of nitrogen and almost 100 per cent of phosphorus, are mineralised. These become available for plant growth following the burn, enabling better crop growth. However, in the long term there is a net decline in nutrients following burning (Grist and Menz, 1996).

Generally, the level of soil nutrients in the *Gliricidia* fallow system moves in the opposite direction to the level in the *Imperata* fallow. Soil nutrients steadily increase in the fallow period. This is due mainly to the effect of mulching the *Gliricidia* foliage. *Gliricidia* is fast growing, accumulating a large amount of biomass over time, it also breaks down quickly. When used as mulch, the foliage has a half life of 20 days, which results in a rapid recycling of soil nutrients (Simons and Stewart, 1994).

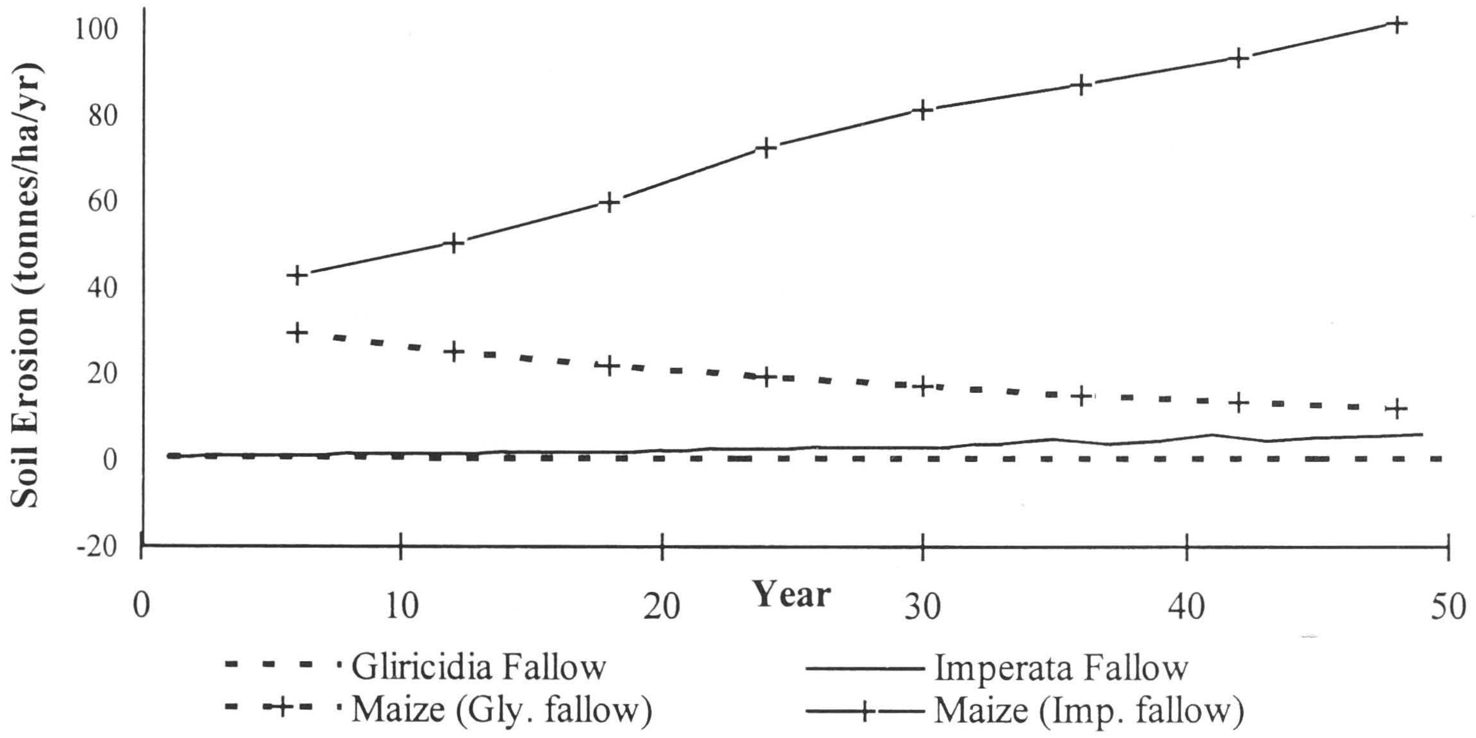
The mulching effect enhances organic matter buildup under the plantation. This enhances soil carbon levels, which increase in line with the increasing levels of soil organic matter. Soil nitrogen levels are improved by mulching the leaves of the nitrogen-fixing *Gliricidia.* The increase in soil phosphorus is due to the nutrient pumping effect of the roots, a percentage of which are deemed in the model to be below the soil depth considered in this analysis. The nutrients are thought to be 'pumped' from the lower soil levels into the leaves and then ultimately in the topsoil by mulching.

In the year of cropping mulching does not occur and the nutrients extracted by the crop are greater than the amount required by *Gliricidia.* As a result, there is a decline in nutrients in the cropping year. With the improved fallow, the increase in nutrients in the fallow period is greater than the nutrient demand in the crop year. Thus, there is a net increase in nutrients over time in the improved fallow. The converse is true with the *Imperata* fallow. Thus, there is a cumulative fertility enhancement under a *Gliricidia* fallow.

5.3.2 Soil Erosion

Annual soil erosion for both the *Imperata* fallow and the *Gliricidia* fallow systems are presented in Figure 5.5. In the *Imperata* fallow, annual soil erosion increases over time, which has a compounding effect. Soil erosion decreases biomass production. Subsequently soil cover and soil stability decrease. Most soil erosion occurs during the cropping years.

Figure 5.5 **Annual erosion over time for the improved and *Imperata* fallow systems.**



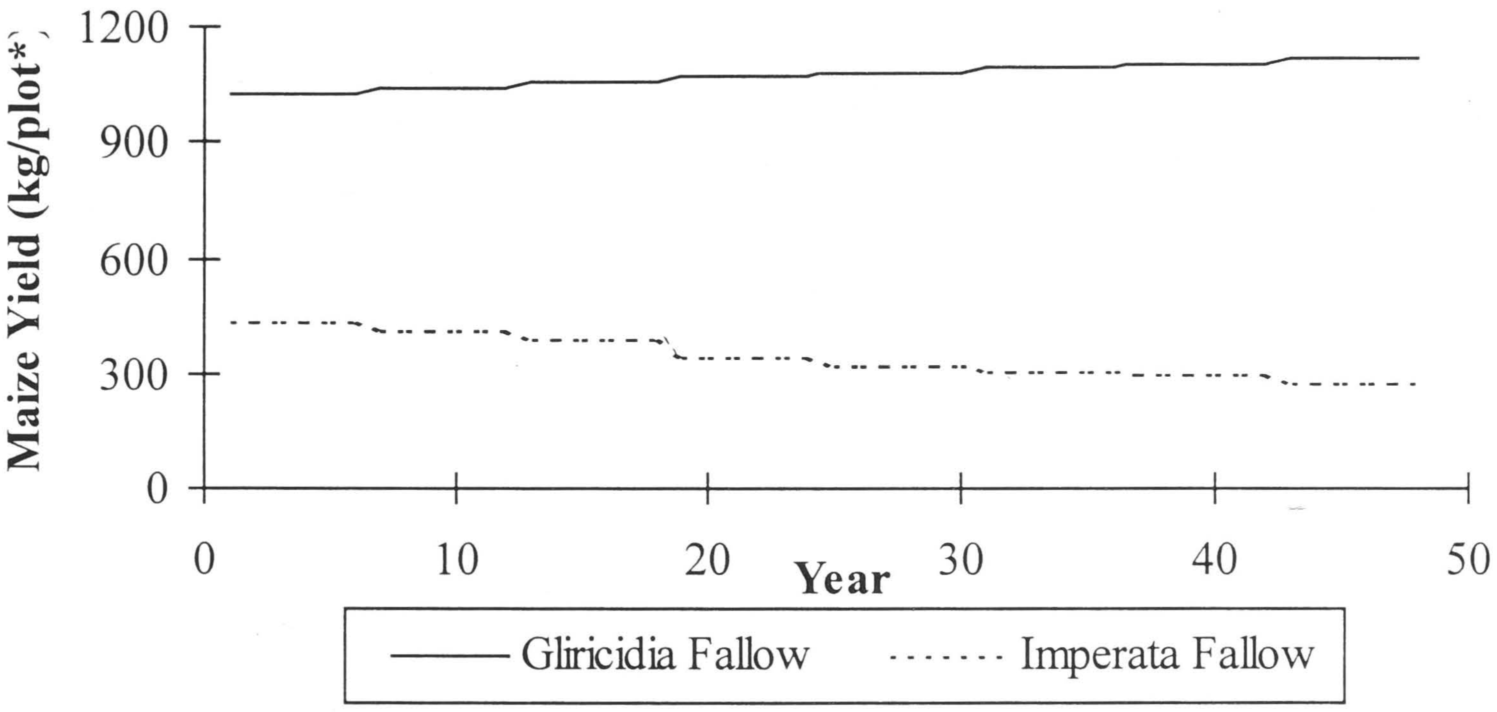
Soil erosion during the cropping phase of the *Gliricidia* fallow system was shown to decrease over time. This decrease is a result of the increase in soil organic matter, associated with mulching, which stabilises the soil, reducing the impact of rain and surface runoff. Also, higher nutrient levels allow increased biomass production, protecting and stabilising the soil. As with the *Imperata* fallow most soil erosion occurs during the cropping years.

Although not depicted here, erosion of soil carbon, nitrogen and phosphorus follow similar trends to soil erosion for the *Imperata* fallow, and for the *Gliricidia* fallow, respectively.

5.3.3 Crop Yield

An assumption inherent in this analysis is that the two hectares of land available to the farmer is divided into six equally sized ($^1/_3$ ha) parcels. This allows for one plot to be planted with maize and harvested in each year on a six year rotation. Figure 5.6 shows the expected annual crop yield for an area available to the smallholder of two hectares.

Figure 5.6 **Expected annual crop yield for the *Gliricidia* and *Imperata* fallow systems for an "available" area of two hectares**
(harvested area $^1/_3$ of a hectare).



* Annual yield is calculated for the whole farm based a two hectare 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 kilograms per one third of a hectare, assuming two maize crops in the year following *Gliricidia* fallow and one maize crop in the year following *Imperata* fallow.

Crop yield is related to soil fertility. Thus, maize yield in the *Imperata* fallow declines over time, and maize yield in the improved fallow shows a slight increases over time. Over the eight cycles (48 years) considered in this analysis, maize yield in the improved fallow system increases by ten per cent and maize yield in the *Imperata* fallow system decreases by thirty percent.

The maize yield decline in the *Imperata* fallow system is consistent with the trends observed by Grist and Menz, 1996; Menz and Grist, 1996; and Trenbath, 1984. However, given that the soil at Claveria is more stable, with less soil erosion and loss of soil nutrients, the yield decline at Claveria is at a slower rate than that found in the other studies.

The initial maize yield of the *Imperata* fallow is lower than the maize yield of the improved fallow. The improved fallow has a greater (faster) recovery of nutrients. Thus, it can sustain the higher crop growth rate. Mulching of *Gliricidia* also enables the soil to better retain moisture (soil water).[5] The result is that the improved fallow can provide two maize crops, a wet season and a dry season crop. Alternatively the *Imperata* fallow cannot sustain a second (dry season) maize crop. As a result, the initial crop yield in the *Imperata* fallow is less than half of the crop yield of the improved fallow (Figure 5.6).

As well as a higher maize yield, the improved fallow supplies firewood. Firewood yield increases over time at a similar rate to crop yield. Small firewood yields of approximately 400 kg per hectare are provided annually as a by-product of mulching (branches are cut in the process of mulching the foliage), and a large firewood yield, of greater than 12 tonnes per hectare, is provided in the cut year.

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[5] Soil water is not included in the SCUAF model. However, the assumption of improved soil under a *Gliricidia* fallow was relevant in specifying the expected initial maize yield and net primary production in SCUAF.

5.4 Conclusion

This analysis has shown that the *Gliricidia* fallow system has significant potential from a biophysical perspective. The nitrogen fixing ability of the tree and the deep rooting, which cycled nutrients from deep in the soil profile, improved soil nutrient levels. The thick mulch layer, resulting from the regular pruning of the *Gliricidia* foliage, led to improved soil stability and slowed the rate of erosion. The net result was an increase in productivity of the maize crop, which followed the *Gliricidia* fallow period.

The *Imperata* fallow system, which is used as the baseline in this analysis, did not fare as well. A five year *Imperata* fallow was too short to see an improvement in soil nutrients after a period of cropping. Biomass production was low due to the low soil nutrient levels, providing a low level of ground cover, which in turn led to a high level of soil erosion. The *Imperata* fallow system proved to be unsustainable in the long term due to the slow recovery of soil nutrients and high levels of erosion. Crop yields continually declined over the period under consideration in the *Imperata* fallow.

Although still practiced by smallholders, this analysis has shown that the *Imperata* fallow is unsustainable over the long term. Thus, from a biophysical perspective the *Imperata* fallow system is relatively unattractive. The *Gliricidia* fallow system, in comparison, proved sustainable in the long term. Thus, was very attractive from both environmental and productivity standpoints. As a result, it has potential for adoption based on these biophysical criteria. However, farmers are driven as much by economic imperatives as they are by environmental factors and productivity. 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). The next chapter will assess the economic potential of the *Gliricidia* fallow system and the *Imperata* fallow system, from both private and social perspectives.

Chapter 6. An Economic Appraisal of the *Gliricidia* Fallow System

6.1 Introduction

Based on environmental criteria alone, the *Gliricidia* fallow system was shown in the previous chapter to be a more sustainable system than the *Imperata* fallow system. Improvements in crop yield and a reduction in soil erosion and soil nutrient loss were achieved, when compared with the *Imperata* fallow system.

However, environmental criteria are not the only factors that determine the adoption of new farming systems. The systems also need to be proven to be beneficial economically. This chapter assesses both the net private economic benefit to the smallholder, as well as the net social benefit, of adopting an improved fallow system. A financial analysis approach is used to determine private benefits and a social cost benefit analysis approach is used to determine social benefits. The social cost benefit analysis will focus on market distortions, identifying the shadow prices of labour inputs and maize. Environmental and off-site benefits do exist in these farming systems, although an empirical estimate is not made in this study due to unavailability of data and appropriate techniques. This analysis should be seen as a conservative calculation, or an underestimate, of the net social benefit of the *Gliricidia* fallow system, as the benefits would be greater if the environmental benefits were included.

This chapter begins by describing the model for both the financial and cost benefit analyses. It will then define the parameters used in the financial analysis and the cost benefit analysis, with particular attention given to the determination of the shadow prices for both labour and maize. The model will then be used to calculate the net present value of the *Imperata* fallow and the *Gliricidia* fallow systems. This is followed by a short discussion of the analytical basis of the measure of benefits to society.

6.2 The Computer Model

Both the financial analysis and the cost benefit analysis carried out in this chapter use the same spreadsheet modelling approach. The spreadsheet model simply involves a calculation of the revenues and costs derived in each year by the farming system under consideration. The costs are then subtracted from the revenues to provide the annual return, which is discounted and added to provide the net benefit from the farming system. Once calculated the net present value of the *Imperata* fallow system and the *Gliricidia* fallow system can be compared to demonstrate the preferred farming system.

The analysis of both systems is carried out over a period of 48 years. Some may question the suitability of consideration of the farming systems over this long period in light of the discounting effect. This question is not unreasonable, as at a discount rate of 12 per cent the present day value falls to less than 10 per cent its value in less than 20 years and approximately 0.5 per cent of its value after 48 years. At a 25 per cent discount rate it takes only 11 years for the present value to fall below 10 per cent. However, it can also be argued that at a 12 per cent discount rate the net present value of the farming system is not significantly different to the present value for 20 years. Similarly, at a 25 per cent discount rate the net present value is not significantly different to the present value for 11 years. The 48 year period was chosen to observe the environmental effects which are more long term, especially given that a single rotation requires six years. For consistency this was carried over into the financial and cost benefit analysis, although as explained above these analysis are representative of much shorter periods.

The benefits and costs occur at various times during the year, however in this analysis they will be considered to be occurring at the end of the year. The monthly distribution of the costs and benefits were not considered, due to the long time horizon that is considered in this analysis. It was also felt that given other variables in the model are treated at an aggregate or average level, averaging costs and benefits over the year was acceptable, as long as the timing of costs and benefits are consistent, that is both occurring at the same time of the year.

If costs and benefits were calculated on a monthly basis the total horizon for the 48 years considered in this analysis would be 576 months (48 x 12). The monthly discount rate would be ${}^{r}/_{12} = \rho$. If the months are labeled as j, then:

$$\mathbf{NPV_{nx12}} = \sum_{j=0}^{nx12} \frac{\mathbf{B_i}}{\mathbf{(1+\rho)^j}} - \frac{\mathbf{C_i}}{\mathbf{(1+\rho)^j}}. \qquad \mathbf{j = 0, 1, 2, \ldots\ldots, n \times 12}$$

Calculated in years, with all costs and benefits occurring at the end of the year, if the years are labeled as i, the equation becomes:

$$\mathbf{NPV_n} = \sum_{i=0}^{n} \frac{\mathbf{B_i}}{\mathbf{(1+r)^i}} - \frac{\mathbf{C_i}}{\mathbf{(1+r)^i}}. \qquad \mathbf{i = 0, 1, 2, \ldots\ldots, n}$$

where **NVP** = the net present value of the system over the number of years considered

B = the stream of the benefits - $B_1, B_2, B_3, \ldots\ldots, B_n$

C = the stream of the costs - $C_1, C_2, C_3, \ldots\ldots, C_n$

r = the discount rate

n = the number of years

For smallholder farming systems, which include both the *Imperata* and *Gliricidia* fallow systems, by far the most significant input costs are associated with labour. Other costs must also be included, such as the purchase price of maize seed, but these will be minor compared to the total labour input. In most cases, the labour input into the system consists of the farmer's own labour and the labour of other family members, none of which will derive a direct wage from his or her labour. However, there is an opportunity cost as the farmer and his or her family can do other things with their time, whether it be paid work for someone else, fishing, mending the house or leisure activities. As there is an opportunity cost to the farmer and his or her family working on the farm, a wage rate is applied for farm labour.

6.3 Economic Factors of the Claveria Region

The data used in the economic analysis was derived from three sources: a computer based (biophysical) agroforestry model, SCUAF Version 4; a literature review; and an economic survey, carried out by Nelson et al. (1996c).

Crop yield and *Gliricidia* biomass production, calculated using SCUAF in the biophysical analysis, were fed directly into the financial analysis and cost benefit analysis spreadsheets. These were used to help calculate the annual revenue from each of the systems. Details of SCUAF, the biophysical analysis and the time series of yields derived have been provided in the previous chapter. Details of the literature review and the economic survey carried out by Nelson et al. (1996c) are provided in more detail here.

6.3.1 Labour Requirements

The labour requirements for the *Gliricidia* fallow system are adapted from data obtained from a survey by Nelson et al. (1996c) on *Gliricidia* hedgerow systems. The number of trees/shrubs of 20,000 per hectare within the *Gliricidia* plantation is double that of the hedgerows system surveyed by Nelson et al. (1996b). The labour required for land preparation in the *Gliricidia* fallow system was found to be 10 man days, involving a burn followed by a single ploughing. Labour for collection and planting of cuttings was estimated at 70 man days per hectare; pruning labour at 16 man days per hectare per year (Table 6.1).[6] There are no weeding requirements during the *Gliricidia* plantation phase. To cut and carry the firewood, an extra man day is estimated to be required at each pruning (thus four extra man days per year), and another four man days for the major removal of firewood in the year of plantation harvest.

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

Table 6.1 **The labour requirements of the two fallow systems.**

Operation	***Imperata* fallow** #	**Improved fallow** ##	
		Crop cycle	**Tree cycle**
	man days/ha	**man days/ha**	**man 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	
Post harvest 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

\# one maize crop during the crop year of the cycle.
\## two maize crops during the crop year of the cycle.

In the *Imperata* fallow system, land preparation requires approximately 30 man days per hectare (Conelly, 1992), and planting maize requires approximately 13 man days per hectare (Nelson et al., 1996c). During the cropping period there is a significant amount of weed competition. This is due to rhizomes and seed that remain in the soil after clearing (Eussen et al., 1976). Regular weeding during the cropping period requires approximately 30 man days per hectare (Conelly, 1992).

Land preparation for the two maize crops planted following the *Gliricidia* harvest was estimated at 30 man days per hectare and the labour required for planting maize at 25 man days per hectare (Nelson et al., 1996c). The labour requirements for weeding maize after a *Gliricidia* fallow were estimated at 30 man days for the two maize crops (Nelson et al., 1996c).

The quantity of labour required for these tasks will not change between the financial and cost benefit analysis as these are physical factors and not market related factors. Thus, this table will hold true for both sets of analysis. The following subsections detail the market related factors and identify the differences associated with the financial analysis approach and the social cost benefit analysis approach.

6.3.2 Wage Rate

The productivity of males, females and children in a smallholder farming system are quite different. Adult females mostly do part time work on the farm but do participate in harvesting and post-harvesting activities (Menz et al. 1995). Thus, in this study it is assumed that the productivity of females is approximately half that of males. Rarely do children engage in full time work on the farm, with their activities usually restricted to household chores and feeding small livestock, such as pigs and chickens (Menz et al. 1995). Thus, in this study it is assumed that the labour productivity of children is one quarter that of male. In this analysis, labour is calculated in man days, with one man day representing the labour provided by an adult male member of the household. The labour provided by females and children are thus one half and one quarter of a man day per day respectively. Within the smallholder farming system represented here, it is assumed that the whole family is required to at work different times during the establishment and harvesting phases of the crop and the establishment and clearing phases of *Gliricidia* fallow. In all analysis carried out in this study, labour wage rates are calculated using the rule outlined above.

For agricultural labour, the standard wage for hired labour in Claveria is ₱50 per man day plus an additional ₱10 per day paid in the form of food, (the market rate, equalling ₱60 in total) (Nelson et al., 1996b). However, smallholders have limited opportunity for off-farm employment, thus the hired labour rate is seen to overstate the opportunity cost of labour. Consequently, Nelson et al. (1996b) proposed a more realistic opportunity cost of the farmers' labour, ₱40 per man day (termed the 'own labour rate').

The financial analysis uses the economic factors that directly impact on the smallholder. As a result, the market labour rate or 'hired labour rate' of ₱60 per man day is used in the financial analysis. This assumes a perfect market for labour, such that the smallholder pays himself and family members at the same rate he would pay casual employees.

The cost benefit analysis accounts for market distortions, thus given limited opportunity for off-farm employment, a wage rate of ₱40 per man day is used. This was seen as a more realistic opportunity cost of the farmers labour. However, if opportunities for off-farm employment improve, the 'own labour' rate is likely to rise to a level closer to the 'hired labour' rate.

6.3.3 Maize Price

The dry matter farmgate price for maize grain was ₱5.60 per kg (wet season) and ₱6.70 per kg (dry season).[7] A weighted average season price of maize of ₱5.90 per kilogram[8] is used as the price of maize in the *Gliricidia* fallow system, which produces a crop in both the wet and dry seasons. An *Imperata* fallow system only produces a crop in the wet season, thus the wet season price of maize, of ₱5.6, is used

Currently, trade barriers maintain the domestic maize price in the Philippines above the price observed in a free trade environment. David (1996) observed that the warehouse price of maize in Manila exceeded the border price by an average of 76 per cent between 1990 and 1994. This is due to restrictions on maize imports that

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[7] The average farmgate price for the maize crop, in 1994 prices, was ₱4.60 per kilogram in the wet season and ₱5.50 per kilogram in the dry season (Nelson et al., 1996c). These prices are calculated on the sale of maize at 18% moisture content. However, SCUAF uses dry matter production figures for maize (0% moisture content). Thus, these prices are adjusted by a factor of 1.22 = [1.0/(1.0-0.18)], to provide the dry matter price for maize.

maintain the nominal protection rates above the published tariff rates. Based on the Manila maize price being 76 per cent above unprotected levels, Nelson et al. (1996b) calculated an adjusted farmgate price, representing the free market price of maize once restrictions on imports are lifted.

The adjusted farmgate price, ₱_F', of ₱2.30/kg for wet season and ₱2.60/kg for the average season, was calculated using the following equation:

$$\mathbf{\text{₱}_F' = (\text{₱}_W - C_M) / 1.76}$$

where ₱_W is the warehouse price, farmgate price plus marketing costs, of maize in Manila and C_M is the marketing cost, ₱1.80 /kg. Revenue from maize sales were calculated using the farmgate price as well as the adjusted farmgate price. This allows assessment of the effect of a policy change, with regard to maize price, on the economic viability of the two farming systems.

As the financial analysis does not account for market distortions, it uses current market prices, thus the *Gliricidia* fallow system has a maize price of ₱5.9 and the *Imperata* fallow system has a maize price of ₱5.6. The cost benefit analysis does account for market distortions, of which trade barriers are a clear distortion. Thus, in the *Gliricidia* fallow system the cost benefit analysis uses a shadow price for maize of ₱2.6 and the *Imperata* fallow system uses a shadow price for maize of ₱2.3.

6.3.4 Discount Rate

Nelson et al. (1996) surveyed farmers in the Claveria area in an effort to derive the market borrowing rate faced by 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 also asked to give details of the price premium, net of marketing costs, that they received on the resale of farmer's produce.

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[8] Given dry season production is approximately one third of the wet season production, the average

In this survey, Nelson et al. (1996) observed interest rates paid by farmers on loans from local money lenders at between 16 and 40 per cent, with an average borrowing rate of approximately 25 per cent per annum.

The social discount rate is a more appropriate rate to use when comparing systems from the broader viewpoint of society. As discussed in chapter 4, government intervention in financial markets in the Philippines has distorted the capital market. This has resulted in the social discount rate in the Philippines being higher than the interest rate in international capital markets, which is approximately 4 per cent in real terms (Perkins, 1994). Lambert and Lim (1987) calculated the weighting factor for credit in the Philippines to be approximately a factor of three. This can be used to approximate the social discount rate at 12 per cent. Farmers are unlikely to borrow much, if any, to invest in the farming system at the market borrowing rate. Most of their investment is their own labour time. Thus, the 12 per cent discount provides a more realistic social rate of return for the farmers investment.

As the financial analysis considers the private perspective, the actual borrowing rate of 25 per cent is used. The cost benefit analysis, which takes the broader viewpoint of society, uses the social discount rate of 12 per cent.

6.3.5 Other Factors

A price for firewood in Claveria for the *Gliricidia* fallow system was obtained from a special survey of smallholders near Compact who had adopted a *Gliricidia* hedgerow system. The average price of firewood was ₱1,000 per tonne (Magcale-Macandog et al., 1997). As this is not considered to be affected by market distortions, this price will be used in both the financial and cost benefit analyses.

Improved cultivars of maize seed are used, but otherwise no other cash costs are included in this analysis. The cost of the maize seed, variety Pioneer 3274, is priced at ₱6.50 per kilogram. Again, maize seed prices are not considered to be subject to market distortions, thus this price will be used in both sets of analysis.

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price for wet and dry season crops is ₱5.90 per kilogram (5.6 x 0.667 + 6.7 x 0.333).

6.4 Results

6.4.1 Financial Analysis

Using the financial analysis, the *Imperata* fallow system is only marginally profitable, providing a net present value of ₱760 over the 48 year period on a 2 hectare plot (Table 6.2). This was expected, as farmers practicing the *Imperata* fallow system and other shifting cultivation systems in the Philippines, barely maintain a subsistence existence. The biophysical analysis in the previous chapter showed that the *Imperata* fallow system was not sustainable, with productivity steadily declining. This analysis shows the *Imperata* fallow system is also not sustainable from an economic perspective, with the system providing negative returns after 13 years. If the system were to run for only 12 years the system is still only marginally profitable providing a net present value of only ₱811.

In comparison, the *Gliricidia* fallow system is reasonably profitable. From the private perspective, it provides a net present value of ₱20,000 under the same circumstances (Table 6.2). This can be attributed to improved soil fertility and associated higher crop yields, and to the sale of firewood. Firewood production also reduces the variability of economic returns over time, through product diversification.

Table 6.2 **Components of Net Present Value (NPV) for the *Gliricidia* fallow system and the *Imperata* fallow system.**

	***Imperata* fallow (thousand ₱)**	***Gliricidia* fallow (thousand ₱)**
Discounted PV of gross return – maize	11.9	30.4
Discounted PV of gross return – firewood		25.4
Discounted PV of total cost	11.1	35.5
Net present value - maize only	0.8	-5.1
Net present value - maize + firewood		20.3

The costs associated with *Gliricidia* fallow are more than double the costs associated with traditional *Imperata* fallow (Table 6.2). However, this is countered by a higher maize yield, due to improved soil fertility and the ability to plant two crops per year, compared to one in the *Imperata* fallow system, plus additional returns from firewood. This results in the *Gliricidia* fallow system providing a much better return to the farmer. If the profitability of the *Gliricidia* fallow system is calculated based on maize production only, a loss is incurred (- ₱5,100) (Table 6.2). It is mainly due to the high labour requirements of establishing and maintaining the *Gliricidia* fallow. The labour requirement of the *Gliricidia* fallow system is over three times that of the *Imperata* fallow system (Table 6.1). Thus, a market for firewood is important to offset the higher costs of establishing and managing the *Gliricidia* plantation.

6.4.2 Cost Benefit Analysis

As expected, the results of the cost benefit analysis were different from those of the financial analysis. The *Imperata* fallow system is no longer profitable, providing a net present value of – ₱6,500 (Table 6.3). The lower shadow price of maize is not fully compensated by the lower shadow wage rate of own labour. The lower discount rate used in the cost benefit analysis will also mean that both costs and revenues are relatively higher than in the financial analysis as there is a low opportunity cost of time. In relative terms, costs decline slightly while revenue falls more substantially. The net result is a reasonably heavy loss from the *Imperata* fallow system. From a social perspective, the *Imperata* fallow system is unjustifiable. Farmers would not continue to practice the *Imperata* fallow system if their decision was based on social benefits rather than private benefits.

Table 6.3 **Components of Net Present Value (NPV) for the *Gliricidia* fallow and *Imperata* fallow systems.**

	***Imperata* fallow (thousand ₱)**	***Gliricidia* fallow (thousand ₱)**
Discounted PV of gross return – maize	8.8	24.9
Discounted PV of gross return – firewood		47.4
Discounted PV of total cost	15.3	46.9
Net present value - maize only	-6.5	-22.0
Net present value - maize + firewood		25.4

The *Gliricidia* fallow system is profitable from a social perspective. The cost benefit analysis shows the *Gliricidia* fallow system provides a net present value of ₱25,400. This is higher than the return provided by the *Gliricidia* fallow using financial analysis, indicating that the *Gliricidia* fallow system provides greater benefit from a social perspective than from the private perspective. When only the revenue from the maize crop is considered, the net present value of the *Gliricidia* fallow system provides a return of – ₱22,000. This indicates that, from a social perspective, the *Gliricidia* fallow system is reliant on a market for firewood. However, it must be remembered that this is a conservative estimate of the benefits, as other social gains, such as environmental benefits, are not included in this analysis. If the value of environmental benefits, such as the value of lower level of erosion observed in chapter 5, is included, the *Gliricidia* fallow system could potentially be profitable even without the sale of firewood from the social perspective.

6.4.3 Labour Productivity

Capital inputs are small in both the *Gliricidia* and *Imperata* fallow systems. Labour is the predominant component of total cost. Most labour used in smallholder farming systems is either farmers' own labour, or that of immediate family. Therefore, the wage rate used in net present value calculations may not always be pertinent. If the wage rate chosen for the calculations is not appropriate, it may distort the conclusions drawn from the net present value calculations. Thus, measurement of labour productivity may be useful when considering the potential of the new fallow system.

At both the social and the private level, labour productivity of the *Gliricidia* fallow system is significantly higher than that of the *Imperata* fallow system (Table 6.4). It is worth noting that the *Gliricidia* fallow system provides a return to labour that is almost double that of the wage rate, when addressing both private and social benefits. The *Imperata* fallow system, in comparison, provides a return to labour that is only marginally (10%) above the wage rate, when considering the private benefits, and is below the wage rate when considering the social benefits. If a market for firewood is not available, the labour requirement of the *Gliricidia* fallow system changes little. Without a market for firewood (ie considering the benefits from maize only), the labour productivity of the *Gliricidia* fallow falls to slightly less than that of the *Imperata* fallow. From a labour efficiency perspective, the *Gliricidia* fallow is better only if revenue accrues from both maize and firewood. Although yields increase significantly under the *Gliricidia* fallow system, the maize yield increase is not sufficient to cover the increased labour requirement to establish and maintain the *Gliricidia*.

Table 6.4 **Average annual labour productivity (gross revenue/labour unit[9]) of the systems with different product prices.**

Case	**Maize Price** (P/kg)		**Labour Productivity Imperata Fallow** (P/manday)	**Labour Productivity Improved Fallow** (P/manday)
Private	5.60/5.90	Maize and Firewood	66.09	112.03
		Maize only		61.42
Social	2.30/2.60	Maize and Firewood	27.15	77.36
		Maize only		26.86

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[9] Revenue is used as a measure of output in order to allow aggregation of the two inputs of the system (maize and firewood).

6.4.4 Value of the Marginal Product of Labour

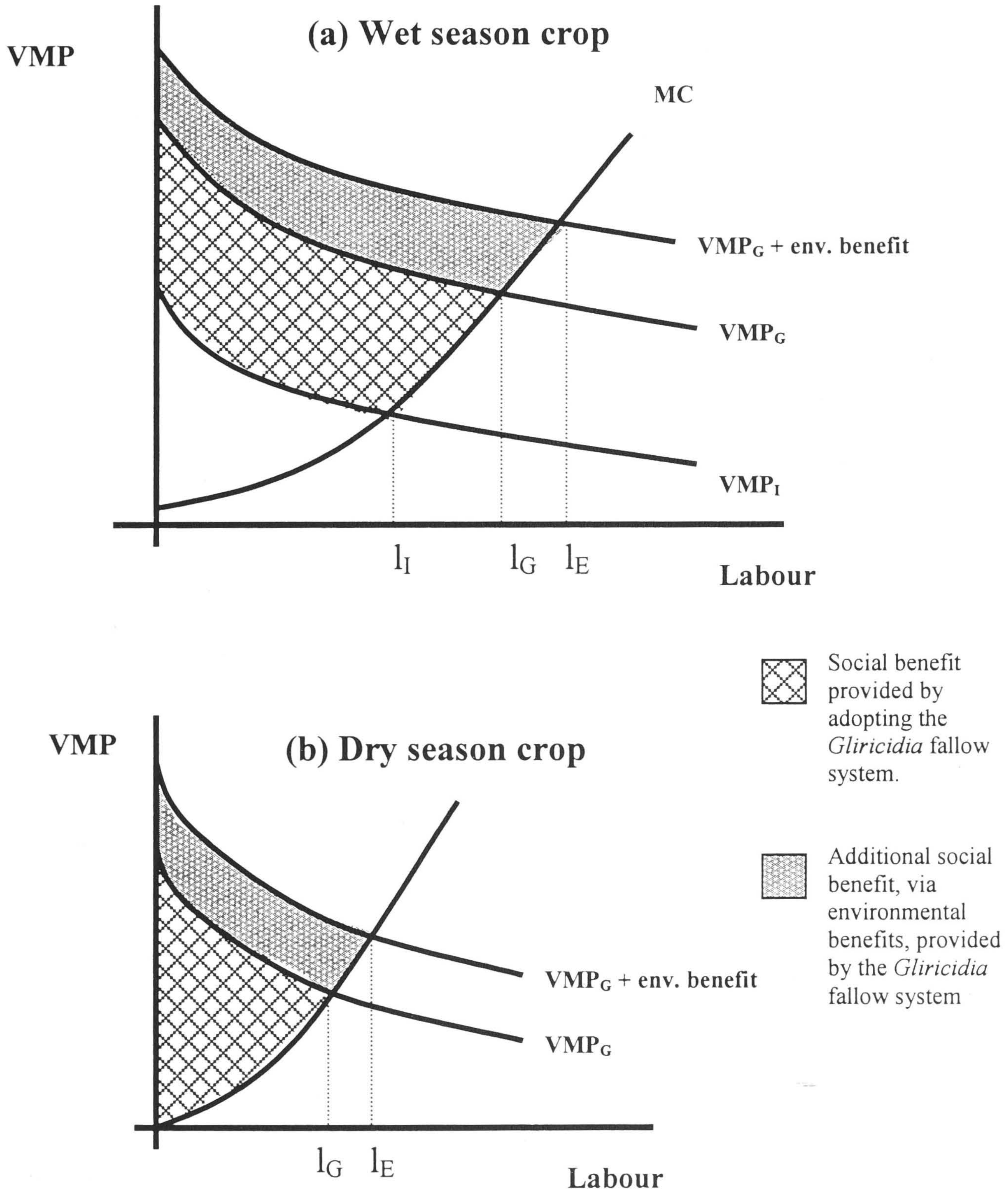
The marginal product (MP) of labour is the increase in the total product resulting from a one unit increase in the quantity of labour employed. The average product of labour is equal to the total product divided by the quantity of labour employed. The labour productivity calculated above corresponds to the average product of labour.

The value of the marginal product (VMP) of labour is the marginal product multiplied by the price of the product. The nature of the gain in labour productivity in the two systems can be represented by Figure 6.1a. The VMP of labour also reflects the demand for labour. The location of the VMP of labour schedules reflects the relative productivity of labour in the system. In the case of a higher producing system such as the *Gliricidia* fallow system, it is at a higher level than that of the *Imperata* fallow system.

The hatched area shows the benefit to society as a result of the farmer switching to the *Gliricidia* fallow system. This is equivalent to the difference between the net present values of the systems. It must also be recognised that additional benefit accrues because of environmental benefits. Thus, the gain to society of the *Gliricidia* fallow system is even larger, as shown by the shaded area. If the environmental benefit is recognised by society, more labour will be used.

It must also be recognised that the *Gliricidia* fallow system provides a benefit in the dry season also, whereas the *Imperata* fallow system does not. The dry season benefit can be shown by figure 6.1b. The hatched area corresponds to the net present value of the benefit in the dry season. Additional environmental benefit to society in the dry season is the shaded area. The total additional benefit to society is the hatched area and the shaded area in both diagrams.

Figure 6.1 **Gain in social benefit provided by the *Gliricidia* fallow system for wet season and dry season crops.**



6.5 Discussion and Conclusions

This analysis has shown the *Imperata* fallow system to be only marginally profitable from a private perspective. Although the return from the *Imperata* fallow system is low, it is positive, which explains why the farmers in the Claveria region continue to practice it even though they barely maintain a subsistence existence. The labour rate used in this analysis also goes some way to explaining why farmers practice this system. The hired labour rate of ₱60 per day is high. Most of these farmers would have little opportunity for work at this rate. Thus, if this system can maintain a return to the farmer's labour equivalent to the hired labour rate, then it is reasonable to assume farmers will continue to practice this system, as they are unlikely to find regular work at this rate elsewhere.

When considered from a social perspective, using cost benefit analysis, the *Imperata* fallow system looks unjustifiable. In the cost benefit analysis, government policies restricting trade are removed. These policies maintain a high price for maize, in effect subsidising the farmer's activities. The labour rate also changes. The hire labour rate is substituted with the own labour rate, which is considered to be closer to the price the farmer would place on time spent working on his own land. Analysis from the social perspective also uses a social discount rate of 12 per cent, which better represents the farmer's opportunity cost of time. The *Imperata* fallow system is clearly unprofitable when these market distortions are taken into consideration.

The earlier chapter has shown that the *Imperata* fallow system is not sustainable from an environmental perspective, with productivity on a steady decline over the period of analysis. This is also observed in the financial analysis, with the system providing a negative return after 13 years. From a social perspective, the shifting cultivation system is not beneficial. The cost benefit analysis showed the *Imperata* fallow system to be unprofitable, when trade restrictions, which maintain unrealistically high market prices, are removed. Thus these trade restrictions are affecting the farmers decision, encouraging farmers to maintain farming systems that are not viable.

The *Gliricidia* fallow system was shown to be profitable from both the private and social perspective, with both the financial analysis and cost benefit analysis providing relatively high returns. From a long-term economic perspective, the *Gliricidia* fallow system shows significant potential as a viable system for upland farmers in Claveria and potentially other upland areas in Southeast Asia.

This corresponds with the biophysical analysis that shows the *Gliricidia* fallow system to be a sustainable system over the long term. Soil fertility was enhanced by mulching of the *Gliricidia* leaves, which maintained a thick humus layer and cycling of soil nutrients. Even with two crops per year, crop productivity remained relatively stable in the *Gliricidia* fallow system.

Costs are significantly higher in the *Gliricidia* fallow system, but the system is much more productive allowing two crops per season, and providing an additional marketable product, firewood. However, the higher costs in establishing the *Gliricidia* fallow make the system reliant on the sale of firewood to be profitable. Based on revenue from maize alone the *Gliricidia* fallow system does not provide a positive return. The labour requirements in establishing and maintaining the *Gliricidia* fallows are high, the *Gliricidia* fallow system requiring over three times the man labour days than the *Imperata* fallow system. This is compensated in part by the higher maize production, thus higher maize revenue, but the sale of firewood is still necessary. This is more important from a social perspective as the lower maize price reduces maize revenue to just under 60 per cent of total costs, compared to the maize revenue recovering 85 per cent of costs from the private perspective.

Observation of the labour productivity and the value of the marginal product of labour from both social and private perspectives indicate that the *Gliricidia* fallow system provides a return to the farmers labour double that of the *Imperata* fallow system. The *Gliricidia* fallow system also provides a return to the farmers labour that is greater than the market wage rate, indicating that the farmer is better placed to maintain his plot under a *Gliricidia* fallow system than to seek work elsewhere.

Labour availability within a smallholder farming system is high relative to the labour requirements of either the *Gliricidia* or *Imperata* fallow systems. Menz and Grist (1995) estimated labour availability of approximately 300 person days 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 two hectare farm), it is still well within the smallholders capacity. Most smallholders on a two hectare farm would be capable of adopting the *Gliricidia* fallow system without placing excessive strain on their labour resources.

This analysis has not valued the environmental benefits that the *Gliricidia* fallow system provides in terms of reduced erosion and the associated off site costs. If these environmental benefits were measured and included in this analysis, the social benefits of the *Gliricidia* fallow system would be greater and the system could potentially provide a positive return from the maize revenue alone.

Chapter 7. The Bioeconomics of the Transition Between *Imperata* and *Gliricidia* Fallow.

7.1 Introduction

The economic analysis in the previous chapter suggests that a *Gliricidia* fallow system is quite profitable, while the *Imperata* fallow system is only marginally profitable from a private perspective and not profitable from a social perspective. However, these analyses only consider the long run profitability of the systems. The short run profitability is also important in determining the adoption of the *Gliricidia* fallow system. This is particularly so in the Philippine uplands, as farmers have very little capital available, thus any new system will need to maintain their subsistence existence over any transition period.

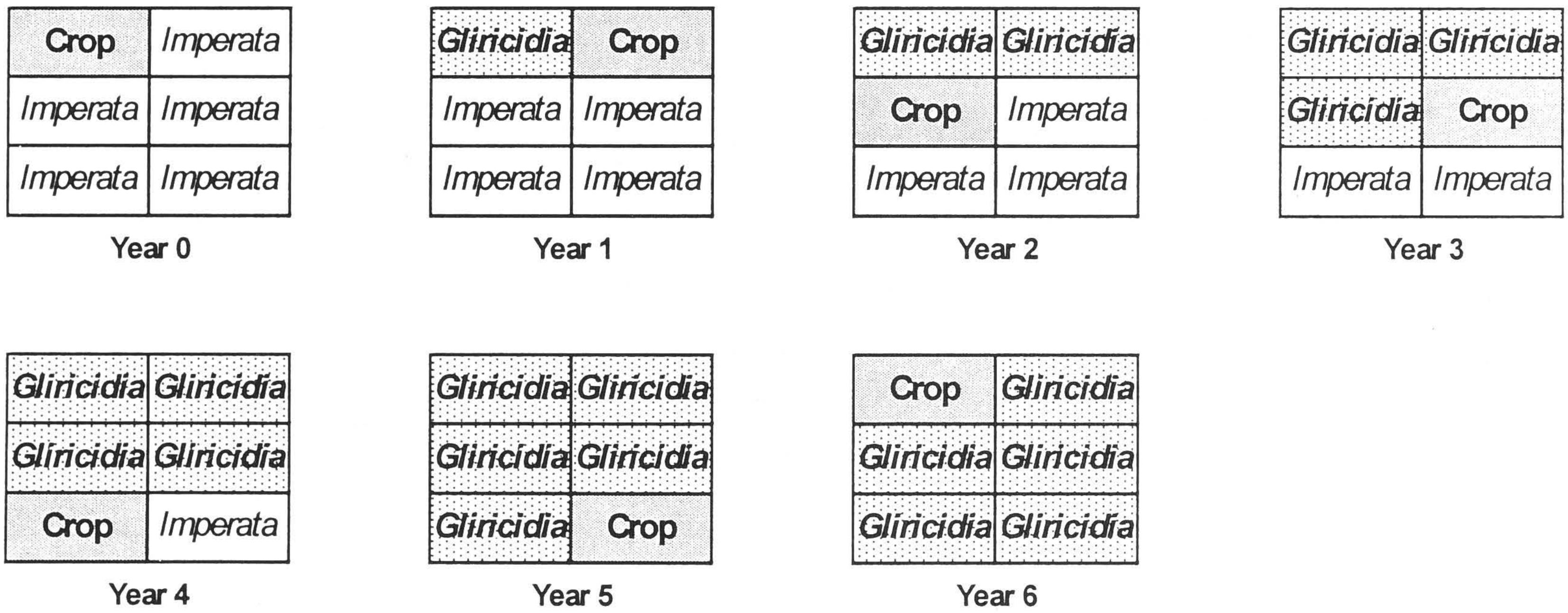
The transition period is the time during which plots, which were previously *Imperata* fallow, are converted to *Gliricidia* fallow plots. The *Gliricidia* fallow period has a six year cycle, thus the transition period will take six years. During this time the *Gliricidia* fallow is not achieving its full biophysical and economic potential. Crop productivity will be the same as the *Imperata* fallow system, as the plot that is being cropped was under *Imperata* fallow the previous period. Revenue from firewood will not be available during this period as *Imperata* fallow and not *Gliricidia* fallow is being cleared to establish the crop.

This chapter considers the impact of the transition period on both the biophysical and economic factors of the Gliricidia fallow system. Initially, the method used to calculate the transition period is explained. The biophysical and economic factors over the transition period is then observed, followed by a short discussion on these results.

7.2 Calculating the transition period

This analysis uses the same six plot, two hectare area that was considered in earlier chapters. One plot is cropped and the remainder are under fallow, either *Imperata* or *Gliricidia*, dependent on the stage of the rotation. After a plot has been cropped, instead of abandoning it and allowing weeds to dominate the site as in the *Imperata* fallow, a *Gliricidia* plantation will be established as the fallow crop. Figure 7.1 illustrates the change in crop and fallow distribution in each year of the transition period.

Figure 7.1 **Crop and fallow distribution over each year of the transition period**



Crop	*Imperata*
Imperata	*Imperata*
Imperata	*Imperata*

Year 0

Gliricidia	Crop
Imperata	*Imperata*
Imperata	*Imperata*

Year 1

Gliricidia	*Gliricidia*
Crop	*Imperata*
Imperata	*Imperata*

Year 2

Gliricidia	*Gliricidia*
Gliricidia	Crop
Imperata	*Imperata*

Year 3

Gliricidia	*Gliricidia*
Gliricidia	*Gliricidia*
Crop	*Imperata*

Year 4

Gliricidia	*Gliricidia*
Gliricidia	*Gliricidia*
Gliricidia	Crop

Year 5

Crop	*Gliricidia*
Gliricidia	*Gliricidia*
Gliricidia	*Gliricidia*

Year 6

To enhance crop development during the transition period, 50 per cent of the *Gliricidia* prunings are used as green manure for the maize crop. The remaining 50 per cent are dropped as green manure under the *Gliricidia* plantation.[10] This will improve maize productivity, with the *Gliricidia* mulch improving soil nutrient levels and soil structure. As the number of *Gliricidia* fallow plots increase over time, the quantity of *Gliricidia* prunings available as green manure increase. This will lead to a steady increase in maize and firewood yield over the transition period. This situation is different from the full *Gliricidia* fallow system, where 100 per cent of the *Gliricidia* prunings are used as mulch under the *Gliricidia* plantation, and the maize does not have green manure applied directly. However,

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[10] For example, given 7 tonnes of *Gliricidia* prunings per year, in the third year of the transition (ie. three plots under *Gliricidia* fallow), each fallow plot will receive 3.5 tonnes of prunings and the maize plot will receive 10.5 tonnes (3 x 3.5) of prunings.

transferring 50 per cent of the *Gliricidia* prunings to the maize crop during the transition period will increase the economic return from maize (via improved soil fertility). In the absence of such a transfer, no maize yield increase would occur until year 6 of the *Gliricidia* fallow period.

The biophysical analysis uses the same SCUAF model, with the same site conditions as the previous analysis. SCUAF is run for the six years of the transition period, with an additional *Gliricidia* component added each year, and the prunings transferred from the *Gliricidia* plots to the crop plots increasing in line with the additional *Gliricidia* plots. Other than the transfer of prunings no other inputs are added.

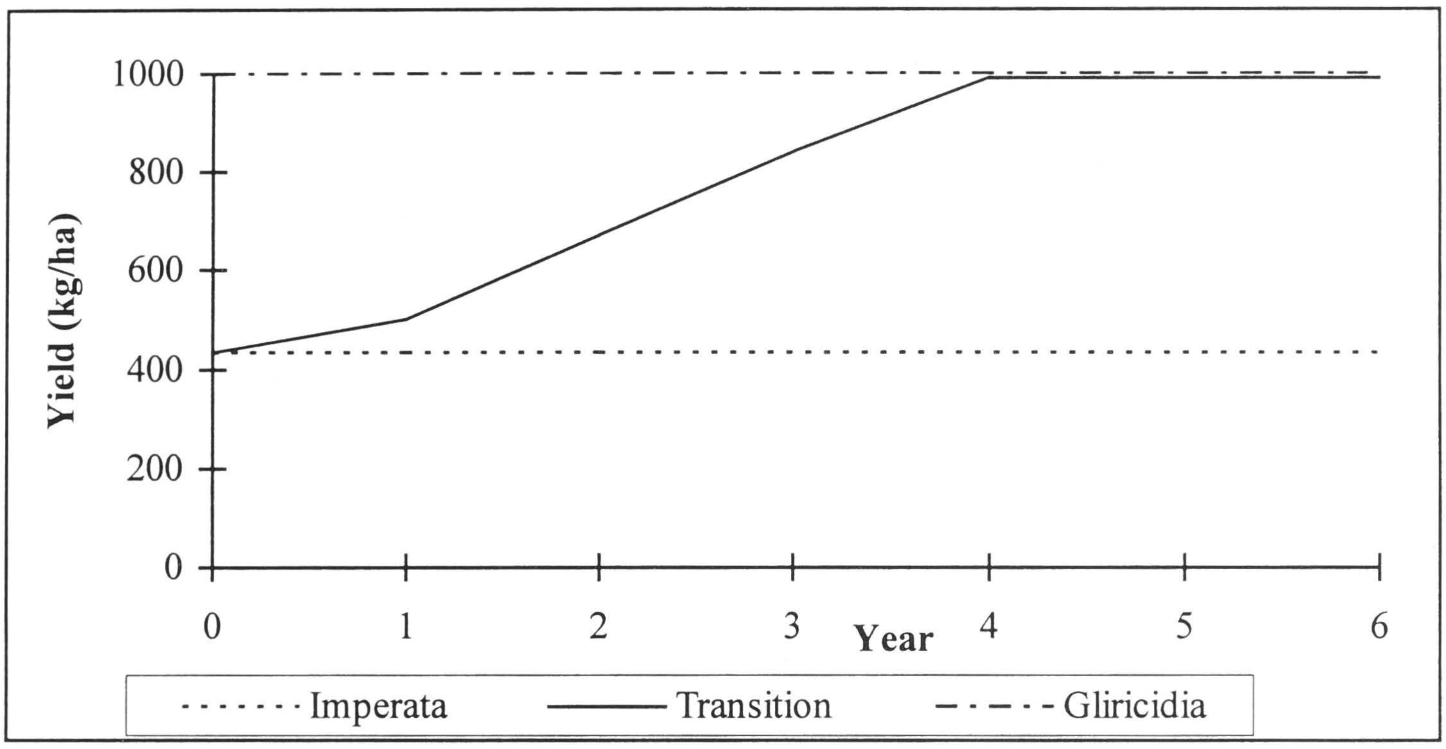
The economic analysis uses the same spreadsheet approach as was used in the previous analysis. The labour requirements and costs are calculated based on the labour requirements of the *Imperata* and *Gliricidia* fallow systems outlined in the previous chapter. Maize and firewood revenue are based on crop and tree yields derived from SCUAF.

7.3 Biophysical changes during the transition period

The change in maize yield during the transition period, is shown in Figure 7.2. 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.

The other biophysical factors show a similar trend, with nutrient levels, such as soil carbon, nitrogen and phosphorus steadily increasing over the first four years. This is due to the increasing quantities of *Gliricidia* used as green manure on the crop plot. The steady buildup of humus associated with the green manure stabilises the soil and leads to a steady decline in soil erosion levels over the same period.

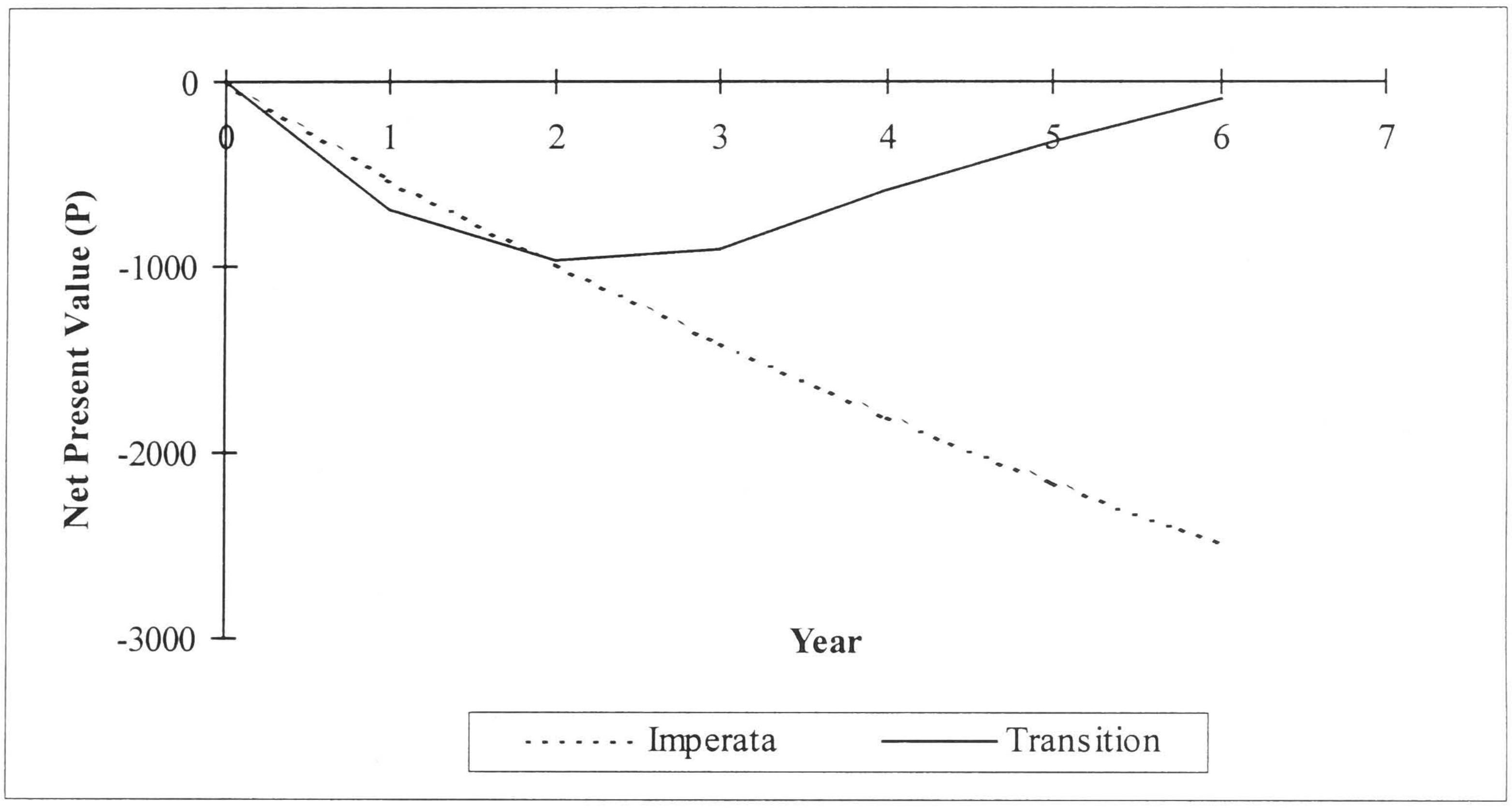
Figure 7.2 **Maize yield in the *Gliricidia* fallow system during the six year transition period.**



7.4 Economic changes during the transition period

The conversion of one plot each year to *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, in the first two years of the transition period the *Gliricidia* fallow system makes a loss (dark solid line, Figure 7.3). By the third year the system breaks even and begins to recover some of the earlier losses. However, it is not until year six that most of the earlier losses are recovered. After the sixth year, the cumulative net present value of the system has returned to zero, such that the system will begin to show a profit in the seventh year. In comparison, the *Imperata* fallow system when calculated from the social perspective does not show a profit over this period. The *Gliricidia* fallow system is more profitable than the *Imperata* fallow system in all but the first year.

Figure 7.3 **Net present values of a *Gliricidia* fallow system during the transition period, and an *Imperata* fallow system, using cost benefit analysis.**



The attractiveness of the *Gliricidia* fallow system is dependent on a smallholder's ability to absorb the loss in the first two years, and to accept a negative return over the six years of the transition period. For subsistence farmers without savings or with limited capacity to borrow, adoption of the *Gliricidia* fallow system would be difficult. The ability to survive a negative return over the first six years of the transition period is critical to the adoption of the improved fallow system. The *Gliricidia* fallow system is clearly the logical choice beyond the seventh year.

7.5 Conclusion

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 two years, and it will take approximately seven years for smallholders to begin to show a positive return on their investment. Unless smallholders are capable of accepting the lower profitability in the first six years, or there is some government assistance, they are less likely to adopt the new system.

Given the long-term nature of the investment in *Gliricidia,* secure land tenure is required if smallholders are to adopt the system. 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.

The role of animals in the context of a *Gliricidia* fallow, is considered in the next chapter. The results indicate a positive economic role for animals, without significantly compromising the positive environmental effects of the *Gliricidia.*

Chapter 8. The Bioeconomics of Raising Cattle in the Farming System

8.1 Introduction

Gliricidia foliage also has potential as a feed supplement for animals, offering the potential for the cattle to be included in the *Gliricidia* fallow system modelled in the previous chapters. The *Gliricidia* foliage that is fed to cattle will not be available as mulch. Thus, there is a trade-off between maize and cattle through the effect on soil fertility. The addition of each animal reduces the expected returns from maize production.

In this chapter, cattle are incorporated in the *Gliricidia* fallow system. Cost benefit analysis is used to estimate the net present value of the system, and the biophysical detail of the system is modelled using SCUAF (Soil Changes Under Agroforestry). Economic data and model parameters are obtained or extrapolated from research data on hedgerow intercropping systems, *Gliricidia* plantations and cattle production.

8.2 The Farming System

For the *Gliricidia* fallow system examined in earlier chapters, total farm area was two hectares. This was divided into six plots of one third of a hectare each. Plots were rotated annually, with one plot used for subsistence maize production and the remainder fallowed with *Gliricidia*. The same system is modelled in this analysis. However, given the grazing (grass feed) requirement of cattle, it is not possible to convert all plots to *Gliricidia* fallow. The number of plots that can be converted to *Gliricidia* fallow will depend on the number of cattle added to the system. One *Imperata* fallow plot supplies most of the grass required to feed one animal, with the balance obtained from maize crop residues.[11] As a result, the addition of one more animal, reduces the number of plots that can be converted to *Gliricidia* by one.

Table 8.1 presents the land distribution for the three land use types (maize crop, *Imperata* fallow, *Gliricidia* fallow) in order to meet the feed requirements for up to three animals, on a two hectare farm under a *Gliricidia* fallow system. A one animal system requires one plot to be allocated to maize production, one plot retained as *Imperata* fallow, and the remaining four plots are planted to *Gliricidia* fallow. This land use allocation has the potential to meet all the requirements of the system, including maize production, feed for cattle and mulch for soil fertility.

Table 8.1 **Partitioning of land use for a *Gliricidia* fallow system with animals, on a two hectare farm.**

Number of Cattle	Maize		*Imperata*		*Gliricidia*	
	Area (ha)	No. Plots	Area (ha)	No. Plots	Area (ha)	No. 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. Each year two maize crops (wet and dry season) are planted per plot. Figure 8.1 presents a schematic diagram of the improved fallow system. Resources flow between the *Imperata* fallow, *Gliricidia* fallow and maize crop, producing cattle, firewood and grain. Cattle and fuelwood are then sold to provide a cash income to the farmer, while maize can either be sold or kept for domestic consumption.

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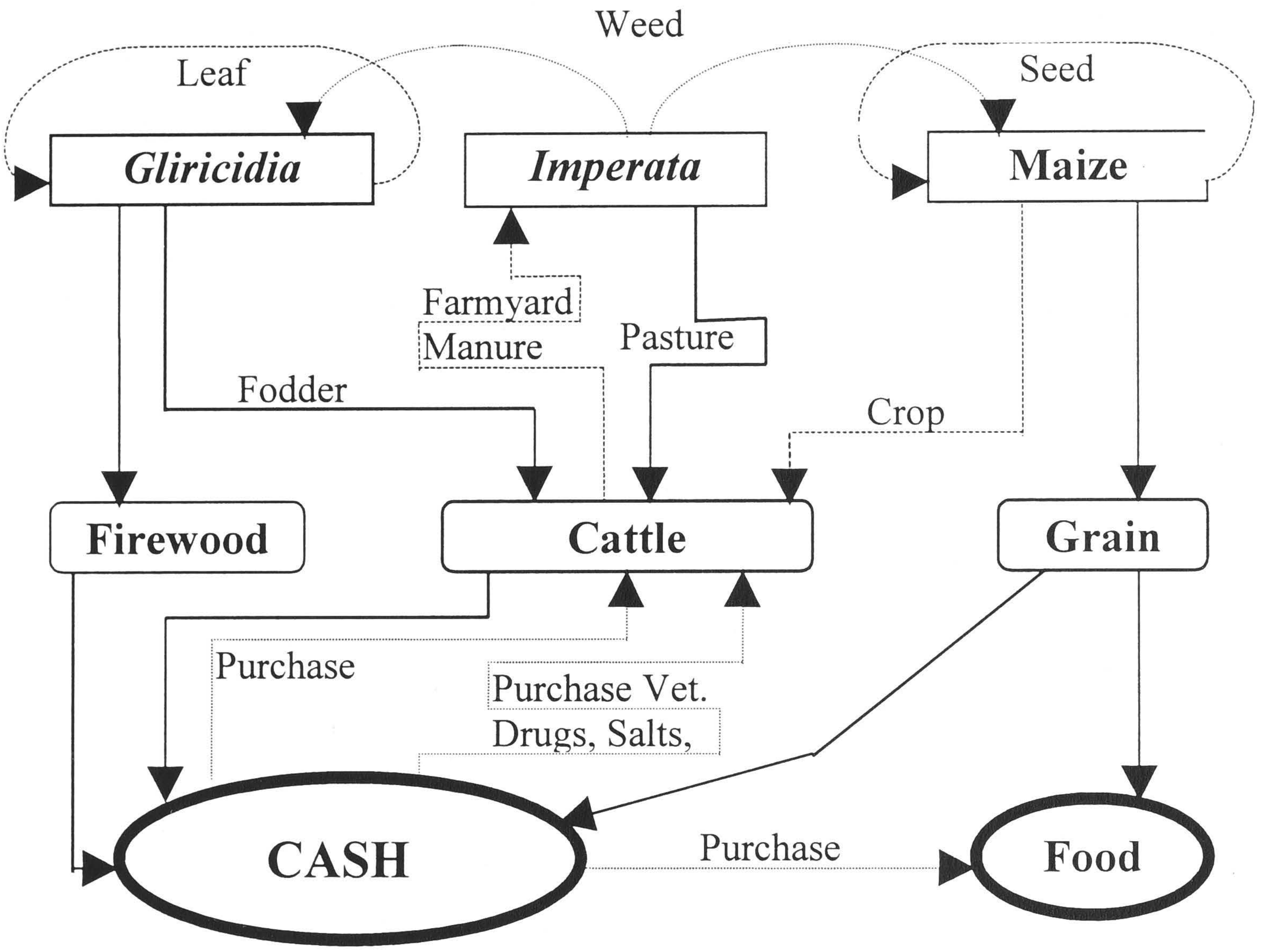
[11] Crop residues can contribute significantly to fodder requirements following harvest. However, due to the limited time that these residues are available, they do not feature significantly as contributions to animal feed supply in this analysis.

Figure 8.1 **Flow of resources in the *Gliricidia* fallow system with animals.**



8.3 Adaptation of the Bioeconomic Model to Include Cattle

Data used to model the *Imperata* and *Gliricidia* fallow systems in previous chapters was supplemented by a subsequent survey of the Claveria region by Magcale-Macandog et al. (1997) which focused on cattle in a smallholder system.

The cost of cattle is included in the model as interest accruing on the initial purchase price of cattle, that is the model assumes the farmer borrows 100 per cent of the cattle value. In practice, the farmer will not be able to borrow the full amount of the value of cattle, but the ability to borrow to purchase cattle is only relevant during the establishment phase of the system. Each year the smallholder will market mature cattle and replace them with calves, thus will sustain an opportunity cost of holding cattle. This assumption is contrived to represent the long-term opportunity cost of cattle to the smallholder.

Revenue from cattle, which is only realised at the time of sale, is calculated as annual weight gain times market value.

Several changes to the *Gliricidia* fallow system spreadsheet, from chapter 6, are required with the addition of animals. These include labour activities to represent the labour requirement to cut and carry the fodder, and annual costs associated with raising animals, such as veterinary fees, drugs, salts and rope for tethering.

8.4 Model Inputs

8.4.1 Feed mix

In traditional shifting cultivation systems, the fodder available to feed cattle consists mainly of grasses and crop residues. These feed sources are low in digestible nutrients, deficient in minerals, and the consumption of grass and crop residue is low relative to other feed sources (Nitis, 1985). The poor quality and low consumption of grass and crop residue limits the number of cattle that can be supported by a shifting cultivation system. Under a traditional shifting cultivation system, a smallholding of two hectares tends to support only one or two animals (Franco et al., 1996). These cattle are typically poorly nourished and have low productivity (Moog, 1991).

Supplementing the diet of cattle with *Gliricidia* foliage has been shown to significantly improve their nutritional intake (Lowry et al., 1992; Jabbar et al., 1996; and, Payne, 1984). Details of the nutritional value of *Gliricidia* are presented in Chapter 3. It has been shown that using *Gliricidia* foliage in combination with grasses and crop residues, can support commercial cattle production (Moog, 1991; Atta-Krah and Sumberg, 1988; Gutteridge and Shelton, 1993). The improved feed quality can support up to three cattle on a two hectare farm.

8.4.2 Weight gain

The quality of a feed source has a significant impact on the potential growth rate, or weight gain, of cattle (Sturr et al., 1994). Payne (1984) and Calub (1995) observed very low annual weight gains of around fifty kilograms per year or approximately 0.15 kg per animal per day when cattle were feed a diet of grass and crop residue. Feeding cattle a diet of 50 per cent *Leucaena* and 50 per cent crop residue, Morbella et al. (1979) reported an average gain of 0.52 kg per animal per day. This is similar to the rate of growth expected for a 300 kg steer or heifer fed seven kilograms of *Gliricidia* dry matter per day, which were presented in tables by Kearl (1982). Even greater gains (between 600 grams and one kilogram per animal per day) have been observed by feeding higher percentages of *Leucaena* or *Gliricidia* to cattle (Sturr et al., 1994; Moog, 1991).

A conservative approach will be used in this analysis to calculate the annual weight gain of cattle. Based on a diet of 50 per cent *Gliricidia* combined with 50 per cent grass and / or crop residue, an average weight gain of 0.52 kilograms per day (or 190 kilograms per year) is used (Morbella et al., 1979; Kearl, 1982).

Based on a beef price of ₱40 per kilogram (Calub pers comm, 1996) and an average weight gain of 190 kilograms per year, the net annual gain in inventory value of an animal in a *Gliricidia* fallow system is ₱7,600.[12] The initial purchase cost of a young (150 kg) animal at ₱40 per kilogram is ₱6,000. This is incorporated into the analysis as the opportunity cost of purchasing a young animal to farmers.

8.4.3 Feed intake

The feed requirement of cattle is between two and three percent of body weight per day. For a 300 kg animal to achieve a weight gain of 0.52 kg per animal per day,

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[12] From a survey of smallholders in the Claveria area (Magcale-Macandog et al., 1997), the average annual increase in inventory value of cattle in a smallholder farming system was specified to be ₱2,215 per year. In those smallholder farming systems, 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 per kilogram for a total of ₱2,200.

Payne (1984) estimated a feed requirement of around 2.28 per cent of body weight.[13] For a similar weight gain, tables by Kearl (1982) show animals requiring an average feed requirement of 2.33 per cent of body weight for the same weight gain. In this analysis, an average body weight of 300 kg is assumed, with an average feed requirement of 2.33 per cent of body weight (seven kilograms 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 per cent of feed (Ross Gutteridge, pers comm 1996). A conservative estimate of 15 per cent of the feed requirement (one kilogram of dry matter per day for a 300 kg animal) will be added to account for refusals. Thus, the total feed requirements of a 300 kg animal adds to approximately eight kilograms of dry matter per day, or approximately three tonnes of dry matter per animal per year. Given a feed mix of 50 per cent *Gliricidia* and 50 per cent *Imperata* and/or crop residue, approximately 1.5 tonnes of each feed source is required per animal per year.

8.4.4 Manure

The quantity of manure produced by cattle is approximately 40 percent of the dry matter ingested by the animal. This is calculated as an average of dry matter digestibility, which is 60-65 per cent for *Gliricidia* (Norton, 1994; Lowry et al., 1992; Gutterige and Shelton, 1994), and 58 per cent for *Imperata* (Soewardi and Sastradipradja, 1980). Thus, an animal fed three tonnes of dry matter per year produces approximately 1.2 tonnes 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 Banos (unpublished data) found a carbon to nitrogen ratio of 18:1 in cattle manure. The carbon content of manure is approximately 50 per cent, so the nitrogen content of manure is 2.8 per cent of the dry matter of the manure, or 1.1 per cent of the dry matter fed to the animals.

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[13] Eight kilograms of dry matter per day for a 350 kg steer or heifer.

It is assumed that all manure is deposited on *Imperata* plots on which the cattle graze. The manure will add nutrients and organic matter, improving the soil of the *Imperata* fallow. Manure is added to the *Imperata* fallow plots, within the model, at a rate equivalent to 3.6 tonnes of manure is added per hectare per year.

8.4.5 Modelling animals in SCUAF

Although SCUAF does not directly model cattle, grazing can be simulated by harvesting animal fodder. The dry matter yield of *Gliricidia* is approximately 7.7 tonnes of leaf material per hectare per year and approximately four tonnes per hectare per year for *Imperata* (Agus, 1994; Soewardi and Sastradipradja, 1980). The *Imperata* produced by $^1/_3$ ha (1.33 tonnes) plus a small allowance for feeding some crop residues, provides 1.5 tonnes of dry matter per year of grass. The *Gliricidia* component of the animal's diet is available from the regular prunings of the plantation, and any *Gliricidia* foliage remaining is retained in the *Gliricidia* plot as mulch.

Table 8.2 **Quantity of *Imperata* and *Gliricidia* leaf material available, and percentage of leaf material fed to animals**
(total farm area = 2 ha).

	Imperata		***Gliricidia***	
Number of Animals	**Quantity Available** (tonnes)	**Fed to Animals** (%)	**Quantity Available** (tonnes)	**Fed to Animals** (%)
1	1.33	100	10.27	15
2	2.66	100	7.70	40
3	4.00	100	5.13	90

The *Imperata* and *Gliricidia* leaf material available in the system and the percentage removed to feed the animals, is presented in Table 8.2. Each animal introduced reduces the area of *Gliricidia* fallow and the amount of *Gliricidia* foliage available as mulch at a rate of 1.5 tonnes of *Gliricidia* foliage per animal.

8.4.6 Labour requirements for feeding animals

The inclusion of animals within a *Gliricidia* fallow does not significantly increase the labour demands (Table 8.3). The only change is an increase in labour for the cut and carry of *Gliricidia* to cattle. Cutting and carrying grass for fodder requires approximately two hours of labour per animal per day (Payne, 1984; Franco et al., 1996). In the *Gliricidia* fallow system, only half of the feed requirement is obtained by cut and carry. Also, *Gliricidia* will require less labour to harvest, as it has a higher dry matter content than grass, thus a smaller volume of fresh material is needed. The labour requirement was adjusted to half an hour per animal per day, or approximately 23 days per animal per year (based on an 8 hour workday).

Table 8.3 **Labour requirements of the *Gliricidia* fallow system with one animal.**

Operation	**Crop**# (days/ha)	**Tree** (days/ha)	**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*
Maize harvest	18		
Post harvest 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 *Glir.*, $^1/_3$ ha *Imp.*)		118	

\# two maize crops during the crop year of the cycle.

* labour requirement for one animal; each additional animal requires a further 23 days.

Imperata is grazed by cattle in the field, thus no labour is required for maintenance or feeding from *Imperata* plots. Each additional animal reduces the number of plots under *Gliricidia*, reducing the labour required to prune and carry firewood. Table 8.3 presents a summary of the labour requirement of a *Gliricidia* fallow system, including the additional labour requirements associated with cattle.

A summary of unit costs and unit returns for the *Gliricidia* fallow system with animals is presented in Table 8.4.

Table 8.4 **Unit costs and returns used in the analysis.**

Labour cost of Smallholder		P40 / day	
Maize seed Cost		P6.50 / kg	
Maize Grain Value	Wet Season	P2.30 / kg	
	Average Season	P2.60 / kg	
Firewood		P1,000 / tonne	
Cattle	Initial Purchase	P6,000	(150kg @ P40/kg)
	Annual Maintenance Cost	P1,882	
	Net Annual Change in Inventory Value of Cattle	P7,600	(190kg @ P40/kg)
Interest Rate	Social Interest Rate	12%	

8.5 Results and Discussion.

8.5.1 Biophysical Aspects

The biophysical aspects of the *Gliricidia* fallow system without animals were described in chapter 5. In that system, soil is 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 organic matter and soil nutrients, such as nitrogen and phosphorus (Figure 8.2). These predicted improvements in soil fertility produced an improvement in predicted maize yield in the long term (Figure 8.3).

Figure 8.2 **Changes in soil nutrient levels with increasing animal numbers in the *Gliricidia* fallow system.**

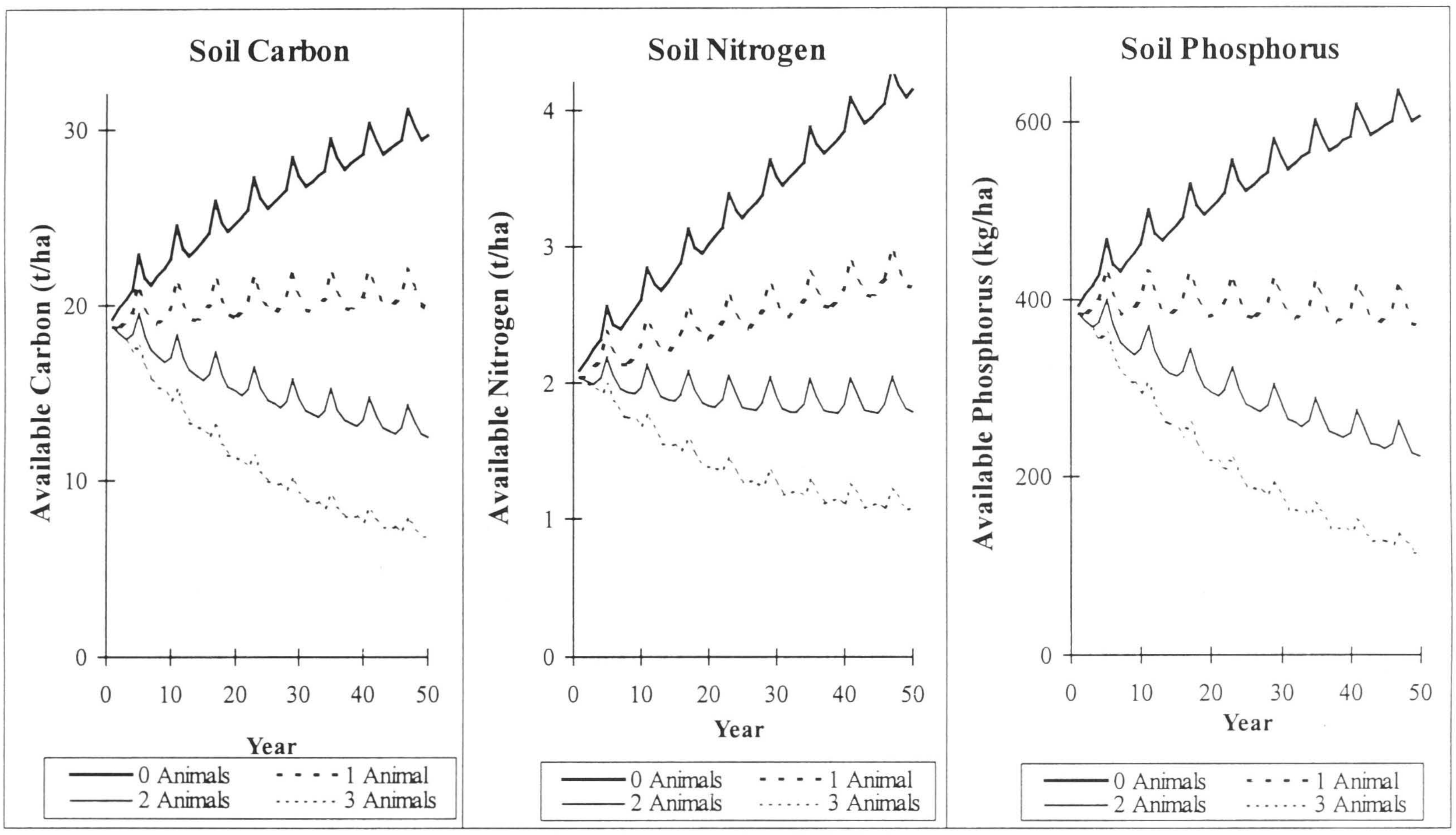
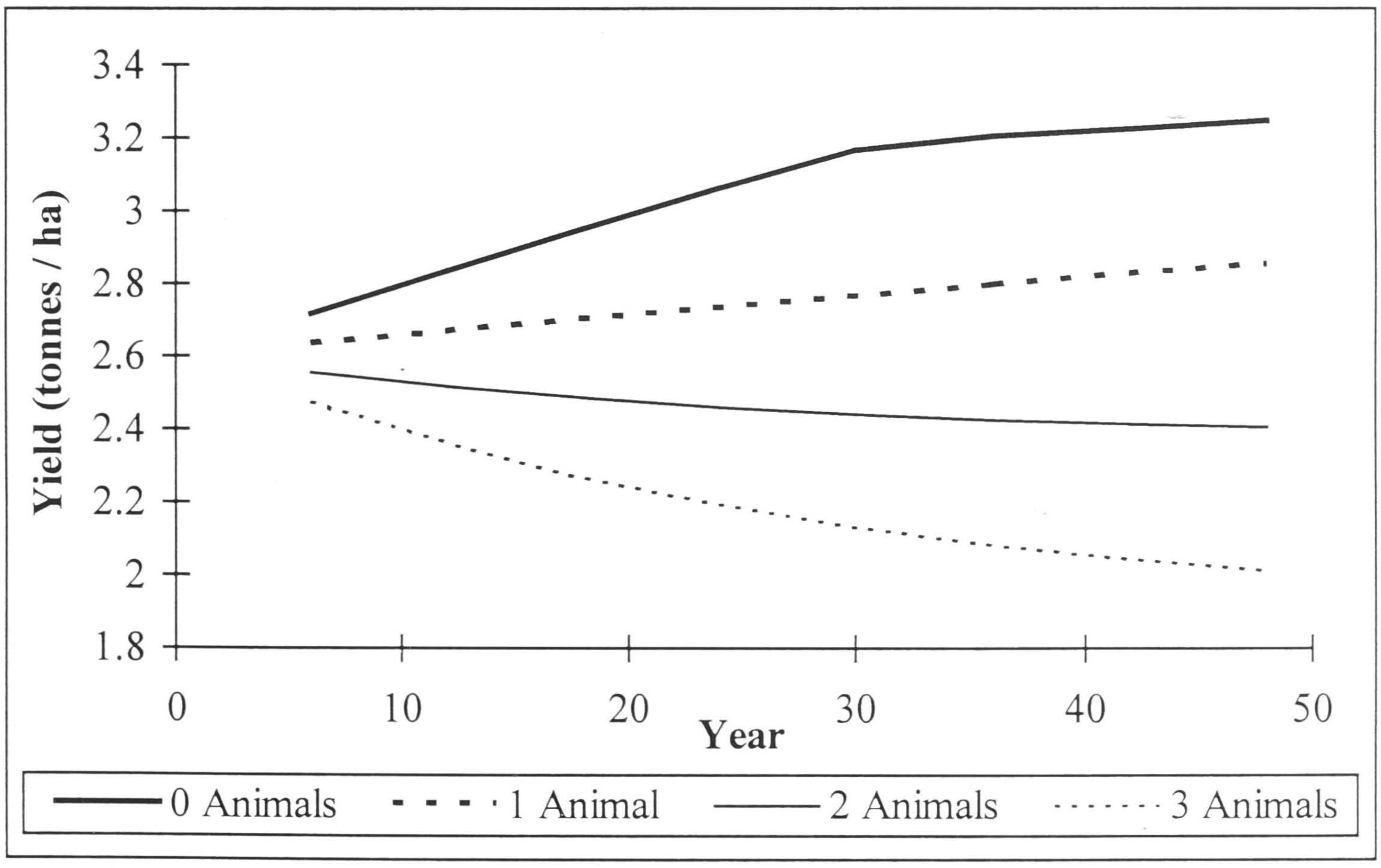


Figure 8.3 **Changes in maize yield with increasing animal numbers.**



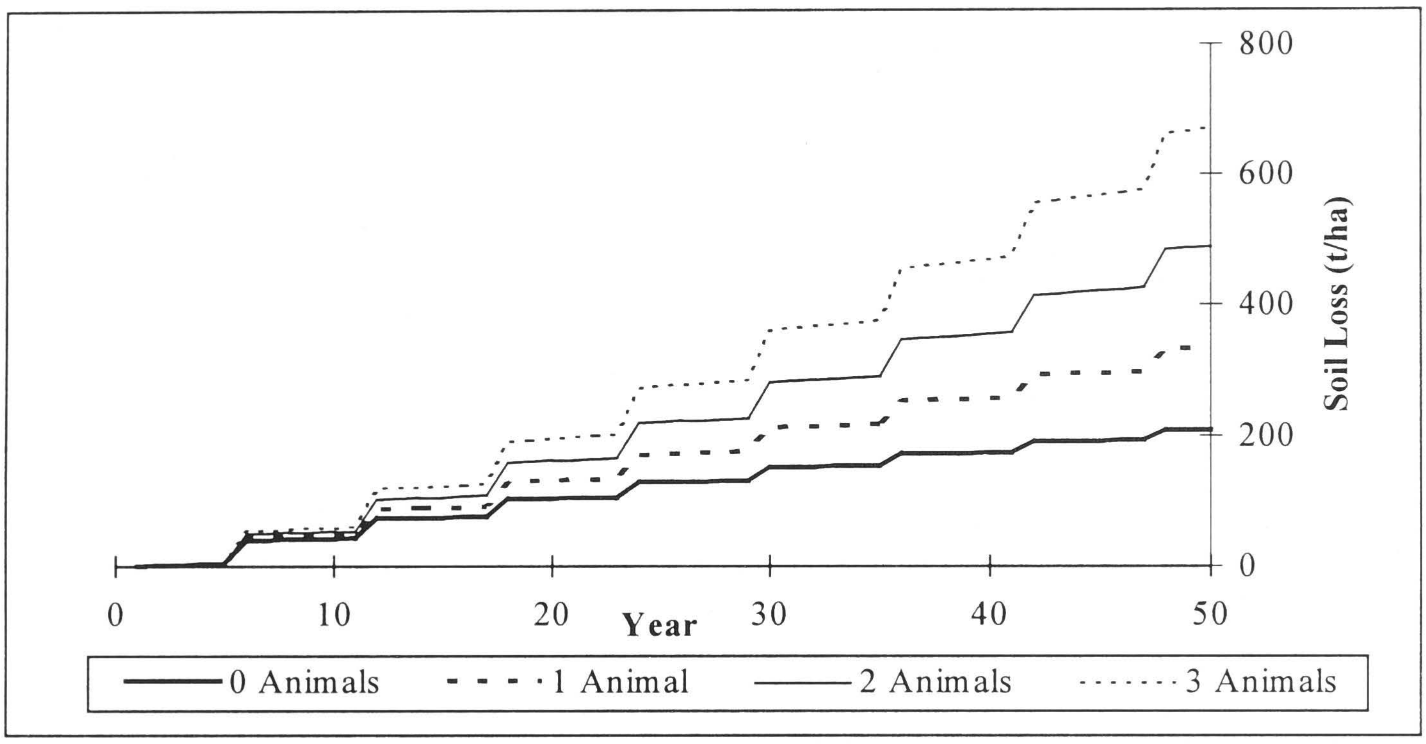
The introduction of animals into the *Gliricidia* fallow system reduces the amount of mulch available for maize production. Feeding the *Gliricidia* prunings to animals removes nutrients from the crop / fallow system. As cattle numbers increase, soil nutrient levels and crop productivity are lower than without cattle. Nevertheless, with one animal soil nutrient levels are sustained around initial levels (Figure 8.2). The sustained soil fertility is reflected in predicted maize yields (Figure 8.3). Although the introduction of an animal into the *Gliricidia* fallow system is a drain on the level of soil fertility, soil fertility and maize yield are still sustainable in the long term.

Two animals reduce the amount of *Gliricidia* foliage available for mulching to 60 per cent of the total produced. As a result, soil fertility is not sustained. Over fifty years, soil organic matter and nutrient levels decline an average of 25 per cent (Figure 8.2). This is reflected in predicted maize yields, which decreases by 5 per cent over the same period (Figure 8.3).

Three animals are predicted to have a negative effect on the sustainability of the farming system. Ninety percent of the *Gliricidia* foliage is required as animal fodder. Soil organic matter and nutrients are predicted to fall to less than 50 per cent of their initial levels (Figure 8.2). Consequently, there is a 25 per cent reduction in maize yield over fifty year (Figure 8.3).

The erodability of the soil at Claveria is relatively low, averaging 26.6 tonnes per hectare per year for open field maize farming (Nelson et al., 1996b). This is despite high rainfall, averaging 1,800 mm per year (Agus, 1994), and a moderate slope of around 20 per cent (Nelson et al., 1996b). The introduction of cattle increases soil erosion, lowering crop productivity. Cumulative soil erosion, with and without cattle, is shown in Figure 8.4. With no cattle, the total amount of soil erosion in the *Gliricidia* fallow system over fifty years is relatively low, around 200 tonnes per hectare. The addition of each animal is predicted to increase soil erosion by an additional 150 tonnes per hectare per year.

Figure 8.4 **Cumulative soil erosion with increasing cattle numbers.**



8.5.2 Economic Analysis.

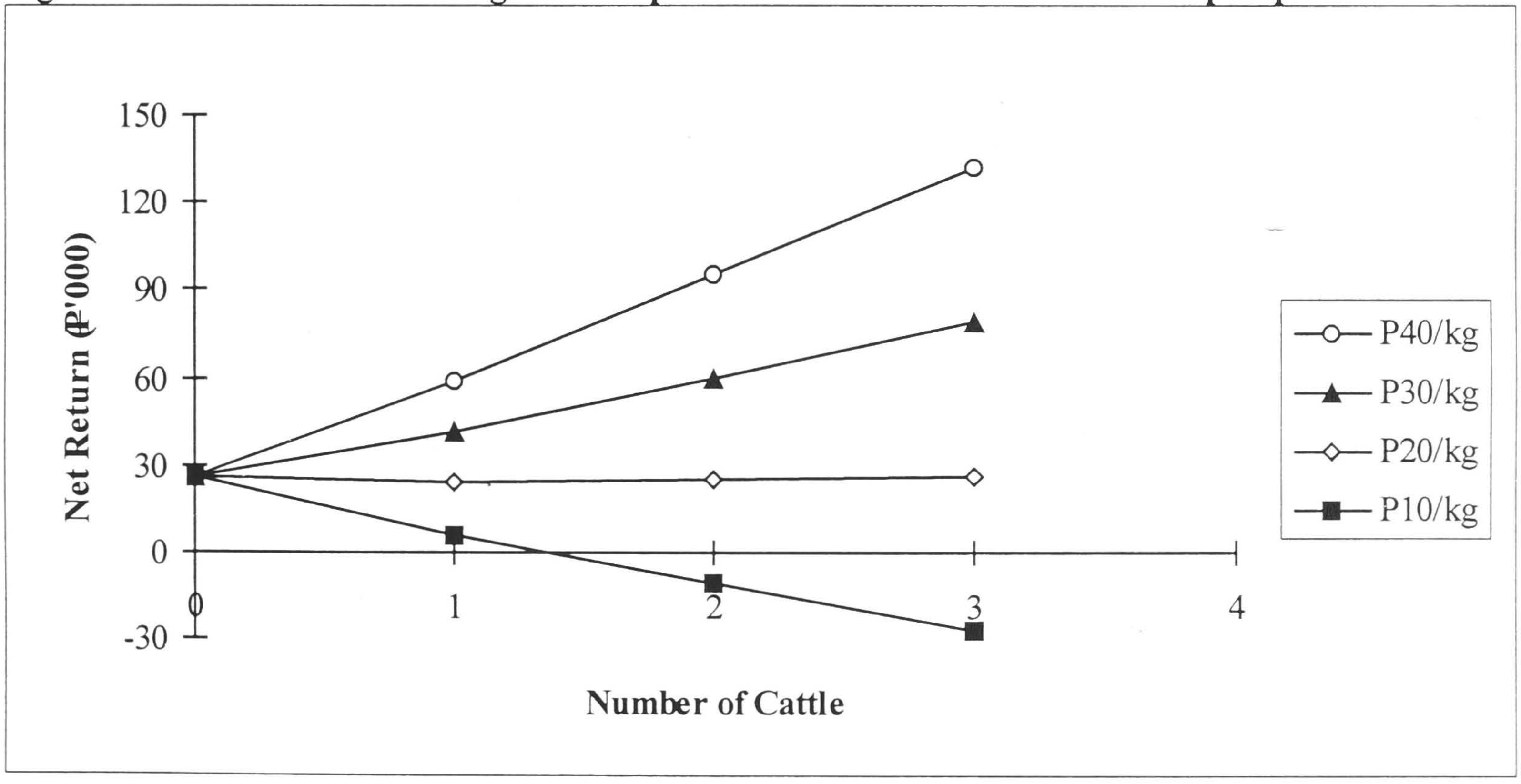
Chapter 6 predicted that a *Gliricidia* fallow system without animals may be substantially more profitable than a traditional *Imperata* fallow system. The increased revenue from higher maize yields off-set the costs of establishing the *Gliricidia* planation. The improvements in maize yield were complemented by returns from the sale of firewood. This result applied at prices faced by farmers in Claveria, and still held after a significant increase in the wage rate, or a decrease in the maize price.

From a social perspective, using a maize price of ₱2.6, a wage rate of ₱40, a beef price of ₱40 per kilogram and a discount rate of 12 per cent, the *Gliricidia* fallow system is more profitable with cattle. Over the fifty years viewed in this analysis, the addition of each animal increases discounted farm costs by approximately ₱24,000 and reduces discounted revenue from maize and firewood by an average of ₱12,000. However, this is off-set by the expected revenue from the sale of cattle, of approximately ₱70,000 per animal (Table 8.5). For up to three cattle, the addition of each animals adds to potential profits. When compared a *Gliricidia* fallow without cattle, the net present value increases by over 100 per cent with one animal, almost 400 per cent with two animals, and over 500 per cent with three animals

Table 8.5 **Total revenue, total costs and net present value for the *Gliricidia* fallow system, with and without animals from a social perspective.**

Social Perspective	*Discount rate 12%* *Wage rate P40/day* *Maize Price P2.58/kg*	*0 Animals*	*1 Animal*	*2 Animals*	*3 Animals*
Total Revenue		**72,359.44**	**111,662.69**	**153,815.11**	**196,202.53**
	Firewood	47,433.58	37,361.74	27,720.01	18,299.14
	Crop	24,925.86	21,331.86	20,156.92	18,996.13
	Cattle	0.00	52,969.09	105,938.18	158,907.26
Total Cost		**46,885.39**	**70,445.79**	**94,006.19**	**117,566.59**
	Fallow System	46,885.39	44,407.30	41,929.21	39,451.13
	Cattle	0.00	26,038.49	52,076.98	78,115.47
Net Present Value		**25,474.06**	**41,216.90**	**59,808.92**	**78,635.93**

Figure 8.5 **The effect of a change in beef prices on net returns from a social perspective.**



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, the beef price will fall (Figure 8.5). While beef prices are above ₱30 per kilogram, it is profitable to include animals in the *Gliricidia* fallow system, with profit increasing with each additional animal. At beef prices of ₱20 per kilogram or lower, 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.

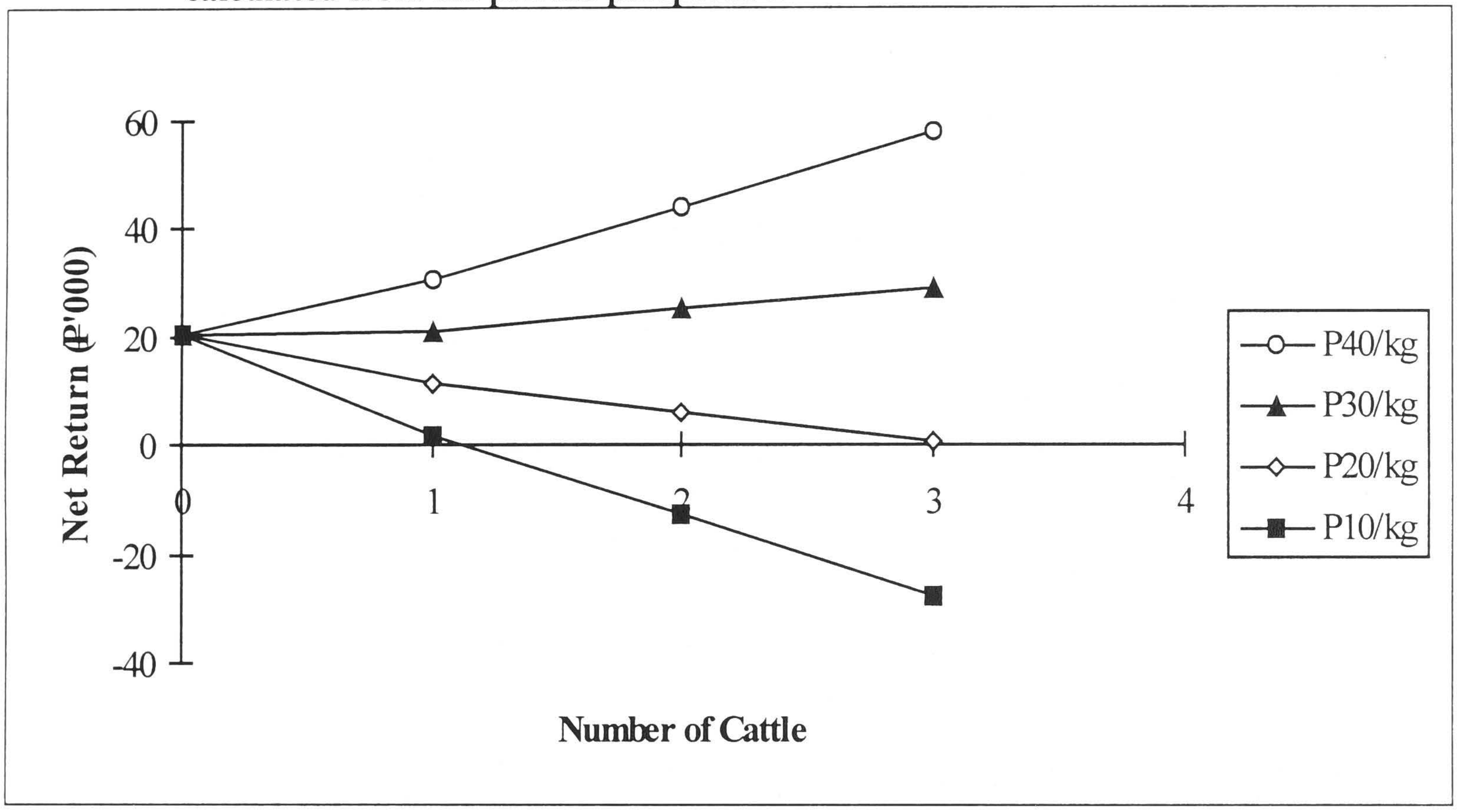
The above calculations are carried out from a social perspective, from a private perspective, using a maize price of P5.90 per kilogram, a labour wage rate of P60 per day, a beef price of P40 per kilogram and a discount rate of 25 per cent, the general trends are maintained. There is an almost linear increase in profitability with the addition of animals, but the size of the increase is less. The net present value of the system increases 50 per cent with the addition of one animal, 100 per cent with two animals and 150 per cent with three animals (Table 8.6).

Table 8.6 **Total revenue, total costs and net present value for the *Gliricidia* fallow system, with and without animals from a private perspective.**

Private Perspective	*Discount rate 25%* *Wage rate P60/day* *Maize Price P5.9/kg*	*0 Animals*	*1 Animal*	*2 Animals*	*3 Animals*
Total Revenue		**55,789.18**	**84,180.22**	**116,006.24**	**147,897.04**
	Firewood	25,390.32	20,141.09	15,012.03	9,953.41
	Crop	30,398.86	26,039.97	24,995.90	23,946.17
	Cattle	0.00	37,999.15	75,998.31	113,997.46
Total Cost		**35,525.87**	**53,735.47**	**71,945.06**	**90,154.66**
	Fallow System	35,525.87	33,525.92	31,525.96	29,526.01
	Cattle	0.00	20,209.55	40,419.10	60,628.65
Net Present Value		**20,263.30**	**30,444.75**	**44,061.17**	**57,742.38**

The effect of changing beef prices from the private perspective is shown in Figure 8.6. Again, the same general trends are observed. Below ₱30 per kilogram, the addition of animals to the system is no longer profitable.

Figure 8.6 **Graph of changing net present value of the system with a change in beef prices, calculated from the private perspective.**



The analysis so far has focussed 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 in Chapter 7 indicated 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.

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.

8.6 Summary and 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, increasing the rate of soil erosion and lowering maize yields. The rate of increase in erosion is approximately in proportion to the number of cattle. Although the soils at Claveria are of low erodability, maize and firewood yields are still affected. On soils of higher erodability, adding cattle is expected to have a more dramatic effect on soil erosion and maize yields.

At current beef prices in the Philippines, significant economic benefits can be derived from the introduction of cattle into a *Gliricidia* fallow system. The modelling exercise indicates that improved fallows enable up to three cattle to be profitably carried on a two hectare farm, given a diet of one half *Imperata*, one half *Gliricidia*. While three cattle produce higher returns, production is not biologically sustainable. The profitability of a two animal system was predicted to be more than twice that of a *Gliricidia* fallow system without cattle, and is potentially sustainable in the long term.

As the number of farmers adopting a fallow system that includes cattle increases, the currently relatively high beef price is expected to fall. At lower beef prices, the introduction of cattle into the *Gliricidia* fallow system is less economically attractive. Beef prices around ₱30 per kilogram provide only marginal improvements in farm profitability. Prices at or below ₱20 per kilogram for beef, provide no profit to farmers with the inclusion of cattle in a *Gliricidia* fallow system.

Chapter 9. Summary and Conclusions

9.1 Introduction

The objective of this study was to investigate the biophysical and economic potential of an improved, *Gliricidia* fallow system as an alternative to shifting cultivation. The form of shifting cultivation considered to be common to upland smallholder farmers in many areas of the Philippines and other parts of Southeast Asia is a short term *Imperata* fallow system. As the *Gliricidia* fallow system is not currently practiced in any parts of the Philippines or Southeast Asia, this study is a preliminary investigative analysis of the system. Computer simulation modelling was used to compare and contrast the biophysical and economic benefits of the two systems. Considered within the context of dynamic technology development and design, this analysis is intended to develop the *Gliricidia* fallow system from a 'notional' stage to a 'preliminary' stage. More research, such as extensive field trials of the system are required before the *Gliricidia* fallow system can be considered fully developed and ready for implementation.

9.2 Summary of Results

From a purely biophysical perspective the *Gliricidia* fallow system shows significant potential to improve soil nutrient levels, reduce soil erosion and improve crop productivity. Soil nutrient levels improved by up to 80 per cent after 48 years of a *Gliricidia* fallow system. In comparison, under a continuous *Imperata* fallow system, some nutrients fell to approximately 30 per cent their initial levels. Soil erosion was also significantly reduced under the *Gliricidia* fallow system. The rate of soil erosion in the *Gliricidia* fallow system declined over the 48 year period, while a significant increase over time was observed in the *Imperata* fallow system. Total soil erosion under the *Gliricidia* fallow system was less than one third that of the *Imperata* fallow system. The *Gliricidia* fallow system was found to be sustainable, with crop yield maintained over the long term. This was not true under the *Imperata* fallow system, which saw crop yield decline over time.

Over the 48 year period crop yield under the *Gliricidia* fallow system was able to show a slight increase, of around 10 per cent. This was associated mainly with the improving soil nutrient levels and low levels of erosion. The *Imperata* fallow system, in comparison, showed a steady decline in crop yield over the 48 year period, falling to less than 25 per cent of the initial levels. Again this reflected the change in soil nutrient levels and rate of soil erosion. In general, from a biophysical perspective, the *Gliricidia* fallow system showed significant improvement over the *Imperata* fallow system. A five year *Gliricidia* fallow system was shown to be sustainable in the long term, whereas the *Imperata* fallow system cannot be sustained in the long term, leading to significant environmental impacts in terms of soil erosion and soil nutrient levels.

From an economic perspective the choice between a *Gliricidia* fallow system and an *Imperata* fallow system is less clear cut. Two forms of economic analysis were used, financial analysis and cost benefit analysis. Financial analysis considers private impacts, thus only considers factors that impact directly on the farmer. Cost benefit analysis considers the social impacts, making adjustments for market distortions due to government intervention, etc. In both analyses, the *Gliricidia* fallow system requires a much greater investment, due to the requirement to establish and manage the *Gliricidia* plantation fallow, compared to simply abandoning the site under the *Imperata* fallow.

Using a financial analysis approach, costs associated with the *Gliricidia* fallow system were more than three times higher than costs in the *Imperata* fallow system. Revenue from the *Gliricidia* fallow system was five times higher than the *Imperata* fallow system if a market for firewood is available, but slightly less than three times higher based on the revenue from maize only. The net result of the financial analysis was that the *Imperata* fallow system was only marginally profitable in the long term. To some extent this explains why poor upland farmers continue to practice this system, given that it is not sustainable from a biophysical perspective. In comparison, the *Gliricidia* fallow system was shown to be much more profitable when a market for firewood exists. However, based on revenue from maize only a small loss is incurred. Thus, from a private perspective, for a farmer to consider adopting a *Gliricidia* fallow system, a market for firewood must be available for the farmer to regain some of the extra costs of establishing and managing the *Gliricidia* plantation fallow.

From a social perspective, using cost benefit analysis, revenue from maize is relatively lower. This is a result of the world price for maize, used in the cost benefit analysis, being less than half the domestic price of maize, used in the financial analysis, due to import restrictions. Labour rates are also lower in the cost benefit analysis as a shadow wage rate is used. The *Imperata* fallow system becomes quite unprofitable when viewed from the social perspective, with costs almost 75 per cent higher than revenues. The *Gliricidia* fallow system maintains its high level of profitability if a market for firewood is available. This is due mainly to the firewood price remaining unchanged, and representing a greater proportion of the revenue. Without a market for firewood the *Gliricidia* fallow system is unprofitable, as with the lower maize revenue the system is not able to recover the cost of the high labour requirement to establish and maintain the *Gliricidia* plantation fallow.

Upland farmers in Southeast Asia maintain an almost subsistence existence, thus they are not able to absorb short-term losses associated with changing farming practices. As a result, the transition period, which is the period in which plots under *Imperata* fallow are transformed into *Gliricidia* fallow plots, is important in determining a farmer's ability to adopt the new *Gliricidia* fallow system. From a biophysical perspective it takes four years for crop yields to rise from the low levels obtained from an *Imperata* fallow system to the higher levels obtained from a *Gliricidia* fallow system. From a social economic perspective the system incurs a loss in the first two years of the transition period, and it is not until after the sixth year that these initial losses are recovered. Thus, unless farmers are able to absorb these losses in the first two years, they will be unlikely to adopt the *Gliricidia* fallow system, even though over the long term the system is significantly more profitable than the *Imperata* fallow system.

Introducing cattle in the *Gliricidia* fallow system has the potential to improve the profitability of the system significantly. The nutrient rich *Gliricidia* foliage when supplemented into an animal's diet, has the potential to increase weight-gain, and thus the value of cattle in the market place. However, the introduction of cattle into the system involves a trade-off between the use of *Gliricidia* for cattle fodder and for green manure to improve soil nutrient levels. Cattle require a mixed diet of grasses and *Gliricidia*, thus there is also a trade-off between the number of plots that will remain *Imperata* to supply the grasses component of the animals diet and the number of plots that are converted into *Gliricidia* fallow. It was found that while up to three animals can be supported on a two hectare *Gliricidia* fallow system, to maximise both economic and environmental benefits, a system with two cattle, two *Imperata* fallow plots, three *Gliricidia* fallow plots and one maize crop plot should be used. This provided a sustainable maize crop and provided a high return to farmers from cattle, maize and firewood.

9.3 Comparison with previous Research

This research reinforces and lends empirical support to previous research, which has predicted that improved fallow systems have potential to improve productivity in shifting cultivation systems.

Garrity (1993) suggested that managed tree fallows, of leguminous cover or tree crops, may be practical in some circumstances to improve productivity in shifting cultivation systems. However, he noted that empirical evidence of their practical utility were sparse. Garrity (1993) cited an example in Leyte, the Philippine, where leguminous crop of Kudzu (*Pueraria phaseoloides*) was successfully established by broadcast seeding in *Imperata* fallows. This fallow crop successfully controlled the *Imperata* in less than one year and increased the rate of soil recovery. MacDickens (1990), discussed an example of an indigenous fallow system, where a dense stand of naturally reseeded *Leucaena leucocephala* allowed farmers to reduce fallow lengths from 6-8 years to 2-4 years between upland rice and maize plantings. In this example crop yields were not quantified, however they were reported by farmers to be at least as high under the shorter *Leucaena* fallows. Stewart (1992), in a study assessing the potential of a *Leucaena leucocephala* fallow used for charcoal production, found the improved fallow system to be economically sustainable as an added enterprise in shifting cultivation systems in Iloilo, Philippines. These examples were observations of indigenous farming practices. This research has provided a means of testing the adaptability of the previous research, lending both biophysical and economic support to the potential these systems may offer.

Other examples include the research by ICRAF in Kenya (Swinkles et al., 1996) which developed an improved fallow prototype, established by direct seeding of *Sesbania sesban* following maize cropping. They found this technique was economically viable and offered promise for reclaiming depleted land. Success in this technique was measured by continued smallholder farmer adoption of the technique and continued practice. Farmers main reason for using this technique was to restore soil fertility in degraded lands and labour shortages encouraging farmers to fallow land. This research has been supported by later work by Kwesiga et al (1999), which demonstrated the potential of 2 to 3 year *Sesbania* fallows in restoring soil fertility and increasing maize yields. This research showed the improved fallow systems were feasible, profitable and acceptable to farmers, due to improved maize yields as a result of improved nitrogen and organic matter following the fallows.

9.4 Conclusion

The approach to evaluation reported in this study has merit, as it is relatively inexpensive, yet powerful. 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 miniscule in comparison to what would be involved in field experiments. Furthermore, the modelling approach allows the researcher to exercise 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 *Gliricidia* fallow system that was assessed in this study offers the potential to provide significant improvements to a range of soil biophysical measures. This enables higher levels of farm outputs to be achieved. So, from environmental and productivity perspectives, the *Gliricidia* fallow system is quite attractive.

Smallholders, however, are also 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 from both private and social perspectives. The ability of the *Gliricidia* fallow system to provide additional marketable products further enhances the potential of the system. The sale of firewood and the potential to include animals in the system, are attractive additional benefits provided by the *Gliricidia* fallow system.

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 second, and it will take approximately six years for smallholders to recover this initial loss. Unless smallholders are capable of waiting six years to recover their initial investment, 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*, 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. However, it is still too early to be sure of the full extent of benefits that can be derived from the *Gliricidia* fallow system, as extensive field trials are needed before this new technology can be considered fully developed. Insofar as this system, and other improved fallow systems with similar characteristics, have been shown to be potentially attractive to smallholders from economic, environmental and productivity perspectives, it gives confidence that more substantive research efforts into this systems, such as extensive field trial, should be undertaken.

9.5 Further Research

In terms of its aim of providing an inexpensive approach to assess the potential of an improved fallow system to provide both environmental and economic benefits to smallholder farmers in Southeast Asia, this research has achieved its goal. It is now up to govenments and research organisations to take the next step. This involves setting up extensive field trials to assess, in more detail, the site specific characteristics of the system. This should be done through farmer field trials and extension, rather than within a controlled research environment, as the adaptability of the system is highly dependent on the farmers ability to overcome the potential losses that will be incurred during the transition period. Further research into appropriate support, via government policies or community initiatives, to help farmers overcome the transition period and assist them to adopt the improved fallow system should also be considered.

References

Agus F. (1994) Soil processes and crop production under contour hedgerow systems on sloping oxisols. Ph.D Dissertation. Raleigh: North Carolina State University.

Almendras A.S. and Serohijos R.C. (1994) Tree/shrub legume residues in upland cropping in the Philippines. In: Lefroy RDB, Blair GJ and Craswell ET (eds) Soil organic matter management for sustainable agriculture. A workshop held in Ubon Thailand: ACIAR Proceedings No. 56.

Anderson J.R. and Hardaker J.B. (1979) Economic analysis in the design of new technologies for small farmers. In: Vades A, Scobie GM and Dillon JL (eds) Economics and the design of small farmer technology. Ames: Iowa State University Press, pp 11-29.

Andriesse J.P. and Koopmans T.T. (1984) A monitoring study of nitrogen cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia I: The influence of simulated burning on form and availability of plant nutrients. Agriculture, Ecosystems and Environment 12:1-16

Anoka U.A., Akobundu I.O. and Okonkwo S.N.C. (1991) Effects of Gliricidia sepium and Leucaena leucocephala on growth and development of Imperata cylindrica. Agroforestry Systems 16:1-12.

Atta-Krah A.N and Sumberg J.E (1988) Studies with Gliricidia sepium for crop/livestock production systems in West Africa. Agroforestry Systems 6:97-118.

Balasubramanian V. and Blaise N.K.A. (1993) Short season fallow management for sustainable Africa. In Ragland J. and Lal R. Technologies for Sustainable Agriculture in the Tropics. American Society of Agronomy. Madison, Wisconsin, USA.

Barbier E.B. (1990) The Farm-level economics of soil conservation: The uplands of Java. Land Economics 66:199-211

Barbier E.B. (1996) The economics of soil erosion: theory, methodology and examples. Paper based on a presentation to the fifth biannual workshop on economy and environment in Southeast Asia, Singapore, November 28-30, 1995.

BIOTROP (1980) Proceedings of BIOTROP workshop on Alang-alang. Bogor, Indonesia: BIOTROP Special Publication No. 5.

Blaikie P. and Brookfield H. (1987) Land degradation in Society. Methuen and Co. London. United Kingdom.

Boardman A.E., Greenberg D.H., Vining A.R. and Weimer D.L. (1995) Cost Benefit Analysis: Concepts and Practice. Prentice Hall. USA, New Jersey, Saddle River.

Boserup E. (1965) The conditions of agricultural growth: the economics of agrarian change under population pressure. Aldine Publishing Company. Chicargo, Illinois, USA.

Brady N.C. (1996) Alternatives to slash-and-burn. Agriculture, Ecosystems and Environment 58:3-11.

Brook R.M (1989) Review of Imperata cylindrica (L.) Raeuschel with particular reference to Southeast Asia. Tropical Pest Management 35:12-25.

Brown L. (ed.) (1995) Shorter Oxford English Dictionary. Oxford University Press, Kent, United Kingdom.

Bunce A.C. (1950) The Economics of Soil Conservation. Iowa State College Press, Iowa USA.

Burt O.R. (1981)Farm level economics of soil conservation in the Palouse area of the Northwest. American Journal of Agricultural Economics 63:83-92.

Calub A.D (1995) Livestock in agroforestry systems. Paper presented at the First National Grassland Congress. Ecosystems Research and Development Bureau, Manila, Philippines.

Cassen R.H. (1976) Population and development: a survey. World Development 4: 785-830.

Castillo E.T. and Saipno F.E. (1995) The current state of vegetation and soil fertility of the grasslands and pasturelands of Nueva Ecija, Nueva Vizcaya and Isabella provinces. Los Baños, Laguna, Philippines: Paper presented to the First National Grassland Congress.

Conelly W.T. (1992) Agricultural intensification in a Philippine frontier community: impact on labour efficiency and farm diversity. Human Ecology 20:203-223.

Dasgupta A.K. And Pearce D.W. (1972) Cost Benefit Analysis: Theory and Practice. Macmillan Press. London UK.

David C.C. (1996) Food policy and economic incentives, Presented at the annual conference of the Philippine Economic Society, Price stability and sustainable growth: Policy issues and trade-offs. Makati: Hotel Nikko. 9 February.

dela Cruz R.C. (1993) Imperata cylindrica grassland in the Philippines. In: Vanderbeldt RJ. (ed.) Imperata grasslands in Southeast Asia: summary reports from the Philippines, Malaysia and Indonesia. MPTS Network Report No. 18. Winrock International and USAID, Bangkok, Thailand. 9-20.

Dove M.R. (1986) The practical reason of weeds in Indonesia: Peasant vs. state views of Imperata and Chromolaena. Human Ecology 14:163-190.

Dreze J. (1974) Discount rates and public investment: a post scriptum. Econometrica 41:52-61.

Dvorak K.A. (1992) Resource management by West African farmers and the economics of shifting cultivation. American Journal of Agricultural Economics 74: 809-815.

Eckholm E.P. (1976) Losing Ground. Environmental Stress and World Food Prospects. Norton Press, New York, USA.

Ella A., Jacobsen C., Stur W.W. and Blair G. (1989) Effect of plant density and cutting frequency on the productivity of four tree legumes. Tropical Grasslands 23:28-34.

Ella A., Stur W.W., Blair G. and Jacobsen C. (1991) Effect of plant density and cutting frequency on the yield of four tree legumes and interplanted Panicum maximum. Tropical Grasslands 25:281-286.

Eussen J.H.H. (1981) Studies on the growth characteristics of alang-alang (Imperata cylindrica (L.)Beauv.) and some plants. Bogor, Indonesia: BIOTROP Buelletin No. 10.

Eussen J.H.H., Slamet S. and Soeroto D. (1976) Competition between alang-alang (Imperata cylindrica) and some crop plants. Bogor, Indonesia: Biotrop Bulletin No. 10.

FAO (1979) A provisional method for soil degradation assessment. Rome: Food and Agriculture Organisation.

Feldstein M. (1964) The social time preference discount rate in cost benefit analysis. Economic Journal 74:360-379.

Franco M.A., Reithmuller P. and Smith D. (1996) Characteristics of backyard cattle producers in the Philippines.

Fujisaka S. (1993) A case of farmer adaptation and adoption of contour hedgerows for soil conservation. Exploratory Agriculture 29:97-105.

Gaffney, M.M. (1965) Soil depletion and land rent. Natural Resources Journal 4:537-557.

Gardner K. and Burrows R. (1985) The impact of soil conservation investment on land prices. American Journal of Agricultural Economics 67:943-947.

Garrity D.P. (1991) Sustainable land use systems for the sloping uplands of Southeast Asia, Technologies for sustainable agriculture in the tropics. (Draft version used with the permission of the author).

Garrity D.P. (1993) Sustainable landuse systems for sloping uplands in Southeast Asia. In: Technologies for sustainable agriculture in the tropics. Madison: American Society of Agronomy, Crop Science Society of America and Soil Science Society of America. ASA Special Publication 56.

Garrity D.P., Kummer D.M. and Guiand E.S. (1993) The Philippines, in Committee on the Sustainable Agriculture and the Environment in the Humid Tropics International Development and National Research Council, Sustainable agriculture and the environment in the humid tropics. National Academy Press, Washington DC, USA.

Glass D.V. (ed.) (1953) Introduction to Malthus. Watts Press, London United Kingdom.

Grist P. and Menz K. (1996) Burning in an Imperata fallow / upland rice farming system. Canberra, CRES, ANU: Imperata Project Paper (1996/7).

Gunasena H.P.M. and Van der Heide J. (1989) Integration of tree legumes in cropping systems in the intermediate zone of Sri Lanka. In: Nutrient management for food crop production in tropical farming systems. 327-330.

Gutteridge R.C. and Shelton H.M. (1993) The scope and potential of tree legumes in agroforestry. Agroforestry Systems 23:177-194.

Gutteridge R.C. and Shelton H.M. (1994) Animal production potential of agroforestry systems. In: Copeland JW, Djajanegra A and Sabrani M Agroforestry and Animal Production for Human Welfare Proceedings of the 7th AAAP Animal Science Congress, Bali, Indonesia. ACIAR Proceedings No. 55.

Hayami Y. and Ruttan V.W. (1985) Agricultural Development: An International Perspective. John Hopkins Press, London, United Kingdom.

Harberger A.C. (1972a) On discount rates for cost benefit analysis. Project Evaluation, Macmillan, New York, USA.

Harberger A.C. (1972b) Professor Arrow on the social discount rate. Project Evaluation, Macmillan, New York, USA.

Huszar P.C and Cochrane H.C. (1990) Subsidisation of upland conservation in West Java: The Citanduy II project. Bulletin of Indonesian Economic Studies 26:121-132.

Huszar P.C., Pasaribu H.S. and Ginting S.P. (1994) The sustainability of Indonesia's upland conservation projects. Bulletin of Indonesian Economic Studies 30:105-122.

ICRAF (not dated) Productivity and sustainability of forage legumes and grasses, contour hedgerow systems, and amelioration of scouring effect. International Center for Research into Agroforestry, Claveria, Philippines.

Jabbar M.A., Larbi A. and Reynolds L. (1996) Alley farming for improving small ruminant productivity in West Africa: ILRI's experiences. Socioeconomic and Policy Research Working Paper No. 20. International Livestock Research Institute, Addis Ababa, Ethiopia.

Kearl L.C. (1982) Nutrient Requirements of Ruminants in Developing Countries. Utar Agriculture Expt. Logan.

Kent T. (1985) Development and Extension of the Agroforestry / Hillside Farming Programme in Zamboanga del Sur. AIDAB, Melbourne, Australia.

Kikuchi M., Hafid A., Saleh C., Hartoyo S. and Hayami Y. (1980) Changes in Community Institutions and Income Distribution in a West Java Village. IRRI Research Paper Series 50, International Rice Research Institute, Manila, Philippines.

Kwesiga F.R., Franzel S., Place F., Phiri D. and Simwanza C.P. (1999) Sesbania sesban improved fallows in eastern Zembia: Their inception, development and farmer enthusiasm. Agroforestry Systems (in press).

Lal R. (1975) Role of mulching techniques in soil and water management. International Institute of Tropical Agriculture, Technical Bulletin No. 1.

Lal R. (1989a) Agroforestry systems and soil surface management of a tropical alfisol, II: water runoff, soil erosion and nutrient loss. Agroforestry Systems 8:239-242.

Lal R. (1987) Effects of erosion on productivity. Critical Reviews in Plant Sciences. 5:303-367.

Lal R. (1988) Soil erosion control with alley cropping. Proceedings of the Fifth International Soil Conservation Conference – Land Conservation for the Future. 18-29 January, Bangkok, Thailand, PP 237-245.

Lambert M.B. and Lim J. (1987) Rural financial markets: a review of literature. Staff Paper Series No. 8702. Philippine Institute for Development Studies. Manila, Philippines.

Larbi A., Jabbar M.A., Atta-Krah A.N. and Cobbina J. (1993) Effect of taking a fodder crop on maize grain and soil chemical properties in Leucaena and Gliricidia alley farming systems in Western Nigeria. Experimental Agriculture 29:317-321.

Larson W.E., Pierce F.J. And Dowdy R.H. (1987) The threat of soil erosion to long term crop productivity. In: Harlin JM and Berardi GM. (ed) Agricultural Soil Loss: Processes, Policies and Prospects. Westview Press. Boulder, Colorado, USA.

Limbaga C.M (1993) Evaluation of hillylands for appropriate conservation-oriented farming systems. Ph.D. Dissertation, University of the Philippines, Los Banos.

Londhe S.R., Pascual N.P., Van Wagner K., Gabunada F. and Pomeroy R.S. (1989) Adoption and economic viability of the sloping agricultural land technology on small upland farms in Eastern Visayas.

Lowry J.B., Petheram R.J. and Tangendjaja B. (1992) Plants fed to village ruminants in Indonesia. ACIAR Technical Report No. 22, Canberra, Australia.

MacDickens K.G. (1990) Agroforestry management in the humid tropics. In: MacDickens K.G. and Vergara N.T. Agroforestry: classification and management. John Wiley and Sons. New York, USA.

Maclean R. (1991) The decomposition rate of Gliricidia sepium and Cassia spectabilis mulch and its influence on biomass management in an alley cropping system in Southern Philippines. Nitrogen Fixing Tree Research Reports 9:43-46

Maclean R.H., Litsinger J.A., Moody K. and Watson A.K. (1992) The impact of alley cropping Gliricidia sepium and Cassia spectabilis on upland rice and maize production. Agroforestry Systems 20:213-228.

Magcale-Macandog D., Menz K., Rocamora P. and Predo C. (1997) Smallholder timber production and marketing: The case of Gmelina arborea in Claveria, Northern Mindanao, Philippines. Canberra, CRES, ANU: Imperata Project Paper (1997/9).

Magcale-Macandog D.B., Predo C.D., Menz K.M. and Calub A.D. (1997) Napier grass strips and livestock: a bioeconomic analysis. Canberra, CRES, ANU: Imperata Project Paper (1997/1).

Magrath W.B. (1990) Economic analysis of soil conservation technologies, in Doolette J.B. and Magrath W.B. (eds.) Watershed Development in Asia, strategies and technologies. World Bank Technical Paper No. 127. World Bank, Washington DC, USA.

Marglin S. (1963a) The social rate of discount and the optimal rate of investment. Quarterly Journal of Economics 78: 95-111.

Marglin S. (1963b) The opportunity cost of public funds. Quarterly Journal of Economics 78: 274-289.

Marglin S. (1967) Public Investment Criteria. Allen and Urwin, London, UK.

McConnell K.E. (1983) An economic model of soil conservation. American Journal of Agricultural Economics. 65:83-89.

Medella E.M., Del Rosario C.M., Pineda V.S., Querbin R.G. and Tan E.S. (1990) Re-estimation of shadow prices for the Philippines. Philippine Institute of Development Studies: Working Paper 90-16.

Menz K., O'Brien G.C. and Parilla L.S. (1995) A profile of upland farming systems on sloping land in the Philippines. Canberra, Australia. ACIAR Working Paper No. 46.

Menz K. and Grist P. (1995) Shading Imperata with rubber. Canberra, CRES, ANU: Imperata Project Paper 1995/4.

Menz K. and Grist P. (1996) Changing fallow length in an Imperata / Upland rice farming system. Canberra, CRES, ANU: Imperata Project Paper 1996/6.

Menz K.M. and Knipscheer H.C. (1981) The location specificity problem in farming system research. Agricultural Systems 7:95-103.

Menz K. and Wibawa G. (1995) Economic aspects of *Imperata* control in rubber smallholdings in Indonesia. Canberra, CRES, ANU: Imperata Project Paper 1995/2.

Moog F.A. (1991) Role of fodder trees in Philippine smallholder farms. In Speedy A. and Pugliese P.L. Legume trees and other fodder trees as protein sources for livestock. FAO Animal Production and Health Paper 102.

Morbella J.L., Pineda C.I., Bulay R.N., Castillo A.C. and Moog F.A. (1979) Utilisation of rice straw and Ipil-ipil in cattle fattening at Magalang, Pampanga. Philippine Journal of Animal Industry 34:81-87.

Nelson R., Grist P., Menz K., Paningbatan E. and Mamicpic M. (1996a) A cost benefit analysis of hedgerow intercropping in the Philippine uplands using SCUAF. Canberra, CRES, ANU: Imperata Project Paper (1996/2).

Nelson R., Cramb R., Menz K. and Mamicpic M. (1996b) Bioeconomic modelling of alternative forms of hedgerow intercropping in the Philippine uplands using SCUAF. Canberra, CRES, ANU: Imperata Project Paper 1996/9.

Nelson R.A. (1996) Bioeconomic analysis of Hedgerow Intercropping in the Philippine Uplands. Ph.D. Thesis submitted to University of Queensland, Queensland, Australia.

Nelson R.A., Cramb R.A. and Mamicpic M.A. (1996c) Costs and returns of hedgerow intercropping and open-field maize farming in the Philippine uplands. Los Baños, SEARCA-UQ Uplands Research Project: Working Paper No. 11.

Nitis I.M. (1985) Present state of grassland production and utilisation and future perspectives for grassland faring in humid tropical Asia. In: Proceedings of the XV International Grassland Congress. The Science Council of Japan.

Nitis I.M. and Lana K. (1984) The effect of replacing 30% of green roughage with concentrate on the performance of Bali Steer. Final report IRDC

Norton B.W. (1994) The nutritive value of tree legumes. In: Gutteridge R.C. and Shelton H.M. Forage tree legumes in tropical agriculture. CAB International, Wallingford, Oxon, UK.

Nye P.H. And Greenland D.J. (1965) The soil under shifting cultivation. Commonwealth Agricultural Bureau, Technical Communication No. 51. Bucks, England.

Palm C.A. (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. Agroforestry Systems 30:105-124.

Panjaitan M., Stur W.W. and Jessop R. (1993) Growth of forage tree legumes at four agro-climatic sites in Indonesia. Journal of Agricultural Science, Cambridge 120:311-317.

Pasicolon P., Calub A. and Sajise P. (1996) The dynamics of grassland transformation in Salindingan, Ilagan, Isabela, Philippines. Canberra, CRES, ANU: Imperata Project Paper (1996/10).

Payne W.J.A. (1984) A review of the possibilities for integrating cattle and tree crop production systems in the tropics. Forest Ecology and Management 12:1-36.

Perkins F. (1994) Practical Cost Benefit Analysis, Basic Concepts and Applications. Macmillan Educational Australia, Melbourne.

Regional Physical Planning Program for Transmigration (RePPProT) (1989) The land resources of Indonesia: a national overview. Main report. Foreign and Commonwealth Office, UK:NRI, ODA.

Rodriguez D.C., Rodriguez D.M. and Bongolan F.F. (1988) The effect of organic mulches: madre de cacao (Gliricidia sepium) and Ipil Ipil (Leucaena leucocephala) on the yield of corn. Philippine Journal of Crop Science 13:1-15.

Rusastra I.W., Susilawati S.H., Budi G.S. and Menz K.M. (1996) Smallholder Imperata infested districts of South Kalimantan. Canberra, CRES, ANU: Imperata Project Paper (1996/11).

Ruttan V.W. (1982) Agricultural Research Policy. University of Minnosota Press, Minneapolis, Minnosota, USA.

Sabarnurdin M.S., Iswantoro H. and Adjers G. (ed) (1991) Forestation of alang-alang grassland: lessons from South Kalimantan. Gadjah Mada University. Yogyakarta, Indonesia.

Sajise P.E. (1980) Alang alang (Imperata cylindrica) and upland agriculture. In: Proceedings of BIOTROP orkshop on Alang-alang. Bogor, Indonesia: BIOTROP Special Publication No. 5.

Sanchez P.A. (1976) Properties and Management of Soils in the Tropics. John Wiley and Sons Press. New York, USA.

Sanchez P.A. (1982) Soils of the humid tropics. Studies of Third World Society 14:347-410.

Sanchez P.A. (1995) Science in Agroforestry. Agroforestry Systems 30:5-55.

Sandmo A. and Dreze JH. (1971) Discount rates for public investment in closed and open economies. Econometrica 38:396-412.

Seckler D. (1987) Economic cost and benefits of degradation and its repair. In Blaikie P. and Brookfield H. (1987) Land degradation in Society. Methuen and Co. London. United Kingdom.

Simons A.J. and Stewart J.L. (1994) Gliricidia sepium - a multipurpose forage tree legume. In: Gutteridge R.C. and Shelton H.M. Forage tree legumes in tropical agriculture. Wallingford, Oxon: CAB International.

Sinden J.A. And Thampapillai D.J. (1995) Introduction to Cost Benefit Analysis. Longman, Australia, Melbourne.

Sjaatad L.A. And Wisecarver D.L. (1977) The social cost of public finance. Journal of Political Economy 85:513-547.

Soerjani M. (1970) Alang-alang, Imperata cylindrica (L.) Beauv. (1812): pattern of growth related with the problem of its control. Bogor, Indonesia: BIOTROP Bulletin 1.

Soewardi B. and Sastradipradja D. (1980) Alang alang and animal husbandry. In: Proceedings of BIOTROP workshop on alang alang, Bogor, Indonesia. BIOTROP Special Publication No. 5.

Stewart T.P. (1992) Land-use options to encourage forest conservation on a tribal reservation in the Philippines. Agroforestry systems 18:225-244.

Stocking M. (1987) Measuring land degradation. In Blaikie P. and Brookfield H. (1987) Land degradation in Society. Methuen and Co. London. United Kingdom.

Stocking M. (1984) Erosion and soil productivity: A review, consultant's working paper No.1, Soil Conservation Programme, Land and Water Development Division, Food and Agriculture Organisation of the United Nations. Rome.

Sturr W.W., Reynolds S.G. and Macfarlane D.C. (1994) Cattle Production under coconuts. In: Copeland J.W., Djajanegra A. and Sabrani M. Agroforestry and Animal Production for Human Welfare Proceedings of the 7th AAAP Animal Science Congress, Bali, Indonesia. ACIAR Proceedings No. 55.

Swinkles R.A., Franzel S., Shepard K.D., Ohlsson E. and Ndufa J.K. (1996) The economics of short rotation improved fallows: evidence from areas of high population density in western Kenya. Agroforestry Systems. 55:99-121.

Templeton S. and Scherr S. (1996) Macroeconomy of land management under population pressure in hills and mountains of developing countries. (Draft version used with the permission of the author).

Thampapillai D.J. and Anderson J.R. (1993) A review of the socioeconomic analysis of the soil degradation problem for developed and developing countries. Review of marketing and Agricultural Economics 62:291-315.

Trenbath B.R. (1984) Decline of soil fertility and the collapse of shifting cultivation systems under intensification. In: Tropical Rainforest: The Leeds Symposium. Chadwick A.C. and S.L. Sutton (eds) Leeds Philosophical and Literary Society Ltd, Leeds, UK.

Turvey N.D. (1994) Afforestation and rehabilitation of Imperata grasslands in Southeast Asia: identification and priorities for research, education, training and extension. Canberra, Australia: ACIAR Technical Report No. 28.

UNIDO (1972) Guidelines for Project Evaluation. United Nations, New York, USA.

Van Noordwijk M., Tomich T.P., Winahya R., Muridyarso S., Suyanto, Partoharjono S. and Fagi A.M. (eds) (1995) Alternatives to slash and burn in Indonesia, summary report of phase 1. Bogor, Indonesia: ASB Report No. 4.

Vasey D.E. (1979) Population and agricultural intensity in the humid tropics. Human Ecology 7:269-283.

Veloz A., Southgate D., Hitzhusen F. and MacGregor (1985) The economics of erosion control in a subtropical watershed: A Dominican case. Land Economics 61:145-155

Vermuelen S.J., Womer P., Campbell B.M., Kamukondiwa W., Swift M.J., Frost P.G.H., Chivaura C., Murwira H.K., Mutambanengwe F. and Nyathi P. (1993) Use of the SCUAF model to simulate natural Miombo woodland and maize monoculture ecosystems in Zimbabwe. Agroforestry Systems 22:259-271.

Vesteeg M.N. and Kodoukpon V. (1993) Participative farmer testing of four low external input technologies, to address soil fertility decline in Mono Province. Agricultural Systems 42:265-276.

Wade J.C. and Heady E.O. (1979) Measurement of sediment control impacts on agriculture: Reply. Water Resource Research 15:1281-1284.

Young A. (1989) Agroforestry for soil conservation. Wallingford: CAB International.

Young A., Menz K., Muraya P. and Smith C. (1998) SCUAF Version 4: A Model to Estimate Soil Changes Under Agriculture, Agroforestry and Forestry. ACIAR, Canberra Australia.