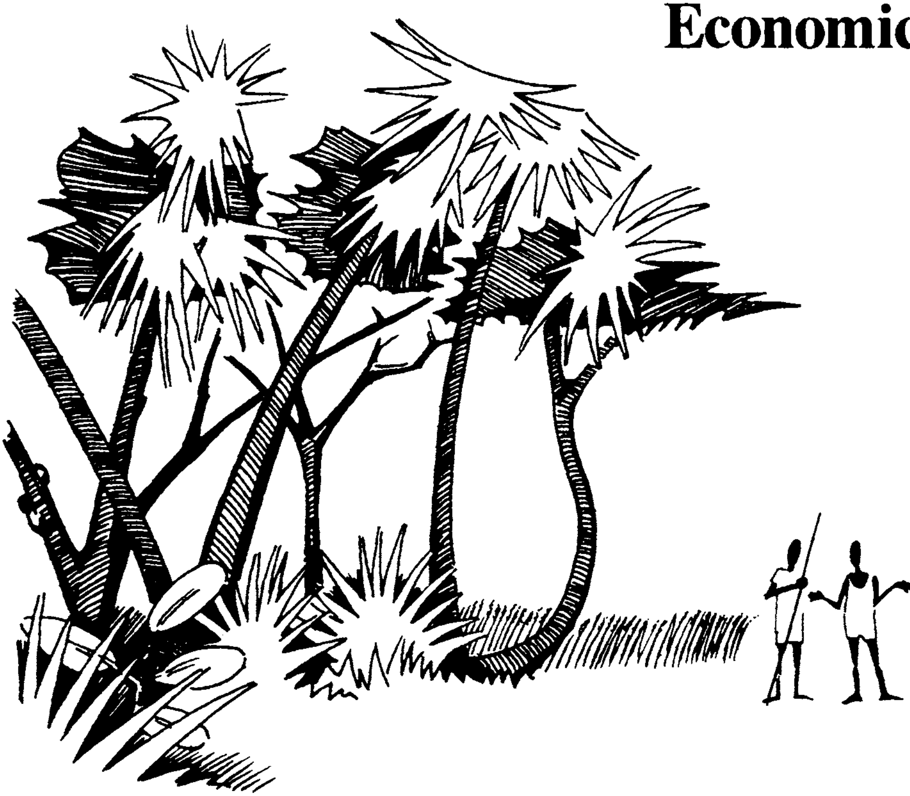
AGROFORESTRY FOR SUSTAINABLE PRODUCTION

Economic Implications

Commonwealth Science Council

AGROFORESTRY FOR

Economic



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Agroforestry for Sustainable Production Economic Implications

SUSTAINABLE PRODUCTION

Implications

Roslyn Tamara Prinsley

Commonwealth Science Council

Other books on agroforestry by the Commonwealth Science Council

Amelioration of Soil by Trees:
A Review of Current Concepts and Practices
Edited by R T Prinsley and M J Swift
Commonwealth Science Council, 1987

Guidelines for Training in Rapid Appraisal for
Agroforestry Research and Extension
N O J Abel, M J Drinkwater, J Ingram, J Okafor, R T Prinsley
Commonwealth Science Council, 1989

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Preface

Agroforestry, a sustainable land use suited to resource poor farmers, is being promoted as a contributory solution to the problems of land degradation.

Economics has a crucial role to play in decision-making in households, communities, institutions and governments.

Economic development in most developing countries relies on the sustainability of natural systems.

This book discusses how economic and financial analysis can be used to assess the net benefits of agroforestry enterprises for peasant households, institutions and society. Economic, financial, social and technical issues are examined.

Special attention is paid to:

* incentives for agroforestry and analysis of peasant economic decisions

* the use of cost benefit analysis as a method for assessment of agroforestry enterprises

* the quantification and valuation of the perceived benefits of agroforestry - soil conservation, multiple products and efficient resource use

* economics for sustainable production

* the use of a spreadsheet model for economic analysis of agroforestry

This volume represents the collection of papers presented at the Commonwealth Science Council's meeting on 'Agroforestry for Sustainable Development - Economic Implications' in Swaziland in 1989. The participants of the meeting who contributed to this volume include natural scientists, social scientists and economists so that the approach to the subject is of an interdisciplinary nature.

Acknowledgements

The preparation of background papers for this book was funded by a grant from Ford Foundation. The workshop was supported by grants from Ford Foundation, IDRC, ODA, FAO and British Council.

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INTRODUCTION

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A large development project burns down all the trees in its domain, kills off all the wildlife, pollutes the air with smoke and clogs up the rivers with silt. Does the country thus become poorer? Yes, says common sense. No, say conventional economics.

If a country's man-made assets (factories, machinery) depreciate faster than they are being replaced, it is clearly living beyond its means, and economic growth is not sustainable (Repetto et al 1989). In conventional economics no such concept applies to the depletion of natural resources. As they are used up, no decline in value is registered to reflect the fall in future potential production.

However in the same sense that a machine depreciates, soils depreciate as their fertility is diminished since they can produce only at higher costs or lower yields (Repetto et al 1989). In particular for developing countries which are more dependent on natural resources for income , jobs, livelihood and exports, the danger of treating natural resources as valueless is even greater. Natural resources which are not accounted for are such countries' main assets ignored.

This view that natural resources are "free gifts of nature" is held from the national level of economist and policy maker to more localised cost - benefit analysis of development projects down to the household level of the peasant farmer who cannot see the need to plant indigenous trees as they are given freely by God in the communal woodland (which is all but cleared).

'An asset which is undervalued will inevitably be misused' (Repetto, 1988)

There is a clear need for the valuation of natural resources, and for estimates of the costs and benefits of investment in their conservation and use. Cost Benefit Analysis is an approach to this type of problem. It can be used to assess the net benefit or loss to the economy as a whole, as well as to the private users of natural resources.

Trees are a particular example of a natural resource that has been traditionally undervalued. Deforestation has resulted in land degradation and wood shortages. Now, agroforestry is being promoted by scientists as a contributory solution. **Could Cost Benefit Analysis and other methods of economic assessment be used to assess the net benefits of agroforestry enterprises in terms of sustainable development?**

Although much of the loss of woodland and forest can be attributed to pressures from growing population, clearance for arable land and use for fuelwood, construction wood and forage - government policies lie behind the wastage of forest resources in many countries (Repetto, 1988). In many cases, various incentives have been given to land users to cut down trees rather than to conserve or plant them (Abel et al 1989). **What appropriate incentives could be given to farmers to plant trees?**

These are among the issues which the Commonwealth Science Council addressed at a workshop held in Swaziland on April 21-25, 1989 entitled 'Agroforestry for Sustainable Development - Economic Implications'. This volume represents the collection of papers presented at the workshop.

Part I is a discussion paper of the key issues involved in financial and economic analysis of agroforestry. This paper was prepared by Mike Stocking, Jan Bojö and Nick Abel as a background paper for the workshop. As it contains its own introduction, very little more will be said about it here, except that it combines an economic perspective with a study of natural resources in the setting of agroforestry enterprises for poor farmers. It addresses the question 'How can rational decisions be made on whether to invest in or support agroforestry?'

Part II comprises the other papers presented at the workshop.

Clearly the subject of this volume has far reaching implications (see Table I). We started off by discussing at the national level but we have also mentioned the peasant farmer. It is thus clear that the social and spatial scale in such a discussion can vary greatly. Social and economic aspects have been mentioned - however methods for assessing the value of natural resources must also be developed. In Table I these are denoted 'technical issues'. The spatial scale of these can also range from household/farm level to catchment to national level. Both the effects of trees on erosion with respect to the crop productivity of the individual farm as well as in relation to the problems of flooding, river flow and dam siltation which may affect a whole district or nation are relevant. To further complicate the calculation, technical, financial, economic and social issues need to be considered in both the short and long terms. In Table I these issues are clarified. Although most of the issues shown in Table I are discussed in this volume, it has been necessary to focus on certain aspects (which are discussed in the following text).

Incentives for Agroforestry

Agroforestry in developing countries is targetted at the peasant farmer. In the final analysis, it is the peasant farmer who will have to adopt such conservation schemes. Peasants differ from capitalist farm enterprises because non-market interactions figure in their access to resources, in the farming systems they adopt, and in the social principles to which they conform (Ellis 1988). Agricultural economics as a discipline usually makes no such distinctions with respect to social organisation of farm production (Ellis 1988). However, analysis of these social relations along with financial analysis done from the farmer's perspective, are extremely useful in determining how to design and implement incentive schemes such as those involving compensation and subsidies. Incentives for farmers to adopt agroforestry are discussed in Part I, and more extensively in Part II by Scoones, Pretty, Bradley, Falconer, Gumbo, Mukamuri and Muzondo. All authors demonstrate clearly that there is great variation between different peasant households, groups, villages

TABLE I: CLASSIFICATION OF AGROFORESTRY SOCIO-ECONOMIC AND TECHNICAL ISSUES BY TIME, SPATIAL AND ECONOMIC SCALES

SOCIAL & SPATIAL SCALE	SHORT TERM		LONG TERM	
	A. TECHNICAL	B. FINANCIAL/SOCIAL	C. TECHNICAL	D. FINANCIAL/SOCIAL
HOUSEHOLD/ FARM/ SITE	A1 Quantification of direct outputs - fruits, wood, fibre, fuel, posts, poles, shade, mulch, fodder, etc A2 Quantification of indirect positive & negative effects - shade, micro climate, nutrients organic matter, allelopaths, inter-ception of rain, etc A3 Possible use of householders estimates of A1 & A2 in absence of measurements	B1 Valuation of out-puts by households in use & exchange B2 Labour allocation to enterprises B3 Costs of inputs B4 Reliability of supply of inputs & markets for products B5 Risk of change in prices & costs B6 Social relations of production, especially autonomy of household in decision-making & labour-sharing B7 Categorisation of households by production strategy and access to means of production	C1 Environmental trends, eg deforestation, changes in scarcities of land and tree products C2 Perceptions of wind, drought, pests, diseases & other hazards -> private discount rate C3 Modelling the hazards in C2 C4 Modelling environmental trends, especially land degradation & productivity decline	D1 Household life-cycle considerations D2 Risk of change in prices -> private discount rate D3 Security of tree & land tenure -> private discount rate D4 Perceived income decline without conservation. Conservation as loss-reduction. Modelled estimates of declines

	E. TECHNICAL	F. ECONOMIC/SOCIAL	G. TECHNICAL	H. ECONOMIC/SOCIAL
CATCHMENT/ LANDSCAPE/ REGION/ NATION	E1 Land cover under agroforestry & alternatives ie: How do the land cover changes on myriad farms in aggregate affect the cover, hydrology and erosion rates of a catchment?	F1 Shadow prices of products F2 Foreign exchange component of various approaches to conservation, including agro-forestry F3 Research & extension requirements of agroforestry vs alternative approaches	G1 Catchment effects of land use change if agro-forestry introduced - sediment loads & net soil losses, flooding/ river flow, dam siltation G2 Flood hazard assessment G3 Landscape effects of land degradation - some sites may be gaining productivity through deposition	H1 Costs of flooding (= Benefits of control) H2 Costs of sedimentation (= Benefits of control)

(After Nick Abel & Roslyn Prinsley, unpublished 1989) and regions in their likelihood to adopt a technical change such as agroforestry. Bradley, for example, compares two small areas in the Kakamega district in Kenya, and two individual farms to demonstrate this. It is made clear that it is difficult to generalise about peasant economic decisions. Scoones and Pretty emphasise that in order to develop appropriate policy and development strategies, investigations from the national to the local level need to be integrated. Information gathering and analytical techniques that can provide an understanding of local complexity as part of the development process are provided by Scoones and Pretty and by Gumbo et al with reference to case studies in Sudan and Zimbabwe. These include semi-structured interviewing, maps, transects, seasonal calendars, historical profiles, preference rankings, direct matrix rankings, wealth rankings, Venn diagrams, matrices and key informant interviews.

Falconer adopts a different approach, and assesses agroforestry in the light of household food security on the assumption that food security is often a major production goal of the peasant farmer.

Technical Issues

Economists rely upon accurate technical data to calculate benefits and costs. The data required for natural resource and conservation aspects of agroforestry are lacking. For instance, although soil erosion is recognised as an economic cost to society because it often leads to a serious decline in primary productivity, there is a lack of quantitative models for relating soil erosion to loss of crop yield.

Indeed, at the project level - where cost benefit analysis is customarily used to look at such parameters as productivity of crops and timber production from trees against costs of land preparation, planting and labour - the issues of soil productivity and sustainability are not often considered. These issues are explored in Parts I and II of this volume.

Agroforestry is commonly perceived to control erosion and to conserve soil for sustainable production. If such issues are to be taken account of in economic analysis it is necessary to quantify and value these benefits and to predict what would happen to these values in the future. Before this can be done the benefits (or otherwise) which agroforestry confers to the soil must be identified and the processes understood.

The role of trees in soil productivity is comprehensively reviewed by Julie Ingram in Part II. She emphasises the importance of defining the effects of trees on soils and for standardising units of their measurement. Together with Stocking et al in Part I, Ingram's paper makes it clear that there is very little evidence from rigorous scientific studies of the effects of trees on soil erosion and soil conservation. Significantly, Stocking et al point out that the number and range of different agroforestry systems make it very difficult to generalise the effects of agroforestry on soil productivity. They propose the use of technical models to predict the performance of an agroforestry system in relation to the soil in both the short and long terms. This quantified information could then be valued in economic terms, and used in Cost Benefit Analysis. Models such as "Soil Changes Under Agroforestry" or SCUAF (Young et al 1987) have great potential. However, their limitations, due to gaps in current understanding, are noted.

Sitaubi goes on to warn us that even biological figures which may seem obvious need careful analysis and thought before economic accounting. He illustrates his point with reference to an experiment which determines foliar nitrogen levels to use as an index for the best trees for supply of green manure. He concludes that foliar nitrogen levels alone can be misleading and that they need to be linked to foliage biomass production for an appropriate index. Mungai explains how biological management and environmental conditions can alter the pre-chosen principal economic parameters for carrying out a cost benefit analysis for the implementation of an agroforestry enterprise.

In her paper 'The technical costs and benefits of agroforestry to the catchment as a whole. Upstream-downstream relationships', Sue White explains that to reliably predict the impact of a proposed catchment management change such as agroforestry is almost impossible. This is because there has been insufficient experimentation in this field to understand the complex processes of runoff and sedimentation. Therefore, at present, it is very difficult to give economists estimates of large scale effects of agroforestry interventions. She goes on to review what is known of the technical costs and benefits of agroforestry to the catchment as a whole.

Economic Modelling of AF Systems

Thomas has developed a spreadsheet model for the economic evaluation of an agroforestry system. Although this model has been adapted for Northern European conditions, Thomas explains that other components could be incorporated to make it more suited to conditions in developing countries. However he also emphasises the need for data of high quality, and we are reminded of the difficulties of quantifying and valuing components described in the chapters on socio-economics and technical issues.

Economics for Sustainable Development

Scientists, in particular ecologists, have for some time promoted the concept of sustainable production. What do economists think of this? Barbier, an economist, explains in his paper that although economists have been reluctant to accept the ecological view of sustainability, they have increasingly recognised that the pursuit of economic efficiency does not always guarantee the sustainability of agricultural production. He goes on to operationalise this concept by assuming that sustainability is dependent on the constancy of natural capital stock. He warns us however that this is not a sufficient condition for sustainability of production and that it is necessary too for appropriate incentives to be developed to replace those which are aimed solely at the pursuit of economic efficiency.

Sekhwela is of the opinion that formal cost-benefit analysis, a rational decision making process, cannot better the informal cost-benefit analysis which farmers use to make decisions based on the real situation of their existence in terms of their physical world. He expresses concern that formal cost-benefit analysis has been developed by economists for economists and that its use by others requires appropriate adaptation, particularly where the monetary unit does not appear to capture fully the nature of sometimes unquantifiable benefits and costs.

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PART I

FINANCIAL AND ECONOMIC ANALYSIS OF AGROFORESTRY: KEY ISSUES

FINANCIAL AND ECONOMIC ANALYSIS OF AGROFORESTRY: KEY ISSUES

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SUMMARY

Economics has a crucial role to play in decision-making in households, communities, institutions and governments. Agroforestry is seen by many as a solution to environmental problems and a sustainable enterprise especially suited to resource-poor farmers. Is agroforestry amenable to economic analysis? Have we any basis for making rational decisions as to promoting agroforestry? Especially, can the perceived advantages of agroforestry -- better use of resources, erosion control, multiple products -- be quantified and valued? This paper addresses Cost-Benefit Analysis as a method for systematically assessing the excess of benefits over costs of agroforestry enterprises for individuals, households and institutions and from the perspective of society as a whole.

The major steps of CBA relevant to agroforestry are described: (1) establishing decision criteria - including distributional consequences on different income groups in society; (2) identifying, (3) quantifying and (4) valuing the costs and benefits; (5) setting an appropriate time horizon because benefits may only accrue in the long term; (6) the controversial question of discounting; (7) dealing with risk and uncertainty; and finally (8) the making of policy conclusions as to whether investment in agroforestry should proceed.

These steps of CBA rely on the provision of technical information especially as to the performance of an agroforestry system over time. Few data are available. Many complicated technical questions remain, such as the identification and quantification of temporal and spatial complementarity between species. The benefits of erosion control and soil conservation are the future production that they assure. The long term maintenance of soil fertility, and hence the sustainability of agriculture, is a distinguishing feature of agroforestry that needs to be emphasised. But to do this, estimates of future production have to be made.

In view of the paucity of data, prediction models have to be employed. The paper reviews a number of them, including erosion prediction models and the only one specifically designed for agroforestry: SCUAF (Soil Changes Under Agroforestry). At the

current stage of development, the models have limitations and must be used with caution.

The paper reviews six cost-benefit studies of agroforestry and concludes with an identification of the key issues that will need to be addressed before further advance can be made. The studies show the considerable potential for economic and financial analysis of agroforestry, while the key issues underline the need for further research.

PREFACE

This paper breaks new ground in combining an economic perspective with a study of natural resources (especially, soils) in the setting of agroforestry enterprises for poor farmers. We use existing information from a number of disciplines -- economics, sociology, development studies, ecology and environmental sciences -- to address a problem critical to rural development. How can rational decisions be made on whether to invest in or support agroforestry?

Each of us from our different perspectives has attempted to produce a coherent argument. We found it a fruitful and stimulating exercise, even when our different backgrounds made it hard for us to agree! We produced a draft for the **Workshop on Agroforestry for Sustainable Development - Economic Implications**, held in Swaziland, 17-21 April, 1989. This is a revised version incorporating suggestions and comments from the Workshop.

Several sources have been influential in guiding this paper. From ICRAF (International Council for Research in Agroforestry, Nairobi) the Working Papers of Anthony Young (1986; 1987) and Young et al (1987) on the conservation and soil advantanges of agroforestry; the ICRAF book edited by Huxley (1983) on the outputs from agroforestry systems; the book by Ellis (1988) on peasant economics. The ICRAF Documentation Service provided bibliographic material and Sara Scherr advice on the comparative review of cost-benefit studies. Otherwise we have employed ideas and approaches used in other forums, the main sources being: Stocking (1984); Bojö (1986); and Abel et al (1988).

The work for this paper was made possible with funding from the Ford Foundation through the Commonwealth Science Council. We gratefully acknowledge Dr Roslyn Prinsley who not only read most of the drafts of this paper but also initiated and administered the project.

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1. AIMS AND DEFINITIONS

1.1 Introduction

Agroforestry is receiving substantial attention as one way in which to avoid what many perceive to be the failure of rural and agricultural development aimed at the poor, developing-country, subsistence household. The possible causes of failure are already well reviewed and are outside the scope of this paper (Heyer et al, 1981; Harriss, 1982; ICIHI, 1986; IFAD, 1986). As a rural remedy, agroforestry is said to:

* "mimic nature" and should therefore be more environmentally sound;

* exploit ecological relations between plants;

* preserve the quality of the soil through cycling of nutrients, and additions of organic matter;

* utilize solar radiation more efficiently than sole arable crops;

* capture soil nutrients and moisture from different root zones; thereby decreasing dependence on inputs;

* increase the productivity of land or labour without high capital requirements;

* produce the range of products required by the subsistence household.

Clearly, not every agroforestry enterprise can encompass the full range of these potential benefits. Nevertheless, indigenous and derived (i.e. research-station) agroforestry systems have been able to realise at least some of them (Wiersum, 1982; Torres, 1983; Michon et al, 1986; Nair & Sreedharan, 1986). There is now a need to develop methods for appraising potential agroforestry systems, evaluating existing ones, and assessing the acceptability of a proposed agroforestry enterprise within a farming system.

This need arises because governments and funding agencies are already promoting policies and allocating budgets for agroforestry often without sufficient knowledge of the value of agroforestry in relation to other sectors, or of the various options within the agroforestry sector. Other governments and agencies may be underfunding agroforestry because they are unaware of its economic potential. Furthermore, many indigenous agroforestry systems are already well developed, and it is necessary to assess their contribution to household and rural economies with a view to supporting and improving them locally, or promoting similar systems elsewhere. This paper is a contribution to the development of agroforestry appraisal and evaluation methods for these purposes.

Other workers have dealt with the appraisal of agroforestry from the perspective of "diagnosis and design" at the farm level (Raintree, 1987; Abel et al 1988). The emphasis here is different: while being complementary to and partly subsumed by the "D & D" approach, this paper is about the financial and economic analysis of agroforestry proposals and existing enterprises at a range of scales from the peasant farming household to public sector projects and programmes.

The dominance of economics in the analysis of projects and programmes has been widely discussed and variously applied. However, its usefulness is not universally accepted especially in the literature on peasant decision-making (Thorner et al, 1966; Scott, 1976; Hyden, 1980) where it is implied that financial analysis is irrelevant because decisions are not based on economic criteria. Ellis (1988) presents a contrary view where he describes the five main "competing" microeconomic theories of farm households -- profit maximisation, risk aversion, drudgery aversion, "new" household economics, share tenancy -- as being merely variations on the single theme of the household aiming to maximise the joint welfare of its members. Such an aim is clearly amenable to financial analysis. Nevertheless, as Ellis points out, this apparent economic simplicity is complicated by the internal characteristics of peasant households, and their external relations. Our objective in this paper is not, therefore, to reduce peasant decision-making to the simplicity of farm-budget analysis, a level at which unmodified cost-benefit analysis can be readily but misleadingly applied, but rather to identify the characteristics of peasant production around which cost-benefit analysis should be elaborated. Such an understanding permits analysis of the roles and values of agroforestry within the complexities and varieties of peasant production strategies.

The main questions this paper examines are:

* what physical input and output information does financial and economic analysis require?

* what technical models of agroforestry systems and of land degradation processes are available to provide estimates of physical inputs and outputs for appraisal and evaluation; how adequate are they; and what development do they require?

* how can we value these inputs and outputs for economic and financial analysis, given market imperfections or even absence of any market?

* how are the private discount rates of peasant farmers determined, and how do these affect the future values of conservation and agroforestry proposals?

* how should social discount rates for conservation and other long-term projects be set, and what planning horizons are appropriate?

* what equity considerations are relevant to agroforestry proposals?

* how do risk and uncertainty affect the valuation of agroforestry and alternative enterprises?

* what are the policy implications of our findings?

1.2 Some definitions

It is not the intention of this paper to make a sortie into the semantics of agroforestry. Definitions of agroforestry itself are numerous -- the interested reader is recommended to look at the 12 given in a 1979 ICRAF mimeo and the Editorial "What is Agroforestry" in the first issue of **Agroforestry Systems** [vol. 1, No.1, 1982] where also is justification for considering agroforestry as an interdisciplinary science. A number of other concepts used in this paper are equally elusive and problematical in their definition.

We give below the working definitions that we shall use for the most important terms and concepts:

Agroforestry: is a collective name for land use systems where woody perennials (trees, shrubs, palms, bamboos etc.) grow on the same land management unit with agricultural crops and/or animals and where there are both ecological and economic interactions between the different components. [abridged from several definitions proposed by ICRAF]

Within such a term there are a large number of separate land use practices, a classification of which is given in Table 1. Wood and Burley (1989), however, see the range of practices as a continuum from pure crop or livestock production to pure forestry with all combinations in between and three principal activities involving trees (woodlots, biomass plantations and agroforestry systems) -- see Figure 1. Either way, the possible permutations of plants, activities, management levels, and spatial and temporal arrangements are enormous, and make it impossible to generalize about the costs and benefits of agroforestry. Each system will have unique features which demand specific analysis.

Soil Conservation: is any set of measures which controls or prevents soil erosion, or maintains soil fertility.

This is the broad approach to soil conservation consistent with the possible benefits which may accrue to the soil by using agroforestry (Young, 1986) and follows recent developments in the actual practice of soil conservation as evidenced through the papers at the 6th International Soil Conservation Conference, Bangkok, 1988.

'Sustainability' and 'productivity' are stated benefits of agroforestry, and we shall seek to include the concepts in economic analysis. Yet, it is far from clear what they mean. Most uses of the words give some notion of guaranteed production in the long term future, as opposed to resource depletion. Some authors draw a distinction between "sustainable utilization" and "sustainability", the former seen as a technical concept, bound by rules of efficiency, while the latter is a broad phenomenon incorporating ethical and moral values (Turner, 1988). O'Riordan (1988) further makes the point that sustainable utilization is a prior condition to sustainability, but not a sufficient one. This is not a debate that will be pursued here. The following working definitions are used:

Sustainable land use: is that which achieves production combined with conservation of the resources on which that production depends. (Young, 1986)

Productivity: is a measure of the rate of accumulation of energy, or, in the context of soil productivity, it is the productive potential of the soil system that allows energy in the form of vegetation to accumulate at a ceratin rate (Stocking, 1984. Note: distinguished from 'production' which is the total accumulation of energy or standing crop biomass)

In economic terms it is the net increment of valued product per unit of resource (e.g. land, labour, energy or capital) per unit time and is commonly measured as annual yield or net income per hectare, or man-hour or unit of energy or investment (Conway, 1987)

Sustainability: is the ability of a system to maintain its productivity when subject to stress [i.e. regular, relatively small and predictable disturbances; e.g. growing indebtedness, soil salinity] or shock [an irregular, infrequent, large and unpredictable disturbance; e.g. flood, new pest]. (adapted after Conway, 1987)

Because we distinguish carefully between them, three main terms in economics are defined here.

Cost-Benefit Analysis: a method to identify, quantify and value information about benefits and costs in order to determine the net worth of an enterprise.

Financial analysis: analysis using market prices.

Economic analysis: analysis using economic prices reflecting people's actual willingness to pay for goods and services, whether marketed or not.

A further three terms in economics are of especial importance in CBA and its application:

Opportunity cost: the benefit foregone by using a resource for one purpose instead of the next best alternative.

Shadow price: the value set for a cost or benefit when the market price does not represent its value to the national economy.

Sensitivity analysis: a means of testing predictions about the earning capacity of an enterprise by varying one or more component inputs or outputs, and measuring the resultant effect on the prediction.

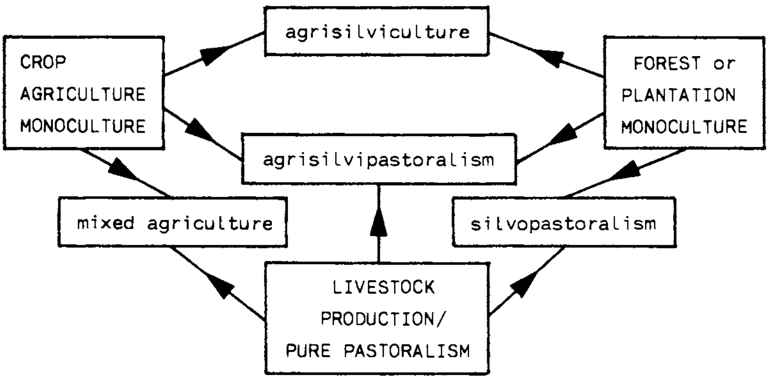


Figure 1. A continuum of land use systems involving agroforestry. (from Wood & Burley, 1989)

Table 1. Agroforestry practices – a classification (from Young, 1986)

A. MAINLY AGROSILVICULTURAL (trees with crops)

Rotational:

1. Planted tree fallow
2. Taungya

Spatial mixed:

3. Trees on cropland
4. Plantation crop combinations - with upper storey trees
   - with lower storey tree/shrub crops
   - with herbaceous crops (cf. also 12)
5. Tree gardens - multistorey tree gardens
   - home gardens

Spatial zoned:

6. Alley cropping
7. Boundary planting
8. Trees for soil conservation - barrier hedges
   - on grass barrier strips
   - on bunds, terraces, etc.
9. Windbreaks and shelterbelts
10. Biomass transfer

B. MAINLY/PARTLY SILVOPASTORAL (trees with pastures and livestock)

Spatial mixed:

11. Trees on rangeland or pastures
12. Plantation crops with pastures

Spatial zoned:

13. Live fences - mainly barrier function
    - multipurpose
14. Fodder banks

C. TREE COMPONENT PREDOMINANT

15. Woodlots with multipurpose management
16. Reclamation forestry leading to production
    - on eroded land
    - on salinized land
    - on moving sands

D. OTHER PRACTICES AND SPECIAL ASPECTS

17. Apiculture with forestry
18. Aquaforestry (trees with fisheries)
19. Trees in water management
20. Irrigated agroforestry

2. COST-BENEFIT ANALYSIS OF AGROFORESTRY

2.1 Approaches to Cost-Benefit

What is "good" agroforestry? The answer depends upon who asks, who hears and who replies. For an economist, economic efficiency and an excess of benefits over costs are necessary criteria. Methods for systematically undertaking such an assessment from private and institutional perspectives, and from the standpoint of society as a whole have been collectively termed Cost-Benefit Analysis (CBA) -- see Dasgupta et al (1972); Little & Mirrlees (1974); Gittinger (1982); and Common (1988).

To allocate limited resources to achieve development objectives in an economically efficient way one must either select enterprises that reach the desired aims at lowest cost, or that attain the highest level of goal achievement with the resources available. Any method that compares the achievement of objectives with the costs incurred is a cost-benefit analysis in the general sense. It is not necessarily a CBA as described by Dasgupta et al (1972) and the other references above.

Other cost-benefit methods include:

* Linear Programming (Prou & Chervel, 1970)

* Environmental Impact Assessment, EIA (Bisset, 1983)

* Goals-achievement Analysis (Lichfield et al, 1975)

* Planning Balance Sheet (Lichfield et al, 1975)

* The Impact Approach of the US Agency for international Development (USAID) and the Swedish International Development Authority (SIDA)

* The Advocacy Approach used during the Rapid Rural Appraisal (RRA) of agroforestry enterprises (Abel et al, 1988), and other RRA methods (Conway, 1985; McCracken et al, 1988).

We selected CBA rather than these methods because:

- the level of complexity and information requirements of CBA are appropriate for most agroforestry enterprises, whereas Linear Programming and EIA are excessively complex and data-hungry;

- the information generated for CBA is (or can be put) in a form relevant to both officials and land users -- this is not the case with Linear Programming and EIA;

- CBA can be used as a component in EIA, Goals-achievement Analysis, Planning Balance Sheet and Impact Approaches, and its use does not necessarily preclude the use of these methods;

- RRA mthods can be elaborated, if sufficient information is available on the physical quantities and values of inputs and outputs, to become formal CBAs.

The aim of this section is to consider the role of CBA in the appraisal and evaluation of agroforestry enterprises, where 'enterprise' is taken to mean projects, on-farm interventions or existing indigenous practices. Here we introduce the method primarily for the non-economist, and discuss for economist and non-economist alike the particular problems of applying CBA to peasant households. CBA literature is vast and we shall not cover it fully but our bibliography cites several useful guides to its application.

2.2 CBA and Its Major Steps

CBA entails the organization and generation of information in order to value for individuals, households, institutions and society the costs and benefits of an enterprise. These steps are normally followed (Bojö et al, 1988):

(1) The establishement of **decision criteria** by which to judge the enterprise -- this may involve considering distributional consequences such as the impact on different socio-economic groups.

(2) The **identification** of the costs and benefits.

(3) The **quantification** of costs and benefits; for example, in assessing changes in crop yield and fuelwood production.

(4) The **valuation** of costs and benefits; estimation of private and social values of the effects of the enterprise.

(5) Setting an appropriate **time horizon**.

(6) **Discounting** using a real private or social rate of discount to estimate the value today of the stream of future costs and benefits.

(7) Identify the variables with the greatest **uncertainty** about future values and the use of **sensitivity analysis** to show how changes in these may affect the outcome.

(8) **Policy conclusions**: a statement which indicates whether a project or programme should proceed, be rejected or modified.

The type of CBA will depend to an extent on the perspective to be adopted. It may be:

- **ex-ante appraisal**: to decide whether or not to implement a new enterprise

- **on-going**: assessing the costs and benefits of an existing enterprise

- **ex-post evaluation**: judging the costs and benefits of a completed enterprise.

CBA is an activity requiring resources. It has its own costs and benefits. It should not, therefore, be carried out to the point where the value of increased information becomes less than the cost of gathering it. Thus the level of investment of resources should be adjusted to the potential gains. Can we avoid costly mistakes by carrying out further analysis? This must be asked repeatedly in the iterative process between analysts and decision-makers.

A CBA may be quick, inexpensive and informal -- a type of "Rapid Rural Appraisal" -- or it may be lengthy, costly and highly structured. Both have the same steps, which are considered in greater detail in Section 2.4.

2.3 CBA and Its Critics

While CBA has a relatively strong -- but not universal -- following among (neo-classical) economists, others may disagree with its use. A full discussion of the controversy is outside the scope of this report, but some of the arguments raised against CBA are briefly addressed here.

(1) **Monetary measurement is unethical** is a message popularised in the book "Small is Beautiful", where Schumacher (1973, p.38) says, ".... what is worse, and destructive of civilization, is the pretense that everything has a price or, in other words, that money is the highest of all values." This view confuses the use of money as a unit of account with its role as something desirable. A monetary unit of account is based on practical considerations; it is widely understood and utilised. If another unit of account (shells, camels ...) becomes more practical, then in principle values could be converted. This would maintain the requirement of CBA of making costs and benefits comparable.

Another argument raised against CBA is based not on a rejection of the method but on its utility. The objection may be stated as:

(2) **monetary measurement is impractical.** The strength of this argument varies according to the enterprise under study. As the case studies reviewed in Section 4 will show, a degree of monetary measurement is possible. There are usually some components of the analysis left unquantified. This does not appear to be a valid reason for not attempting to measure what can be measured. Should a hill not be climbed because the top of Mount Everest is unattainable?

Related to this is the claim that:

(3) **CBA overemphasises the quantifiable.** By calculating the value of only some important variables, it is claimed that the rest are relegated to secondary status. Again, the argument can only be judged in relation to actual CBAs. Some carefully point out intangibles left out of the monetary calculation; others pay inadequate attention to them. Proposition (3) is not convincing as a general critique of CBA but the implied criticism of actual practice should be addressed. However, even if intangibles are given insufficient attention, a valuable, if partial, result still remains that can be used to improve decision-making.

It is sometimes claimed that the aggregation of values across individuals:

(4) **hides conflicts.** This argument is related to the debate on income distribution discussed further in Section 2.4.1. CBA **can** take account of the distribution of costs and benefits by (a) a verbal description of to whom they accrue and (b) using explicit weights to affect the result of aggregation.

CBA is a planning instrument which usually includes corrections for market distortions. Instead of regular market prices, economic "shadow prices" are often used (see Section 2.7). However, if the government is serious about correcting the distortions, why not do that directly by:

(5) **general economic policy rather than piecemeal CBA?** Such an argument assumes that there are more efficient ways of correcting distortions than enterprise CBAs. That can be true and is the reason for economists' preoccupation with adjusting prices and improving market performance in the overall economy. But there are limits to what the government can accomplish by general economic policy. The argument seems to assume that, for example, unemployment can be eradicated through appropriate macroeconomic measures, rendering the shadow price for labour unnecessary. Governments with sophisticated forms of control find this difficult. Developing country governments, even with the

will to adjust, face tight restrictions in their ability to deal with market distortions. Thus, in an imperfect economic reality, micro-level analysis such as CBA is necessary.

Another argument raised against CBA is that it can be used to:

(6) **manipulate the results in order to underpin preconceived notions**, thus creating a "scientific" cover for vested interests (Hudson, 1986). This argument is about the **abuse** of CBA, not its **use**. While it is certainly true that CBA can be abused, it is an argument for re-educating analysts and decision-makers about its proper use, not its abandonment. For example, inappopriate choice of species and spacing of trees can severely damage crop production. Yet, nobody would consider this a valid reason to reject agroforestry; rather, it should encourage its more intelligent use.

Some also argue that:

(7) **CBA incorrectly assumes rational use of economic results for decision making.** At national policy level, decision-makers may indeed act on grounds of prestige and patronage. There may be limited understanding of the utility of CBA results, especially at household level. Goals other than income maximisation (e.g. risk aversion; drudgery aversion) could instead determine choice of farming system (Ellis, 1988).

In this last respect, a final criticism of CBA sometimes made is that:

(8) **the criteria for project selection may stress return to capital rather than return to labour.** A main criterion is the Internal Rate of Return which could overemphasise capital at the expense of ignoring critical labour bottlenecks in the household.

Our response to these arguments (7 & 8) is that, while some conventional CBA criteria are inappropriate in some circumstances, their standard usage is not mandatory. Others can be applied such as returns to labour; to foreign exchange; to fossil fuel; or to any other scarce factor. Nevertheless, under most circumstances a sustainable agroforestry enterprise will have to achieve financial and economic viability, as well as fulfilling other criteria. Therefore, CBA has a role, and it is flexible enough to accommodate considerations other than returns to capital. The rational use of CBA for agroforestry can be no more prescribed than the rational use of a bread knife!

2.4 Decision criteria

In considering agroforestry, farmers, governments and agencies have a variety of objectives. These mainly fall under the headings of: growth in farm household consumption; improved household security; improved income distribution; job creation; regional balance; national self-reliance; improvement of the environment; or similar objective. Confining the discussion to **economic** criteria may appear excessively limiting and not wholly representative of the range of objectives. However, nearly all objectives can be considered within the framework of CBA and built into it. Particularly when facing a multitiude of goals, CBA is helpful in reducing complexity. However, first, decision criteria must be chosen.

The criteria themselves encompass a substantial amount of information and lead directly to decisions as to how far one agroforestry option is "better" than another. Analysts usually use one or more of the following (Gittinger, 1982; Bojö, 1986a):

- **Net Present Value** (NPV): the value today of all present and future benefits minus the value today of all present and future costs. If this is positive, the project or enterprise is estimated to earn a surplus;

- **Internal Rate of Return** (IRR): the maximum interest that a project can pay for the resources used while still recovering all investment and operating costs;

- **Benefit-Cost Ratio** (BCR): the value today of all benefits divided by the value today of all costs. If this is more than one, the project is estimated to earn a surplus.

These measures provide somewhat different information, and the choice of appropriate criteria will depend on circumstances -- see Gittinger (1982).

2.4.1 **Income distribution.**

Income distribution objectives are especially relevant to agroforestry enterprises aimed at poor farmers. Should a change in income for the very poorest be counted on a par with a similar change for the social elite? Assessing such distributional consequences is a part - implicitly or explicitly - of the use of decision criteria. This can be seen in the assigned weighting given to the sum of costs and benefits pertaining to various individuals and groups. Usually the weighting is set to 1.0 for all, which is itself a value judgement which could (and should) be altered according to social policies. This is particularly relevant in developing countries where wide discrepancies in wealth tend to occur. Income distribution has received much discussion among economists. Three approaches may be distinguished:

(a) to ignore the issue without further comment; an approach rarely defended but often practised (see Bojö, 1986a for examples);

(b) to confine the economic analysis to questions of **efficiency** rather than **equity**; achieved, for example, by presenting the significant costs and benefits for different income groups and refraining from explicit assignment of distributional weights (see Gittinger, 1982 and Mishan, 1982, for a defence);

(c) to introduce distributional weights explicitly to illustrate "switching values" -- that is, values of the income distribution weights that make the evaluation according to decision criteria change. (e.g. NPV could change from negative to positive). The weights are derived by repea tedly facing decision-makers with the necessity to weigh efficiency and equity together (see Dasgupta et al, 1972; Little & Mirrlees, 1974; Helmers, 1979; Cooper, 1981; Pearce & Nash, 1981; and Squire & van der Tak, 1975).

Position (a) is indefensible in that it dodges the issue. Between (b) and (c), several arguments have been raised which may be summarised as:

(1) Distributional objectives might be better met by general fiscal policy -- taxes, subsidies etc. -- than by project selection.

(2) There exists no "objective" way of weighting one group against another. The exercise is therefore arbitrary. However, this argument ignores the equal weighting given to all groups in most assessments of costs and benefits -- itself a value judgement.

(3) The distribution of costs and benefits between the various groups is difficult to detect. This is indeed a problem and may explain why so many empirical analyses simply disregard the issue. But this is not a valid reason for not trying.

(4) Perhaps it is naïve to assume that decision-makers will assign weights to the various income groups. We are not aware of any practical instance where a government has adopted systematic social weights. However, this should not prevent the analyst from illustrating the differential effects of using weights.

In summary, while arguments have been raised for the inclusion of income distribution as a concern in CBA, the issue is often avoided in practice. We suggest generally, but with particular emphasis on agroforestry interventions, that:

* the search for significant distributive effects should be obligatory

* significant effects should be presented to decision-makers

* such effects should not be weighted implicitly or by default, but switching values should be used to illustrate the influence on income distribution of weights.

2.5 **Identification of costs and benefits**

Commonly only one proposal is appraised. However, it is good to appraise several options, a practice which is more likely to lead to a successful enterprise.

It is important to delineate the geographically and economically relevant area. This may be the household, a cooperative, business or group enterprise, an institution such as a forestry department, a public sector project such as a woodlot, or a programme involving groups of households and covering an extensive area.

The "with-and-without project" approach should be used, rather than "before-and-after". The latter does not account for changes which would have occurred without the enterprise. The analysis should include **only such factors that change because of the proposal**. Variables such as capital investments already undertaken for other reasons ("sunk costs") that do not change because of the proposal should be excluded.

2.5.1 **Direct v. indirect costs and benefits**

Costs and benefits are sometimes called "direct" or "indirect". We will use these terms to express **intention.**

An agroforestry proposal may be intended to increase output (e.g. crops, fodder, fuelwood) by using inputs (seedlings, fertilizer, labour). Everything related to these are termed direct costs and benefits. The proposal may, however, also raise income among farm households so that a new shop can open locally. This would be an indirect (or secondary) benefit and a net addition to economic activity, provided that the shop did not displace economic activity from elsewhere.

This paper focuses on direct benefits. But indirect impacts should be documented and quantified wherever significant.

2.5.2 Internal v. external costs and benefits

Another important distinction is that between "internal" and "external" costs and benefits. These are defined in relation to **markets**. External impacts (or "externalities") are those not registered in market transactions. If, for example, erosion upstream decreases the economic life of an irrigation reservoir downstream, and no compensation is made for the damage done, the impact is external to the market system. However, if the irrigators receive compensation, the market transaction internalises the environmental impact. Social CBA should, whenever possible, quantify external costs and benefits.

2.5.3 Identifying costs

Identifying the costs of agroforestry presents no major conceptual difficulty. However, there is sometimes the temptation to neglect overhead costs for supervision and central administration of a project or enterprise. For example, should the cost of expensive expatriates be manipulated by deducting 50% as a 'social cost' for training and left unaccounted (EEC, 1980)? Actual costs must be used, and any temptation to reduce them will only give a false picture of economic performance.

2.5.4 Identifying benefits

The clearest benefit of an agroforestry enterprise is the increased value of production -- for instance, grain, fodder, fruit, fuelwood. The increase is in relation to what production would have been **without** the enterprise.

Environmental benefits are usually advanced as one of the major reasons for agroforestry or similar projects (Bojö, 1986a). But care is necessary not to double-count this benefit. If, for example, the aim is soil conservation, then this will be captured in CBA by an increase in production over time. It cannot also be covered in identifying improvement in soil quality or nutrients that are retained -- a point which will be reiterated when considering "Technical Issues" in Section 3.

Employment is sometimes advanced as a benefit (Das & Singh, 1980). Two assumptions are implied: first, that employment will improve income distribution; second, that agroforestry counters seasonal unemployment and the implied waste in human resources. The first assumption is more properly dealt with under income distribution (Section 2.4.1); the second under valuation (Section 2.7.2) where unemployment is reflected by adopting a lower economic price for labour than the financial wage. Labour is a **cost** item, and the wage bill should not be added as a benefit to other benefit items.

External benefits may include reduced flooding, prevention of siltation of rivers or similar. This may in turn affect hydropower generation, irrigation potential, river navigation, fisheries, tourism, reclamation costs, checklists for which can be found in references on environmental impact (e.g. Munn, 1975). Analysts must use common sense and knowledge of local and regional circumstances to identify the significant costs and benefits. The benefits should be seen in terms of **people's willngness to pay for them** -- the value of the extra fish to consumers or the irrigation water to crop producers, for example.

2.6 Quantification of costs and benefits

Our aim is to compare conditions with and without the proposal. This involves quantifying differences in physical inputs and outputs "with" and "without", and then converting physical quantities to monetary values.

Quantification will present problems. Section 3 of this paper shows how physical changes under agroforestry can be translated to quantities which can be valued for CBA. CBA is a useful aid in organizing available information. By using sensitivity analysis it is possible to test to what extent uncertainties in quantification will affect the outcome.

2.7 Valuation of costs and benefits

Valuation entails applying "price tags" to the effects that have been quantified. A brief review of terms will clarify the most important valuation items.

2.7.1 Financial v. economic prices

Two valuation perspectives are relevant when considering agroforestry: the **economic** and the **financial**. The first concerns changes in the national economy as a whole resulting from the implementation of a proposal. The valuation of economic prices should reflect the **willingness to pay** of society for the use of a particular resource. This commonly differs from the market price because of market distortions. There may be no market at all. The second, the financial perspective, deals with changes in the income and expenditure of a household, a group, project, region or institution because of implementation. The distinction is crucial: a proposal yielding a high positive financial net present value (NPV) for farmers may show a negative NPV for the national economy (or vice versa). One example of how this can occur is the case where fertilizer is sold at US$10 per bag in the open market but this includes a subsidy of $5 paid by taxpayers via the government. The total cost to the economy is $15. Another example is where taxation of produce reduces household income from an agroforestry proposal so that financial NPV is negative. Since taxation involves a transfer of money within the national economy, not a deduction from it, the economic NPV might well be positive. That should not lead decision-makers to recommend the proposal, however, because farmers would not and could not adopt it.

An example of the difference between the economic and financial perspective is the decrease in flooding damage downstream because of better forest cover upstream. There is no market reflecting the valuation of this, and hence no financial price. However, there is a value attached to this change by society, so there is an economic price, which might be estimated by reductions in national expenditure on flood relief.

Estimates of economic prices are known as "shadow" or "accounting" prices. These are intended to reflect costs and benefits to the national economy. They may be used to account for non-marketed environmental costs and benefits, to correct market distortions in labour or commodities, and to adjust expenditure on imports and exports to a price representing societies' willingness to pay for foreign exchange. The economic perspective is therefore that of society as a whole.

Financial prices are market prices and usually reflect the costs to the budgets of peasant households, projects and institutions. Problems arise where there are no markets. This particularly affects the valuation of peasant production. The financial perspective is therefore that of private or individual rationality, and is an important way of predicting the likelihood of adoption of a proposed agroforestry enterprise. Financial prices may also be applied to institutions and government agencies. Any discussion about social intervention should compare the economic and financial perspectives. The financial (private) perspective is covered in Section 2.7.3 and the economic (social) perspective below.

2.7.2 **Economic valuation**

Real v. nominal prices. Discussions about valuation are often confused by misunderstanding the difference between **nominal** and **real** values. Nominal values are expressed in current prices: e.g. the cost of one litre of milk today, say $1. Real values are constant prices: they remain fixed to a particular point in time. If the nominal price of the milk was $0.50 ten years ago and inflation has been 100% in ten years while the real price has remained constant, then the nominal price has doubled.

CBA concerns the comparison of values in real prices over time. Inflation is a separate issue because a uniform rise in the value of all costs and benefits will not affect the result in terms of our decision criteria. This does not mean that changes in relative prices are excluded. If the cost of fuelwood, for example, is expected to rise 10% more than inflation per year, this increase in real price should be reflected in our estimates.

Taxes and tariffs. In general, revenue-based taxes on input items should be eliminated from economic analysis. This applies equally to tariffs and similar fees. Consider the purchase of tree seedlings for an afforestation project. If a project displaces the consumption of seedlings elsewhere in the economy, the opportunity cost is the value of these to the alternative buyer. This may well be the market cost including tax. However, if demand by the project actually increases the supply of seedlings, the opportunity cost is the supplier cost, exclusive of tax. Taking a national perspective on, say, imported vehicles, a tariff is simply a transfer from the project to the government and is not a net cost to the economy.

Capital. Capital items - buildings, machinery, vehicles - may be affected by indirect taxes, tariffs, distorted exchange rates and similar. CBA textbooks discuss the calculation of the shadow price for capital, yet it features rarely in applied studies. Usually, capital investments are valued at financial cost as and when they occur. Depreciation -- reflecting real wear and tear rather than tax rules -- need only enter our economic calculation if scrap values have to be determined. These can be credited to the enterprise at the end of the time horizon considered.

Foreign exchange. Few developing countries let the market determine the value of foreign exchange. Often the domestic currency is overvalued: i.e. local consumers will pay more for an extra dollar than the official price of a dollar. Therefore, many countries employ some form of rationing of foreign exchange. In principle, the economic price of foreign exchange is the ratio of domestic prices to official import prices. If any item imported for $1 clears the market for two local currency units, the economic price of a dollar is two units. In practice, deriving an exchange rate to replace the official one is a delicate and difficult undertaking. The black currency market gives some indication of the degree of distortion to the market. The national financial authorities or international financial management agencies may be able to provide some guidance.

Labour. As an item of especial importance in a labour-intensive practice such as agroforestry, the use of a lower shadow wage than the financial wage for unskilled labour is common when there is under-employment. This reflects the fact that in these circumstances the **opportunity cost** in terms of production lost elsewhere in the economy is often low. However, the appropriate shadow wage rate may vary considerably between seasons. During peak labour demand, the actual market wage may be a good measure of the opportunity cost of labour. At slack times, setting it to zero may come closer to reality. By observing seasonal variations, agroforestry interventions may be better appraised and designed to fit the local labour market.

Skilled and semi-skilled labour are often in short supply and are valued at their financial wage. If a training programme is instituted to replace expatriates with local staff, then both the cost of the training and the future saving in salaries may enter the calculation.

2.7.3 **Financial valuation in peasant farming**

A peasant household is defined as one having direct access to land on which it uses mainly family labour (Ellis, 1988). It produces most of its own food and many of its requirements for other materials, but is also involved in markets. The degree of market involvement varies between households and over time, thereby making the valuation of land, labour and credit difficult. Household decision-making is normally rational (Adams, 1986), but the extent to which the household is a profit-maximising unit depends on the nature of markets, especially in land and labour but also in credit; internal organisation and cultural norms; external social, political and economic relations; and the level of environmental risk and uncertainty. Other things being equal, the greater the dominance of profit-maximising as an household aim, the more amenable the household economy is to CBA.

In the rest of this section the financial valuation of the factors of production and products from the perspective of the peasant household will be discussed, and we shall review the problems arising from non-involvement in markets. Particular attention is paid to the valuation of factors and products over time, since the appraisal and evaluation of long-lived interventions (i.e. trees) is our aim.

(i) **Financial valuation of credit.**

Peasant farming systems show a strongly rational response to the relative scarcities of the factors of production. The smallness of the peasant farmer's cash income, its tendency to vary greatly over time with environmental and price fluctuations and with level of market involvement, the high risk of default and the lack of collateral, all tend to make formal credit markets inacessible to the peasant household (Ellis, 1988). Capital is invariably scarce and applied sparingly relative to other factors. Merchants and moneylenders may be preferred sources of credit even though interest charges are higher than in formal credit institutions. Reasons for this preference may arise from familial or personal relationships between borrower and lender; the timeliness, flexibility and informality of alternative lenders; the need not to make lengthy journeys to remote towns; and, most important, the lack of requirement to provide collateral. The agroforestry economist cannot therefore assume that the lowest interest rate is the one paid. In valuing the cost of credit for agroforestry purposes, the economist may, in the absence of a formal credit market, need to probe the informal market where interest levels are likely to be both high and extremely variable between cases.

(ii) **Financial valuation of land.**

Land value and intensity of use. Continuing with the theme of peasant rationality, the intensity of application of land and labour are generally closely correlated with their relative scarcity (Clayton, 1983). Consider two extremes of population/ land ratios: first, still commonly encountered in sub-Saharan Africa (e.g. Botswana, Mozambique, Tanzania, Zambia), land is abundant, labour scarce. Here, shifting cultivation is still common. The response to incentives for greater production is to extend cultivation, not to intensify on existing land. Technology which raises labour productivity is readily accepted, while yield-increasing recommendations are ignored. In such circumstances, agroforestry is unlikely to be attractive since the abundant land supplies local needs in woodland products. If it is necessary to assess the value of land for agroforestry, its opportunity cost to the household is likely to be close to zero.

In contrast, in a densely-populated area, the opportunity cost to the household of labour is low while land is valued highly. Production strategies maximise returns to land by high yields, double-cropping and good management (Allan 1965). High value crops requiring intensive management tend to be grown (Clayton, 1983), as in the intensive agro-silvopastoral systems of Kilimanjaro (Fernandes et al, 1984). Use of trees is often highly developed by peasant farmers and agroforestry already attractive. In these circumstances land is valued highly by farmers. If an agroforestry enterprise involves a change in land ownership, or the purchase of land, it must carefully be valued (see "Land markets and land values" below). But when the enterprise does not require a change in ownership, but only in land use, the cost of the land is its contribution to the value of the land use which is abandoned in order to adopt agroforestry. A separate valuation of the land should not therefore be entered as a cost, as this means that the cost of land is entered twice. In the common case in agroforestry (e.g. boundary planting) where no land use is displaced, no cost for land should be entered.

Land tenure and land value. Security of tenure will also affect value. Insecurity will reduce land values and encourage exploitative practices whereas security will promote conservation including measures such as tree planting.

Land markets and land values. Obtaining land prices from formal markets is unlikely to match the perception of land value among peasants (Ellis, 1988). There may be duality of land tenure as in Botswana and Zimbabwe, where a formal market exists for large freehold commercial farms but none for peasant "communal areas". "Traditional" tenure has the restriction that land cannot legally be bought or sold. In these circumstances, because commercial farms are far too large and credit too expensive and inaccessible for peasants, commercial prices would **undervalue** land from the peasant's perspective. A better way to value land may be in terms of its net output under the best alternative use.

(iii) **Financial valuation of labour.**

Adoption of agroforestry requires extra labour. Should the cost be included in the financial analysis? The answer depends on circumstances:

* if agroforestry is adopted by a household which gives up leisure and does not abandon another activity in order to provide the labour, the opportunity cost is zero, and no cost entry is made for labour;

* if the household reduces or gives up another enterprise in order to adopt agroforestry, then the "with-and-without" approach advocated in this paper already values automatically the cost of the labour diverted to agroforestry. This cost is the income to labour from the enterprise which is abandoned. Since this income is deducted when the "with-and-without" approach is applied, no additional entry should be made for family labour costs;

* if off-farm work by household members is abandoned in order to adopt agroforestry, then the labour cost of agroforestry is the amount of earnings foregone, and a cost entry should be made;

* when workers are employed by the household for agroforestry, their wage should be entered as a cost.

Peasant labour allocation strategies and the associated opportunity costs vary (i) with income-earning opportunities; (ii) between wealth categories of farmer; (iii) over the season; (iv) with access to waged labour markets; and (v) within a single household. Complexity is added by the numerous non-marketed labour transactions that also occur between households.

Population density and the opportunity cost of labour. A general reason for spatial variation in labour allocation is differences in population densities. As these increase, natural woodlands and wildlife tend to decrease along with opportunities for charcoal-making, honey-gathering, hunting and fishing. These off-farm, income-generating opportunities should feature in any assessment of the opportunity cost for labour of adopting an agroforestry enterprise.

Social differentiation and the opportunity cost of labour. Social differentiation and the consequent access to and control over the factors of production account for much of the variation in labour allocation in a rural economy. In Botswana, wealthier peasants tend to obtain much of their living from livestock, while poverty encourages pursuit of off-farm opportunities such as pottery, beer-making and casual labour (Flint, 1986). Again, evaluators need to be alert to these labour allocation strategies and the resulting differences between households in their labour opportunity costs.

Seasonal variations in the opportunity cost of labour. Labour allocation and the opportunity cost of labour also vary over a growing season especially where rainfed annual crops are grown. Labour bottlenecks (Upton, 1973) can raise opportunity cost at times of peak labour demand when failure to plant or to weed on time may jeopardise the whole season's production. Such bottlenecks may occur even when population/land ratios are high. Evaluators need to recognise labour bottlenecks, the effect they have on subjective valuations of opportunity cost of labour at various times of year, and the potentially conflicting demands for labour between existing and proposed enterprises. Whether these labour costs should be included in the analysis or not has been discussed above.

Labour markets and the opportunity cost of labour. The effects of population/land ratio on the valuation of labour is complicated by labour markets. When no such market exists, peasants may willingly adopt a new enterprise such as agroforestry because there are no options competing for their labour. Here, the peasants' own valuation of their labour is low. In contrast, access to waged work may mean that the opportunity cost of labour is set by the current unskilled formal wage. Such is the case in Botswana where government is attempting through subsidies to lure waged workers back into agriculture from mines and towns. Evaluators therefore need to know wage rates in the formal labour market.

Variation in the opportunity cost of labour within households. At any one time, variation in the opportunity cost of labour also occurs within a household. The "new household economics" theories of Barnum and Squire (1979) and Low (1986) cope fairly well with circumstances, typical in southern Africa, where young males leave peasant farms for waged work on commercial farms, and in towns and mines, remitting cash to rural households consisting mainly of women, children and older men. Low (1986) explains this strategy in terms of differences in labour productivity according to age and gender. Young males, particularly the educated, have a comparative advantage because they can get relatively well paid work. They migrate and remit. Older men return to the farm to enjoy the fruits of their earlier remittances. Women tend to remain on the farm because of their child-minding role and the fact that their gender lowers their comparative advantage in the manual labour market. The function of the farm in these circumstances is not so much income-earning and food-producing, but as a rent-free place to live with free fuel and communal pastures on which to keep cattle in which remittances are rationally invested (Doran et al, 1979; Abel et al, 1987).

The relevant opportunity costs for agroforestry in these circumstances are, first, the subjective probability of obtaining a job and the wage labour rate. The product of these gives the expected income from waged work for those not yet employed in the formal sector. The expected income shows what level of net income an agroforestry enterprise would need to generate in order to attract male labour. The second relevant cost is the value women place on their own time in agricultural and related activities. While "society" may rate this as low, they nevertheless have culturally-determined domestic duties to perform in child-rearing and housekeeping, apart from farm work. Agroforestry enterprises in southern Africa may thus be competing for labour with domestic commitments and with a relatively high formal wage.

Long term changes in the opportunity cost of household labour. Changes in income-earning strategy with age, as in the return of older males to the farm, are examples of peasant households evolving through "Chayanovian cycles" (Thorner et al, 1966). In the context of agroforestry, such a cycle may begin with a young couple, recently married, lacking household labour and savings, and therefore unable to invest time or cash in establishing trees. Their position may worsen when they have young children: i.e. a higher ratio of consumers to workers. Later, with more labour and capital, they may diversify production and plant trees for their longer-term benefits and security in old age. Later still, with their own children married and labour and cash income in decline, once more lack of resources and awareness of impending death may discourage interest in planting trees. In estimating the value of labour to the household, each of these phases has a characteristic opportunity cost which affects the adoptability of agroforestry. Whether the cost should be included as a separate item in financial analysis has been discussed at the beginning of this subsection (iii).

Non-marketed labour transactions have already been noted as a complication. Included are the multitude of cooperative activities that characterise peasant production: weeding parties; reciprocal cultivation arrangements; cooperative herding on a rota. Where the transactions are fully reciprocal, estimating labour input is not a problem, the labour time required for a crop being sufficient information regardless of whose labour was used. Where there is considerable social differentiation, reciprocity is less likely, and labour may often be provided by poorer to wealthier households which pay in kind. Here the evaluator needs to establish the number of days of labour provided and the value of the "wage".

The classification of households. Although it may appear from this section that the valuation of labour inputs in peasant production to agroforestry is fraught with variations between places, wealth categories, labour markets and seasons such that all individual households must be separately assessed, in practice we suggest that the problem is amenable to analysis. Generalizations can be made and financial (i.e. household level) valuations of labour made through careful classification of households, selecting criteria from this section, and estimation of the financial value of labour for each category of household.

(iv) Financial valuation of products

The valuation of products by peasant households is crucial for financial CBA. It is needed for calculating the opportunity cost of adopting agroforestry and for assessing its benefits. The main problems are: (i) the valuation of benefits over time; (ii) the effects of risk on perceived values of products; and (iii) the valuation of products when there is no market.

The valuation of benefits over time by peasant households. Any household will value a benefit accruing now more than the same benefit obtained later. The difference between the two depends on the discount rate (Section 2.9). Obtaining private discount rates for financial analysis is problematic, and is best done from discussions with farmers. Here we limit ourselves to discussing factors which should raise or lower private discount rates.

Factors tending to raise private discount rates stem from risk and uncertainty (Section 2.10). These include insecurity over land tenure and perceptions of risk of falling prices, war, landslides, floods, winds, drought, disease and damage from livestock. Reassurance in any of these should lower a private discount rate. All are, however, real risks and run counter to the adoption of long term enterprises such as agroforestry. Despite this, however, peasants do place a value on the future and the welfare of succeeding generations: e.g. investment in education for children and security of income in old age.

The capitalist farmer, with access to insurance and pension markets is less dependent than the peasant on the farm for security. The peasant farmer has to plan for security based on local resources: the maintenance of extended family links as a social security network is a common way of doing this. Investments in livestock and trees are other ways of planning security. A West Indian example cited by Clayton (1983) is that of farmers who plant cocoa which would not yield for several years, rather than bananas, which would have given a high value product within a year. Yield of cocoa is reliable, it needs little labour to plant and it is easily harvested: cocoa thus provided security and long-term income for old age, and is more suitable for this purpose than bananas. This type of choice can be accommodated in financial CBA provided an appropriate private discount rate -- low in this case -- is set. An intimate knowledge of farmer decision-making is clearly indicated.

Risk and expected income. Perception of risk also affects the financial valuation of annual crops (Section 2.8). The concept of "expected income" (Upton, 1976) provides an estimate of crop value. This is a function of the probability of obtaining a certain yield level, the (linked) probability of getting a certain price and the area planted. If perennial crops have more reliable yields (better probability levels) than annual crops, their expected income can be higher even if market prices are less.

The value of non-marketed products. The valuation of arable crops is needed for agroforestry CBA so that changes in output because of trees can be valued. However, absence of formal markets for many subsistence crops makes estimates of their financial value difficult. For example, crops such as finger millet and sorghum, grown for their drought tolerance, taste or beer-brewing qualities may not be bought and sold by parastatal agencies. If a local cash market exists, it may provide a price; similarly, if the product is bartered for another which does have a market price, then relative values can be fixed.

The establishement of financial values for agroforestry products can be especially problematic. Where woodland resources are accessible, households may obtain fruit, game, honey, medicines, poles, posts, fuelwood and fibre at no cash cost. However, the labour invested in obtaining them gives an insight into their value (Munslow et al, 1988). Alternatively, the price at which households would be willing to switch to a marketed alternative provides an estimate of cash value. This can be determined by interview.

2.8 Setting an Appropriate Time Horizon

In principle, an infinite length of time should be considered. There is nothing in economic theory which prevents this. Economics is not, therefore, inherently "short-sighted" although some of its practioners may be! Any length of time appropriate to long-lived trees can be selected. In practice, however, CBA often limits the time horizon to 20, 30 or 50 years (Bojö, 1986a). Over the years in a typical project the physical and economic impact will often decline.

The choice of time horizon is also related to choice of discount rate: the higher the rate, the lower the weight attached to long-term effects. At high discount rates (10% is a fairly common one to apply), additions in time horizon have little effect, as seen in the following illustration. Consider an investment of $100 today, assume it will yield $10 in each subsequent year and take the benefit stream as uniform. A comparison of four possible cases shows:

Time (years)	Discount rate (%)	NPV ($)
30	10	-6
50	10	-1
30	2	116
50	2	206

Although uncertainty over the levels of costs and benefits does increase with the future, this is no reason to shorten the time horizon. Rather, an attempt to model a likely scenario should be made using discount rate as one guide to fix an appropriate time horizon. Other considerations are the nature of the enterprise and the possibility that the stream of benefits may increase over time (e.g. through soil improvement and rehabilitation). Illustrations of the actual use of time horizons will be provided in the case studies of CBA later in this paper.

2.9 Discounting

Few issues in environmental economics have aroused such heated debate as the discounting of future costs and benefits to present values. Lind (1982) gives an in-depth review of the issues. Views range from the hostile to the friendly. Future values can only be gauged by people's actual behaviour upon which theories of the underlying rationale are constructed in order to model the real discount rate.

2.9.1 Approaches to discounting

It is natural to regard the value of a dollar today as greater than its value in ten years, even if the future dollar can be received with absolute certainty and compensation is made for inflation. Several reasons can be cited:

(a) dollar now could be invested and be worth more in ten years: i.e. there is an opportunity cost in terms of return of capital foregone;

(b) if I am richer in ten years than now, an extra dollar means less to me then:i.e. the marginal utility of income diminishes;

(c) I am impatient to use the dollar now rather than later: i.e. there is a pure rate of time preference.

These perceptions have been formalised by economists and have led to three major, but not distictly separable, approaches to the determination of actual rates:

* the **social opportunity cost of capital** (SOC) approach which looks for empirical evidence of (before tax) profits on alternative investment opportunities. An agroforestry programme funded by grant aid is likely not to apply, but as a measure of economic performance SOC may still be used as a standard for comparison (Helmers, 1979; Gittinger, 1982);

* the **consumption rate of interest** (CRI) approach which is based on market data revealing consumer preferences for consumption today versus that tomorrow. Empirically, this entails looking at (after tax) returns to the investor on risk-free savings (Lind, 1982);

* the **social time preference rate** (STPR) approach which takes the rate to be mainly a political parameter set on a basis of (a) the per capita income growth; (b) the rate at which utility of increases in marginal income diminishes; and, sometimes, (c) an assumption of the pure rate of time preference among consumers (Dasgupta et al, 1972; Little & Mirrlees, 1974; Squire and van der Tak, 1975).

Amongst all the theory it is revealing to note what happens in practice and what discount rates are arrived at. Many economists are extremely hesitant to offer specific advice: suggestions as to discount rate range from 3 to 15%. A survey of 18 empirical studies of soil conservation (Bojő, 1986a) found that most authors used rates of 10 to 15%, usually with unclear rationale. Later in this paper, we review agroforestry examples.

The suggestion is sometimes made that different rates should be applied according to the nature of the project or enterprise and the type of costs and benefits incurred (Price, 1973). Arbitrary choice of rates may lead to manipulation of results, and the suggestion should be rejected in favour of employing a national standard. Only this way can CBAs be comparable.

2.9.2 A low discount rate to protect the environment?

Environmental costs, it is sometimes said, are particularly prone to underestimation (Cooper, 1981). To account for this it may be suggested that these costs be discounted at a particularly low rate, or, put another way, to reflect environmental risks, discount rates should be adjusted downwards (Brown, 1973). Are these valid arguments? Although our knowledge of environmental impacts is limited, especially in long-term effects, for two reasons we reiterate that social discount rates should not be tampered with in this way.

First, uncertainty and risk are concerns at the stage when costs and benefits are quantified and valued. Their weighting in the future as against the present is not a relevant concern. If there is reason to believe that environmental damage has been underestimated, their costs should be varied to see how they affect net benefit. This is a more explicit way of adjustment than to manipulate discount rate. Secondly, it is inconsistent to isolate environmental effects by adjusting discount rate from the other, equally valid, human welfare concerns which are valued in costs and benefits. The same losses in income might be altered in totally different ways. For example, erosion-induced crop losses may cause a $100 drop in income, and the same loss incurred through crop wastage in transport. It would be difficult to argue with the farmer that the actual loss of one kind is more serious than the other -- yet that is what would be implied if discount rate had been adjusted for the erosion losses. The conclusion is that environmental impacts should be valued as far as possible in terms of actual costs and benefits such as increased yield or higher labour costs.

2.9.3 **A high discount rate to protect the environment?**

Environmental concerns have not only led to suggestions for lower discount rates, they have also led to higher rates on the grounds that the considerable risk of environmental damage should be reflected (Prince, 1985). Discounting the costs of risky projects with a low rate is consistent with discounting the benefits with a high rate.

Again, there is no reason why environmental concerns should receive special analytical treatment. Risk premiums on discount rate lump together various effects that are best discussed separately. They also imply that the risk grows progressively. The addition of a 5% risk premium to a 5% base rate adds about 5% [(1+0.1)/1+0.05)] to the discount factor the first year, but about 10% $[(1+0.1)^2/(1+0.05)^2]$ the second year and so on. This is not necessarily a correct prediction of future risk levels.

Our approach to discount rates is as described by Mikesell (1977):

> "There is no justification for a lower rate of discount for evaluating costs and benefits ..... that may involve future environmental amenities. The use of differential rates of discount for evaluating streams of benefits and costs that may exhibit differing rates of change over time does not constitute a proper alternative to estimating the future streams of benefits and costs directly and employing the same rate of discount to both streams." (p.39)

2.10 **Risk and uncertainty**

Formally, a distinction is often made between risk and uncertainty. Risk is "quantifiable uncertainty" -- see Dorfman (1962) and Mishan (1980) on decision strategies under uncertainty. In practice, there is a range of uncertainty over variables such as the effect of windbreaks on maize yield or the price of fuelwood in the future. Whatever probabilities can be assigned -- even subjectively -- the recommended practice is to calculate the **expected (mean) value** by multiplying each outcome by its assigned probability (Dasgupta et al, 1972; Irvin, 1978).

The expected value of a variable is the first step: the next is to examine the probability dispersion around the mean. The usual technique for dealing with this is **sensitivity analysis**. By varying the assumption on a particular factor, the result will change: the degree of change reflects the sensitivity to that assumption. Of particular interest in CBA are the switching values (see Section 2.4.1(c)) where a change in one factor will make the evaluation according to the decision criteria change.

Risk aversion is understood and accepted as a rational strategy for the farm household. However, should society adopt the same perspective? Most agroforestry proposals are relatively modest and do not substantially affect the national economy or even particular markets. Assuming that (i) the general state of the economy can be taken as constant with and without the agroforestry enterprise, (ii) the result of the intervention does not correlate with the general state of the economy and (iii) the risk is sufficiently spread among individuals, this justifies "risk neutrality". One important qualification exists, however.

Environmental effects do not necessarily spread to all individuals. The costs of adverse impacts may actually be borne, not by the general taxpayer, but by individuals exposed to additional danger, failing crops, health problems or declining income. Environmental costs often take the form of "public bads", the salient feature of which is that one person's risk is not diluted by more persons sharing the risk (Fisher, 1973; Cooper, 1981). Take a new alley cropping system: if a crop fails because of excessive and unpredicted plant competition, then it is the land user alone who suffers. The position of risk neutrality for society as a whole from environmental effects is not valid.

Several solutions may be advanced. In theory, there is a way of quantifying risk costs by obtaining from individuals a "certainty equivalent" of money that they would be willing to pay (or to receive as compensation) to get rid of the risk (or to live with the risk without loss of welfare). The cost of risk is the difference between expected outcome (the sum of the probabilities times their values) and the certainty equivalent (Markandya & Pearce, 1987). In practice, this may not be an operable suggestion because (a) the persons affected may live in ignorance about the environmental effects; and (b) eliciting their preferences may be impractical. We are left then with the problem of determining attitudes to risk by political decision-making or by an administrative process. Sensitivity analysis techniques can be employed, illustrating "worst case" scenarios and the groups affected. An insurance scheme may be indicated, for example, to counter risk involved in a new technology.

Finally, care should be taken not automatically to assume increase in risk with all changes. Alleviation of risk is one of the principal arguments used by proponents of agroforestry. Risk-averse farmers have already found low risk management strategies within the currently available set of options. New agroforestry technology will enlarge the set of options, and, many hope, introduce more stable, resilient farming systems that actually entail less risk.

2.11 **Policy conclusions**

CBA ultimately rests on ethical values. It is aimed at providing policy relevant conclusions in order to aid, not to dictate to, decision-makers. While a CBA of agroforestry may itself proceed through a series of reasoned steps based on sound criteria and sensible planning goals, the use of that information cannot be so structured. Value judgements are always involved in the execution and interpretation of CBA. Efficiency considerations have to be weighed against other social values. CBA enables part of the decision-making in the political process to have access to quantified information: gains in relation to other goals can be explicitly traded against losses of net present value.

For example, agroforestry in a fertile and relatively prosperous part of a country may produce a substantial NPV. If the same resources are devoted in a poor part, the result may likely be less impressive in terms of increased production. There is a trade-off between efficiency and equity for which CBA gives the data. But CBA cannot make the decision.

In the final analysis, CBA is a tool for decision-makers, fashioned by economists. CBA can be no better than the level of the least exact of its component parts and the information upon which they are based. Much of that information relies on specific data on values of agroforestry products, but more problematic is the demand placed on information about the long term performance of physical systems under new, innovative technologies (or even indigenous technologies that we do not yet understand). These technical demands are the subject of the next Chapter of this paper, the theme for which is, "How can we get the right information on agroforestry to supply CBA and to provide decision-makers with a balanced data set on the net benefits to be derived from promoting agroforestry?"

3. TECHNICAL ISSUES RELEVANT TO ECONOMIC ANALYSIS

3.1 Technical Demands

Economic analysis makes demands on technical information. These demands may be classified under the following headings:

* identification, quantification and valuation
* timely data, in the right form
* discrimination between relevant and irrelevant
* ability to handle the future

Two practical problems arise in meeting these demands. First, there is a dearth of relevant information. The complicated nature of agroforestry systems means that in only a few cases have inputs and outputs been quantified. For example, in only one known case have erosion rates and the effects of changes in surface litter been monitored under agroforestry as compared to forestry or single cropping (see the review by Wiersum, 1984 from Indonesian experience). Estimates, often no better than guesses, have to be made and results have to be inferred from the large literature in agriculture, forestry and multiple cropping. Secondly, the number of possible agroforestry systems makes it very difficult to generalise. Checklists may help. Indicative values of output and ways of translating the measures into economically-meaningful figures may also be useful. However, it has to be recognised that each agroforestry system is essentially unique: their commonality is complexity, ecological robustness, multiple outputs and longevity.

Identification, quantification and valuation. These were the second to fourth steps for CBA described in Section 2.2. To identify costs and benefits, the structure of the agroforestry system and its boundaries must be understood. A homegarden for an individual household has quite different potential costs and benefits from a hedgerow intercropping project designed for a whole catchment or a national fuelwood programme. A model of the system would enable specific identification of:

direct v. indirect costs and benefits (Sect. 2.5.1)
internal v. external costs and benefits (2.5.2)

Two examples of models are provided at Figures 2 and 3. In the first, a detailed view (from the work of Brunig, 1982) of the role of evergreen trees in a lowland forest is attempted where the flows and stocks within the system are modelled. Reflected in the model is the uncertainty of the sizes of some of the flows. A model of this nature might be appropriate where initial decision criteria had highlighted the output of primary production as the main focus of interest. Where future production will likely be critically dependent on flows within the system, such modelling could be very important. Figure 3, derived from recent fieldwork in Vietnam, takes a simplified view of an extremely complex system, isolating only those parts which would be needed and readily-available for a CBA.

Quantification translates the identified costs and benefits into measures relevant to CBA. In practice, this is probably done at the same time as identification. Some identified items may not be possible to quantify, but remain listed in their qualitative impact. Others may be dismissed as insignificantly small (e.g. erosion of a footpath). Some environmental impacts such as changes in organic matter levels which, in turn, affect future production, need to be processed through dynamic models (see Section 3.4). Valuation means attaching "price tags" (Section 2.7). It needs information on the use of the output, its continuity of supply, quantity and quality -- all technical demands which may or may not be easy to supply.

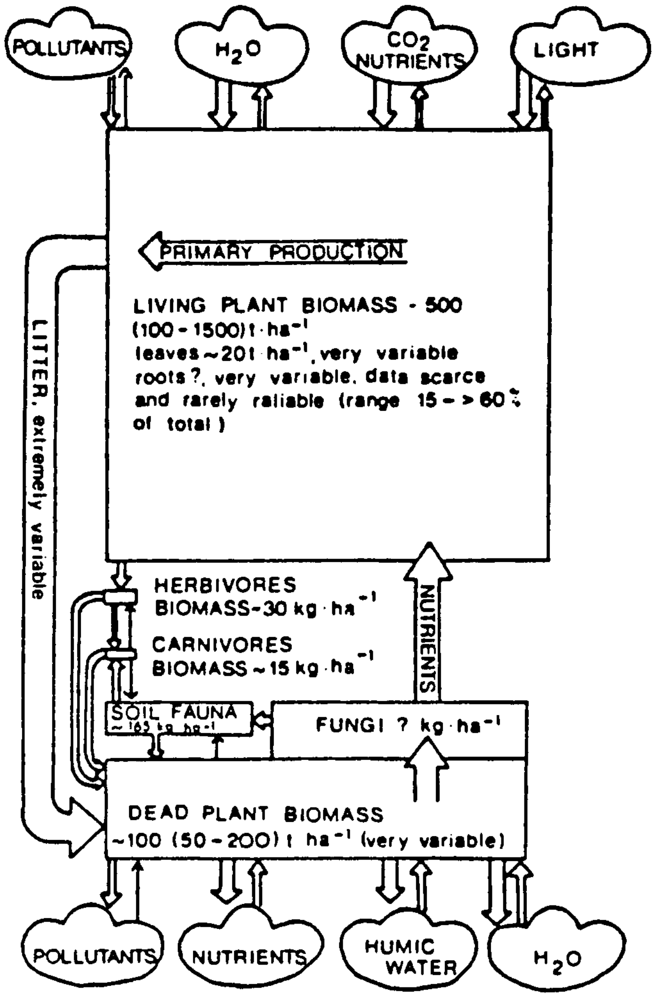


Figure 2. A model of a mature, humid, tropical equatorial, mainly evergreen, lowland forest. Note the variation and range in stocks and flows of phytomass which reflects uncertainty in the working of the system. (Source: Brunig, 1982).

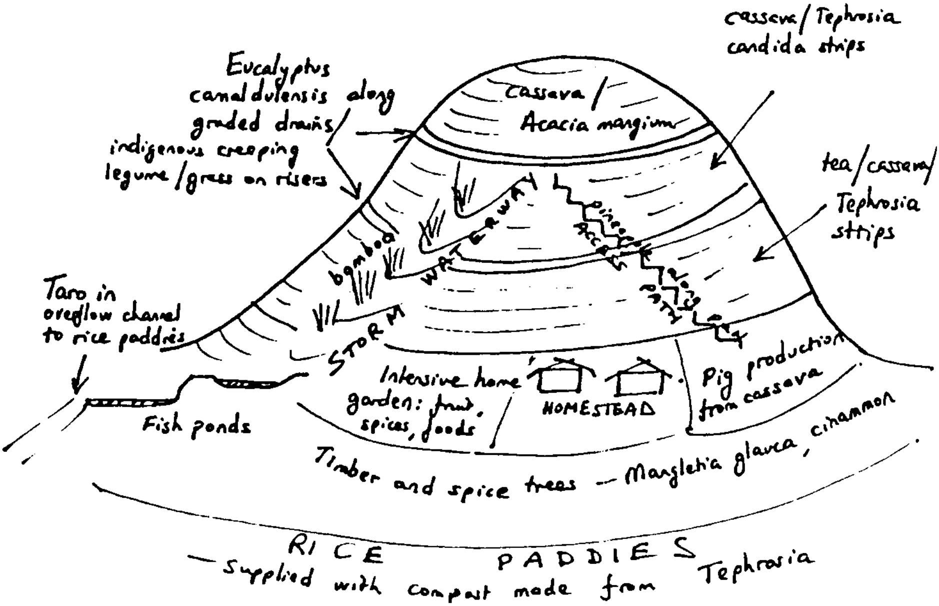


Figure 3. A simplified model of an household agroforestry production system in northern Vietnam. Note: cassava, tea, rice and homegarden outputs stand as before. External environmental benefits not taken as a benefit to the household.

INPUTS	OUTPUTS
[additional to previous paddy rice/cassava system]	
Tree seedlings bought in: Acacia mangium Eucalyptus camaldulensis	Cassava - only extra yield from soil conservation, assumed 100% after Yr.5
Other plants/seeds: Bamboo, improved tea, pineapple, vegetables	Pig meat - only extra as above Rice - extra yield after Tephrosia mulch
Labour - initial construction (1000 man-days/ha) - maintenance of contour terraces/drains/banks etc (100 man-days/ha/yr)	Other products: bamboo poles fish, vegetables, pineapples, timber (after 10 years)

In quantification and valuation, the greatest difficulty is likely to be encountered in variability and non-transferability of data from one site to another. As already noted, agroforestry effects are site-specific: a benefit, for example, to one soil of a tree/crop combination of *Leucaena*/beans may be positive but on another soil with lower water-holding capacity it may be negative. The manipulation of such technical factors as the pruning of woody species to act as a mulch can make enormous differences to the productive output from the system. Evaluators need to be alive to this sometimes extraordinary variability, flag the differential effects and use sensitivity analysis to calculate likely output values.

The technical demands on the provision of data for CBA can be stringent. It is notable that CBA of soil conservation in the United States can only rarely justify an investment in mechanical works based on increased production. For example, Mitchell et al (1980) conclude that most farmers would lose personal income by investing in erosion control terraces. However, if, as in the case of most tropical soils, a very steep initial decline in yield with erosion can be demonstrated, then this completely alters cost-benefit ratios and soil conservation is frequently justifiable by economic analysis (Wiggins, 1981). The difference between the two situations is one of technical knowledge: in the first case, an assumption of linear decline usually based on soil depth criteria and artificial desurfacing experiments; the second case, on a more accurate understanding of the nature of the relationship (see Stocking & Peake, 1987; Biot 1988 for more detailed discussion).

As the research effort in agroforestry increases through such initiatives as the AFRENA network in Africa, more precise estimates of the benefits and the costs of agroforestry in a variety of situations should become available.

Timely data, in the right form. Compatibility with economic models is the main criterion. This does not necessarily mean translation of all technical quantities into monetary values. To be avoided is the necessity for the economist to have to make routine technical interpretation of results before they can be used. The example of soil loss measurements is typical: commonly they are quoted in tonnes per hectare or millimetres lowering of the ground surface. Both are equally meaningless to on-site impact. Ten tonnes per hectare is potentially disastrous to productivity on a tropical Luvisol (concentrated nutrients in topsoil, low water-holding capacity), but probably tolerable on an Andosol (volcanic, large reserves of weatherable minerals). The economic planner or decision-maker cannot be expected to make such a critical interpretation, and it therefore remains the responsibility of the natural scientist to translate the result into a suitable form: for example, yield losses, value of nutrients lost and extra inputs required to maintain production. Such data are rarely provided.

On timeliness of data, there is a growing literature on the advantages and techniques of gathering data quickly, usually directly from land users and local field staff (e.g. Khon Kaen University, 1987). "Rapid Rural Appraisal" has been applied recently to agroforestry training, enabling a much more flexible, interdisciplinary and pragmatic response to local issues to be reflected in agroforestry interventions (Abel et al, 1988).

Discrimination between relevant and irrelevant. Technical data are not the unbiased, objective items that they are made to appear. They are hidebound by the thoughts and perceptions of the scientist and the selectivity of the user (Abel & Stocking, 1981; Stocking, 1989), and may be used for ulterior, often political, motives. As discussed by Warren & Agnew (1988) in the case of desertification, the physical environment may be blamed in lieu of social, political or economic ills. Therefore, merely to address stated environmental problems is often to touch the symptom, not the disease itself, with minimal consequent benefit. Many existing statistics are, at best, distortions of the truth (e.g. "each year 21 million hectares of once productive soil are reduced by desertification to a level of zero or negative productivity.....": UNDCPAC, 1987) and, at worst, downright misleading. Therefore, in even the most apparently technical of exercises, fact must be distinguished from fancy, and relevance discriminated from irrelevance. Agroforestry, riding a bandwagon and subject to exaggerated claims, could be a candidate for spurious benefits. The technical output must be subject to rigorous analysis.

Ability to deal with the future. In common with forestry, soil conservation or other natural resource projects, agroforestry may result in benefits (or costs) which are accrued far in time, often by future generations. Described by Sfeir-Younis (1983) of the World Bank as "the myopia of today's generation" (p.86), and by Pigou (1920) as the "over-hasty exploitation of stored gifts of nature" (p.27), the planning horizon of present land users may differ significantly from that of society (Sections 2.8 & 2.9). Technically, however, there is the critical need to model the dynamic changes in the environment and outputs from agroforestry over the medium to long term. Even if there are heated debates over the length of planning horizons and the level of discounting rates, it is still necessary to be able to estimate the performance of an agroforestry system in 20, 30, 50 or, perhaps, 100 years. Only with this information can tests be made on, for example, the sensitivity of alternative discount rates.

Technical arguments for paying especial attention to the future in agroforestry enterprises distill to the following:

- implementing agroforestry can involve a large immediate opportunity cost to the land user in land preparation and planting, from which very few returns can be expected in the first years;

- agroforestry systems may involve considerable learning and the need for empirical site experience, monitoring, evaluation and adjustment. The learning takes time and full benefits cannot be expected in the short term;

- one of agroforestry's main "selling points" is improvement in soil fertility (Young, 1987), brought about largely by the slow increase in the store of organic matter in the soil. Again, this takes time;

- agroforestry is also advanced as one means of rehabilitating degraded environments. Rehabilitation is necessarily a slow process with very little initial response per unit input of resources (Stocking & Peake, 1987).

3.2 Quantification of outputs

Agroforestry has multiple outputs which are often grouped into two broad types:

* products -- food, fuel, timber, shade, fruit, fibre, medicines, poles, posts, honey -- the tangible objects for which there is either a market or some other economic mechanism whereby a price may be assigned and value be quantified;

* environmental benefits -- erosion control, maintenance of soil fertility, sustainability, decrease in exposure to risk -- most of which are not normally considered as directly quantifiable and whose value may be determined culturally, or by willingness to pay, or by moral and ethical considerations, or, with present information, they cannot be quantified.

However, it is important to note that in this paper it is assumed that all outputs can in principle be translated into monetary benefits in order to be compared with input costs. Therefore, items such as erosion control and soil fertility are not benefits in themselves, but are the basis for production leading to higher incomes and ultimately to better welfare. Sustainability is a long term view of production, and not an intrinsic benefit of itself. Similarly, risk aversion is an aspect of the variability of production, "Environmental benefits", then, are simply means whereby production can be maintained or increased in the future -- they are not, for us, some mystical benefit which has to be divined from nature by totally new means. Nevertheless, the two broad groups do involve different degrees of difficulty in their derivation.

3.2.1 Quantification of Direct Outputs

This section looks primarily (but not exclusively) at direct outputs, and the problem of quantifying in a way meaningful to economic analysis. Because of the enormous range of agroforestry interventions and the possible permutations of plants, techniques, management levels, physical environments and products, the approach will be that of:

(i) a checklist of appropriate questions to consider which would lead the investigator to considering the main costs and benefits;

(ii) a listing of the main species, the direct products and the ways in which they could be measured.

(i) Technical questions

Table 2 is a checklist to remind the scientist of the sort of technical questions that may have to be answered to provide an assessment of costs and benefits for economic analysis. It deliberately focuses on the tree component because this tends to be the main distinguishing feature of an agroforestry system. However, similar considerations could apply to annual and perennial crops and to any animal or fish component.

The literature on intercropping (e.g. Willey, 1979; Beets, 1982) illustrates the types of questions that are appropriate when considering the trade-offs between competing species. Derived from the review by Willey et al (1983), the questions to ask may be categorised under the following subheadings:

Better use of environmental resources: e.g. sorghum/ pigeonpea is one of the commonest intercropping combinations; sorghum grows for 3-4 months, maturing at the end of the rains; pigeonpea flowers after the sorghum harvest and grows for a further 2-4 months. There is therefore good temporal complementarity, greater light interception, and possible better uses of plant-available water and nutrients as well as an intensified use of land and the spread of labour demand. Agroforestry combinations such as coconuts/cassava, cocoa/rubber, timber/spices, can all be justified in their more efficient use of "fixed" environmental resources.

Legume benefits: legume/non-legume combinations are the commonest intercrops with annuals, and, as Willey et al (1983) state, it is usually assumed that the presence of the legume confers a net nitrogen benefit to the system. This assumption must be qualified:

(i) even when legume growth is good, nitrogen does not necessarily benefit the non-legume especially when the two grow at the same time;

(ii) if legume growth is poor, potential benefits will be small;

(iii) competition between legume and non-legume may negate any nitrogen benefit;

(iv) much of the benefit may be derived in subsequent seasons through soil improvement.

This leads to the conclusion that potential benefits from legume combinations should be treated cautiously. Hedgerow intercropping systems with species such as *Leucaena* which are intended to supply nitrogen-rich mulch, or tea interplanted with the leguminous shrub *Tephrosia candida* have yet to be proven as suppliers of beneficial quantities of nitrogen.

Control of weeds, pests and diseases: weed suppression is achieved largely through plant competition; if the agroforestry system involves an intensification of land use, then weeds will usually be lessened with consequent benefits of reducing labour. For pests and diseases, it is often quoted that mixing species provides a barrier to the spread to another crop. The barrier theory is, however, insufficient to explain the benefit of sorghum in controlling *Fusarium* wilt disease in pigeonpea. In other cases, pest problems may be increased: trees providing a roosting place for *Quelea* birds which feed on millet is an oft-mentioned example given by farmers in southern Africa. Effects can, therefore, be ambivalent and should not be overstated.

Table 2. A checklist of technical stages, processes and questions in agroforestry with associated socio-economic implications (adapted from ideas in Huxley, 1983).

Technical stage	Technical questions	Socio-economic implications: Questions	Costs	Benefits
GERMPLASM	1. Where to get germplasm?	1. Can the land user collect own seed?	Cost of collection; opportunity lost	Use of 'free' or spare labour
		2. Buying seed?	Seed cost	Better seed source/ better growth
	2. Seed viability? seed testing necessary?	3. Can seed be stored?	Storage cost	Saving thro' use of own seed
		4. Are testing facilities available?	Equipment, laboratory facilities	Seed reliability
	3. Seed dormancy problems?	5. How may this affect adoption?	Special equipment; knowledge of techniques	-
	4. Seed pests & diseases?	6. Need for special treatment?	Treatment cost; help & advice	-
PROPAGATION	5. Propagation methods? - seeds - cuttings - tissue culture - budding & grafting - rhizobium & mycorrhizal fungi	7. Skills & equipment for various methods?	Equipment; help & advice	Use of existing knowledge
		8. Special problems thro' use of clones?	Specialist knowledge	Better, more consistent growth
		9. Requirements for seed inoculation?	Materials; skills	Better growth
	6. Use of nurseries?	10. On-farm, village, district nurseries? Who pays/provides?	Materials; advice; seedling cost to farmer; distribution	Local materials/ skills; vigorous plants; timely production
		11. Nursery problems? - management; pests etc.	Specialist advice	-
PLANTING OUT	7. Soil/environmental conditions?	12. Access to suitable soils/site?	N.B. AF should be less demanding in soil and site conditions - often uses degraded land; more intensive land use. - costs and benefits assessed relative to what would have been land use	
		13. Site preparation requirements?		
	8. Planting time and specific techniques? e.g. - right season - plant size/combinations - shelter/support - irrigation, fertilizer, mulch	14. Are the knowledge, management skills and labour available?	Specialist advice; inputs; maintenance etc.	Optimum growth
	9. Special problems? - pests, disaeases, weeds, animals/birds	15. - as 14. -		

[Table 2 – continued]

Technical stage	Technical questions	Socio-economic implications: Questions	Costs	Benefits
JUVENILE PHASE	10. Morphology & early growing of plants? - plant competition - training/pruning - rooting character	16. Is land user willing and able to develop specific skills?	Training costs	Beneficial interactions -- shade, water conservation
	11. Need for protection (9.above also applies)	17. Are animals/other humans likely to be attracted to site?	Fencing, protection; negotiation	More secure rights to land & produce
		18. Can browsing by animals be allowed at this stage? Useful produce? - leaves, herbs, spices etc?	Reduced growth	Fodder/ produce
MATURE GROWTH PHASE	12. Morphology and branching habit? Phenology? (shoot dormancy, leaf fall etc.) Competitveness?	19. Specific skills and labour requirements?	Training; opportunity costs etc.	-
		20. Harvestability? - terminal or sequential, single or multiple?	Labour; timeliness; transport; marketing	Subsistence; market value
	13. Management and soil conservation?	21. Weed control, ridging or other operations?	Labour; inputs; opportunity cost	Erosion control; future production
		22. Pests and diseases? Storage losses?	Equipment, treatment; loss of produce	-
SENESCENCE & REPLACEMENT	14. Onset of ageing and senescence?	23. Decisions as to replacement? Perceptions of need to replace?	Declining productivity; credit/help for renewal; other resources; effects on crops, other produce	Opportunity to improve system; harvesting timber
	15. Replacement operations?	24. Technical options for final harvest	Soil erosion, nutrient loss; special equipment; interrupt normal farming	Harvest
		25. Crop/soil management in transition period?	- as above -	Utilize stored nutrients, organic
		26. Specific replant problems? e.g. land preparation, pests	Specialist advice; equipment	-

AND SO ON BACK TO PARTIAL OR COMPLETE RE-ESTABLISHMENT OF AGROFORESTRY SYSTEM

Yield stability: different mechanisms are sometimes advanced:

(i) better control of pests and diseases - but see above;

(ii) greater relative advantages in yield output in a stress year, providing a useful buffer against low yields;

(iii) risk alleviation in that if one crop fails, the other can compensate.

Rao & Willey (1980) have shown for sorghum/pigeonpea that for any required monetary return per hectare, sole crops failed much more often than an intercrop [sole sorghum, 1 year in 8; pigeonpea, 1:5; the intercrop, 1:36]. Similar arguments could apply to agroforestry systems, but the data are scarce and generally unavailable.

Following from these considerations, the main technical questions that affect outputs from an agroforestry system revolve around 5 main themes:

* **Plant competition.** How does the juxtaposition of plants in space and time affect the total output from the system? Some systems claim a greater biomass production and larger economic yield; other systems offset lower outputs by social and environmental benefits. In either case, quantification is achieved by valuation of the stream of costs and benefits. Plant competition is simply one variable which alters the stream.

* **Resource utilisation.** Spatially and temporally, agroforestry uses natural resources differently. Some resources are essentially "free"; solar radiation, for instance. Any additional use of incoming light does not normally involve an opportunity cost in some other activity foregone. Other resources, irrigation water or tree seedlings, might have been used elsewhere. But in whatever case, the technical requirement is to quantify the additional production, and the losses incurred in achieving the production.

* **Knowledge and adoption.** Where the agroforestry system is already tried, tested and accepted locally, the skills and knowledge may be assumed to exist. But with so-called 'improved systems' or introduced technologies, access to the information, knowledge transfer, testing and training will all involve significant costs.

* **Risk and uncertainty.** Any new technology involves risk of failure in, for example, unpredicted pests. Agroforestry is claimed to reduce risk to the land user in bad years. Such costs and benefits are difficult to quantify (e.g. a reduced but assured supply of a good versus higher output in the long run) but, as key components in household production strategies, there is nothing in principle which should prevent their valuation in terms of future production and willingness to pay for certainty of supply -- see Section 2.10.

* **Management.** Agroforestry systems are, in general, more complicated than sole stands of trees, crops or pasture. They require complex decisions and actions to be undertaken at the right time and place. The acquisition of the necessary managerial skills or extension advice could be seen as a cost. Deficient management could jeopardise the whole output. Management requirements can, again, be built in as a cost of provision of the necessary training facilities or services

Agroforestry is also often advanced as the solution to specific problems: rehabilitation of eroded land, live fences in grazing schemes, protection of plantation forestry. In such cases the benefits are specific to the problem and the technical questions must address how well the system responds. Again, there is nothing intrinsically difficult about quantification of direct outputs, except that the performance of the system over time must be modelled sufficiently accurately to give acceptably reliable estimates of costs and benefits in the long run.

(ii) **Main species and products**

Here we identify briefly some principal species involved in agroforestry systems worldwide. For arable crops, the product is **economic yield**; that is, the part of the plant that is directly used for consumption or is sold in the market. Tables of indicative (and actual) yields are regularly published by FAO, agricultural compendiums (e.g. ILACO, 1981) and national statistical offices. No attempt will be made here to repeat that information, because it is specific to individual sites, environments, management-levels, and, in agroforestry, to the combination of plants grown especially with regard to density of planting and any interactions between species. It cannot be assumed that yields will approximate those of sole stands; they will almost certainly be lower, as intercropping systems show. Better measures by which to make initial estimates of overall yield are the yield per plant and the density of plants.

Table 3 is a listing of species derived largely from ICRAF's Crop Sheets Manual (Nair, 1980). Not included are many under-exploited and localised species, many of which have great potential for agroforestry. Some examples are: **food crops** - bambara nuts, cucurbits in general, winged bean; **fruits and nuts** - brazil nut, custard apple, durian, guava, mangosteen, rambutan, sapota; **spices** - fenugreek, nutmeg, anise, coriander, fennel; **beverages and stimulants** - betel vine, cola nut, guarana, mate, vanilla; **medicinal and aromatic plants** - basil, bay tree, cananga, citronella grass, lemon grass, camphor, palmarosa, vetivier; and hundreds of **miscellaneous plants** which have local specialised markets - babacu palm, buriti palm, guayule, jojoba, sago palm.

Table 4 lists a selection of trees and their products which have potential for inclusion as agroforestry species. Both tables show the range of products available from agroforestry systems.

Table 3. Some agroforestry crop species of major economic importance. (Source: Nair, 1980)

CROP	SCIENTIFIC NAME	AGROFORESTRY NOTE
CEREALS		
finger millet	*Eleusine coracana*	hardy, "catch crop"
maize	*Zea mays*	preferred cereal; needs assured rainfall
pearl millet	*Pennisetum glaucum*	good in marginal areas
sorghum	*Sorghum bicolor*	easy management; v. imp. agroforestry species
PULSES		
cowpea	*Vigna unguiculata*	needs full sunlight
mung bean	*Vigna radiata*	similar to cowpea
pigeon pea	*Cajanus cajan*	adapts to marginal envs.
TUBERS		
arrowroot	*Maranta arundinacea*	needs shade; lowlands
cassava	*Manihot esculenta*	"insurance crop"
potato	*Solanum tuberosum*	tropical mountains
sweet potato	*Ipomoea batatas*	easy; shade tolerant
taro	*Colocasia spp.*	v. tolerant
yam	*Dioscorea spp.*	v. adaptable
FRUITS		
banana	*Musa spp.*	shade tolerant
breadfruit	*Artocarpus altilis*	homegardens
papaya	*Carica papaya*	border planting
passion fruit	*Passiflora edulis*	good under shade
pineapple	*Ananas comosus*	good in marginal areas
OILS, FATS & BEVERAGES		
castor	*Ricinus communis*	v. adaptable
coconut palm	*Cocos nucifera*	multi-products; good smallholder mixed crop
groundnut	*Arachis hypogea*	short duration legume
oil palm	*Elaeis guineensis*	overstorey species
rapeseed/mustard	*Brassica spp.*	catch crop
sesame	*Sesamum indicum*	adaptable; esp.to drought
soya bean	*Glycine max*	adaptable; high protein

[**Table** 3 - continued]

CROP	SCIENTIFIC NAME	AGROFORESTRY NOT
cacao	*Theobroma cacao*	high economic returns
coffee	*Coffea spp.*	mix with trees
FIBRES		
kapok	*Ceiba pentandra*	easy manage; high returns
sisal	*Agave sisalana*	hardy; drought resistant
SPICES & OTHER		
cardamom	*Elettaria cardamomum*	needs shade
cinnamon	*Cinnamomum zeylanicum*	low input; adaptable
clove	*Syzygium aromaticum*	low input; high returns
ginger	*Zingiber officinale*	shade tolerant
pepper	*Piper nigrum*	on tree support
turmeric	*Curcuma longa*	easy manage; shade
arecanut	*Areca catechu*	amenable to combinations
cashew	*Anacardium occidentale*	high returns; protein
cinchona	*Cinchona spp.*	specialist alkaloid

Table 4. A selection of trees often used in agroforestry and their products. (Source: ICRAF)

TREE	PRODUCTS
Acacia albida	dry season fodder; nitrogen fixer; some wood
A. cyanophylla	fodder; wind-break; farm implements
A. holosericea	nitrogen fixer; fodder; mining spoil restore
A. mellifera	fodder; shade; honey; fencing poles
A. nilotica	firewood; termite-resistant farm use; fodder
A. senegal	firewood; gum arabic; fodder; erosion control
A. tortilis	charcoal; fodder; live fence; building
A. victoriae	fodder
Atriplex nummularia	high protein forage; reclamation salt soils
Azadirachta indica	fuel; furniture; seed oil + cake; tannins; soap; azadirachtin systemic pesticide
Balanites aegyptiaca	fruit; fodder; charcoal; snail pesticide
Calliandra calothyrus	firewood; nitrogen fixer; fodder
Cassia alata	medicine; tannin; root juices; honey
C. siamea	firewood; furniture; fodder
C. sturtii	protein-rich fodder
Casuarina equisetifolia	highest calorific firewood; poles; timber; pulp; erosion control esp. salty areas
Cordeuxia edulis	food from seeds (in Somalia); dye; fodder
Erythrina abyssinica	fencing; fuelwood
Gliricidia sepium	firewood; building timber; furniture; live fence; fodder; green manure; shade; honey
Grevillea robusta	shade; fuelwood; timber; honey
Leucaena leucocephala	fodder; fuel; timber; soil improvement; hedgerow intercrop; green manure; mulch
Melia azedarach	fuel; furniture; tools; beads
Moringa oleifera	fruit as vegetable; live fence
Parkinsonia aculeata	firewood; charcoal; fodder
Prosopis alba	firewood; fodder; food (flour); windbreak
P. chilensis	fodder; fuel
P. cineraria	fuel; forage; timber
P. juliflora	fuel; posts; furniture; honey
P. pallida	forage; syrup; fuel; posts
P. tamarugo	fuel; furniture
Samanea saman	edible pods; timber
Sesbania grandiflora	fuel, forage; pulp; food; gum; support for creepers; land reclamation; windbreak

[**Table 4** - continued]

TREE	PRODUCTS
S. sesban	shade; fibre; medicine; vegetable
Simmondsea chinensis	liquid wax; livestock feed
Tamarindus indica	fruit; spice; fuel; honey; timber; firebreak
Zizyphus mauritiana	fruit; hedges; fuel; silkworms

3.2.2 **Erosion Control and Soil Conservation Benefits**

These benefits, it has already been emphasised, accrue through the maintenance of future production. As such, they are real and valuable benefits which need to be analysed in terms of:

* how soil properties are changed or affected by the agroforestry intervention;

* how difference in the soil (as compared to the "without-project" situation) might affect the stream of costs and benefits.

These questions are exceedingly difficult to answer. Section 3.4 will present several models which attempt to look at parts of the processes involved and which may provide some of the needed information. In this section, we consider what agroforestry can do to the soil in order to ensure future production. Choices between agroforestry systems and sole stands may well hinge on the technical efficiency of crop combinations in maintaining soil fertility, and the ability of the natural scientist to identify and quantify such differences.

It is worthwhile, as Young (1986) does, to distinguish between erosion control and soil fertility maintenance. The **erosion control** function describes the ability of the system to reduce erosion rate to a level below that which would have occurred with another land use. Agroforestry's potential for erosion control lies in (i) the vegetal cover provided by the tree canopy and understorey layers in intercepting raindrops; (ii) litter and mulch on the ground surface which similarly intercepts raindrops and reduces peak runoff; (iii) the barrier function of stems and roots in reducing runoff; and (iv) an increase in soil organic matter which decreases erodibility. In tropical environments the first two are the most effective. The best and simplest way of quantifying the erosion control function is to measure the mean vegetation cover provided by the system -- this is one of the principal variables in erosion prediction equations (see Section 3.3). But along with direct cover, the following technical points must be considered:

- employing living barriers on steep slopes for erosion control means that hedgerows must be closely spaced; this may be unacceptable to land users and incompatible with the intervening crop;

- a tree canopy alone does not substantially reduce erosion; indeed it may increase erosion through the coalescence of large raindrops falling several metres onto bare ground. Litter and/or living ground cover are essential elements for erosion control.

From the work of Wiersum, Young (1986) reports an experiment which compares the relative effects of tree canopy, undergrowth and litter in a 5-year-old *Acacia auriculiformis* plantation in Java. By removing each element of the cover singly or in pairs, it was deduced that tree canopy alone and the canopy with undergrowth were relatively ineffective in controlling erosion. Litter cover alone reduced erosion to only 5% of bare soil erosion and to only marginally more than full natural forest. It may safely be concluded that the primary role of an agroforestry system in erosion control is the supply of litter.

The evaluator will therefore need evidence on the following in order to assess how far an agroforestry system can control erosion:

(i) the ability of the system to maintain a ground cover; and the variation in cover through the season;

(ii) the amount of litter provided by the system; and its variation through the season;

(iii) the efficiency of the system as a barrier to runoff and wind erosion.

The answers to these questions provide the inputs to erosion prediction models, which, in turn, give the input to productivity models which, in turn, allow estimation of future production.

The **soil fertility maintenance** function describes the soil's capacity to support the growth of plants. It is, therefore, closely related to erosion control which is one aspect -- some think, the main aspect -- of that support. Fertility is often seen as maintenance of nutrients, but this is far too narrow conceptually. Instead, soil fertility is the aggregate effect of:

* nutrient status generally; cation exchange capacity, base saturation, acidity:

* adequacy of specific nutrients; notably N and P;

* soil physical properties; bulk density, infiltration; surface crusting;

* supply of plant-available water; available water capacity, suction, pF;

* specific toxicities and problems; acid sulphate, salinity, sodicity, aluminium toxicity etc.

If the use of the soil initiates any process that reduces fertility, then future production is jeopardized. One of the most alarming effects on tropical soils is slight acidification through leaching after tree clearance, causing aluminium toxicity and an almost complete destruction of plant growth (e.g. Moberg, 1972). If an agroforestry system prevents depletion of soil fertility, then its benefit is the production that is not lost.

The single variable which best integrates most of the above aspects of soil fertility is soil organic matter -- this is the variable which the SCUAF model described in the next section uses to show soil changes under agroforestry and production of total dry matter in the future. Clearly, organic matter is not the whole story, but there is a tendency for the other deficiencies to be related to changes in organic matter, and therefore this factor acts as a good surrogate for them all.

Another way of integrating the soil fertility function is to consider the R-factor of the soil (a measure of the duration of cultivation in the whole cropping-and-fallow cycle), a variable used initially to estimate the relative ability of soils to support shifting cultivation (Nye & Greenland, 1960; Ruthenberg, 1976). A more recent elaboration of the same idea is the "rest period requirement" for a soil, or the R-factor necessary to maintain soil fertility under annual cropping (Young & Wright, 1979). In both measures, it is recognised that, apart from the intrinsic quality of the soil, the main variable in changing R is level of technology. For agroforestry systems, R should approach 100%: i.e. continual use of the land. Therefore, its fertility maintenance function could be quantified in terms of how much the R-factor can be increased from its level under existing land use to its 100% under agroforestry. Then, the additional years in which production is possible will yield a stream of benefits. We do not know of any case where this technique has been used, but it would appear to be one useful way of assessing agroforestry's role in maintaining soil fertility.

3.3 Technical Models

In this section we consider how the technical benefits of agroforestry may be predicted and how these benefits may be translated into values that are meaningful to economic analysis. An especial concern will be how to predict the performance of an agroforestry system over a run of years since some benefits may only accrue in the long term. The two major challenges are:

* how does agroforestry affect the soil? In a sense, it is the soil which stores the "technical benefit". Have we any models which may predict the nature and the degree of change to soil parameters?

* how do changes in the soil affect future production? Have we any models that give yield output over time consequent on a known change in a soil parameter?

3.3.1 Modelling effects on the soil

The soil benefits under an agroforestry system through the supply and maintenance of:

(i) a living ground cover of vegetation which intercepts the kinetic energy of raindrops, thereby preventing detachment of soil particles and minimising erosion. The tree canopy is of minor importance and may even exacerbate the erosion process (Rickson & Morgan, 1988);

(ii) a surface litter of dead vegetation. This acts as (i) above and helps detain runoff and provide the source for a range of benificial soil processes;

(iii) increased infiltration of water;

(iv) retention and balanced supply of nutrients;

(v) better soil physical structure.

Most of these processes can themselves be summarised as soil and water conservation. Indeed, according to Young (1986; 1987), the primary benefit of agroforestry is through erosion control and fertility maintenance. Fertility is maintained mainly by preventing the export of nutrients out of the system. Young notes that the experimental data for rates of erosion and nutrient losses under agroforestry practices are very scanty, but none of the information to hand contradicts the hypothesis that agroforestry can reduce erosion to low and acceptable levels. A first step in modelling soil changes under agroforestry is, therefore, to predict rates of erosion. The rate of erosion will subsume the deleterious effects of runoff, loss of nutrients, depletion of organic matter, structural deterioration and plant-available water.

Erosion prediction. Three models have been most widely used to predict eroion:

Universal Soil Loss Equation (Wischmeier & Smith, 1978)
Soil Loss Estimator for Southern Africa (Elwell & Stocking, 1982)
FAO Methodology for Soil Degradation Assessment (FAO, 1979)

In addition, there are a number of variants on these three, such as a modified USLE (Onstad & Foster, 1975). There is also a growing number of mathematical models based on sediment budgets, hydrological principles and shear resistance. Models that have been tested include: a watershed planning model, ANSWERS (Park et al 1982); an hydrological sediment transport model, FESHM (Ross et al, 1980); and a field scale model, CREAMS (Knisel, 1980). While the future of erosion prediction clearly lies in the further development of models based on the actual physical processes, none so far is workable in practice.

For agroforestry the particular technical demands lie in the ability of an erosion prediction model to (a) distinguish changes in soil characteristics which determine erodibility, (b) model accurately the interception of rainfall by a mixed vegetation cover and the effect on splash erosion, and (c) identify the management effects which reduce erosion rates.

There is no ideal erosion prediction model, but some are more suitable than others. If the model is wholly empirical (i.e. a statistical model reliant on the results of experiments only) then the complexities and dynamics of agroforestry systems are unlikely to be well represented. For example, the USLE takes soil erodibility as a fixed function of certain apparently unchanging soil parameters; whereas, the erodibility in an agroforestry system will be dominated by soil organic matter, the most transient constituent of a soil. More significantly, erosion prediction models measure the soil that is lost but not the changes to the quality of the soil that remains. It is the remaining soil that determines future production. Therefore, by themselves, these models have limited application to economic analysis and would have to be incorporated in more complex models that use erosion information to estimate on-site changes and the effects of those changes on yields.

Soil-life model. This attempts to model the way that soil erosion progressively limits the productive potential of the soil. Its essence is that degradation induces a finite time limit to the use of the soil by reducing soil depth (as modelled in the original approach developed in Zimbabwe - Elwell & Stocking, 1984) and by affecting plant available water (Stocking & Pain, 1983; Biot, 1988). The model therefore links changes in land use to yields through the following steps:

1. Erosion's effect on topsoil depth
2. Soil textures and available water capacity
3. Rooting depth for minimum water requirements
4. Plant tolerance to depletion of soil moisture
5. Yield response factors.

A variant of this type of model developed for rangeland in Botswana by Biot (1988) calculated a "residual productive lifespan of land" under present communal livestock densities and showed that the system is in fact quite resilient -- sustainable at least for 400 years.

Soil-life is a useful concept for economic analysis in giving a measure of sustainability of the system. In its original formulation it does not explicitly include future production. But extensions of the model show that time and soil depth are good proxies for change in biomass yields (Biot. 1988). Agroforestry systems would add considerable complexity and may be difficult to deal with under current designs of soil-life models.

Three **classificatory models** have possible application in the economic analysis of agroforestry. The **Fertility Capability Classification** (Buol, 1972) groups soils having similar limitations to fertility management. The **Soil Productivity Index** (Kiniry et al, 1983; Rijsberman & Wolman, 1984) evaluates long term effects of erosion on productive potential of soil. The relative productive potential is assessed through five "root response functions" which measure the "fractional sufficiency" of any soil layer to support root growth. Sufficiencies were originally assessed for water storage capacity, aeration, bulk density, pH and electrical conductivity. Other factors would be needed for many tropical soils; in particular response curves of yield against organic carbon, gravel layers and soil strength. **Soil potential ratings** (McCormack & Stocking, 1986) offer a third classificatory approach which evaluates the quality of land in terms of the yield-equivalent cost of ameliorating and counteracting soil fertility deficiency, erosion and other limitations.

Such models have only limited application to agroforestry and economic analysis at their current stages of development. They are primarily users of existing information and are unlikely to be able to deal with the required complexities and time-scale.

3.3.2 Modelling future production

Erosion-Productivity Impact Calculator (EPIC). This is the only model specifically designed to calculate the relationship between soil erosion and productivity (Williams et al, 1983). It has eight submodels, including a variant of the USLE, plant growth functions such as energy interception, and plant growth limitations such as water and air temperature. EPIC has still to be evaluated properly and its complexity can lead to strange and anamolous results. Limitations for the economic analysis of agroforestry are (a) the serious lack of validation and calibration; (b) inability to deal with more than one output product; and (c) the difficulty of re-running the model for a span of years. Yet it is the single most comprehensive attempt to model erosion-induced effects on production.

There are a number of models explicitly intended to be **economic models** that assess the cost-effectiveness of investing in soil conservation. Two have received most attention. **COSTS** (Raitt, 1983) assembles input costs for US agriculture and calculates the cost per acre or per tonne for a reduction in soil loss through conservation practices. **SOILEC** (Eleveld et al, 1983) is a more ambitious computerized, long term physical and economic model which is intended to guide conservation subsidies and to present the physical and economic trade-offs in erosion control to the farmer. Both models are critically dependent on erosion-yield data and apply to intensive commercial agriculture. Their application to agroforestry would be dependent on knowing soil loss under agroforestry (i.e. applying a soil loss model - SOILEC does this through the USLE) and how production changes over time. These are critical constraints, and there would seem little to be gained in employing these models rather than Cost-Benefit Analysis -- for further discussion on this, the next chapter reviews actual studies on the economics of agroforestry.

In order to address the lack of suitable ways of predicting the long-term impact of agroforestry, ICRAF has recently developed a model that is specifically designed to monitor soil changes. It is called by its acronym, SCUAF.

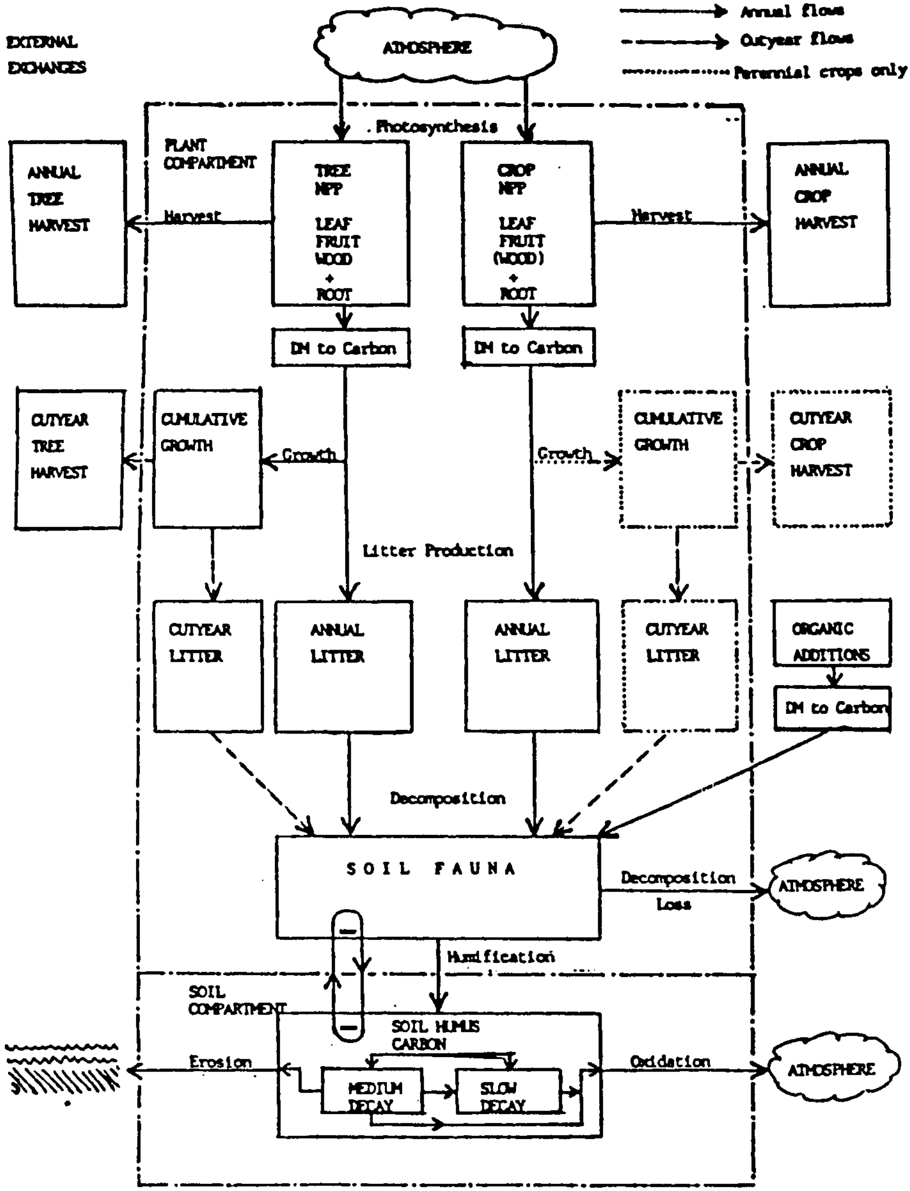
Soil Changes Under Agroforestry, SCUAF. This model incorporates erosion prediction, but extends the prediction to changes in soil organic matter and nutrients over time given different combinations of trees and ground cover. The following is a brief synopsis taken from the ICRAF Working Paper on SCUAF (Young et al, 1987).

SCUAF is a computerized model designed to predict the effects upon the soil of specified agroforestry systems in different environments. It is intended to cover the prediction of erosion and changes in soil fertility. Fertility maintenance is taken as the central requirement for sustainable production. At the present stage of development of the model, a carbon (or organic matter) cycle is taken. A new version in draft form has both carbon and nitrogen as submodels. It operates through a series of annual iterations, calculating the changes in soil carbon due to oxidation, humification, harvest, erosion, litter production and other organic additions (such as leaf prunings for mulch). The basic balance equation for the "soil store" is:

$$\text{Soil } C_{\text{year } t} = C_{\text{yr.}t-1} + \text{humification} - \text{oxidation} - \text{erosion}$$

There are two plant components: the tree and the crop. These can be adjusted according to type of plant, density of planting and their rate of biomass production. All plant components are subdivided into four: leaf, fruit, wood and root. "Litter" refers to all plant residues not removed from the system. Agroforestry systems can then be described in the model according to their production of different component parts and the harvest management of the system. Figure 4 gives an outline of the SCUAF model, showing the different elements and linkages.

Figure 4. Outline of the SCUAF model (Source: Young et al, 1987)



The four principal outputs of SCUAF which are plotted over time, typically 30 or 50 years, in order to see the stability of the agroforestry system are:

* soil carbon
* erosion
* biomass
* harvest

The latter output is especially interesting in that it presents a selection from the biomass production of plant parts that are to be harvested. For economic analysis this is of particular significance because it allows an assessment of any or all plant parts that have economic value over a run of years. And this assessment is specifically based on changes induced in the soil system by implementing agroforestry.

SCUAF clearly has great potential in providing the right information in the right format for economic analysis. As such it is the only model which comes anywhere near being directly applicable. Nevertheless, users have to be aware that models are potentially dangerous, even ones such as SCUAF which are basically simple input-output models. Young et al's (1987) words on this are worth quoting directly:

> "When operating with computerized models it is easy to get carried away. The results look so plausible, and internally consistent, that one is in danger of believing that they represent reality. Predictions from models are only as good as the data fed into them.... It is ... an adjunct to experimental work, not a substitute." (p.67)

4. REVIEW OF COST-BENEFIT STUDIES

4.1 The studies

To our knowledge the most extensive bibliographical information on studies of the economics of agroforestry is Hoekstra & van Gelder (1985), from which twelve of relevance to this paper were identified. ICRAF staff helped in the search for additional, more recent studies and we had information on a few studies from other sources. From these, several were unavailable in time, and others, after screening, were found unsuitable, although they contained data of some relevance.

The search left six studies detailed enough to give comparative data on CBA of agroforestry. While the number is small, they are sufficient to illustrate current applications of CBA. The following studies are used:

Author	year	Country	Study type
Anderson	1987	Nigeria	ex-ante
Ehui	1988	Nigeria	ex-ante
Joseph	1986	Cameroon	ex-ante
Montgolfier-Kouevi & Houerou	1980	several(*)	ex-ante
Verma	1987	India	ex-post
Williams	1988	Nigeria	ex-post

(*) examples based on partial data from Cape Verde, Malawi, Senegal, Sudan and Tunisia

The same procedure is adopted as in the earlier review of CBA of soil conservation (Bojö, 1986a). The review is organized according to the steps of CBA outlined in Section 2 of this paper. First, the separate enterprises are described very briefly, sufficient to identify the kinds of agroforestry options being considered. Then evaluation criteria are discussed along with distributional aspects of income. This is followed by identification, quantification and valuation of costs and benefits. The especial concerns of agroforestry CBA - time horizon, discounting and uncertainty/risk - are compared. Finally, policy conclusions are assembled based on this review.

4.2 Enterprise description

In order to define research priorities and to arrive at approximate estimates of benefit, Anderson (1987) compares the traditional sorghum-millet-cowpeas-groundnuts system of the arid, northern part of Nigeria with two possible agroforestry options:

(1) shelterbelts of neem and eucalyptus
(2) farm forestry with a wide range of tree species.

Ehui (1988) has a similar objective in comparing the traditional bush fallowing system of western Nigeria which has a four year fallow period against five potential management technologies for maize:

(1) alley cropping with *leucaena* hedgerows at 2m interval
(2) as (1) but at 4m intervals
(3) as (1) with herbicides
(4) as (2) with herbicides
(5) a no-till farming system

Seven possibilities are considered by Joseph (1986) in a village settlement project in the Cameroon. Only the first two are currently practised:

(1) mixed cropping of coffee and annual crops
(2) mixed cropping of cocoa with plantains and annual crops
(3) plantains as sole crop
(4) Robusta coffee as sole crop
(5) cocoa as sole crop
(6) Robusta coffee intercropped with plantains
(7) cocoa intercropped with plantains

Plantations of browse trees or shrubs are assessed as to their economic performance by Montgolfier-Kouevi & Houerou (1980) for several African countries. The options considered are:

(1) spineless cacti
(2) *Atriplex*
(3) several *Acacia* species
(4) *Prosopis*
(5) *Leucaena*

Verma (1987) provides an ex-post study where a 4 hectare village woodlot, producing both fuelwood and fodder from *Casuarina equisetifolia* in Dhanori, Gujarat, India, established in 1974, was felled ten years later. The costs and benefits of the enterprise are evaluated, and compared to the "without-project" alternative.

Williams' (1988) analysis takes one traditional and three new crop and livestock production systems in southwest Nigeria. Relative efficiency of resource use is compared. The livestock alley farming systems are "cut-and-carry" with 25% of the tree foliage used to feed the animals:

(1) traditional maize cultivation
(2) alley cropping (*Leucaena*) with maize
(3) alley farming with goats
(4) alley farming with sheep

A variety of agroforestry systems are therefore represented. Geographically, there is a bias to Nigeria, while analytically all the studies except one are "ex-ante" and look at prospective management systems.

4.3 Evaluation criteria

For deciding success or failure of an enterprise, three evaluation (or decision) criteria are discussed in Section 2.4: Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit-Cost Ratio (BCR). Below we summarise the approaches taken, although other indicators of project performance were sometimes used:

Author	NPV	IRR	BCR
Anderson	yes	yes	yes
Ehui	yes	yes	no
Joseph	yes	no	no
Montgolfier-Kouevi & H.	no	yes	no
Verma	no	yes	no
Williams	no	no	yes*

* but see explanation below

Ehui (1988) expresses the NPV as a sum which includes:

(a) the change in net returns depending on chosen option for conventional time horizons of a few decades;

(b) the expected percentage of the salvage value to be received by the farmer at the end of the planning horizon, times the change in the private salvage value because of the new technology.

He therefore incorporates an indefinite time horizon by allowing for an increased salvage value of the land because of soil conservation. In a perfect land market, this increased value is equal to the NPV of all future net increases in production on the land. However, because of imperfect land markets, the farmer will receive less than 100%.

Montgolfier-Kouevi & Houerou (1980) sometimes use the IRR criteria "backwards" to derive "shadow" costs for forage production that, given world market prices for the valuation of output, yield a pre-determined IRR, set at 10 or 15%.

Verma (1987) quotes a high financial IRR (38%) but it remains unclear how he derived it [Note: from the figures he gives in his Table 7, p.100, the rate is 44%]. Although not shown, he says that economic IRR is higher than financial IRR. This is supported by the potential shadow pricing on labour, but is countered by government spending which would have to be added to the costs. Benefits to the poor are stressed -- see further discussion on income distribution below. The fact that the investment has been renewed and enlarged is taken as a sign of success.

Williams (1988) takes a different route. He uses a particular variety of the (inverted) benefit-cost ratio, the resource cost ratio (RCR). RCR is defined as the quotient between the cost of non-tradeable resources (valued at opportunity cost in world market prices) and a partial value added (gross benefit minus **tradeable** inputs) valued at world market prices. A ratio greater than one is taken to indicate a non-viable project.

Caution is needed in interpreting results based on RCR. The size of the RCR depends on the arbitrary allocation of costs between "tradeable" and "non-tradeable" items. Williams allocates tools and animals as non-tradeable, but seed and fuel as tradeable. To illustrate, assume the gross benefits to be 100 units and total costs 80. If all are considered non-tradeable, RCR is 0.8. But, if half are tradeable, RCR is 0.66 [i.e. 80/100 compared with 40/(100-40)]. We can only conclude that comparisons based on RCR are limited to options where exactly the same allocation is made between tradeables and non-tradeables. A further note of caution concerns the use of RCR in ranking of projects. Assume the farmer and society both wish to maximise net income (NPV) from any enterprise they undertake. We can conceive the circumstance of two enterprises, A and B, with present values of benefits (PVB), present value of costs of tradeable (PVC(t)) and non-tradeable (PVC(nt)) inputs and resource cost ratio (RCR) as follows:

Enterprise	PVB	PVC(nt)	PVC(t)	NPV	RCR
A	100	48	32	20	0.71
B	10	3	2	5	0.38

A should be chosen in preference to B because of higher NPV. However, looking at RCR alone, B with its lower cost relative to benefits is preferable to A. RCR is, therefore, unsuitable for ranking projects which utilise different amounts of resources.

4.4 Income distribution

Although conceptually part of the choice of decision criteria, questions of income distribution are either ignored or feature as an add-on. Questions to pose are: have different effects for different groups been identified? If so, is there any implicit or explicit weighting of these effects?

None of the ex-ante studies discusses differential effects on income groups. Perhaps this is justified in an ex-ante perspective since no actual impact has yet been observed. Nevertheless, it still needs to be addressed and predicted when designing a project. For example, which social group will benefit most? Which groups will most likely adopt the enterprise? How will social stratification be affected?

The only exception is Verma (1987) who has an extensive discussion on distributional impact. The distribution of benefits for the woodlot project he describes are tabled below as percentage of revenue received for seven different groups:

Category	% of total revenue
Village Panchayat	35
Forest Department	27
Traders	12
Landless	8
Small farmers	7
Marginal farmers	5
Others	5

No similar division is made for distribution of costs. This would have enabled **net benefit** to be calculated for each group. Verma notes that some of the poorest had also foregone their grazing rights when the woodlot was established.

4.5 Identification of costs and benefits

The main questions to ask are: have important effects been left out? Have improperly-defined effects been incorporated? In general, we answer "no". Benefits have been identified as the differential yield of crops, wood, fruit and livestock products. Costs have been categorized financially and economically. However, a few points deserve special mention:

(1) The perspective on benefits is traditional and rather narrow. The focus is on **on-site** agricultural impact. **Off-site** environmental effects rate small mention.

(2) Only Verma discusses explicitly the secondary benefits for the community from the spending of increased incomes. He notes that village footpaths and a school were improved from income received from tree-felling. Employment is listed in the number of man-days created. Indirect benefits such as diffusion of technology, development of self-confidence and the formation of a Tree Growers Society in the village are also discussed.

(3) Management costs often receive obscure treatment. Only direct costs for planting and harvesting are accounted. Rarely discussed are back-up services such as extension and infrastructural improvements, while project administration and the provision of costly experts is also ignored.

4.6 Quantification of physical effects

As discussed in Section 3 this can be the weakest link in the analytical chain.

Anderson (1987) takes crop yields from (unspecified) local surveys of traditional agriculture. Crop yield decline from erosion is set at 0 - 2% per year. No source is quoted. In contrast, an impressive 174 measurements on the effects of shelterbelts on crop yield are used to support estimates of yield increase of 15 - 25% with mature trees. Farm forestry has an assumed effect of 5 - 10% yield increase, but without data backing.

Ehui (1988) randomly surveyed 25 small-holder farmers from villages near Ibadan to obtain his variable cost estimates. Maize yield with/without the project was assumed to decline according to a function derived by Lal (1981):

$$Y = 6.41 \exp(-0.017) Z_t$$

where, Y is maize yield; Z is cumulative soil loss rate in tonnes per hectare; and t is the time index.

Using this equation, maize yields are projected for 20 years. Cumulative soil erosion is obtained from SCUAF (see Section 3.3.2), a simulation model designed at ICRAF, with some supporting measured rates made by Lal which were used to estimate initial soil erosion rates. Total prior erosion was set at 25.6 t/ha for all land uses, but it is unclear why. A 20% reduction in yield was postulated where *Leucaena* was grown at 4m spacing, and 30% for 2m spacing, because of the space devoted to trees.

Joseph (1986) also interviewed a random sample of settlers (n=140) from 16 pioneer villages in the project in proportion to their population. He used extension and project staff also, and applied the Delphi expert panel system to get a "panel of talented literate settlers" (p.70) to answer questions on input-output relationships.

Montgolfier-Kouevi & Houerou (1980) obtained yield data from many, referenced sources. Recognising the possible errors, yields are allowed in their study to vary widely (see "sensitivity testing").

We are uncertain how Verma (1987) got his yield data, but presumably, being an ex-post study, there was greater certainty over actual yields of grass and wood.

Williams (1988) quotes data from IITA, Ibadan and his own farm survey of three villages in southwest Nigeria in March–September 1987 to justify a basic maize yield of 1 tonne/ha with a decline of 10% per year (p.7). No source is given for this last, rather drastic, figure.

In summary, the empirical basis for what are crucial assumptions as to the long term performance of agroforestry systems is sometimes weak and obscure. However, the uncertainty in most assumptions is often stated, and a few give solid evidence.

4.7 Valuation

Valuation concerns the attachment of social and private "price tags" to quantified effects. Our main interest here lies in how shadow pricing, particularly concerning foreign exchange and labour, has been approached. Many developing countries administer exchange rates that deviate substantially from marginal rates of willingness to pay. Also, since labour is a major input component in agroforestry and chronic un(der)employment persists in many labour markets, shadow prices should be considered.

In the following table, WMP and DMP signify World Market Prices and Domestic Market Prices. Either can be chosen as an accounting unit provided that translation between them is carefully done. This often means using a special shadow exchange rate (SER). Shadow Wage Rate is denoted SWR:

Author	Prices	SER	SWR
Anderson	WMP	yes	yes
Ehui	DMP	no	no
Joseph	DMP	no	no
Montgolfier-Kouevi & H.	WMP	no	no
Verma	DMP	no	no
Williams	WMP	yes	yes

Anderson (1987) is the only author who discusses price trends. He assumes an annual increase in agricultural output prices of 3% on the basis that this is the Nigerian population increase once there is no more freely-available land. This is projected to be in 15 years time. The argument used is that land scarcity will:

(a) drive up the value of land;
(b) raise yields;
and (c) encourage food imports.

(a) and (b) would increase the value of farm output and soil protection relative to costs, whereas (c) would do the opposite. Anderson believes that the counter effect will be limited. Furthermore, large increases in food imports would put a downward pressure on the Naira against foreign currency, thus raising the price of tradeables (e.g. food crops) in relation to non-tradeables (unskilled labour). This would reinforce the effects of (a) and (b). However, the world market price of food crops, forming the valuation basis for agroforestry outputs, is also determined by forces external to Nigeria, its population growth and land potential. Technological advances and type of agricultural policy, including subsidies, applied by the major producers are relevant. Anderson does not explicitly mention these concerns, and it is therefore difficult to determine whether a 3% annual rise in relative prices is reasonable. It is an assumption which ought to be tested.

Another important output, fuelwood, is priced according to its nearest substitute, kerosene. The price of poles was multiplied by the national standard conversion factor (s.c.f. = 0.35; the use of these conversion factors to transform domestic values into world market values is explained in Little & Mirrlees, 1974, and Gittinger, 1982). The labour shadow wage is one third of the financial wage set with reference to the value of traditional agriculture in border prices, rather than in considerations of the local labour market. All other non-tradeables are converted at an s.c.f. of 0.35. Anderson claims (p.62) that this conversion factor is "widely agreed".

Other differences in Anderson's economic v. financial calculation are: (a) the cost of farmer labour is included in the economic calculation, and (b) the economic (opportunity cost) value of land is used, not the actual compensation paid to farmers for taking land for shelterbelts.

Valuation by Ehui (1988) is done in Nigerian currency and farm gate prices. Despite particular Nigerian economic conditions, no discussion is entered into on world market prices, shadow pricing, price trends and subsidies. Labour costing is avoided and "treated as a stock, because it is essentially derived from the family" (p.15). Returns to labour are shown in Naira per working day, and no cost is apparently attributed to labour, financially or economically.

Neither Joseph (1986) nor Verma (1987) discuss social pricing. Financial wages and prices are used by Joseph in the Cameroon. If the shadow wage is below the financial wage, this disbenefits labour-intensive systems. Tools are priced in annuities based on purchase cost and estimated lifespan.

Montgolfier-Kouevi & Houerou (1980) value the enterprise in forage units (FU) and digestible protein (DP) at 1979 world market prices. Some reference to costs is made but shadow pricing is not explicit. The authors complain of the lack of information and they derive operating costs themselves and investment costs from other African projects.

In contrast, Williams (1988) gives sources for market and world market prices. Financial farm enterprise budgets are developed separately. The cost of working capital (defined as labour and seed) is calculated as the direct financial cost plus the interest based on a market rate of 10%. Williams bases the interest charge on the time period the capital is tied up in, for example, land preparation (3 months) and other labour (1 month) and an annual interest of 10%. Wages paid (or opportunity cost charged) for labour is not "released" back again for renewed investment. The recommended practice would be to charge all the costs as they occur, compare them with all the benefits as they occur and discount the totals with an appropriate rate. Cost of capital (investment in animals) is charged at 25% real rate.

Shadow pricing of the exchange rate is explicitly made according to the extent of Naira overvaluation through the differential between the consumer price index locally and for industrialised countries for base year 1973. As Williams acknowledges, this gives only an indication as it ignores the influence of high tariffs and other import controls on the rate of exchange. As in Anderson's study, the adjustment in exchange rate is substantial: from an official 1984 rate of N0.76 per US$ to N1.95. Interestingly, the applied adjustment factor, 0.76/1.95 = 0.39 is similar to Anderson's 0.35 for 1985.

Labour, the single most important cost item, is explicitly shadow priced but at full financial wage due to "minimum distortion on wages" (p.10). In other words, the labour market is assumed to be in long-term, non-seasonal, equilibrium; an unusual assumption for a developing country, but perhaps warranted for this particular labour market.

To summarise, there are substantial differences in the approaches chosen by various authors. In several cases, valuation is obscure, partial or ad-hoc.

4.8 Time horizon

What time horizon has the analyst considered when accounting for costs and benefits? The chosen periods for the six studies are:

Anderson	50 years
Ehui	20
Joseph	20
Montgolfier-Kouevi & H.	20
Verma	9
Williams	3 (but not strictly comparable)

Williams (1988) deals with the period 1984-86 with all costs and benefits as annuities. Thus, it is a special case not comparable to a three year investment in the other calculations.

In the cases of Anderson, Joseph and Montgolfier-Kouevi & Houerou the choice of time horizon is not explained. In the last, spans of 30 years and the lifetime of *Acacia albida*, 80 years, are partly considered. Ehui claims that, "the choice of time horizon is arbitrary, but can be considered as a reasonable measure of the farmer's own operation life time" (p.12). Frequent comments about the shortsightedness of peasants is consequently contradicted. Such argumentation may be good reason for choice of time horizon in **financial** analysis, but not relevant for the **economic** perspective. Verma's study, a special case, takes the rate of return on an observed 9-year cycle for trees: i.e. the actual length of the project. It could be argued that data on prices and mean incremental yield would make an interesting discussion on optimal economic enterprise length, but this possibility is not explored.

4.9 Discounting

Choice of discount rate implies a judgement about how future effects should be weighted against present effects. The primary concern of the studies is the social discount rate, and the following shows the choices made by the authors (figures in parenthesis signify the rates used in sensitivity testing):

Author	Chosen Real Social Discount Rate (%)
Anderson	10
Ehui	(2), 10, (25), (35)
Joseph	10, 15, (20)
Montgolfier-Kouevi & H.	10, 15
Verma	n/a
Williams	10, 25

n/a, not applicable as Verma calculates IRR only, not NPV.

All chosen rates are positive, significantly higher than zero and are similar to those found in a review of eighteen soil and water conservation projects (Bojö, 1986a). What governs their choice? Anderson and Ehui state no reasons. Montgolfier-Kouevi & Houerou mention an opportunity cost of capital perspective, although there is no direct evidence. Joseph claims that, "the opportunity cost of capital in Cameroon lies between 12 and 15%" (p.72), without specifying the source or the time period for this information.

The highest (base case) rate is used by Williams - 25%. He notes that, "this rate represents an educated guess based on the interest rates charged by commercial banks on non-agricultural loans and the rates charged by private money lenders in rural areas" (p.10). If these really are **real**, not nominal, rates, the demands on borrowers are indeed high. The rate charged by private money lenders can be expected to include a high risk premium due to insufficient risk pooling/spreading. [Note: risk pooling refers to the case where many projects are undertaken, some failing, others succeeding. Risk spreading is where risk of a single project is shared by many individuals]. This should not be a concern for an aid donor or the government if sufficient risk pooling/spreading is achieved. Thus, a lower rate should be used by government for a social evaluation. The choice of 25% contradicts Williams' own choice of a 10% "market rate" (p.9) to calculate the annual cost of working capital tied up in the production process.

To summarise, significant, positive real rates of 10 to 15% are often chosen. Sometimes a passing reference is made to the opportunity cost of capital, but mostly the choice is arbitrary. This possibly reflects the lack of agreed national standards on social preferences for weighting benefits and costs over time.

4.10 **Uncertainty and risk**

The main question is whether the major uncertainties have been identified. If they have, what sort of sensitivity and probability analysis has been undertaken? Views as to what constitutes a major uncertainty differ. Given the diverse nature of the enterprises, this is only natural.

Anderson (1987) tests for change in NPV, IRR and B/C-ratio in relation to several scenarios:

(1) Low yield/high cost
(2) High yield

(3) No erosion
(4) More rapid erosion
(5) Soil restored to initial condition and yield increase
(6) Wood benefits only

With minor adjustments, the same tests are applied to farm forestry. NPVs were generally found to be positive regardless of which scenario was tested.

Ehui (1988) examines uncertainty and risk from two standpoints:

(1) He tests four different discount rates: 2, 10 (base case), 25 and 35%. With the highest discount rate, the traditional farming system is found to be the most profitable. This is interesting in that it may explain the rationality of current land use, and the potential difficulty to be encountered when introducing new enterprises.

(2) Ehui assumes that the farmer receives none of the long term change in salvage value of the land. He tests for cases when the farmer receives half and when he receives all the increased salvage value.

Joseph (1986) conducts sensitivity testing by examining how far (1) higher costs and (2) lower revenues arrive at switching values for NPV. No further discussion is entered as to which factors are likely to vary most and to what extent.

Montgolfier-Kouevi & Houerou (1980) emphasize the uncertainty of their calculations through an array of tests concerning:

(1) 10 and 15% discount rates
(2) Alternatives without enclosures to compare with hedges and barbed wire
(3) Production levels per ha subject to change
(4) Cut-and-carry v. direct grazing
(5) Wood production v. none
(6) Gum and forage v. forage as a by-product of gum

In Verma's (1987) ex-post study, there is less rationale for sensitivity testing. Uncertainties in the data could have been discussed and tested. Different lifetimes of the woodlot could be calculated to determine the optimal cycle.

Williams (1988) tests for:

(1) The incorporation of mulch into soils which increases maize yield but also demands more labour.

(2) Supplementary feeding of *Leucaena* to animals, resulting in increased animal productivity,

All the ex-ante studies have at least some discussion about uncertainty, and some attempts at dealing with it through sensitivity testing. This is good, although the textbook situation of analysis using statitically-derived probabilities is still far away. Rule-of-thumb has guided analysis of uncertainty, not statistical variance.

4.11 **Policy conclusions**

Have clear policy implications been drawn from the various studies?

Anderson (1987) concludes that by registering an IRR of 15% in his base case, the study shows that prospective returns to farm forestry and shelterbelt investment may be good when so-called "ecological benefits", by which he means yield effects of improved soil fertility, are taken into account. He also argues that it is better to rehabilitate soil before degradation has progressed because of greater potential returns. Such policies have not been applied in Africa, says Anderson, because of a lack of public recognition of their need. Implications as to research priorities are fourfold:

(1) Shelterbelt impact on crop yield
(2) Influence of agroforestry on soil conditions
(3) Influence of farming systems on the returns of shelterbelts and farm forestry
(4) Studies of optimal spacing of trees

Ehui (1988) compares NPVs of five management systems **before** labour costs and the returns to labour input. The IRR is 34% for the most profitable system -- 4m spaced hedgerows without herbicides. However, since labour input varies, the NPVs are partial only and do not give a balanced result. A reasonable shadow wage for labour could have been introduced. But it is still interesting to note that the traditional farming system yields the highest return **per labour day** of all systems studiedby Ehui. He remarks that the additional labour input in alley cropping must be reduced by about half to make the system attractive.

All seven land uses in Joseph's (1986) study have positive NPVs. He argues that the study shows that intercropping or planned multi-cropping with cocoa, coffee and plantains is an important improvement on mixed cropping with arable crops. However, we note that sole cultivation of plantains is the single most profitable system. Excepting plantains, Joseph concludes that intercropped systems are the most profitable and reliable, followed by mixed cropping, and then sole cropped systems. He says, "the implication of these results is that, in less developed countries generally and in the project under study in particular, the farmers' practice of mixed cropping instead of sole cropping is economically rational." (p.75) Unfortunately, his results do tend to contradict this in that (a) the most profitable system is a sole crop and (b) the systems actually practised by farmers rank only 4th and 5th out of seven. Therefore, declaring the common practice "rational" does not automatically follow, although rationality could perhaps be explained by introducing other restrictions and parameters. Towards the end of the discussion, Joseph introduces additional arguments for sole cropping but, if valid, they could have been incorporated in the CBA.

Montgolfier-Kouevi & Houerou (1980) emphasize uncertainty but show that, if browse plants are treated as supplementary feed to replace bought feed concentrates in drought periods, then the enterprises can probably be justified. A number of options are illustrated with no definite recommendation as to which is best. They note that the economic viability of browse trees and shrub plantations appears uncertain when all factors which limit profitability in Africa are taken into account. More optimistically, the value of browse plantations are judged higher when wood supplies and environmental protection are taken into account.

Verma (1987) concludes that the experience of the Dhanori village woodlot is seen to have implications "invaluable not only for other states in India but also for other developing countries". (p.107) The two greatest problems identified are (a) lack of appropriate institutions and (b) the distribution of benefits. Verma notes that financially sound investments ought to be able to borrow their money commercially and not rely on government subsidies. However, the involvement of the Forest Department for woodlot protection and technical advice is favoured.

Williams (1988) shows that private profitability is higher than social because of government subsidies to maize and small ruminant production. He ranks social profitability according to annual resource cost ratios: (1) alley farming with sheep; (2) alley cropping with maize; (3) traditional maize; (4) alley cropping with goats. He supports the case for the promotion of research and extension in southwest Nigeria in alley cropping and alley farming methods.

In summary, there is the unwarranted tendency to draw general conclusions from a single case study. Furthermore, the conclusions do not always follow from the study itself. Nevertheless, these studies do show examples of economically viable agroforestry systems that would deserve field testing and close monitoring. They highlight key areas of interest for further research and analysis.

5. KEY ISSUES

One of the main purposes of this paper is to highlight those parts of the economic and financial analysis of agroforestry which need most further attention.

Agroforestry clearly has great potential for some parts of the world and the improvement of some land use systems. Indigenous systems, anecdotal evidence, ecological theory and our own review of existing cost-benefit studies all support this conclusion. That potential must not, however, be overstated because agroforestry is not a panacea, a universal solution for rural problems. Agroforestry systems vary enormously in their design, application and acceptability. Tools of analysis are needed to match problems -- land degradation, declining fertility, low yields, poverty -- with possible solutions -- fuelwood plantations, mixed planting, rural industry, sole cropping or perhaps doing nothing. The tools for completing the match are imperfectly developed.

Cost-benefit Analysis, CBA, holds great promise as a tool for the analysis of agroforestry enterprises, because it is an accepted procedure, it deals with a common unit of currency (money) and it has the potential to quantify and therefore compare a broad range of factors, inputs and outputs. Moreover, it is compatible with some other appraisal and evaluation methods. Through its complex nature and long term perspective, agroforestry does, however, bring particular problems to CBA. These problems have been the main subject of this paper. By way of identifying key issues, what then can we conclude? We divide our issues according to the main parts of this paper:

* the technique of CBA and its analytical steps
* rural household decision-making and agroforestry
* quantifying the direct outputs of agroforestry
* technical models to support CBA

The technique of CBA and its analytical steps. Section 2 outlined eight steps. Economic theory can be brought to bear on many of the detailed problems which might arise in applying CBA procedures to particular cases. The key issues we feel that need to be addressed are:

(1) There is little experience and case study material on which to base recommendations as to procedure. Use can, and should, be made of experience in the economics of other natural resources (e.g. soil conservation or plantation forestry), but this is no substitute for agroforestry case material from a broad range of environments, conditions, types of project and enterprises, and individual, household, institutional and government perspectives.

(2) Experience is especially needed in the monitoring of agroforestry systems that (a) are long term, (b) have a suitably identified control area, (c) use a range of sensitivity tests, (d) justify the figures, especially on discount rate, that they use, and (e) provide assessments of external costs and benefits.

(3) Greater attention to timescale is warranted. Fixed prices or constant changes in prices are often arbitrarily assumed. Modelling of long term price changes could influence predictions as to profitability of agroforestry and hence the desirability of investment and further research.

(4) The integration of CBA with other appraisal and evaluation methods, Environmental Impact Assessment (EIA) in particular, has great potential for agroforestry. Also promising is the capability of Rapid Rural Appraisal (RRA) for producing private valuations of costs and benefits through ranking and other techniques. Methods for the economic appraisal and evaluation of enterprises thus form a continuum from RRA, yielding qualitative and ordinal estimates, through to full Social CBA and quantified EIA.

Rural household decision making and agroforestry. Peasant households are taken to be the main target beneficiaries of agroforestry. It is they who are most at risk from an uncertain and precarious environment; who need the technical advantages of agroforestry in, perhaps greater output per unit of labour input or per hour, or maintenance of long term production; who have received relatively little from other development efforts. The rural household has particular characteristics such as the direct production of most of its food and other requirements but, we argue, decision-making is essentially rational, and profit maximisation is often found where market involvement is considerable. The key issues are:

(5) It is often assumed that farmers have a short time horizon and a high discount rate. But examples, such as producing large families for security in old age and planting teak trees to be harvested two generations hence, suggest otherwise. Our understanding of these variables is vague. What determines private discount rates and time horizons? Answers will affect recommendations as to the adoption of agroforestry.

(6) The accurate valuation of credit, land and labour from the perspectives of different categories of peasant household is necessary for reliable prediction of the adoptability of agroforestry enterprises, and realistic evaluations of existing systems. Case studies are needed from a variety of household types in a range of economic and ecological environments.

(7) The financial valuation of products by the peasant household is a crucial factor in the adoption of agroforestry systems. Main problems identified are the valuation of these products **for the household** over time, the effect of risk on perceived values, and valuation where there is no market. These aspects need further analysis and consideration in the context of agroforestry enterprises.

Quantifying the direct outputs of agroforestry. This may seem to be the least controversial aspect of financial and economic analysis. Some may argue it is simply a technical matter of measurement. True, in empirical studies the economic yield of products can directly be measured. However, this is a far different situation from being able to predict outputs with confidence. Agroforestry systems are extremely complex. Competition between species not only affects total production but also the proportions of useful products such as food, fodder, fuel, fibre, timber and medicines. Measurement itself is fraught with difficulties, not least those introduced by the observer. Key issues to highlight are:

(8) Successful modelling of complex agroforestry systems is a prerequisite to identifying, quantifying and valuing costs and benefits. What cropping systems models can help? What are the precise technical demands on provision of data for CBA?

(9) Variability and non-transferability of data is an especial problem, for agroforestry effects are site-specific. Major questions surround the alleged better use of environmental resources, the advantages of legumes, the control of weeds, pests and diseases, and yield stability. How can we estimate these in new environments?

(10) The demands of CBA for technical data cannot be unduly delayed by the provision of long term experiments or mounting full farming systems and resources surveys. How can we provide the data in the right form, quickly enough? What does Rapid Rural Appraisal have to offer?

Technical models to support CBA. We have distinguished between technical models which have a potential to model the effects of agroforestry on the soil and those which model the influence on production. In the first group, there are many prediction models especially of soil loss. Some deal with water use efficiency and competition. The major challenge, however, lies in the second group of models which includes those dealing with changes in soil quality and productivity. and which assesses how yields are affected. Key issues are:

(11) Development of agroforestry-productivity models is only tentative to date. SCUAF holds considerable promise, but is stronger on soil changes than on predicting effects on harvest and production. There are critical needs in validation and calibration of models, as well as incorporating long-run changes in production consequent on increases in soil fertility, the control of erosion and the elimination of other environmental problems. Certainly,

existing models such as EPIC, SCUAF, soil-life, need further examination and comparison with field data in order to refine their design and to make definite recommendations for research and eventual standard application.

In conclusion, the financial and economic analysis of agroforestry is a field where the techniques of the natural scientist and the economist come together to analyse one of the most important types of multiple land use in the developing world. It deserves the support and encouragement of development institutions, aid agencies and governments.

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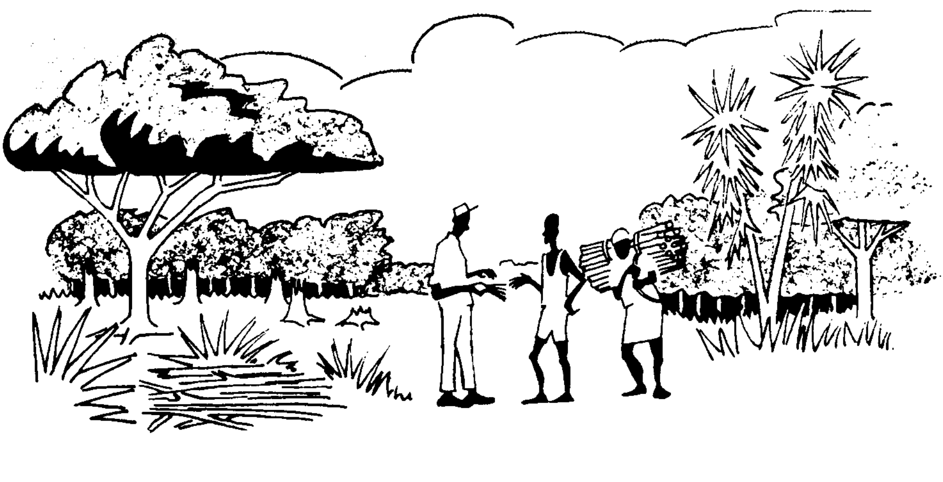
PART II

CHAPTER 1

INCENTIVES FOR AGROFORESTRY



"IF I HAD KNOWN THE DISCUSSION WAS TO BE ABOUT KUNI I WOULDN'T HAVE WASTED MY TIME IN COMING".

Phillip Bradley
Beijer Institute
Nairobi
Kenya

CONTENTS

Introduction

The title is a comment overheard during a group meeting which discussed the problems of kuni (firewood) supply on some farms in southern Kakamega in 1984. It sums up a widespread male reaction to the issue of firewood problems and what might be done to remedy the situation. The theme of this article is the "acceptability" to farmers of technical changes associated with development programmes. In this instance, the material is drawn from the agroforestry initiatives that form part of the Kenya Woodfuel Development Programme. I focus on four situations; three in Kakamega District, and one in Kisii District. Both districts are part of Kenya's high potential agricultural land, with altitudes ranging between 1500 and 2000m and annual precipitation between 1200 and 2000mm, spread over two seasons. Population densities vary from less than 100 per sq.km to as much as 1000. Two examples concern small areas (sublocations[1]): Ebusikhale and Murhanda in Kakamega district, and two look at individual farms: Thomas Nzaywa's in Kakamega, and Zacharia Moyancha's in Kisii. These four examples are employed to present a general thesis about aspects of social change which influence acceptability.

Situations

Ebusikhale is a small sublocation of approximately 7 sq.km, located in the far south of Kakamega District. With a near perfect climate for agriculture, Kakamega District itself forms part of Kenya's high potential zone: the most productive agricultural land in the whole of the state. According to the 1979 census[2], 6034 people lived in Ebusikhale. By now this will

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1. A sublocation is the smallest administrative unit in Kenya, and varies in physical size according to population density. Usually, sublocations will have a total population of between 5 and 10 thousand.

2. Central Bureau of Statistics (1981)

have grown, and it is safe to assume that the rural population density of the sublocation exceeds 1000 per sq.km. Despite its bountiful sunshine and rainfall, the environmental base to Ebusikhale's agriculture is far from benign. The most serious limitation is due to the impoverished nature of its soils. Developed over ancient basement granites, they are exhausted, and prone to sheet wash. These infertile and erodible soils limit the productivity of the area, but by far the greater stress comes from the deep social crisis which inflicts the production system.

For many years Ebusikhale has exported its male labour, leaving behind a residuum of elderly dependents, children, and their mothers, all of whom try to scrape a living from small plots of land. The average farm size is less than 0.5 ha, and the average resident family consists of over 8 people, most of whom are largely unproductive dependents. In many villages, upwards of 75% of the adult male labour force is absent. In theory these men are working in the major urban centres of Kenya, most notably Nairobi (where most domestic staff are from southern Kakamega), and remit part of their wages to support the family at home. In reality, however, many are in very low paid casual employment, frequently laid off, and normally unemployed for considerable periods. Remittances are less than is commonly supposed and in a perverse logic, their absence from the farm is better construed as a shedding of extra consumption than as a loss of productive labour.

Back on the farm the women struggle to grow maize and beans for food, and perhaps a few vegetables and bananas for sale at the local market. Some will care for an undernourished cow, which may provide milk for the children or for sale. There is a busy level of petty commerce in anything that can supplement the family bduget: chickens, fruits as and when they come into season, temporary surpluses in maize and beans, and so on. Although there are small plots of coffee in the surrounding area, in Ebusikhale there are none, and neither is there any other "cash" crop. Effectively, all crop production is for food.

However this is not a subsistence economy. Notwithstanding the sale of labour power on the part of the men, other examples of the imprint of the market are everywhere evident. Small roadside kiosks sell sodas, sweets and other non-essential consumables, women develop all many of small income-generating initiatives (basket and pot making for example) and travel with their meagre goods to the local markets, and the children attend school where possible (representing a considerable financial outlay). Harambee[1] contributions add to the financial strain.

Enmeshed within this social and economic crisis is another: that of firewood. On the one hand it pales into insignificance compared to the wider malaise, but on the other, it imposes a very real burden on the women of the sublocation. Whilst the social world is collapsing around them (and there are many examples of delinquent behaviour that bear testimony), they are nevertheless subjected to the intense social pressue that judges a wife or mother by her ability to fill the kitchen pot and ensure the provision of properly cooked food[2].

The Kenya Woodfuel Development Programme (KWDP) came to this area in early 1984, and spent the first six months enquiring into the nature and extent of the woodfuel problem throughout the district. At the same time the team conducted investigation of existing and potential agroforestry activities in the district, surveys of the social and cultural traditions governing the supply and use of wooduel, and the general resource base of the population. The results of this work led to the selection of Ebuskihale as a representative area in the densely populated southern third of the district, where development assistance for a better provision of woodfuel might be well received. Indeed, the portents were vary favourable. A number of factors led the team to believe that

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1. Harambee literally means "pulling together", and was introduced as a form of self-help to communities all over Kenya. In reality it a form of "quasi-official" taxation, and can impose a real burden on poor people. There is much social pressure to be seen to donate to an harambee fund, and it is in practice extremely difficult for poor farmers to demur.

2. See Chavangi (1984), (1985)

Ebusikhale might be the one sublocation (there were six others scattered throughout the district) where most could be learned, where a rapid uptake of agroforestry initiatives might follow and where a general model for the rest of the district might be developed. These hopes were based on a number of factors.

1. Of all the areas visited in the district, and according to the results of surveys[1], the shortage of firewood was the most severe in this area.

2. As women are the prime movers in firewood collection and use, and as women had been left to manage the farms when their husbands were absent, a programme which would most affect women was thought likely to find a sympathetic response in Ebusikhale.

3. Existing agroforestry practices were well developed in the sublocation, and their implementation and management were very much the responsibility of women[2].

In developing its implementation strategy, the KWDP constantly kept Ebusikhale in mind, and one of its earliest interventions was concentrated in this sublocation. However, before examining

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1. Agroforestry survey -van Gelder and Kerkhof (1984)
   Cultural Survey - Chavangi (1984), (1985)
   District Resource Analysis - Bradley (1984)
   Woody Biomass Survey - Bradley and Kuyper (1985)

2. A common practice, not seen elsewhere, is the use of *Sesbania sesban* as a maize intercrop. The small, quick-growing and nitrogen-fixing tree is cultivated as a dispersed overstorey in maize fields. Its very rapid growth, coupled with a light shade, offers protection for the maize from hail storms. It is known to improve soil conditions, and, most importantly for the KWDP, it provides rapid supplies of firewood.

this action, and its fate, we should first turn to some other situations in Kakamega, and in Kisii District: the second of the districts in which the programme intervened.

Murhanda is another sublocation targeted by the KWDP. it is quite different from Ebusikhale, being larer at 12 sq.km, and with a slightly lower population of 5519 in 1979. It is located between Kakamega town, the district headquartes, and the Kakamega Forest. In fact its eastern boundary abuts the forest itself. Despite its proximity to the major urban centre of the district, it is a quiet and withdrawn area. Like Ebusikhale, its climatic base is good, and the soils are better than in the south. At the same time, farm sizes are larger (mean of 1.2 ha), the predicament of male emigration less severe, and the agricultural production base much healthier. Cash crops are commonly gown, with tea and French beans most prominent. Food resources are good, as the larger farm sizes enable both cash and food crops to be grown. With the greater presence of men, labour supply is adequate. At the same time, firewood supplies were much less precarious than in Ebusikhale. Women were allowed to enter the nearby forest to gather dead wood, and so developed is the practice that small crocodiles of women can be seen leaving the forest each day, all carrying large headloads of wood. Much of this is destined for the market where a small but important trade in firewood is pursued. Unlike Ebusikhale, *Sesbania sesban* is rarely found, and in fact is regarded as little more than a weed. Suggestions that it might become a useful agroforestry species were met with derision, particularly by the men whose vision of a tree was a standard tree of great commerical significance. To them *Sesbania sesban* was little more than a joke - scarcely the stuff of development programmes. The pattern of trees and shrubs on the farms of Murhanda was different from that of Ebusikhale in other ways. Although still present, hedges and formal woodlots of *Eucalyptus saligna* were less prominent than in Ebusikhale, while small ravines harboured remnant riparian forest stips. The fields themselves were relatively bare of trees, and the practice of growing trees on the farm (either through small on-farm nurseries[1], or in small tin cans) was rather unusual. Additionally, the woodlots that did exist frequently contained an indigenous species *Croton macrostachys*.

At the outset, the prospects for introducing a wider balance of agroforestry actions in this sublocation seemed inherently less favourable to the KWDP team, particularly as the primary motive from the team's point of view: a firewood crisis, seemed not to exist. Furthermore, people from the surrounding areas regarded their compatriots from Murhanda as rather staid and traditional. So far social disruption associated with the sale and trading of land which has been experienced over so many parts of highland Kenya has been avoided, for little land seems to have passed out of family hands in the sublocation. Despite its proximity to the modernizing effects of an urban centre, its provident resource base, the continued presence of the men, and a religious affiliation which stressed the continuity of the past, have all led to an inward-looking society with a less than enthusiastic attitude towards external agencies of change[2]. Coupled to this conservative outlook is a strict social demarcation between the roles of men and women. The former guard and manage the trees, the latter collect and use the firewood. The evident functional link between the two does not seem to mitigate the structures of customary social practice. There is an interesting side issue here. Whereas the woodlots of exotic species such as *Eucalyptus saligna* and *Cupressus lusitanica* are regarded as perennial cash crops, with the wood and poles destined for the market, those of *Croton macrostachys* serve ritual purposes, for when the senior

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1. The agroforestry survey found that throughout the district the practice of producing tree seedlings, particularly of the commercial species such as *Eucalyptus saligna* and *Cupressus lusitanica* was widespread, though concentrated and most actively pursued in the densely-populated southern third of the district.

2. Personal report from the extension officer assigned to the sublocation

male of the household dies his funeral pyre must be of *Croton* wood. The connection between planted and managed trees (as these *Croton* woodlots undoubtedly are) and firewood is therefore made, though only for a very particular situation and only under the authority of the men. All in all, Murhanda was regarded in the early period of the programme as a "difficult one", and expectations of early success were focussed elsewhere.

We turn from the general background of small areas to the specifics of individual farms. Two such farms serve as illustrations. The first is situated in southern Kakamega, in an area very similar to Ebusikhale, with poor soils, absentee husbands, small farms and high population densities.

Thomas Nzaywa owns a very small farm of o.3ha in southern Kakamega. His wife and three children, and a grandmother live on the farm, which is almost entirely devoted to the upkeep of four grade dairy cows. Such is the attention paid to these cows, that the normal pattern of land use in the area (maize and beans as a food crop, tea as a cash crop, and some small plots of cassava, sweet potatoes and bananas) has all but been abandoned. Some maize is grown, but most of the food consumed by the family is purchased. The money for this comes from a range of products founded on the zero-grazing unit for the cows, and the fodder grass and leguminous trees with which they are fed. It is an impressive technical solution to the pressures on traditional agriculture which come from insufficient land. Instead of attempting to intensify maize production (as many neighbours have done with hybrid maize and fertilizers) Thomas has switched production to milk and byproducts. The investment needed for such a change is considerable, particularly for the cattle and the stall in which they are housed. He has received support from development agencies for this.

The technical base to the farm is specialized. Fodder grass provides bulk food for the cows. This is supplemented by the protein-rich leaves of *Leucaena leucocephala* and *Calliandra calothyrsus*, two exotic agroforestry species introduced into the area. Thomas is extremely enthusiastic about his trees, and has managed to cross breed the two exotics to produce a hybrid which seems to have captured the best characteristics of both parents. The flowers of the trees provide nectar for the bees in his improved bee hives, the cattle provide manure for the soil (in copious quantities - he even sells it), the trees provide further benefits to the soil as well as fodder for the cows and shade for sensitive plants (he grows various types of spinach and greens). His wife has more than enough firewood within easy distance. The pattern of rows of trees separated by rows of fodder grass, growing on a bed of soil and manure appears luxuriant and always fresh and green. The surplus milk is sold, and provides enough for food purchases and for reinvestment. He has recently bought a new type of shredder which breaks up the grass and tree leaves before they are fed to the cows. He mixes these to a strict formula so that the cows have a properly balanced diet. It is an extremely successful farm, even on such a small piece of land. From its production he has been able to finance his elder children through school, and has managed to accumulate a little and become "richer". The whole enterprise is founded on an easy complementarity between the zero-grazing system and intensive agroforestry.

The KWDP was naturally interested in this farm, for it pointed the way ahead for an agroforestry programme to relieve firewood stress on small farms, and provide many other benefits. We shall return to this later.

In **Kisii**, situated at over 2000m in the northern highlands is **Zacharia Moyancha's** farm[1]. It is long and linear, like many others in this area. In fact subdivision of the farm according to Gusii practice has left Zacharia with a 1.1 ha small holding which stretches 750m from ridge crest to valley bottom, yet is only 20m wide at its widest. His wife Piria, is responsible for 16 children, five from a former wife who has died, the others her own.

The farm is the main source of income, although some baskets made by the wife are occasionally sold to bring in a little extra

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1. Full details of this and a number of other farms in Kisii district, which participated in the on-farm agroforestry trials work can be found in Kuyper, 1988

money. Tea is the only cash crop on the farm, though Zacharia undoubteldy receives cash when he sells any of his trees (principally *Eucalytus saligna* and *Acacia mearnsii*). The tea takes up 25 per cent of the farm, whilst another 50 per cent is devoted to the upkeep of 5 cows. The remainder is used for food crops such as maize, sorghum, beans, cassava and sweet potatoes, and for two small woodlots: *Acacia mearnsii* on the thin stony soils at the top of the farm, and *Eucalyptus saligna* in the valley bottom. A few scattered *Croton macrostachys* and *Cupressus lusitanica* are located along the edges of fields and around the house compound area.

Because there are few trees on the farm, and only very small hedges, firewood supply can be problematic. Piria collects from the hedges virtually every day, but this is often not enough. Zacharia helps by buying small bundles and allowing his wife to cut some of the smaller trees. As a member of a local women's group Piria states that the subject of conversation at meetings frequently turns to firewood. When the KWDP first contacted the farm, both husband and wife expressed keen interest in doing something about the firewood supply.

This farm was selected by the KWDP Kisii team as a site for on-farm agroforestry trials, in which, at the farmers' request, and with his active involvement, large numbers of a variety of tree species were planted on the farm. The choice of species and numbers was the farmer's own, and he arrived at this after visiting the KWDP headquarters in Kisii and following further discussions with KWDP extension officer and agroforestry specialist. The choice of planting sites was also left entirely to the farmer, and on the part of the KWDP no instructions were given. To the eyes of the agroforester the planting density was too high, the selection of sites less than ideal, and the choice of species unadventurous. However Zacharia was given everything he asked for in the way of seedlings. There were no other inputs from the KWDP except for frequent visits to discuss progress and monitor results. As and when he wished for more seedlings these were provided, along with suggestions about seed collection and improved on-farm nurseries to grow his own stock[1].

From the point of view of the KWDP, the whole process was designed to establish a number of things: (1) were the trees acceptable "en masse" as a substantial component of the farm management system, (2) would they find favour in the eyes of both the men and the women, and (3) was it realistic on small farms to suggest that this type of agroforestry initiative could solve the firewood supply shortage?

What Happened

Before elaborating on what happened in these four situations, the early thinking of the KWDP in terms of extension approaches, the content of the extension "package", and technical advice should be reviewed.

From the technical perspective of agroforestry, a unanimous choice for technical advice stemming from local practice was made. The distribution of seedlings grown in centralized nurseries was eschewed in favour of encouraging home production. Efforts were made to test a range of methods for seed collection, storage, and nursery design. Seed for new exotic species was imported at the start, with a view to local production in the near future. Exotic species were favoured, not so much because of their biological properties, but because no prior and hidden values and perceptions would be associated with them.

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1. From the Kakamega experience, the KWDP had produced a number of leaflets describing technical aspects of tree nurseries, seed collection and storage, transplanting and so on. It had built upon the normal practice of on-farm nurseries and designed an improved version which become a major compoment of the extension effort. See Mungala, Kuyper and Kimwe, 1988 for further details.

On the extension and message front, particularly following the results of a cultural survey[1], the team opted for addressing the family rather than women alone, for a strong focus on agroforestry for woodfuel[2] rather than for multiple benefit an finally for providing assistance in the form of animation with only minor physical inputs, free of cost.

First, let us go back to Ebusikhale, upon which so many early hopes rested. Initial contact had already been made through the various surveys that were conducted in early 1984. The middle of the year saw a limited general awareness of the presence of a "tree-planting" programme in the sublocation. A few families were given small quantities of seedlings to gauge opinion. Later in the year, an extension officer gathered small groups of people together to discuss fuelwood issues. The men, as expected, were disinterested, but the women showed every sign of engaged interest. An initial attempt (later abandoned) was made to distribute considerable quantities of seedlings to group members, with guidelines on planting and after care. Subsequent visits to the groups as a whole, and to individuals, followed the progress of the intervention. At a later stage in early 1985, a full-blown local drama programme came to the sublocation, after which a high demand for seed[3] was experienced. These were distributed, along with a "comic strip" version of the drama and technical leaflets on nurseries and tree management. Throughout all this there was an intensive campaign by the extension officer to reenthuse sagging interest where it was noted, to lead the group discussions further, to offer individual support, to take requests for assistance or technical problems back to the offices

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1. Chavangi (1984)

2. A motto "MOTO MWA KA" was adopted as the trade mark of the programme. It is swahili for fire all the year round.

3. The programme had by this stage switched from seedling provision to seed supply and technical advice on tree nurseries.

in Kakamega for consideration and so on. At a still later stage, attempts were made to monitor the impact of the programme. This monitoring exercise covered all the sublocation selected for attention, and not just Ebusikhale.

To the surprise and disappointment of the team, it appeared that all this intensive effort had been to little avail. Interest had waned, the new trees were performing badly, and many had been abandoned or not cared for. The whole effort seemed to be grinding to a halt. One should not be overly harsh in assessing the programme in this way so soon. We are speaking of a time span of only three years, and although there is little sign of a community-wide uptake, there are nevertheless many individual families who have benefited and who are continuing on their own. There is insufficient space here to present a full explanation of the reasons for this disappointing result, but one or two points need to be stressed.

Firstly there is the issue of male and female roles in Luhya[1] society. Although the majority of men are absent from the area, this does not necessarily mean that the women have expanded decision-making powers. It is true that the men traditionally take all decisions regarding trees, but in their absence, it was thought that some of these powers might be transferred to the women. If not openly, the team had thought that the women might discretely get on with the task of planting their own trees. Such it seems, was not the case. Sons, related males such as cousins or brothers, or grandfathers usually interceded and effectively hampered the efforts of women. Even though the majority of men did not consider the small, quick growing species the team favoured as real trees (again the 30m tall *Eucalyptus saligna* is the standard by which they judge other trees), somehow, the old constraints overflowed into a "non-tree" situation, and this despite the fact that *Sesbania sesban*, the locally favoured "agroforestry" tree had provided a precedent for the type of species that was introduced.

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1. The Abaluhya constitute the vast majority of the people of Kakamega.

Secondly, and perhaps much more importantly, was the consequence of deciding to donate, rather than charge for, the seed that was offered. It later transpired that anything given for free was by definition worthless, and therefore could be of no material benefit. This proved to be damning assessment. At the same time, free gifts represented Trojan horses, following an earlier and disastrous flirtation with an agricultural credit scheme.

The result of all this was that far from becoming the pioneering model that had been anticipated, so far Ebusikhale represents one of the KWDP's less successful forays into the district.

As we have seen, the position of Murhanda was different, and a very cautious approach was adopted. The same elements were employed (initial group meetings followed by the drama and then technical advice), and the response though outwardly enthusiastic, was underneath guarded. This was anticipated, and the team was aware of the need for patience, and continuity in their efforts and commitment. Slowly the response has picked up, and although there is still a long way to go before the momentum is self-sustaining, steady progress has been made. What is of great interest in the Murhanda setting, is the change in attitudes that began to emerge in 1988. We have noted that the presence of a source of firewood in the nearby Kakamega forest meant that initial reactions to the programme were less than excited. In 1988 a national drive to encircle all highland forests with a ring of Nyayo[1] tea got underway. The aim of this strategy was to protect the forests from indiscriminate felling and clearance, and to provide a source of income for those in the neighbourhood who had previously relied on the forest for resources. The implication for Murhanda was that the women's access to an unlimited firewood supply would be severely curtailed. Interest in the programme increased, and the extension worker confirms that a much more positive attitude now

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1. Nyayo is the philosophy of President Moi, meaning progress, unity and peace. The tea belts which encircle and protect the highland forests are known as the Nyayo tea zone.

prevails. Her sentiment is that a new "awareness" drive associated with the drama programme would elicit a more enthusiastic response than it did on the first occasion.

The situation with Thomas Mzaywa's farm is quite different. Here is a farmer who by any standards, is progressive. The technical and economic success of his enterprise is clear, although he has only been able to accomplish this with considerable outside support. Nevertheless his example illustrates the possibilities for small farms whose traditional base is in decline. It must be said though that his enterprise sits like a small atoll in a tropical sea. None of his neighbours has copied his approach, few if any of the trees he grows have spread beyond his plot boundaries, and the zero-grazing initiative has only been followed in a few "rich" farms of the area. For the majority, the patterns of land use and farm management remain essentially unchanged. It has all the hallmarks of yet another disappointing "paysant pilot" scheme.

Although the achievements of Zacharia Moyancha are less dramatic in their technical sophistication, unlike Thomas Nzaywa's they have created considerable interest in the neighbouring farms. The team has been inundated with requests for assistance. Zacharia Moyancha himself has given seed and seedlings to neighbours, and many of the local farmers visit his farm to view and discuss the trees. At the moment there are over 550 young trees of mixed species on his farm: mostly of *Leucaena leucocephala, Calliandra calothyrsus, Grevillea robusta,* and *Mimosa scabrella*, but with lesser numbers of many others. They are located all over the farm, alongside hedges, scattered in the maize fields, as lines along terrace edges, around the house compound area, and he is rapidly increasing their number with seedlings produced on his own nurseries with seed he has collected from his own trees. Zacharia is not yet sure whether his small farm can ever become self-sufficient in firewood, but he is keen to utilize what he has as intensively as possible. his wife is able to cut the trees for firewood whenever she wishes, with the exception of his cattle *(Acacia mearnsii)* and gum *Eucalyptus saligna* woodlots. He also uses the new trees for cattle fodder, and is aware of the possible benefits they may bring to the soil.

Generalities

Individuals' case histories such as these provide useful detail of the workings of development initiatives as they touch the farmer, and therefore provide checks and balances in the continued modification and execution of programmes. But because of their very individuality and variability, they can make the design of broad-based, mass intervention programmes fraught with indecision and doubt. The requirement is to perceive and draw out general criteria from such apparently unconnected diversity, and to use these criteria to guide the formative design stages of mass extension programmes. It is assumed that the technical basis of an agroforestry programme is either already known, or can be determined by appropriate trials and experiments. The difficulty is one of making the technical options acceptable to the majority of the people they are directed towards. Extensionists have much to say on this of course, particularly on the mechanics and technicalities of the problem, but I am more concerned to take one step back and to consider what aspects of the nature of smallholder production in Kenya can give guidelines to the design of intervention programmes, even before the technical and extension parameters are drawn up.

In the present example we should first attempt to establish what, if any, are the common threads which run through the differing "success" rates of the four cases described. In searching for commonalitites, I am not assuming that somehow there are some previously missed "hidden" secrets that will finally provide the magic keys. Nor should we anticipate the construction of a "menu" for success.

In the case of Ebusikhale, the consensus of those working in the sublocation is that three issues predominate: the social dislocation associated with prolonged male labour emigration, the continuing tension between men and women in the management of the family enterprise, and the extent to which all things seemed to be assessed in monetary terms. Put together these social and economic circumstances inhibit the diffusion of a technical change which is neither new nor exciting, and offers no immediate prospect of monetary gain. Instead it is modestly attuned to existing technical practices; following on from, and enlarging upon, existing agroforestry activities. It is neither labour demanding in its execution, nor expensive in its inputs, and it responds to the anxieties of the local people - firewood shortage and impoverished and erodible soils. These people do experience directly the impact of these deficiencies, particularly the women who gather the firewood and till the soil. But standing above them is a chronic shortage of money. Far from being a subsistence economy that is painfully adjusting to the penetration of the market, it is in fact little more than a residuum. The men have joined the lumpenproletariate of the cities, the women remain to raise the family, guard the dwindling assets, and scrape what they can from the soil. Their subsistence base is increasingly dependent on external injections of cash, and their farms have been reduced to little more than supplementary gardens. Precisely because of the prolonged and very deep penetration of modernizing forces, the mainstay of peasant production (the ability to withdraw from the market when economic conditions turn against it), is no longer viable. In that picture, tinkering with the residue of a peasant economy is a little like blowing into the wind. In coming to this assessment, the key phrase was the comment that because the assistance was free, it could not be worth anything. Effectively it was too late to attempt to reinvigorate the peasant economy in this modest way. Subsequently, the extension worker in the area has noticed a number of men and women selling seedlings in the nearby market. They seem to have had no difficulty in disposing of their stock. On the basis of this observation, the district team is considering returning to the sublocation with a modified approach that involves the purchase (albeit at a nominal price) of all inputs. In other words, in order to break through, the programme has had to come to terms with the existence of the market, and to tailor the programme to the specific conditions of the particular area.

In Murhanda, market forces are less corrosive in their impact. There is a cash crop base, which gives the farming enterprise a value in the modern world. There is a greater availability of land, and the disruption of the social reproduction system seems less severe. As I have observed, the response to the programme was less than enthusiastic from the start, but because the traditional base (collecting firewood from the forest, producing most of the necesary food on the farm) is still more or less intact, when it was faced with the Nyayo tea belt, the response was an attempt to meaning. In a sense it was in the right place at the right time, and came with a message that articulated well with the changing circumstances of the area.

In the case of the two farms, we are observing two different episodes. For Thomas Nzaywa in Kakamega, adoption of new techniques has effectively meant the complete transformation of his farm. It is no longer representative of its neighbours, and has instead metamorphosed into a completely different economic enterprise. The extension worker has discussed this farm with the neighbours, and they express a view which in effect sees no parallel between Thomas's farm and their own situation. It represents too great a leap, and their response is one of jealousy rather than emulation (Thomas has experienced troubles with his neighbours over land, strange illnesses of his cattle and destruction of his bee hives). Important too is the impact of such a change on social as well as technical matters. By freeing his wife from the arduous job of tilling the soil (little or no food crops are cultivated), by providing sufficient firewood on the farm so that she doesn't have to search far in collecting, by having piped water on the farm so that she no longer has to carry heavy water cans from the local well, Thomas has inadvertantly changed her social world. She now has fewer opportunities to gossip with neighbours and establish her social credentials because many of the more communal activities associated with women's work have been made redundant (group work parties in the fields, group firewood collection, gatherings at the well, etc). Moreover, in bearing all the hallmarks of success, the family is becoming isolated from the community. There are many other and more subtle issues involved here, beyond my competence to assess, but there seems little doubt that a technical change of this nature carries with it profound social consequences.

In the Kisii example, the changes that Zacharia Moyancha has brought to his farm are less dramatic. They are building on an existing model rather than replacing it. His neighbours see a more adventurous version of their own farms, and respond accordingly. The dynamic within the tea zone of north central Kisii is one of reasonably successful absorption of a cash crop, with a real improvement in the economy of the farms. There is enough money for the children to attend school and enough for improvements around the house. In some respects the adoption of new ways (tea came to Kisii in the late 1950's) has been successful, and with this success has come the material base and the inclination to experiment with new ideas., In all of Kissii, it is here that the zero-grazing system shows most signs of being adopted, that investments in farm productivity have kept pace (fertilizers, animal traction, etc); and it is here where a modified smallholder economy is viable and worthy of sustained support and investment. Within this context the agroforestry initiative is well received, particularly when it is promoted in a non-threatening manner (the risk-prone) change. The new system is non-competitive, enforces no radical technical re-orientation, and therefore falls into line with the normal process of experimentation on farms. Above all it comes in to a changing smallholder production system, with a dynamic which so far favours rather than disarms the farmer.

Conclusions

In Kenya, as elsewhere in Africa, development agencies interact with an ongoing process of rapid change. Put crudely this is a transition from a system whose primary goal was subsistence and perpetuation, to one which is fully integrated into a modern and dynamic, external market economy. In the case of Kenyan rural society this still incomplete transformation has taken place in the space of three generations or less. It is an astonishingly rapid process. The intrusion of this market economy affects the technical rationality of the production system, through a host of new demands (new crops, new technologies of cultivation, new patterns of labour use, and so on). It also has impacts on the physical reproduction of the household (demographic changes, different health care systems, altered food production and exchange). Finally, and perhaps most importantly in the present context, it forces realignment of social goals and strategies.

Each individual has not only to secure his or her own physical well being, but has also to establish a social identity and a position within the community. In situations of transition such as exist in modern Kenya, social roles tend to be redefined, and status adjusted. The relationship between men and women within the household is an obvious illustration, in which traditional roles are still recognized, even when the practical reality might suggest their demise. The struggle of maintaining extended family structures is another, in which we see one half of the family attempting to pursue individualistic urban life styles in Nairobi, while the other half expects continuity in the maintenance of former support systems. The emergence of bureaucratic power structures (the local political party, the administration machinery), are also new elements. Many others could be mentioned.

Rural people have to exist and find a role in this new social arena. It is arguable that in making decisions about the adoption of new technologies, this social and non-material essential is weighed with equal importance as the more obvious material necessities of food, shelter, energy and other basic needs.

The situation for women in Ebusikhale is difficult. Should they adopt a new technology which has the potential to offer dramatic help in securing firewood, or should they forego this benefit because it will jeopardize their social standing in the community[1]? Better to find some extra money and out of it (a socially acceptable strategy) than by risking rejection by their peers. In other words, the content of the programme itself was not particularly pertinent. Of much greater significance was the possibility or not of making money, of gaining something to sell. Without that added incentive, interest in the programme waned.

Each community and person enters these changes from different starting points, and adapts to them in different ways. Thus we find some families with enough land, but a shortage of labour. The men migrate to the citities, followed by educated sons and

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1. A frequent response by women when confronted with the opportunity offered by the programme, was that by planting trees, they would undermine their relationship with their absentee husbands, and therby lose standing in the community.

daughters. Younger children and elderly dependents remain on the farm, and labour is hired to pick the tea or coffee. With too little land, reduced opportunities for the education of the children and an escape to the city, the small farm is overburdened with consumers with nothing to do. A myriad other situations can be seen on the ground[1]. For agencies who design and execute large development programmes, it is perhaps more sensible to focus on communiites, or administrative units such as a sublocation, than on individual farms. The same questions apply, however. How does the household (or the community) find itself as market forces intervene? Are people keeping abreast of changes and able to take advantage of the, as in the Kisii highlands, or even possibly in Murhanda, or are they effectively overwhelmed by them as seems to be the case in Ebusikhale?

I have already indicated that the interpretation of events presented here cannot lead to a prescription, or a menu for success. Nevertheless I would argue that much can be gained by embracing some of these concerns, and by adjusting approaches to the design of development programmes accordingly. A little history helps. What has happened over the recent past in the area selected? Has modernization progressed steadily, or has it brought sudden traumatic changes (as is the case in the sugar belt of Kakamega for example). What particular set of circumstances characterize the intrusion of these market forces (new crops demanding radical readjustments in land use, obligatory labour migration, HYV's and the need for each based inputs, land tenurial changes, and so on)? In what ways has the community adopted or resisted this process, and what opportunities exist for individual farmers to respond to the incentives and constraints of the market?

One particular issue of interest is the possibility of community based development in a situation of rapid land privatization. This is especially relevant in the Kenyan case, but has obvious

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1. See Bradley and Ngugi, 1986

implications elsewhere[1]. The privatization of land in most of highland Kenya is now complete, but registration in other areas, particularly those where agricultural environments are marginal, and where new settlement is currently concentrated, are still underway. Because of their marginality, these environments are especially fragile, and risk widespread erosion if cultivation practices come to replace extensive pastoralism. it is in these areas that agroforestry programmes for catchment conservation are frequently identified. Some would suggest that agroforestry based soil conservation programmes are best approached as community programmes, particularly where a resource of the commons, such as a watershed, is concerned. However, if land privatization is anticipated, the impact of this process on community action is difficult to foresee. The experience in Kenya suggests that the readjustment of social processes which follow on from privatization makes communal action extremely difficult. Who would benefit? What advantage is to be gained by giving in to the pressure of being seen to participate in community action, when the very social system that places value on the public display of communalism is being undermined? Public enthusiasm for community-based action may in fact be no more than a reactionary stance in the face of the uncertainties of an individualist future.

An alternative approach might be to downplay the issue of watershed conservation, and instead to promote agroforestry as a private good, conducted under private means, with the broader catchment benefits as a hidden and indirect goal. This latter alternative is only viable however, if the land tenure system is appropriate. Again, the experience in Kenya suggests that the ownership of land and the ownership of trees go hand in hand[2], at

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1. Shutch's (1983) examination of the poor success rate of a community afforestation programme in Tanzania draws explicit attention to the problem of the ownership and use of resources.

2. Chavangi (1985)

least within the smallholder production system[1]. Without the former, interest in the latter is subdued.

Any discussion of the "acceptability" of technical changes is fraught with difficulty, not least because the word itself involves judgement, subjectivity, and context-sensitive perception. Eventually, of course, the farmers decide, but in the meantime, and in the design and planning of development programmes, I would like to suggest that some insights can be gained by taking on board some of the issues that have been raised here. As a frame of reference, it is possible to conceive of an agricultural production system in which market forces impress upon a triad of technical, physical and social reproductive subsystems. Within this dynamic the development programme intercedes. In contemplating the likely success rates of different technical options, the careful examination of the conditions of each of these subsystems, and of how they interact under different circumstances, can provide useful guides for making choices.

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RAPID RURAL APPRAISAL FOR ECONOMICS: EXPLORING INCENTIVES TO TREE MANAGEMENT IN SUDAN

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CONTENTS

Abstract

Understanding the incentives to tree management requires a disaggregated analysis that incorporates regional, village, group and individual perspectives. Rapid Rural Appraisal techniques offer an approach to understanding farming system complexity and local specificity. Examples are given for two villages in the proximity of Khartoum, Sudan that provide illustrations of different determinants of local incentives. Regional level influences on tree management relate to changing patterns of wood product supply and demand and the interaction of urban and rural markets. Uncertainty over economic, tenurial and environmental influences on the village farming system can be seen to affect tree management incentives; land use, tenure patterns and institutional control over communal forest land are also found to be significant. Preferences for different tree species by different sectors of a village influence assessments of the costs and benefits of alternative tree management options. Similarly, different socio-economic groups have varying interests in the local resource base and are affected to different degrees by changes in the wider economy. We argue that a disaggregated analysis, investigating economic incentives at different levels, provides a more complete view of greater use for rural development.

Introduction

The effects of macro policies at the village and household level are complex and variable. However most agricultural or forestry policy research tends to treat rural situations with aggregate data. In this way farmers and rural people are treated as groups en masse, assuming an average behaviour in the face of policy changes. A disaggregated view often provides a different perspective. Local differences in environmental or socio-economic conditions will have significant consequences for rural economic development policy and planning.

Trade-offs in costs and benefits of development options differ according to perspective, whether national, regional, village, group, household or gender. To develop policy and development strategies that are suited to local conditions and acceptable to local people, investigations from the national to the local level need to be integrated.

There is a need for information gathering and analytical techniques that can understand local complexity as part of the development planning process. These can complement aggregate or long-term studies and contribute to strategies that are sufficiently fine-tuned to suit variable and diverse conditions.

In this study to determine the incentives perceived by rural people to the cultivation, maintenance and use of trees, processes acting at various levels will be considered. These incentives take several forms - institutional, economic, cultural, and act at different levels, from national to regional, to village, to cohesive groups within a village, and to individuals.

Rapid Rural Appraisal has been developed over the last ten years in response to concerns over the commonly encountered pitfalls to conventional approaches for rural research and development. The term RRA has now come to refer to a wide range of techniques and methods: indeed not all RRAs are rapid, not all are restricted to rural situations, and not all are appraisals. It can be defined as a structured and systematic activity designed to generate new insights about the range of opportunities open to rural people and the factors and incentives which influence decisions over these opportunities (Pretty and Scoones, 1989).

Procedure for the RRA Exercise in Sudan

The RRA was conducted over a period of 11 days, and included a number of short intensive phases in order to foster progressive and sequential learning. The focus of activities was regularly shifted between workshop and fieldwork. Within the workshops activities were switched between plenary presentations and group work. The team consisted of 17 people from a range of institutions (see Acknowledgements) and split into two groups for the field work and analysis. INSERT OA

The principal objective was to ascertain the key incentives arising from national to individual level incentives to tree management in two villages - Faki Hashim and Sheikh el Siddiq -both within 100km of Khartoum. The fieldwork methods used were based upon various interviewing, diagrammatic and ranking techniques. These included the following: semi-structured interviewing, maps, transects, seasonal calendars, historical profiles, preference rankings, direct matrix rankings, wealth rankings, venn diagrams, matrices, and key informant interviews. Details of all the methodologies employed in this Rapid Rural Appraisal are contained in the workshop report produced by the participants (IIED/IES, 1989).

Regional Profile - Greater Khartoum and Its Surrounds

Greater Khartoum is a significant magnet for both people and goods in the Sudan. The city population doubled between 1973-1983 to about 1.5 million, with some 70% of the increase due to net in-migration. Many rural people were displaced following the severe droughts of the early 1970s and mid-1980s. In 1984 it is estimated that some 120,000 people moved to Greater Khartoum as "environmental refugees" from Kordofan and Darfur (El Sammani et al., 1989). Many more refugees are thought to have immigrated from the eastern provinces. The influx of rural populations is likely to continue, through a combination of deterioration in rural economies together with perceived better options in Greater Khartoum.

The city is not entirely urban: there are large populations of livestock residing in the city. Cattle have been brought by their owners from at least 100 km distant, because the city is the only place where they can purchase fodder; sheep are also fed on fodder, but the population of some one million city goats feed largely on urban wastes and refuse. There is therefore a significant demand from within the city from both humans and livestock for agricultural and forestry products.

The climate in and around Greater Khartoum is largely unfavourable to rainfed agricultural activity. The average annual rainfall is of the order of 150-200mm. Since the early 1970s rainfall has become less predictable, and rainfed agriculture has become increasingly insecure. In Faki Hashim there has been no grain harvest from rainfed sorghum since 1981. The most successful food producing areas are therefore the irrigated lands close to the Nile, and flood retreat agriculture. Nonetheless the drylands remain critical to the livelihoods of many people.

Incentives to Tree Management

We now report on the incentives to tree management, with five examples from the two villages of Faki Hashim, some 30 km to the north, and Sheikh El Siddiq, which is located 100 km to the south of Khartoum. Each example is focussed on a different level of the hierarchy from regional to individual household level. Each example illustrates different uses of RRA techniques.

The examples are divided into five sections:

1. Regional level: patterns of wood and charcoal supply and demand

2. Village level: economic, tenurial and environmental uncertainty as disincentives to tree management (Faki Hashim)

3. Land-use: the impact of tenure and ownership on incentives (Sheikh el Siddiq)

4. Group incentives to tree management (Faki Hashim)

5. Individual incentives to tree management – the consequences of socio-economic differentiation (Sheikh el Siddiq).

1. Regional Level: Patterns of Wood and Charcoal Supply and Demand

A series of key informant interviews were carried out to investigate the changing patterns of wood supply from outside the villages. These aimed to explore the impacts of changes in the regional economy on the local wood resources, and were conducted with brick-makers, a builder, carpenter, cheesemaker, baker, wood merchant, eucalypt pole and charcoal merchant, and farmers and displaced migrants; all of whom are involved in the import of wood products into their respective villages.

Charcoal and wood are widely marketed and the demand is met by three main sources:

- Clearance of savanna woodland for mechanised agricultural schemes to the south and south-east of Khartoum, particularly in Blue Nile and Kassala Provinces.

- Cultivated trees, mainly Eucalyptus and *Sunut* (see Appendix A for Arabic Glossary), on irrigated plots.

- Casual clearance and harvesting of local trees, including from *goz* lands.

The rate of land clearing for mechanised agriculture is expected to decelerate over the coming years. This will constrain access to both wood and charcoal. Taking Blue Nile Province as an example-it currently supplies much of the charcoal for the urban markets, yet most of it is already under cultivation. In 1985 it was estimated that some 900,000 feddans (380,000 ha) remained to be cleared of trees, which could produce 50 million sacks of charcoal. As Dewees (1987) put it "if only a third of the demand from Blue Nile Province, the Gezira and Khartoum were met by these supplies, they would be completely cleared by 1999". However the Mechanised Farming Corporation intends to move extensively into South Kordofan, Upper Nile, White Nile and Southern Darfur Provinces, which all have the potential of becoming significant suppliers of wood and charcoal. The extent of supply from irrigated plots and from peasant farmer clearance of *goz* land is not expected to increase significantly.

The flow of wood and wood products was investigated by a series of interviews in both of the case study villages and Khartoum, and a map was produced to summarise the information (Figure 1). The majority of wood and charcoal is transported long distances. Most travels first to Greater Khartoum, before being transported to outlying villages, such as Faki Hashim and Sheikh el Siddiq. Some does travel directly to villages though: charcoal has long been imported from Kordofan to Sheikh el Siddiq, where clearing of land in the *goz* areas has provided a steady supply. Charcoal is transported by camel to the village and sold to merchants there. Despite the long distances it appears that the costs of the large scale production of both charcoal and wood, together with low transport costs, even over distances of 4-500 km, still produces a product at a competitive price. A recent survey indicates that transport costs account for only 20-25% of total retail costs for charcoal (Dewees, 1987).

Charcoal and wood are uncontrolled commodities, and prices fluctuate freely according to relative abundance or scarcity. Within years charcoal prices are highest during the wet season, when transport becomes difficult and labour costs are high, and lowest at the end of the dry season. In the long run, though, real prices have shown very little change for the Khartoum market (Figure 2). Price fluctuations appear to result from a combination of factors: changes in oil prices that affect transport costs; good agricultural harvests, which cause migrant labour not to seek work in the charcoal industry; high agricultural prices, leading to more rapid clearance of land; pressures on capital markets, which finance charcoal entrepreneurs; formation of temporary cartels between merchants, which drive up prices; and competing export markets to the Middle East (Dewees, 1987). Wood prices trends have not been recorded, but are thought not to have changed significantly in real terms over recent years.

The demand from wood products comes largely from household fuel requirements, brickburning and building. Fuelwood and charcoal demands are high in Greater Khartoum and the heavily populated peri-urban fringe. Demand is likely to increase as the population of the urban and surrounding areas grows, since there is no evidence of widespread switching to non-wood based fuels.

An additional significant demand for wood comes from the many brickworks situated to the north of Greater Khartoum. Firing the bricks requires large amounts of wood, which is purchased from the large traders, not locally. One brickworks in El Faki Hashim fired 7 kilns of 115,000 bricks each in the January-May season of 1988. This used a total of 875 kantars of wood (40 tonnes). There are sufficient brickworks in this region to consume more than 400,000 cubic metres of fuelwood annually (Ahmed and El Magzoub, 1985). This alone is estimated to require the harvesting of 11000

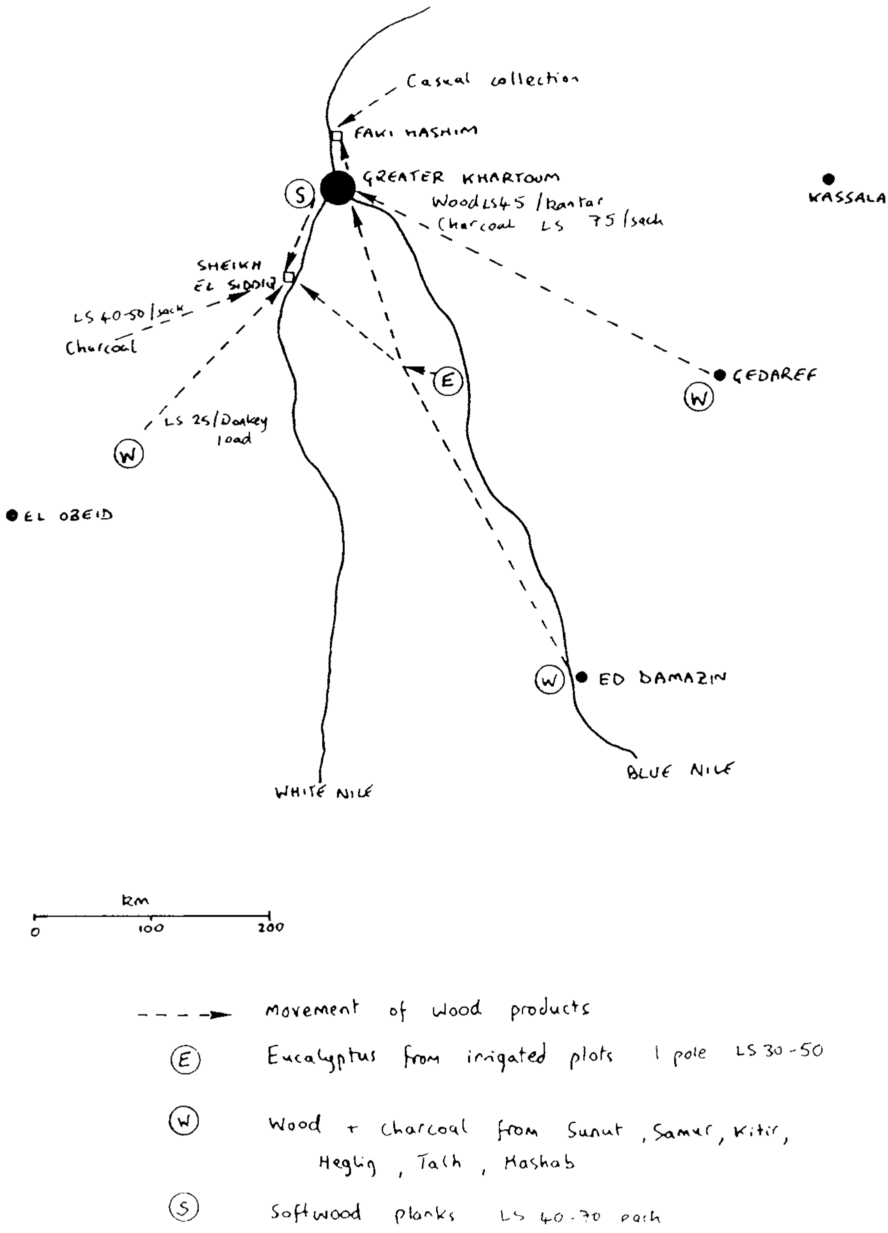

Figure 1 Movements of Wood Products

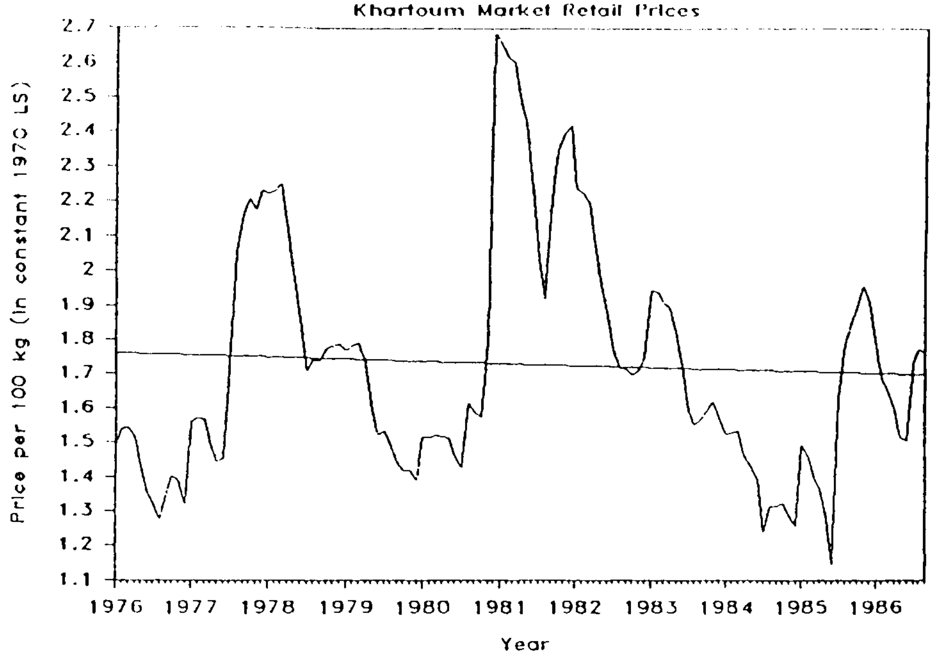

Figure 2 Charcoal Price Trends, Khartoum 1976–1986 (DeWees 1987)

feddans of *Sunut* forest each year, assuming a 20 year rotation with an increment of about $2m^3$ per year. The price of wood is now LS 40–45, though last year it was only LS 16/kantar.

The demand for wood, though, is not just for a fuel. There is also a significant demand for building materials. Since the coming to maturity of the irrigated eucalypt plantations in the

Gezira and in the Khartoum 'green belt', there has been a greater demand for marketed building materials.

The availability and price of alternative wood products at the regional level affects the patterns of local wood use and future substitution possibilities. The regional pattern of demand and supply is therefore important to understand to provide context for investigations at other levels. The relative prices of different wood products was investigated in a series of interviews. The Sheikh el Siddiq changes in prices since the mid 1960s of eucalypt poles, lengths of sawn timber and bags of charcoal relative to a donkey load of firewood are shown in Figure 3. Clearly imported products have become cheaper relative to local firewood since the 1970s. For instance, in 1970 a donkey load of firewood was equivalent to 0.02 eucalypt poles; now it is equivalent to 0.6 poles. Reduced availability of wood from local clearance has pushed up prices. With these prices of local wood resources rising in real terms there is clearly an increased incentive for those with money, to cut local wood for cash sale. Conversely, if protection regulations are respected there will be greater incentives to substitute for imported products with lower real price changes over time (cf Figure 2).

During the 1960's there was an almost complete switch from local wood for building and furniture making to eucalypt poles in Sheikh el Siddiq. As soon as eucalypt poles became available from the irrigated areas around Khartoum, first the builders and later bed makers switched to the imported product. The straight and long eucalypt pole was soon regarded as superior to the wide, uneven trunks of local trees. In Sheikh el Siddiq the heightened protection of the local forest area during the period of the Native Administration (from 1951) provided an additional incentive to import wood from outside.

Substitution of local wood for charcoal is difficult to predict because of the seasonal and interannual unpredictability in charcoal prices. Similarly the factors that would result in substitution of local fuel wood by eucalyptus are also unclear, since individual preferences and specialist qualities are important in guiding substitution decisions. As the cheese maker of Sheikh el Siddiq commented: it would be impossible to change from local wood to eucalyptus since the quality of the burn is so

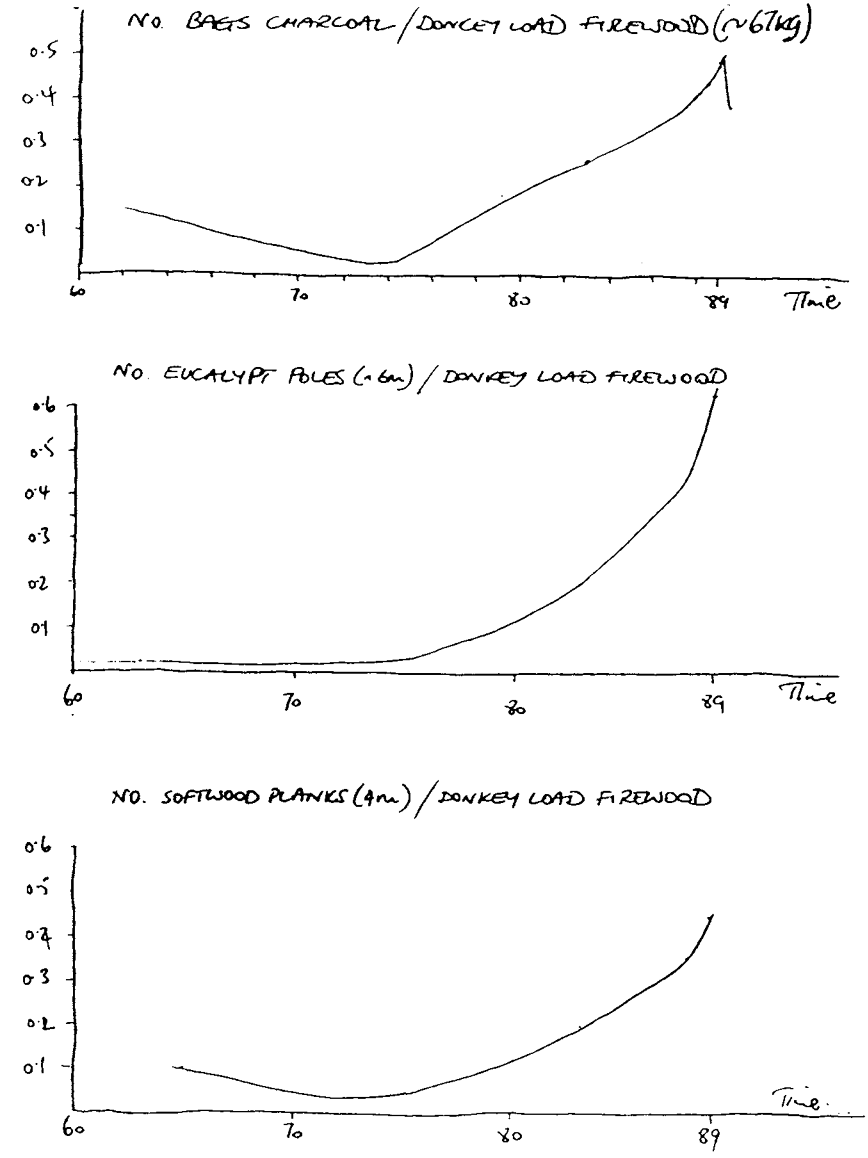

Figure 3 Relative prices of charcoal, eucalypt poles and softwood plants measured against donkey loads of firewood in Sheikh el Siddiq

different and it would affect the final product. Domestic fuel supplies may be different, and like other areas in Sudan, a substitution to other sources than local wood for fuel may appear economic in the future - as in the case of building materials in the 1960s.

2. Village Level: Economic, tenurial and environmental uncertainty as disincentives to tree production

Villages in close proximity to Greater Khartoum, such as Faki Hashim, are in the special position of being near to a very substantial centre of demand for agricultural produce. Like many large cities two important components of this demand are vegetables and fruits; unlike most cities fodder crops are also in high demand. In Faki Hashim almost all privately farmed land is used either for the cultivation of berseem (a type of alfalfa) and Abu Sab'in (a short duration fodder sorghum), or for a widevariety of vegetables (Figure 4). No staple cereal crops are grown on irrigated land. There are two large government owned mango gardens in the village, but very few trees are cultivated on privately owned land, save for a few mango close to the river and citrus trees in courtyards. Tree production and management is not a current feature of the Faki Hashim production system. This is in contrast to villages further away from Greater Khartoum, where land use is much more extensive and where many more trees are grown.

There are three important factors determining this pattern of land use which currently excludes trees. These relate to economic, tenurial and environmental issues. Each factor encourages farmers to adopt a risk averse strategy with low time preference rates and to invest for short term returns because of uncertainty about the future.

The national economic climate is unstable and inflationary pressures are strong. The returns to cultivating fodder and vegetable crops outweigh the advantages of planting mango trees today and waiting several years before the first harvest (Figure 5). This latter option is perceived as too risky. This is despite the fact that the mango is viewed as the "donkey of the market" - demand is always strong. The demand for berseem is stable, if not increasing as urban residents restock with livestock following the drought of the mid-1980s. Berseem is a perennial that is cultivated for 4 years on the same piece of land. It is harvested every 25 days, and net returns are very high. We have no data for returns to vegetables: prices vary seasonally, usually with higher prices for any given crop at the early and late parts of the season. Abu Sab'in is planted after the vegetables have been harvested. It is harvested after 70 days, and sometimes a second crop is grown. Despite the rosy picture for these crops, there may be problems in the future for vegetables. Large scale vegetable farms are now being developed to the south of Greater Khartoum. These may flood the market with goods at prices that small scale producers cannot match.

The second important pressure is that of competition for land. This occurs within the village, and between inhabitants and outsiders. Private land in the village has undergone two redistributions. First in 1925 as a result of the Land Registration Act, and the oldest families still have up to 10 feddans from this time. In 1970 the 3000 feddan private scheme was nationalised, and land redistributed at 3 feddans per household. But all this land is subject to fragmentation, because of division on inheritance and the large size of families. In general land is either too fragmented, or just too small, to allow leaving it unproductive for a long period of time. The village is also sufficiently close to the city to be subject to land speculation. Agricultural land prices are currently LS 11,000 per feddan, and are expected to rise as the city expands. Development is occurring along the asphalt road leading north from Greater Khartoum, and already merchants and speculators are reputed to have purchased land, hoping to build houses in the future. Farmers, perceiving sale of their own land as a possible opportunity at some point in the future, will not be tempted to plant tree crops that have a long lead time.

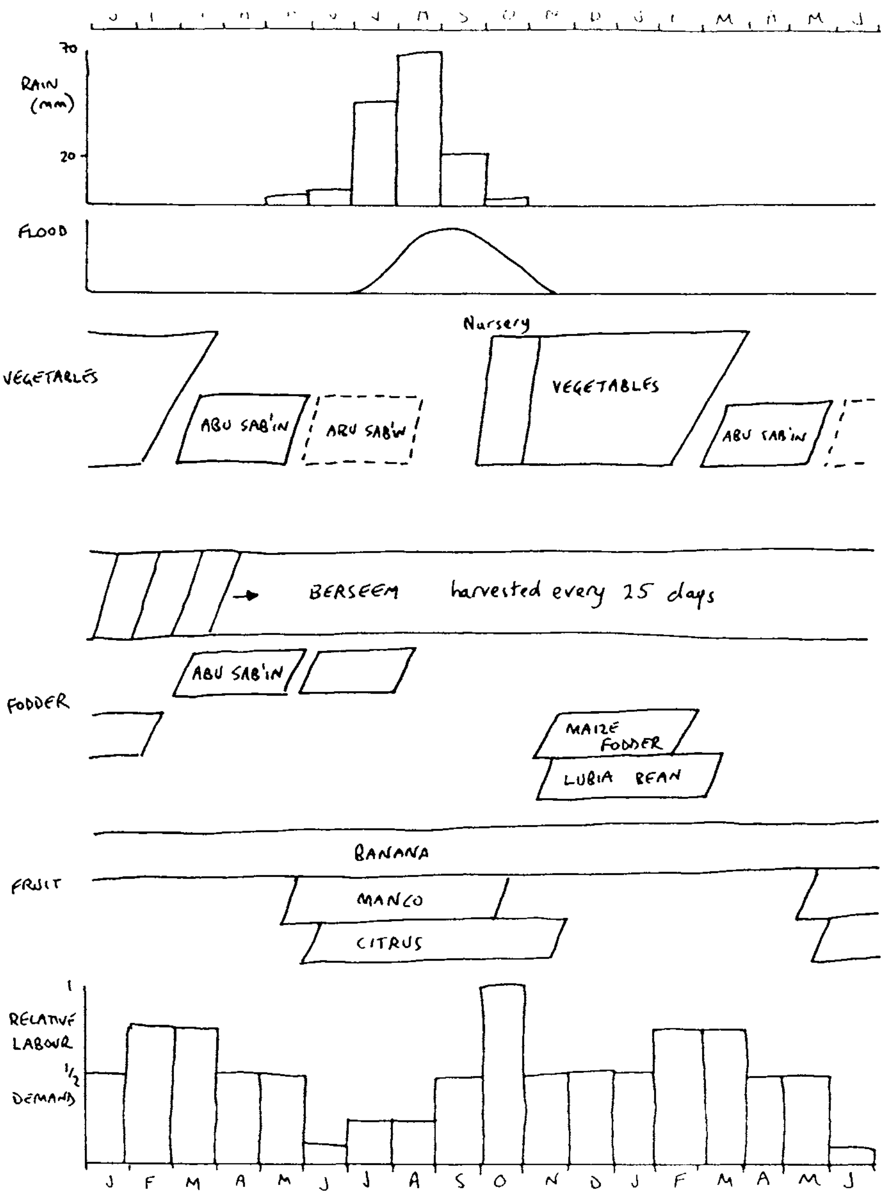

Figure 4 Seasonal Calendar for Irrigated Land in Faki Hashim

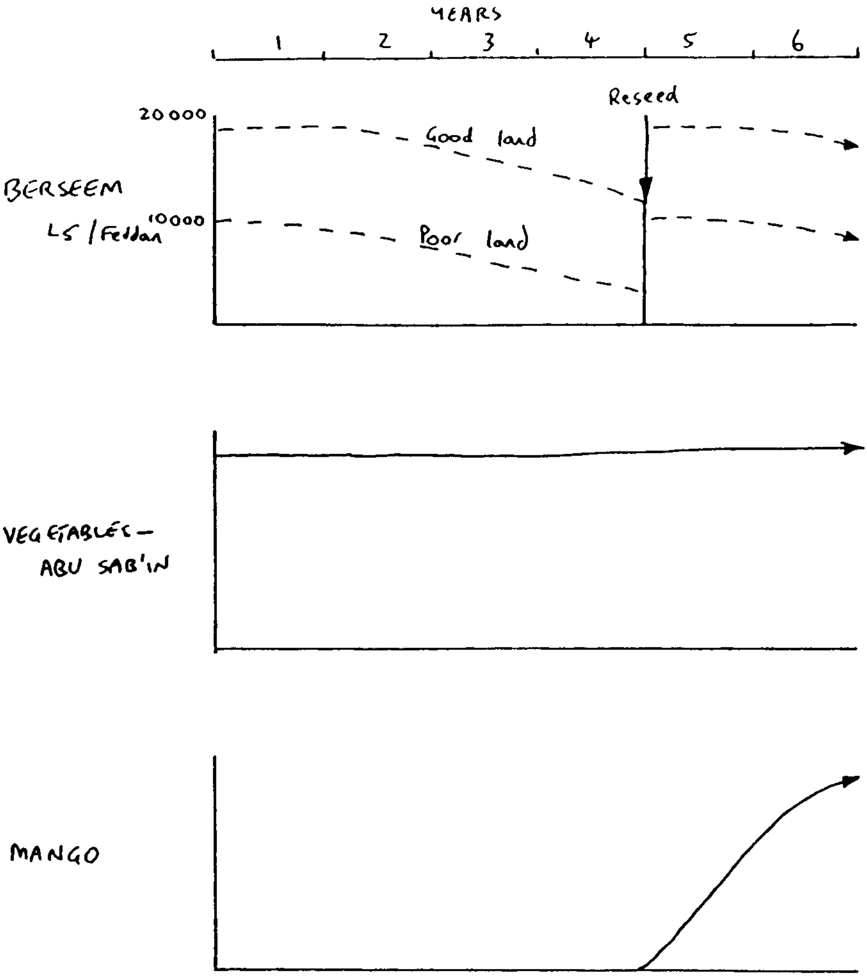

Figure 5 Relative Net Returns from Three Single Feddan Plots of Land used for Berseem Abu Sab'in or Mango

The third factor is the action of climate-driven shocks and stresses. Highly uncertain environmental conditions also influence farmers' perceptions of the riskiness of investment in tree crops. Such environmental factors take the form of:

- droughts, which have killed many trees in the dryland region
- floods, which drowned bananas and berseem (following the floods of September 1988, berseem was back in cultivation by the next February, but many farmers spoke of never growing bananas again because of their ready susceptibility to total loss).
- river migration, where changes in the course of the river have had a major impact upon location of pump sites and the workings of irrigation networks.
- erosion of the river banks, which has been enhanced by the loss of *Sunut* and willow trees from the *jerif* land.

In the village of Faki Hashim, different types of uncertainty about the future have contributed to a general low commitment and investment in tree crops. In particular, local factors have influenced this outlook: the profitability of fodder crops and vegetables, the land speculation because of close proximity to Khartoum and the flooding, river migration and erosion due to the village's site close to the Nile. These factors are not generalisable and the series of interviews with local people that uncovered these themes were necessary to understand the local perspective.

3. Land Use: the Impact of Tenure and Ownership on Incentives

Incentives for tree management are affected by the ownership and tenure of the resources. Different land use categories can be identified in the area of Sheikh el Siddiq. The RRA technique of walking village transects with local people was employed to investigate the patterns of land use and tenure. This was followed up with semi-structured interviews with various key informants. The results are illustrated in a transect diagram that traverses the area from the banks of the Nile to the gozland 25km to the west (Figure 6). A number of categories of private and communal land can be identified for Sheikh el Siddiq village.

Home areas

Different groups in Sheikh el Siddiq have differing degrees of security of tenure in their home areas. Displaced settlers live on the village periphery on illegal sites, although with the permission of village leaders. Other members of the village have secure home sites in the main village area. If increased security of tenure is an incentive for tree management or planting we would expect that people in the main village are more likely to invest in tree management. This does appear to be the case. No trees were discovered to have been planted in the settlers' home areas, whereas some planting was noted in the main village. However, the investment in watering is high with water being purchased from the village well. The labour required is also significant as watering must be carried out virtually throughout the year. This is particularly for the exotic trees favoured in the home compounds. A few people have experimented with the planting of indigenous species with less water requirements, but knowledge of indigenous species propagation appears to be limited.

The *goz* land is marginal, sandy agricultural land where millet is grown. Rotations are necessary to maintain soil fertility and structure. Frequently people shift their field sites, so that continuous tenure is relatively uncommon. The *goz* land is around 25kms from the village, much of it in Kordofan, and is only visited during the rainy season for agricultural activities and some grazing. There is apparently no active management of woodland resources in this area. Use is made of wood resources that have grown up on fallow fields. This is either given away to charcoal makers, or the field owner gets a share of the charcoal product. The output of this is very low as most of the charcoal is derived from newly cleared fields. Some fields are still being cleared in the *goz*. A few villagers noted that the only significant trees in the *goz* area were large *Acacia* spp. left as shade trees in the fields.

The *jerif* land was allocated under land registration laws in the 1920's. Individual people hold title to the land, which stretches in strips of rich alluvial soil out from the Nile bank to the final point of flood retreat. Allocated strips also fall under the individual owner's title. Much of the strip is cultivated using residual moisture. The only trees on *jerif* land are sited along the high flood level. Only *Sunut* can withstand long term flooding. Because of higher water availability the riverine woodland is more diverse, greener and contains larger trees. Some of these large trees are guarded by herd boys, sons of the land owners, with flocks of goats. This ensures that the valuable pods and leaf fodder that are available in the dry season are for the exlusive use of the owner's goats. Tree products on *jerif* land are locally regarded as individually owned. However, there was much confusion over rights to cut trees on *jerif* land. There was also confusion over tenure rights of trees on the boundary between *jerif* land and the communal forest area. There has been no planting apparently on *jerif* land and little cutting or management of trees.

The communal woodland that surrounds the village consists of dense *Acacia tortilis* woodland. It is a protected forest reserve and cutting of wood in the area is forbidden by law. The area is protected through village institutions and through the operations of the local forest guard. Despite restrictions some wood is cut.

Dead wood is collected for firewood and *Acacia* pods, flowers and leaves are a vital source of fodder. People noted that the density of trees had declined over time due both to drought deaths and cutting.

An understanding of the local system for forest conservation observed in the communal woodland area requires an understanding of the local institutions and their impact on the political economy of the village. A number of actors involved in forest management were identified (Figure 7). Different people had different ideas as to what/who was important in forest management. Figure 7 is an overall impression of institutional interactions gained by the appraisal team after a range of interviews. The overlap of circles represents the degree of contact and the size of the circles represents the relative influence in forest management.

DISTANCE FROM HIGH FLOOD	2.5	4	3	2	1.5	0 KMS

LAND TYPE	GOZ LAND	COMMUNAL (WADI) (DISPLACED)	VILLAGE	FOREST RESERVE DISPLACED	JERIF
SOIL	SAND	(alluvium)	GARUD	GARUD	ALLUVIUM
TENURE	TEMPORARY PRIVATE (Taxed)	COMMUNAL (past pvte) (+illegal settlem't)	PRIVATE	COMMUNAL (illegal settlm't)	PRIVATE
PROTECT'N	CUT ± FREELY	TOTAL PROTECTION	CUT FREELY	TOTAL PROTECTION (- illegal cutting) (- exemptions)	CUT WITH PERMISSN.
CONTROL	INDIVIDUALS	SOME LOCAL REGULATIONS	COMP INDIVIDUALS	LOCAL REGULATIONS - SHEIK - VILLAGE COURT - FOREST GUARD	INDIVIDUALS UNDER F.A CONTROL
INCENTIVE ISSUES	LITTLE/NO MANAGEMENT FEW PROSPECTS	PROTECTION EFFECTIVE (near villages)	COMPOUND PLANTING WITH POOR RESULTS	PROTECTION EFFECTIVE; NO MANAGEMENT FOR REGENERATION	CONFUSED UNDERSTDING OF TREE TENURE

Figure 6 Tenure & Control Over Woodland Use in Different Land Categories of Sheik El Siddiq

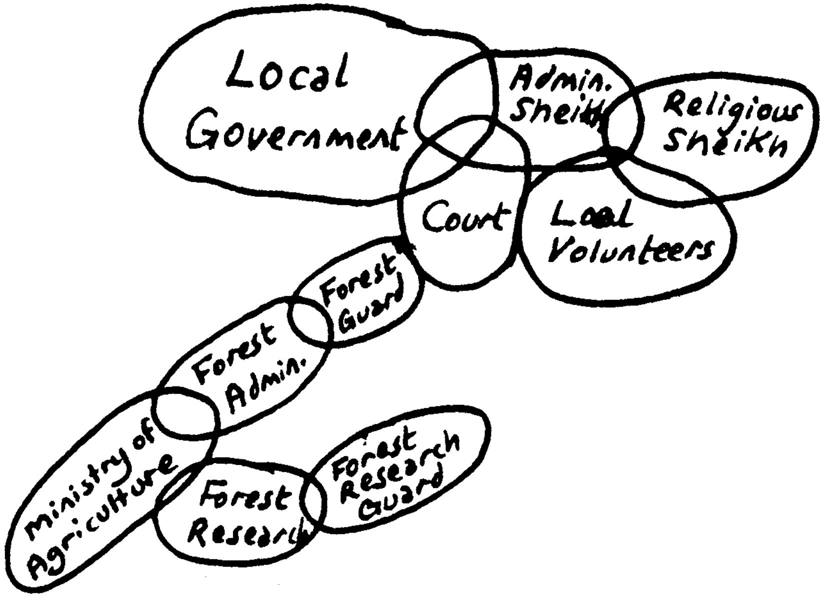

Figure 7 Village Institutions for Forest Management in Sheikh el Siddiq

A key factor seems to be the long term commitment of the Sheikh's family to forest protection. Their role became particularly important during the Native Administration period (1951 - 1971). It appears that the strict enforcement of laws started during the 1960s. In 1971, with the start of the rural councils, the official responsibility was transferred to the government and the Forest Department.

The forest guard first started operating in the late 1970's. He has a large area of responsibility, but his effectiveness is ensured by widespread awareness of regulations (certainly amongst men) and the cooperation of local people and their leaders. In Sheikh el Siddiq a number of volunteers patrol the area to check on wood cutting activities. Prosecutions are brought by locals reporting contraventions of the laws to the guard. The guard has to check on the offence and then brings the accused to court. Two courts are used: either the local court in Sheikh el Siddiq or the district court. The guard commented that the number of offences has greatly decreased since he started work, although there was a sharp rise during the drought. These were the result of people cutting in order to raise money for food. Lenience apparently was shown to such offenders. The standard penalty for an offence involving tree cutting is 25 lashes or up to LS200 fine, if the offender can get a medical exemption. The last local conviction was reputedly some time in late 1988 for a charcoal burning offence.

Forest guards and regulations exist in many other parts of rural Sudan, but few seem to be as effective as that found in Sheikh el Siddiq. It is interesting to speculate why the forest around Sheikh el Siddiq is apparently so well protected. A combination of factors seem to be important:

- The strong and long standing commitment of local leaders
- Widespread knowledge and apparent acceptance of the rules
- An effective enforcement by local people, rather than external forestry agents

Although protection of existing tree stock is ongoing there was no evidence of active management of the communal woodland resource. The existing, conserved trees are c. 30 years old or more and there is little effective regeneration of young trees. This has been due to long term drought and the effects of goat browsing. This is certainly a concern for the long term viability of the forest area.

Land tenure clearly has a significant impact on tree management in Sheikh el Siddiq. It appears that the more secure the tenure over the land, the greater the incentives to plant or manage trees (eg. home compounds within the village or *jerif* land). Any uncertainty over tenure or tree cutting regulations appears to result in reduced management input (eg. the *goz* land and the uncertainty over control over *jerif* land trees). Communal forest land is different. Management is effected in this area through strong, village level institutions, rather than individual incentives determined by tenure.

4. Group Incentives

In order to assess the true economic value of tree resources, together with the likely perceived incentives for management and use, it is important to understand local perceptions of criteria relating to functional uses. Conventional economic assessments of tree resources tend to concentrate on apparent economic benefits such as wood yield, total fodder biomass, value in soil stabilisation. However, rural people use many more parameters in assessing benefits and costs of different tree species or management practices. In order to get an insight into perceptions of economic value it is necessary to investigate local preferences. Recommendations based on Cost-benefit ratios using outsiders' criteria may not be appropriate to local situations. Local perceptions are manifest in terms of preferences for particular species or mixes of species. Although these can differ between individuals, different cultural groups may hold significantly cohesive perceptions of trees.

There are two main ethnic groups in Faki Hashim, comprising of the long-term inhabitants, the families of whom have mostly been present since land registration in 1925, and the more recently arrived displaced migrants, mainly from western Sudan. Each group lives in geographically distinct regions of the village, has access to different resources and has fundamentally different ways of securing a livelihood. A series of Preference Rankings were carried out in order to assess differences in priorities and cost/benefit criteria between the two groups.

The first interview was of eight men from the migrants' encampment situated on the drylands, but close to the main road. They came from Darfur after the drought of the early 1970s, but still live in semi-permanent huts and compounds. They work as agricultural labourers on the irrigated schemes, some are also sharecroppers, and they keep goats and sheep. They have no formal tenurial status over the land or the trees, but they do make use of the local tree products. They do not plant any indigenous trees. The second interview was of a group of farmers from the settled part of the village. They are representatives of a group in which households own small amounts of irrigated land, and also tend to have at least one member involved in a non-farm income generating activity in Khartoum. They are involved in intensive vegetable and fodder production, and have some trees on field boundaries and in the courtyards of houses.

The two groups of informants were first asked to name the six most important trees to them. The name of each was written on a separate piece of paper. The team then asked pair-by-pair which was most preferable, together with the reasons why. The results of the choices were recorded in a matrix. In this way a ranking of most to least preferred is produced, along with all the criteria used to make those choices. The technique takes up to one hour to complete (see McCracken et al., 1988).

This forced choice technique produces many criteria as each pair is compared by the informant group. The results of the two interviews are shown in Figures 8-10. The most important tree species omitted from the two lists of six included Mesquite (*Prosopis* spp.), Tamarind (*Tamarindus indica*), *Kitir*, *Laot* and *Heglig*. In all, the two interviews produced the remarkable total of 31 quite different valued criteria for the use of resources from these eight trees. About half were common to both groups, with the remainder reflecting particular characteristics of each group.

There are several interesting features arising from this analysis:

- Each group chose different trees

- All except the least favoured trees in each ranking had at least 5 valued criteria, emphasising the multiple used of favoured trees

- Some of the criteria are strictly functional, such as value to livestock, wood as a resource for building or for other domestic uses, wood for fuel; some are aesthetic, such as ornamental value and density of shade; and some are strongly culture-based, such as value in funeral and marriage ceremonies.

- Each group had unique criteria: the village residents were particularly concerned with the capacity to grow trees from seedlings and availability of seedlings. Because of the proximity to the Nile only they mentioned the value of *Sunut* for boatbuilding. The displaced migrants described the value of aromatic smoke whilst cooking, important perhaps in their small huts.

- The criteria do not carry equal weighting, for example *Sidir* was the most preferred tree in the displaced Darfur community, yet this was solely because of the critical role of its bark in funeral ceremonies. Because of this it would be difficult to accord a replacement cash value to such criteria.

In conclusion, it is clear that the two groups of people from Faki Hashim recognise a great variety of economic uses for trees, even though they do not actively encourage growth from seedlings- save for in the courtyards. Each group has a different set of criteria to measure the costs and benefits of each species and so comes up with a different overall ranking. This may be equally true for other groupings in the village: men/women, rich/pooretc. These are the factors that determine decisions about planting and management at the local level. The preference ranking techniques therefore provide a valuable insight into the rationale for local prioritisation.

A. Displaced migrants (Western Sudan)

Haraz						
Talh	T					
Salem	Sa	T				
Sunut	Su	Su	Su			
Tundub	H	T	Sa	Su		
Sidir	Si	Si	Si	Si	Si	
	H	T	Sa	Su	T	Si

Preference List:
1. Sidir
2. Sunut
3. Talh
4. Salem
5. Haraz
6. Tundub

B. Long-term residents of Faki Hasim

Haraz						
Talh	T					
Sunut	Su	Su				
Eucaluptus	H	T	Su			
Neem	N	N	N	N		
Sidir	Si	T	Su	E	N	
	H	T	Su	E	N	Si

Preference List:
1. Neem
2. Sunut
3. Talh
4. Sidir
5. Haraz
6. Eucalyptus

Figre 8 Results from two preference ranking exercise conducted in Faki Hashim

A. Criteria suggested only by displaced migrants

1. Bark critical component for washing bodies in funeral ceremonies
2. Fruit pods for tanning leather
3. Aroma of smoke whilst cooking
4. Straightness of wood
5. Wood for mortars

B. Criteria suggested only by Faki Hashim residents

1. Regrowth following pruning
2. Grows from seedlings
3. Availability of seedlings
4. Ornamental and beauty value
5. Wood for boats
6. Perfume and skin colouring
7. Wood for writing tablets
8. Fruit pods used in marriage ceremony
9. Nuisance in compounds: attracts stone-throwing young boys after fruits
10. Windbreaks on field boundaries
11. Fuel for brickmaking and bakeries

C. Criteria common to both groups

1. Fruit edible to humans
2. Fruits/pod/flowers for fodder
3. Leaves for fodder
4. Fruit pods medicinal
5. Strength of fire
6. Susceptibility to termites
7. Wood strength
8. Produces gum - valued ingredient in inks and for mixing with sand for building purposes
9. Branches good for hedges
10. Shade tree
11. Wood for handtools
12. Wood for building - walls
13. Wood for building - roofs
14. Smoke anti-rheumatic
15. Wood for furniture, beds

Figure 9 Comparisons of criteria for tree uses given by two different groups in Fakir Hashim

FAVOURABLE	UNFAVOURABLE

SIDIR: Ziziphus spina-cristi

Favourable	Unfavourable
1. Edible fruits	1. Cannot plant
2. Thorny fencing	2. Source of trouble in courtyards because of thieving children
3. Leaves for fodder	
4. Medicinal bark	
5. Windbreak	
6. Break for washing bodies in funeral ceremonies	
7. Wood for building and furniture	

NEEM: Azadirachta indica

Favourable	Unfavourable
1. Shade tree	
2. Fuelwood	
3. Wood for building huts	
4. Trees will grow after pruning	
5. Grows from seedlings	
6. Ornamental	
7. Multiple uses	
8. Wood for handtools	

SUNUT: Acacia nilotica

Favourable	Unfavourable
1. Pods medicinal	1. Cannot plant
2. Pods used in marriage ceremony	
3. Strong burn - used in brickmaking	
4. Wood for roots, boats, furniture, beds, tools	
5. Produces gum - ingredient for inks and strengthens sand when mixed for building	
6. Pods used for tanning leather	

TALH: Acacia seyal

Favourable	Unfavourable
1. Strong fire	1. Very susceptible to termites and wood-borers
2. Smoke with good aroma	2. Wood has to be soaked for 3 months for resistance to termites
3. Smoke anti-rheumatic	3. Never planted
4. Produces gum	
5. Fuelwood	
6. Skin colouring and perfume	
7. Flowers for fodder	
8. Wood for burning	

Figure 10 Combined criteria for eight trees from the two preference rankings

[**Figure 10** – continued]

SALEM: Acacia raddiana

FAVOURABLE	UNFAVOURABLE
1. Wood for building	1. Moderate fire
2. No aroma to smoke	
3. Straight and strong, good for sticks	
4. Flowers and fruits for fodder	
5. Wood for building huts	

HARAZ: Acacia albida

FAVOURABLE	UNFAVOURABLE
1. Fruit for fodder	1. Susceptible to termites and wood-borers
2. Wood for furniture and beds	2. Mild fire
3. Wood for mortars for grinding	3. Weak wood
4. Shade tree	4. Wood not straight
5. Best wood for building boats - very light	
6. Wood for tablets for writing Koranic verse upon	
7. Young boys use it to float across river	

TUNDUB: Capparis decidua

FAVOURABLE	UNFAVOURABLE
1. Fruit for fodder	1. Mainly branches, no thick stems
2. Used to treat jaundice	
3. Hedges	

EUCALYPTUS: Eucalyptus sp.

FAVOURABLE	UNFAVOURABLE
1. Ornamental and beauty value	1. Too tall for dense shade
2. Seedlings available	2. Wood fragile, not tough enough for building
	3. No regrowth after pruning
	4. Susceptible to termites and wood-borers

5. Individual Incentives and the Consequences of Socio-Economic Differentiation

People's attitudes to tree management are coloured by individual socio-economic conditions. It is necessary to understand how economic differentiation affects people's options if a full picture of incentives is to be developed

During the appraisal of Sheikh el Siddiq village a classification of different income opportunites was produced through a series of key informant interviews and a wealth ranking exercise (Gandin, 1988). Different people combine different opportunites, but the classification proved helpful in focussing attention on the range of livelihood options available in Sheikh el Siddiq.

The socio-economic characterisation of the village was used to identify a range of individuals to interview. The major income sources for each person interviewed were assessed in order to further understanding of the range of livelihood options in the village (Figure 11). The aim was to explore in what ways different people have different access to wood resources. Differences in species use were also explored. Eight in-depth interviews were carried out.

It was found that those of lower socio-economic status were more reliant on collection of local wood resources and did not purchase. The displaced settlers were given special dispensation to cut building materials on their arrival from Kordofan. All other people were reliant on the purchase of building poles,which are imported to the village from outside. The only locally derived wood used for construction or tool making that was found to be roots of dead trees. Firewood was locally collected by most households from dead wood in the local forest area. Some households with higher cash incomes supplemented this with purchased charcoal. Those with livestock as significant components of their income sources also purchased some pods for goats. Changes in regional patterns of demand and supply (see above) will therefore affect those linked with the external wood and charcoal economy to a greater extent, while changes in the local resource base will affect others.

The role of women in wood resource use and management was not effectively pursued and remains an area for further investigation. Women are engaged in firewood collection, but those interviewed appeared less aware of the local regulations about woodland protection than the men. One woman, with her husband working away in Saudi Arabia, did not apparently collect or use any local wood resource and was totally reliant on remittance income to purchase all wood products.

There was no clear pattern of differential use of local tree species. The exception being that the displaced settlers used local species for furniture/building more than any other group.

Depending on amount and type of income received different households are reliant on the local resource base to different degrees. In particular, it is the poorest who are most dependent on local resources for all end-uses. In addition, livestock owners are also dependent on the local supply of pods for the nutrition of smallstock during the dry season. These conclusions imply that there is a common interest transcending socio-economic differences, in sustaining the local forest resource. The difference is that the poorer section of the community are principally interested in the harvesting of wood products (firewood, building) that might require some cutting,where as the richer livestock owners are keen to maintain a mature, pod producing forest largely for small stock production.

The appraisal process thus generated a series of questions about how different sectors of the village have interests in tree management. Socio-economic differentiation is clearly an important factor to consider in any assessment of tree management incentives. Different sectors of rural society weight the costs and benefits of different forest management practices in different ways and feel the impact of external changes at the regional level to different extents.

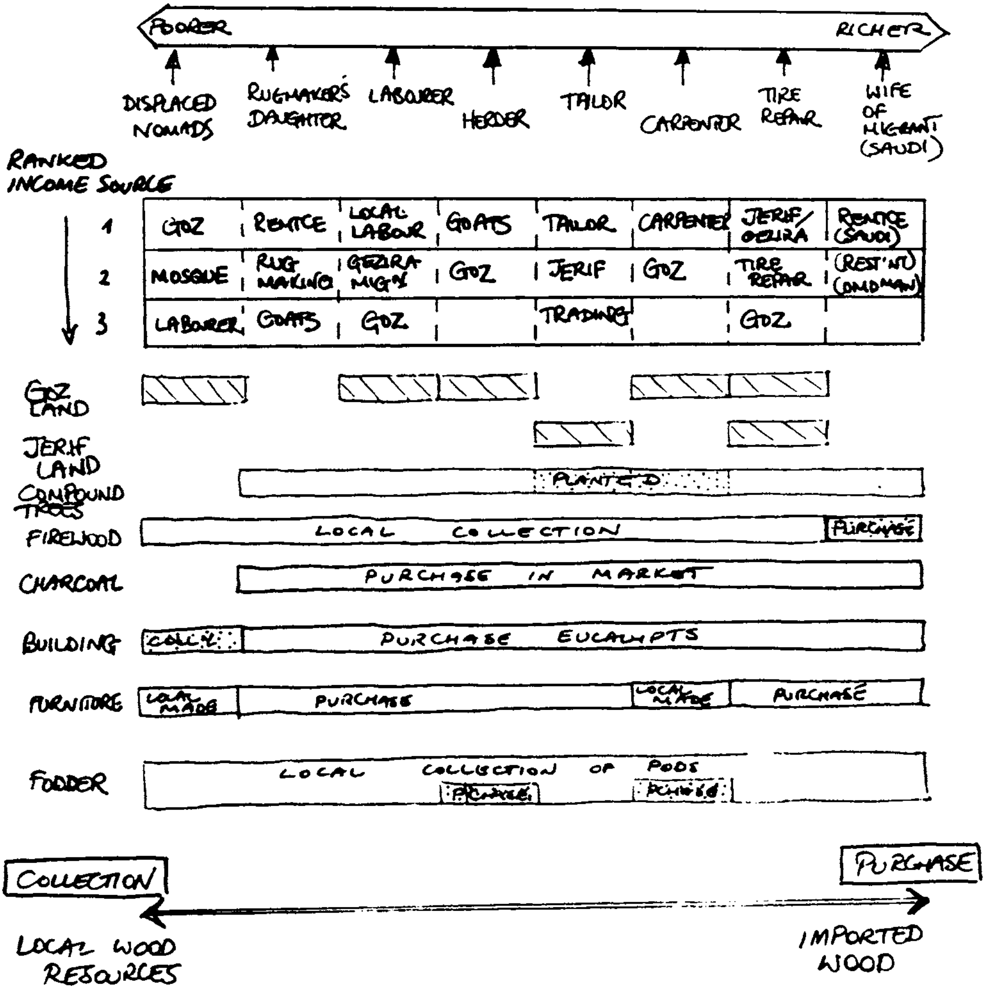

Figure 11 Socio-Economic Differences in Woodland Use in Sheik el Siddiq

Conclusions

A principal objective of any Rapid Rural Appraisal is to generate hypotheses and raise questions about the topic under study. Thus the study of these five different levels has raised a number of important questions about incentives for tree management in rural communities beyond the urban fringe of Greater Khartoum. A sample of the key questions generated by the RRA team are outlined in Table 1.

In communities close to the city, such as Faki Hashim, trees, though important to the household economy, are playing a secondary role to fodder and vegetables. The most important questions relate to the likelihood that these crops will remain just as profitable into the future. Large scale fruit and vegetable farms being developed elsewhere may change the relative benefits of growing these crops compared with other trees.

Trees may further be encouraged if charcoal and wood from the mechanised farming regions does become increasingly scarce as these operations decline. More systematic cultivation of trees on field boundaries could meet some of the local demand for wood and other valued products. Trees on the river bank could certainly increase the sustainability of the production system, but again this would require the provision of seedlings of indigenous species. This requires a major change in how people perceive trees and their cultivation in relation to future uncertainty. The type of trees that might be planted will be affected by local perceptions and assessments of relative costs and benefits. These will differ between groups in the village and so no standard recommendation package can be expected to work.

The final question concerns the expansion of irrigation into the drylands - this could lead to more secure tenure for both the settled and the migrant residents by establishing permanent agriculture before the land is purchased as speculation for housing. In order to increase the tree planting in the dry land areas some significant change in the tenurial system for trees is needed: for example "if you plant a tree, you can use its products, or cut it down, at any time".

Table 1: Key questions developed for the two communities of Faki Hashim and Sheikh el Siddiq.

Faki Hashim

1. What is the likelihood that large scale fruit and vegetable farms elsewhere, together with improvements to transport and roads, will lead to cheaper products that will undercut the small producers of Faki Hashim?

2. Would small scale experiments involving the raising of indigenous species from seed help to demonstrate to local people that the cultivation of trees would be a viable means of increasing the numbers of trees?

3. Would the encouragement of *Sunut* and *Salix* willow trees on the Jerif land succeed in minimising the erosion of the river bank by the Nile?

4. Would expansion of the irrigated land into the drylands to the east of the road improve the sustainability of the agricultural production base of the village?

Sheikh el Siddiq

1. What are the knock-on effects of forest protection in the Sheikh el Siddiq area on regions further away?

2. How can regeneration of *Samur* be improved through the active management of portions of the forest area using the existing and effective institutions as experimenters?

3. Is there a real fodder gap caused by changes in the local woodland that is present every year? Are there locally adapted species that could be introduced or encouraged to fill such a gap to stabilise interannual fodder production?

4. What factors of pricing and marketing of imported wood products would affect the substitution for fuel of local wood sources for imported wood?

The key questions for the more distant village of Sheikh el Siddiq mostly relate to the communal *Samur* woodland. The options for tree planting and management in home compounds are limited by the investment required for watering, although an exploration of opportunities for indigenous tree propagation appear a possibility. On *jerif* land issues relate largely to tenure and the necessity to clarify rights of use.

A combination of factors seem to be important in the maintenance of the communal woodland, including the strong and long standing commitment of local leaders, the widespread knowledge and apparent acceptance of the rules, and effective enforcement by local volunteers, rather than external forestry agents. The structure of local institutions rather than individual economic incentives are seen to be critical in the management of the communal woodland area.

The existing, conserved trees are about 30 years old or more and there is little effective regeneration of young trees. This has been due to long term drought and the effects of goat browsing. This is a concern for the long term sustainability of the forest area, since even in good rainfall years recruitment to the tree population is not taking place. This is of concern both to livestock keepers and those socio-economic groups particularly reliant on the communal woodland resource.

The range of existing tree species may not be meeting local people's needs, particularly those relating to fodder. A number of older informants emphasised the changing species composition of the Sheikh el Siddiq woodland. They noted that a number of tree species have decreased or disappeared, and attribute this to both prolonged drought and cutting. There exists an important complementarity between the different species of *Acacia* resources of fodder, particularly between the dominant *Samur* and others. For instance, *Haraz* has a dry season leaf out, whilst *Samur* has most leaf production during and after the rains. *Laot* flowers and fruits early and has fruit/flower fodder available several months before *Samur*. The reduction or disappearance of certain species that fill critical seasonal fodder gaps could be significant in affecting overall livestock nutrition.

The final issue concerns factors of pricing and marketing of imported wood products. As we have demonstrated earlier, there has been substitution of new wood products for local species in the past. The future preferences of local users and the relative prices of alternative products are uncertain factors, yet ones that could have a significant impact on the local woodland resource base and the ability of particular groups to obtain their wood needs from external sources.

The key questions thus refer to influences operating at the regional, village and household level. The relevant cost-benefit trade-offs relate to issues at each of these levels. It is therefore important to develop an integrated analysis that incorporates factors from the household to the regional economy. Aggregate statistical surveys do not generally acheive this. RRA techniques offer one route to develop integrated insights for a more effective understanding of incentives for tree management.

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APPENDIX A: Arabic Glossary

Abu Sabin	Short duration fodder sorghum
Berseem	Alfalfa-like fodder crop
Feddan	0.42 hectare
Goz	Sandy soil savanna
Haraz	*Acacia albida*
Hashub	*Acacia senegal*
Heglig	*Balanites aegyptiaca*
Jerif	Flood retreat land
Kantar	100 lbs (45 kg)
Kitir	*Acacia mellifera*
Laot	*Acacia nubica*
Neem	*Azadirachta indica*
Salem	*Acacia raddianes* var. *spirocarpa*
Samur (sayal)	*Acacia tortilis* var. *raddiana*
Sidir	*Ziziphus spina-christi*
Sunut	*Acacia nilotica*
12 Sudanese Pounds (LS)	1 US $ (at February 1989)
Talh	*Acacia seyal*
Tundup	*Capparis decidua*

Appendix B:

Major tree species by land-use type and use (Shiek el Siddiq)

Goz land: *Boscia angustifolia, Acacia mellifera, Zizyphus spinocrusta, Acacia seyal, Cordia* spp.

Wadis: A. nilotica, A. nubica, A. tortilis

Compounds: *Citrus* spp, *Z. spinocrusta, Tamarindus indica, A.albida, Eucalyptus spp, Neem, A. tortilis, Albizzia lebbeck.*

Communal forest: *A. tortilis* var. spirocarpa [Samur], *A. tortilis* var. radiana [Sayal], *Balanites aegyptiaca.*

Jerif: *A. nilotica, A. albida, A. mellifera, B. aegyptiaca, A.tortilis.*

INDIGENOUS AND EXOTIC FRUIT TREES: WHY DO PEOPLE WANT TO GROW THEM?

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CONTENTS

Abstract

The 'community management of woodland project' is based on a system of village level planning where communities plan their own planting strategies. The first years of the project's experience has shown that between a quarter and a third of all trees planted were fruit trees. These include both indigenous species and exotic species. The reasons for this local enthusiasm for fruit trees are explored. The reasons people want to plant fruit trees can be explained according to historical factors, marketing and transportation, local preferences, seasonal roles and economic value. Each of these issues is explored with comparisons between project areas. It is concluded that in order to understand why people plant fruit trees it is necessary to address the full range of factors and take account of local conditions.

Introduction

The ENDA-Zimbabwe 'commmunity management of woodland project' operates in four project areas in Chivi and Zvishavane districts in southern Zimbabwe. This is a dryland agricultural area with average rainfall between 500mm and 650mm. The project approach is based on a process of community planning at village level. Community workers carry out research with farmers and develop a village plan for woodland management. Village level research highlights three key issues that form the basis of the project:

* Trees are essential in maintaining the ecosystem and where depleted need to be planted;

* Trees are a multipurpose resource, and to meet the communities' woodland resource needs, a diverse woodland is required;

* Farmers perceive indigenous woodland management as a necessary strategy.

The village plan is thus suited to local needs. A list of local tree requirements is produced through the community worker's village appraisal, and planning meetings. Trees from the list are grown in the community nursery for planting during the wet season. Trees are planted as part of the communal management of grazing lands, or individual planting in fields and at homes.

The value of any woodland product and by-products can only be understood within the context of the prevailing state of the woodland. To this must of course be added the historical perspective which through a number of influences: social, political, religious as well as economic may have contributed towards the current states of the woodlands in the areas that the project is working in. Local perceptions have been investigated through a number of exhaustive interviews and these have assisted the team to gain insights about the present state of the woodland resource.

The project area is divided into four distinct areas each with its own characteristics and levels of woodland stress. In the hilly, sandy soil areas of Chivi south and Mazvihwa a host of indigenous fruit tree species are found. These are areas of relatively low population density and low woodland stress. On areas of clay soils there are fewer fruit trees. In the other two areas of Runde and Chivi north where, in general, woodland stress is higher, the bulk of the indigenous fruit trees are found in the fields and also in the surrounding hills and riverine tracts.

The woodland resources vary within the ENDA project area both in extent and composition. Different socio-economic factors are significant in each of the areas. This paper addressess the question of how biophysical, historical, and socio-economic factors affect farmers' priorities in fruit tree planting.

Although the economic value in terms of cash is clearly an important determinant in guiding farmers' planting priorities, other factors also intervene. These additional factors are important to understand if a full assessment of local incentives to fruit tree planting is to be made. Trees have multiple and complementary uses; all of these need to be taken into account if a useful economic analysis is to be carried out. Not all of the complementary uses are immediately obvious to the outsider. Gaining a farmer perspective on priorities allows a fuller insight.

Community planning and the demand for fruit trees

During the 1987/8 season, when the project was at a pilot stage in one ward in Mazvihwa CA, 3600 trees were planted. Of these 41.2% were fruit trees (39% of fruit trees planted were indigenous and 61% were exotics). A total of 18 different indigenous tree species were planted, half of which were fruit trees. In addition, 6 exotic species were planted.

During the 1988/9 season, planting was carried out by communities and individuals in 24 village development committee (Vidco) areas in each of the four project areas. The data on community planting activities is not yet fully compiled, but the preliminary results are shown in Table 1. The list of different species planted is contained in Appendix 1.

Table 1 Data on community plantings in three project areas (preliminary results)

	Chivi N	Runde	Mazvihwa
No of species	26	15	17
No of fruit spp	13	7	9
No indig fruit spp.	10	5	7
% planted fruit trees	24	34	17
% planted indig fruit	14	27	16
% fruit trees indig	60	81	96
% fruit Mupfura	8.5	23	18

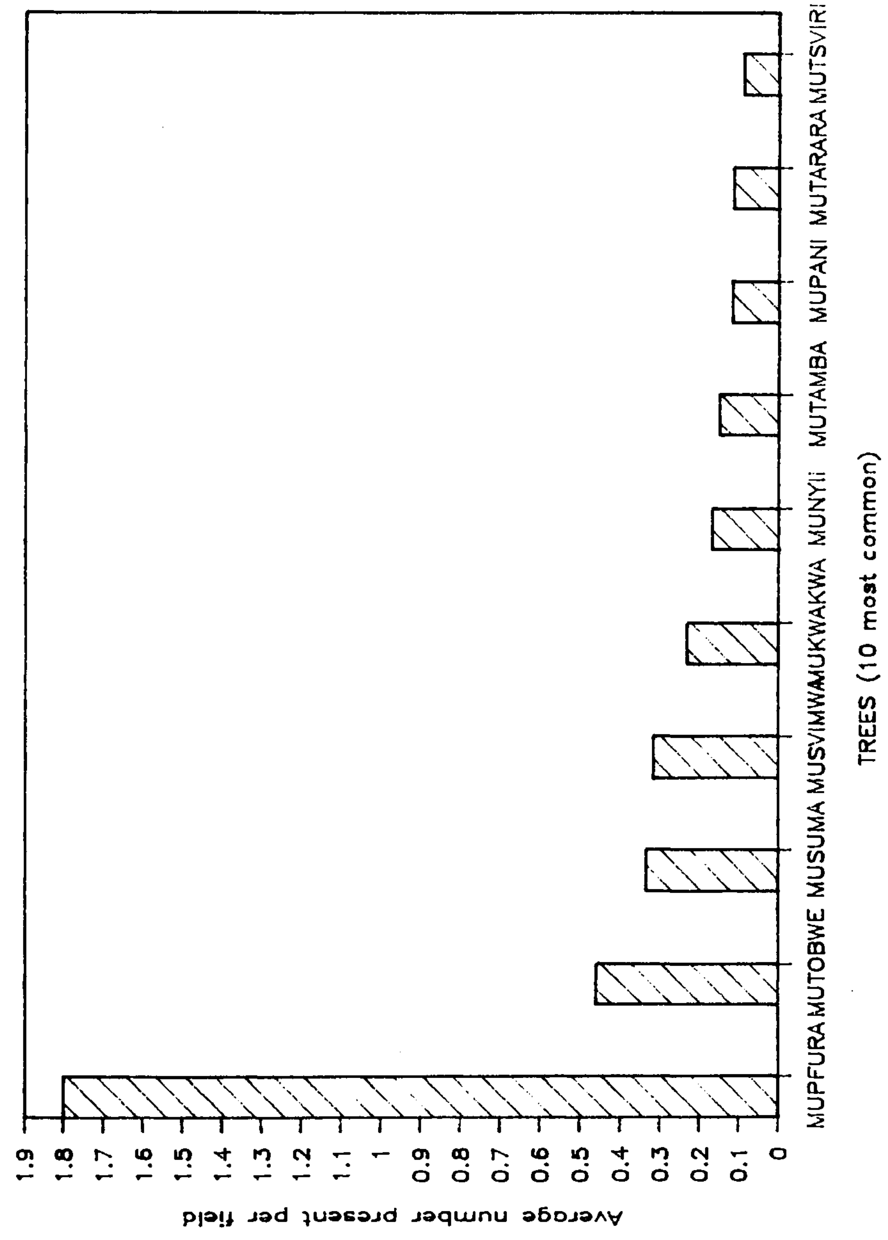


Figure 1 Occurrence of Trees in Fields Gundekunde, Manyarira, Gen'ere, Murowa

From the data available it can be seen that between a quarter and a third of all trees planted are fruit trees; the major portion of these being indigenous species.

The existing fruit tree resource

In this section we attempt to outline the position of fruit trees in the project area. A review of fruit trees at homes, in the fields and in the grazing areas is given.

Fruit trees in fields

Deforestation in Zimbabwe's communal areas is largely a result of clearance for cultivation. There is selective clearance with a clear bias towards saving fruit trees. Data from the Mazvihwa project area shows that the majority of species found on arable lands are indigenous fruit tree species. Figure 1 illustrates this graphically for the ten most dominant trees found in fields in a survey carried out in Mazvihwa.

Of all trees in fields, 81.6% are fruit trees, all of which are indigenous. The ten most important trees that were selectively left in fields in Mazvihwa were: *mupfura, mutobwe, musuma, musvimwa, mukwakwa, munyii, mutamba, mupani, mutarara* and *mutsviri*.

Campbell (1988) found that, through clearance, total canopy cover was reduced from 52% in *Mutondo* woodland to 8% in cultivated lands. However the cover of particular fruit tree species was found not to decrease. Species that were preferentially retained included:*Musuma, Muzumi* and *Mutobwe*, while *Mukwakwa, Munengeni* and *Munhunguru* were reduced.

Fruit trees at homes

Most of the trees found at homes are fruit trees. Of these over 90% are planted exotic fruit trees. The indigenous fruit trees in the home were selectively left out during the establishment of the homestead and very few were planted. The enthusiasm for planting indigenous fruit trees is increasing with improved access to seedlings at the village nurseries. Since the start of the project people have been experimenting increasingly with *Mutobwe*, *Munyii*, *Mupfura* etc. (see Appendix 1). In general, the most common fruit trees found around homes are: Mangos, guavas, lemons, peaches, bananas, naartjies and pawpaws.

The bias towards fruit trees for home planting is reflected in the patterns of collection of seedlings from the village nurseries. Of the trees collected by individual farmers from the Chivi North nursery, 75.8% were fruit tree seedlings. Of these, 53.2% were exotics.

Fruit trees in grazing areas

Trees with edible fruits never form a major component of climax woodland in Zimbabwe. It has been found that in different climax vegetation types, the average canopy cover of edible fruit trees ranges from 2 - 7% (Campbell, 1988). Table 2 shows the average canopy cover of fruit trees in the climax vegetation types found in the study area.

Table 2: Fruit trees in climax vegetation types (after Campbell, 1988).

Climax type	Ave canopy cover
Julbernardia globiflora	7%
Colophospermum mopane	2%
Combretum - Acacia	4%

Tree clearance in the grazing area is highly selective. Generally, fruit trees are left. Commercial or agricultural extension influences have resulted in a certain amount of clearance. In addition, under high woodland resource pressure some fruit trees can be removed for woodfuel or other products.

In all project areas, communities have designed enrichment planting interventions for grazing area plots. To date, 33 Vidco's have established plots in their grazing areas. The size of these plots average 30m x 30m. Data from two such plots is shown in Table 3.

Table 3 Trees planted in Vidco plots (Runde project area)

Plot	% Fruit trees	% Indigenous	% Exotic
Ngombeybani	28.8	93.3	6.6
Mbilashaba	31	86.5	13.5

At this stage it is necessary to ask what determines local preferences for different fruit tree species in order to understand further the factors that have conditioned farmers' responses to the community planning process in the project areas.

Farmers' preferences

A series of preference rankings were carried out with farmers in the Runde project area in order to investigate the basis on which farmers make choices about planting fruit trees. The method used was pairwise ranking (McCracken, Pretty and Conway, 1988). Farmers were asked what they thought the six most important fruit tree species (both indigenous and exotic). Pairwise comparisons were then made and the trees ranked according to the farmer's preference for planting. Both women and men of different ages were interviewed. The ranking results are shown in Table 4.

There was a general preference shown for exotic fruit trees across all groups (old/younger men and old/younger women). However, older women showed a higher preference for indigenous fruit trees than other groups. Men's criteria focussed more on cash value, whereas women's focussed on food value.

The criteria that distinguished each choice were also recorded. The positive and negative qualities of each of the fruit trees that were investigated are listed in Table 5.

The dominant positive criterion for exotic fruits was their role in cash generation. As discussed earlier they have a wider market and receive higher unit price than indigenous trees. This is particularly true of mangoes. By contrast, indigenous fruit trees have a wider range of uses beyond fruit production. These include beer, nuts, medicine, artefact manufacture etc. An advantage of indigenous fruits is their storage properties which allows marketing or consumption throughout the year.

Despite the wider range of potential uses the exotic fruit trees generally ranked higher. This implies that the cash value criterion was probably weighted higher in people's minds than the other criteria shown by the indigenous fruits.

The community plans for tree planting are clearly based on the desire to plant a mix of fruit species, both indigenous and exotic. An explanation for these locally generated strategies can be found in the results of the preference rankings where the multiple functions of trees were stressed by farmers. An additional perspective can be gained by examining the roles of different fruit trees in a seasonal context.

Table 4

Ranking results - all groups combined

Sex	M	M	M	M	M	M	F	F	F	F	F	F	F	F
Age	O	O	O	O	M	M	O	O	O	M	M	M	M	M
AVOCADO	3				1									
MANGO	6	1	1		2	2	1	3	2	1	1			3
NAACHI					3									
ORANGE	2	2			6					5			2	
APPLE	1											1		
PEACH	5		5							4				4
GUAVA						1	2		3	3	1			
BANANA													1	
LEMON				1										
PAWPAW										2				
MUNYII					3									
MUZUMI			3	2	3		3		4					5
MUSHUKU	4													
MATOBWE		3		3		3	4	1	1		3	3	4	2
MUTAMBA		5				4			5			6		
MUCHAKATA		4	2	4										1
MUTENGENI		6												
MUPFURA				5		5	6	4	3			2		
MUSUMA			6				5	5			4		3	6
MUSVITA			4											
MULBERRY								2						
MUONDE						6			6					
MUNUNGURU											5		5	
DZVIR											5			
MUKWAKWA												4		
MUKOSVO												5		
MUCHECHETE				6										

KEY: Sex: M = Male; F = Female

Age: O = Old; M = Middle aged

Rank: 1 (highest) to 6 (lowest)

Table 5

Ranking criteria – combined from preference ranking in Runde project area

FRUIT	GOOD THINGS	BAD THINGS
Exotic fruits		
Mango	Good fruit, cash, shade	Fibres on teeth, cannot store, attract mosquitoes, when unripe affect mouth
Avocado	Nutritious fruit, marketing, high growth rate, baking, butter.	Needs watering
Orange	Tasty fruit, drink, Cash, 'adds blood', prevents disease.	Watering, turn to lemons
Lemon	Fruits, juice for tea, slimming, put in porridge, cures flu	Sour and bitter, thorns
Apple	Good to eat	
Paw Paw	Good fruits	Male trees
Peach	Good fruits, sales, germination easy,	Fruit has no food, too many cause upset stomach
Banana	Body building food	Babies' umbilical cord slow to heal.
Indigenous fruits		
Muzumi	Eating, selling, porridge	Vomit if eat hora, constipation if swallow seeds
Mushuku	Good fruit	Seed damages gums

[**Table 5** - Continued]

Matobwe	Can be cooked and stored, cash, eaten any season, makes teeth and jaws strong whitens teeth, leaves ear medicine, shade, windbreak, browse.	Stomach ache, 'block embryo's gullet', kids can break necks when falling from tree.
Chakata	Beer, stored, food porridge, exchange with mealie-meal, sale	Bad smell
Mutengeni	Good fruits	Thorns
Mutamba	Porridge, storage	
MuDzviri-mombe	Fruit soft and nourishing	No trade
Musuma	Cash, easy to collect, storage	Seeds block gut stomach ache
Musvita	Fruits	Can attract mosquitoes when bad
Mupfura	Fruits, beer, dovi, nuts, animal food.	Social problems (beer) eg fighting; stealing.
Muchech-ete	Fruits to eat, enter-tain kids	Might meet baboons when collecting - dangerous
Mutunguru	Fruits good	Thorns, no trade
Mukosvo	Fruits good, 'jelly liquid loosens stomach contents'	No taste, darkens teeth, causes 'dzviti'
Mukwakwa	Fruits good, stored	
Mukubvu	Fruits, cash	

Historical perspectives

We cannot really understand the presence of trees in an area without looking at the historical background, both in terms of government extension policies and local institutions of resource control. Both these factors have greatly influenced the pattern of fruit trees in the project areas. Historical factors in many ways condition present management practices and the economic potential of the fruit tree resource.

Oral historical interviews have shown that the four areas have a long history of an extension package promoting exotic fruit trees. This dates as far back as the 1930s. This is particularly true for Chivi North and Runde CAs where the influence of the agricultural demonstrators was earlier and more extensive. The success of the exotic fruits in these two areas has been enhanced by the relatively favourable environmental conditions in these areas.

Regulations enforced as part of the Native Land Husbandry Act (1952) have encouraged the removal of trees in fields. Extensive removal of fruit trees was carried out under the instructions of the agricultural demonstrators. The Master Farmer certificate was conditional on the complete removal of trees in fields (Wilson,1989). Interviews with farmers have demonstrated that this was widely resisted in all areas; especially in the sandy soil areas of Chivi North and Runde. Trees such as *Muchakata*, *Muonde*, and *Mupfura* are regarded as important for shade, fruit and as an additional source of organic nutrient input to poor sandy soils (Wilson, 1987; CSC, 1988). Farmers saw this enforced removal as not only an infringement on their traditional practices of protection of large trees, but an additional intervention from the colonial administration that they regarded as of little worth.

The presence of fruit trees can also be attributed to the social and religious significance of the particular tree species. Traditional-religious control of certain indigenous species is evident in the four project areas (Mukamuri, 1987; 1988). This relates in particular to indigenous fruit trees especially,*Muchakata*, *Mupfura*, *Muvonde*, *Mutobwe*, *Mutamba*, *Mukusi*, etc.

The major custodians of religious-political control are the local ruling lineages. They exert power over the natural resources of the area, protecting key components with taboos and local laws enforced by local leaders. The Karanga High God, Zame, is also incorporated into the system of religious resource control to enhance the protection of indigenous fruit trees (Mukamuri,1987). Cutting indigenous fruit trees is considered a breach of taboos and the offenders may be fined a goat. There are also sometimes restrictions on the sale of fruit and other tree products. Stories which deify the indigenous fruit trees are often told to young children in which strangers are said to have survived by eating fruits of mythical trees where ancestral spirits are said to dwell. Cutting the indigenous trees would mean that the spirits have no place to stay. In this regard having large fruit trees, especially *Muchakata*, is an added advantage to the home, thus keeping the useful *Midzimu* (ancestral spirits) in close proximity to the home.

The extent of local religious-political control varies between the project areas. It is particularly strong in parts where established lineage groups have managed to maintain a degree of local power through Independence. In some areas, strong degrees of protection are afforded by newer local authorities who employ local bye-laws to enforce regulations preventing cutting.

Marketing of fruit products

The degree to which fruits are sold for cash differs between the four project areas. This is dependent on the availability of fruit, its shelf life, ownership and tenure, demand patterns and access to markets, the sale price, and social factors that regulate and control the sale of fruit products.

The availability of indigenous fruits is dependent on environmental factors prevailing. The sandy soils of the dry miombo woodlands which occupy a large part of the project area support larger numbers of indigenous fruit tree species (see Table 2). Of the four project areas Chivi South and Mazvihwa are relatively better forested than Runde and Chivi North and as such hold more indigenous fruits than the latter. The shortage of fruits in Runde and Chivi north is often compensated for by (illegal) access to commercial ranches. In areas where the availability of indigenous fruit trees is high there is effectively no local market for the fruits produced thereof. However, in other areas where deforestation or unsuitable environmental conditions (eg heavy soils/ *Mopane* woodland) prevail (which often results in low local availability) specialist collectors, usually children, collect for local sale from the ranches or from well forested areas well away from their areas of residence. The destination of these fruits if sold is usually the local business centre, and in the case of Chivi North this is usually either Madamombe or Mandamabwe growth points where some of the fruits like *matobwe* will sell for about 3 cents per unit. However at this point the amounts sold per individual and returns realised still have to be determined.

Exotic fruit trees are available in large numbers in areas of relatively higher rainfall and where government extension has promoted them for a longer periods. There is generally an active local market for exotic fruits, and in such areas fruits such as mangos, oranges will be sold for as much as 10 cents. For most of the exotic trees the problem lies mainly in the storage techniques available at the local level. Losses are high if the fruits are not purchased or marketted in time and this aspect often lowers the price quite considerably. Preliminary figures obtained from households that have been very active in the sale of exotic fruit trees indicate that as much as $40 to $60 per season can be realised from one single mango tree (Muguti and Kege, personal communication).

As already pointed out fruit trees are individually owned if they are within the home compound. In the fields, trees and their products are held privately only during the period when crops are present. Adults are prohibited from entering another's field during the cropping season, although the restriction does not apply to children (who however will require some kind of permission). During the non-cropping season, fields can be communally used. Trees in the communal grazing land can be cropped by anyone and there are no restrictions, except where one attempts to gather unripe fruit. Access to fruits is therefore determined by these ownership patterns. Exotic fruit trees are almost exclusively planted in the home area and are thus available for individual marketing. This is the case even for abandoned home (*matongo*) and garden sites. Indigenous fruit trees are found in all land types and collection of fruits from trees under communal tenure is based on a first-come-first-serve basis. In areas of low availability this may mean a committed rush to harvest the fruits.

Unit price of exotic fruits is high because of high local and urban demand and relatively lower supply. Indigenous fruits have a low unit price in rural areas because there is a relatively high supply, competition amongst sellers and a relatively low rural demand (low cash flow?). Indigenous fruits have a good urban demand where they are regarded as "exotic". The price of *matamba* per unit is known to increase quite considerably between Siboza (road side business centre) and Zvishavane (from 2 cents to 5 cents). For most indigenous fruits the local market has little to offer and value in money terms is only realised outside their area of origin.

Exotic fruits are more expensive per unit (than indigenous) in most of the rural areas and become even more so where the fruits are "imported" into the area. For instance a mango will cost 5 cents in Runde (where farmers have planted them) while the same unit will cost 25 cents in Chivi south where most exotic fruits have to come from as far afield as Masvingo some 80 km away. The costs of a mango in Runde communal lands is 5 cents while the same unit will go for 10 cents in the nearby mining town of Zvishavane. The greater the distances the fruits (whether exotic or indigenous) are transported the higher the differential between source and sale-point price subject to the state of the market which varies seasonally (see below).

The proximity of markets is a significant factor in determining the commercialisation of fruits, and this is directly linked to the forms of transport available. For most of the farmers the easiest form of transport is the bus, but if near enough they will use an ox-cart. Charges vary from $8 for a donkey drawn cart to $4 per bucket (20 litre tin) by bus. The four project areas have significantly different degrees of access to market centres (see Figure 2). Points of sale include towns, business centres and busy roads. The Runde project area has marketing opportunities at roadside business centres such as Siboza, in the mining towns of Zvishavane and Shurugwi and as far afield as the provincial capital of Gweru.

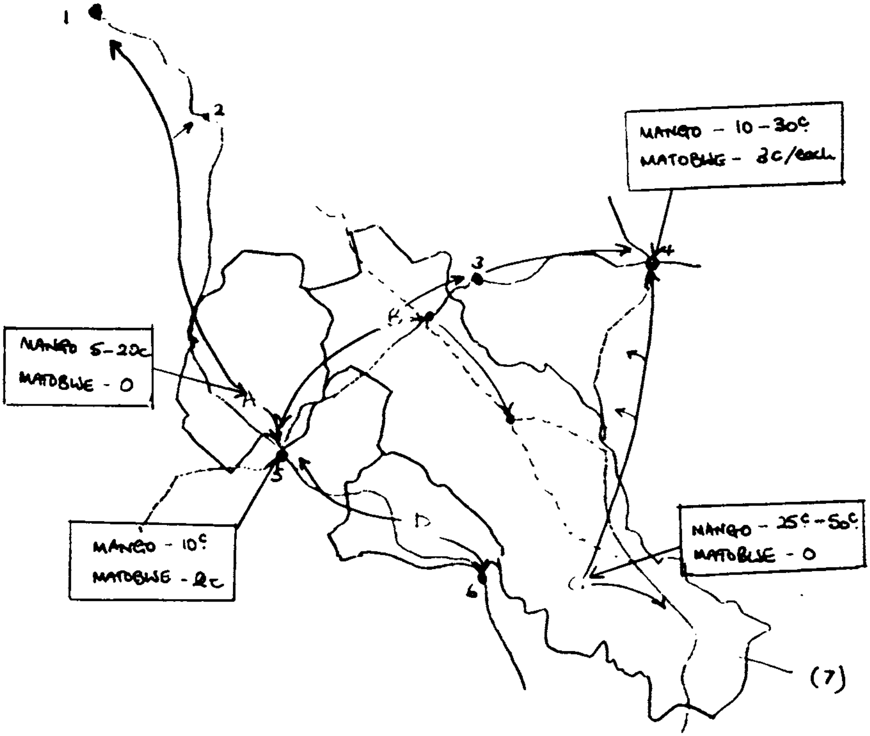
By contrast, Mazvhiwa is more inaccessible with poor transport to Zvishavane and Buchwa. Other producers, usually from outside these areas, easily undercut sales. This is particularly so for the Buchwa market which is supplied by the local Muchipisi valley farmers who have a long tradition of exotic fruit tree growing based on prolific water supplies from Buchwa mountain.

Ownership and marketing of fruits is a fairly gender specific venture. Due to the location of almost all exotic fruit trees on and around the homestead they become the property of the head of the household who is in most cases a man. Marketing outside the area has to be approved by the household head. The actual marketing is carried out by the woman and/or the children. Much as the trees may be owned by the man, the tree care process is usually the responsibility of the children. The marketing of the indigenous fruits is one exercise wholly controlled by women. The children gather fruits during cattle herding forays or go out specifically to gather fruits and are also involved in the actual selling of the fruits on the roadside or at the nearest commercial centre.

Marketing is to a large extent constrained by transport as briefly outlined above. However storage also plays an important part in limiting sales. For fruits like *matobwe*, sales can be boosted by cooking, drying and salting such fruits and then marketing them during the months when there is none available. This will increase the value per unit by as much as an extra 2 cents per unit in the urban areas. The other exciting prospect here is that fruits in this form will also find some limited commercial value even in their areas of origin.

Social factors also influence the degree of marketing of fruit products. Some areas have had a long association with urban markets and are well integrated with the urban economy. Such areas as Siboza in the Runde project area are highly commercially orientated and production of fruit is very much geared towards sale. This is due to the fact that this is an area where there is a large population of immigrants whose respect for social taboos has remained limited and so have been involved in the sale of

Figure 2 Patterns of Fruit Tree Marketing: Zvishavane and Chni Districts



Towns	Project Areas	Marketed Fruit Trees	
1. Gweru	A. Runde	Orange	Mango
2. Shurugwi	B. Chivi North	Guava	Peach
3. Mashava	C. Chivi South	Avocado	Lemon
4. Masvingo	D. Mazvihwa	Apple	Mulberry
5. Zvishavane		*Mutobwe*	
6. Buchwa		*Mutamba*	
(7) Chiredzi		*Musuma*	
		Makosvo	
		Dzvirimombe	
		Munyii	
		Mushuku	
		Mukwakwa	
		Muchakata	
		Musumi	
Scale 1:1000 000		*Dhorofia*	

fruits for a long time. However in the other areas taboos still govern the sale of indigenous fruit products. These are areas where there has been a long standing religious-political control by lineage groups, such as the case in some parts of Chivi South, Mazvihwa and Runde. Fruit trees are generally regarded as belonging to *Mwari* (God) and so are the property of everyone. It is therefore offensive to the guardians of the resource, the autochtonous ancestral spirits, to sell fruits or their products.

These taboos have changed over time. They regained ascendency during the war of liberation and continue to do so after local disasters (such as drought, baboon population explosions, epidemics etc.). Such disasters are regarded as a sign of disapproval of commercialisation in any form by the ancestors. In Chivi South, Mazvihwa and some parts of Runde project areas, there have been increasingly strong restrictions on sales since the 1982/3 drought after a period of more extensive sales in the early 1970's.

A wide range of factors therefore determines the marketing and sale for cash of indigenous and exotic fruits. Specific local conditions determine the economic role of fruit trees in the four project areas (Table 6).

Seasonality - understanding the interrelationship of indigenous and exotic fruit trees

The seasonal patterns of fruit production is illustrated in Fig 3 for 10 exotic and 17 indigenous fruit tree species. This is based on a series of interviews with farmers in the four project areas. There is a certain amount of variation in species phenologies between areas, but a general pattern is presented here. The overall availability of fruit trees varies considerably between areas (see above).

The seasonal calendar illustrates the pattern for a diverse dry miombo woodland. However many of the species mentioned are widely distributed. The results show that indigenous fruits are available throughout the year, except in May and June when no fruits are available (according to the interviews). Their availability is also extended due to the storage properties of certain fruits. On the other hand, exotic fruits are largely available in the rainy season. Certain exotic species can provide fruit in the dry season (*chirimo*), but usually only with good access to water.

The availability of fruits can be related to other activities. Relative labour requirements are described by a simple labour calendar (Fig. 3). This is derived from a series of interviews where farmers are asked to rank the relative amounts of labour required in different months/seasons. Exotic fruits are available at a peak labour season, especially during weeding and early harvests. This may hinder marketing opportunities especially if attempts are made to market outside the area. However since there is an active local demand for exotic fruits in most of the project areas this may not be a major constraint.

Indigenous fruits are available at other times of year, particularly in the dry season, when labour requirements are lower and more flexible. This is the time when 'work at home' is dominant; such activities include building, fencing, thatching etc. There are no herding obligations during this period also. The labour involved in the collection and marketing of indigenous fruits may be higher. This is because most harvested indigenous fruit trees are found either in the grazing areas or in the arable areas away from homes. Similarly, the principal cash market for indigenous fruits is outside the area, requiring travel to market centres. In addition, the possiblities of storage of indigenous fruits means that they can be marketed throughout the year and be responsive to labour availability or cash needs. For both indigenous and exotic fruits, there is a seasonal variation in price with a peak during highest production. Indigenous fruits, because of their storage properties, may be sold outside the production season and so gain a good price and ready markets.

The seasonal calendar shows that exotic fruits are available when other foods are also around. Crops can be harvested from Feb/March, depending on area and season. Collected vegetables and other wild foods are available with the onset of the rains (Wilson, 1987). Exotic fruits therefore are important to nutrition in the early part of the rainy season, while indigenous fruits are available during the dry season. The importance of

Figure 3 Labour Calendar

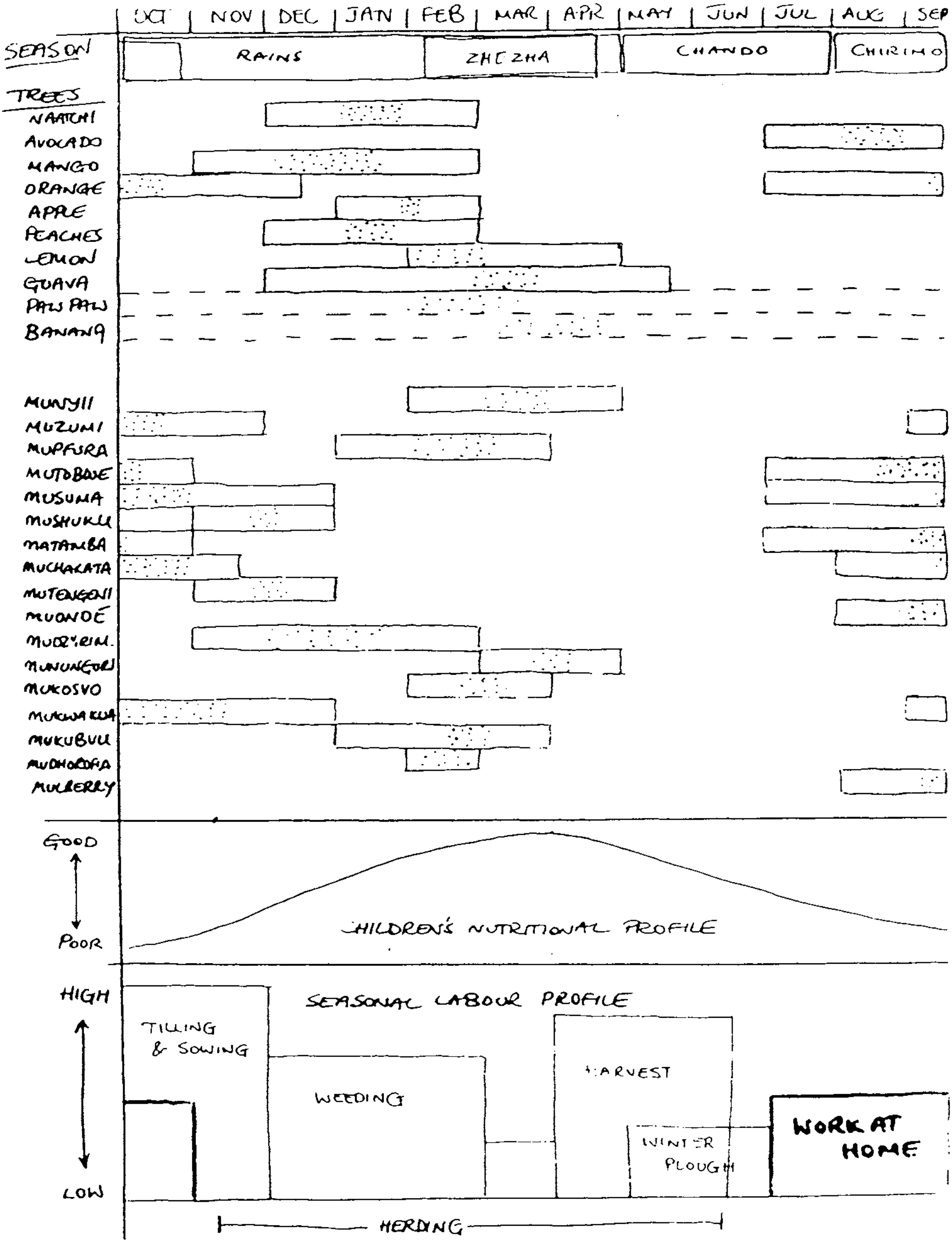


Table 6

Marketing of fruits - combined results from appraisal in Runde project area

SPECIES	STORAGE	PRICE	MARKET	TRANSPORT
Exotic fruits				
Orange	No	10-20c/each	Local/Zvish	Bus
Guava	No	2-10c/each; $7/bkt	Local/Zvish	Bus
Avocado	No	80c/each	Local/Zvish	Bus
Apples	Short	5-20c/each	Local/Zvish	Bus
Mango	No	5-10c/each; $1,5 - 4/bkt	Local/Zvish	Bus
Peach	No	3c/each	Local	
Lemon	Short	10-15c/each	Local/Zvish	Bus
Indigenous fruits				
Mutobwe	Cook, dry salt	2c/each	Zvish/Gweru	Bus
Mutamba	Short	5c/each	Zvish	Bus
Musuma	Dried, under ash	20c/small cup; exch for grain	Local/Zvish/ Gweru	
Makosvo	No	20c/bunch	Zvish	Bus
Hubvu		50c/cup	Zvish	Bus
Dzviri-mombe	No	10c/cup	Zvish	Bus
Muonde		-	-	-
Munyii	Dried	20c/small cup/plate	Local	
Mushuku	Dried	1c/each		
Mukwakwa	Dry, roast			
Muchakata	Compress, form meal	20c/plate; exchange w. grain flour	Zvish	Bus
Mulberry	No	20c/plate	Zvish	Bus
Muzumi	Dried	5-15c/each	Zvish	Bus
Dhorofia		2c/each	Zvish	Bus

indigenous fruits for dry season nutrition, particularly for children is regularly emphasised in interviews. This is supported by research that show wild fruits to be an important source of carbohydrates, vitamins and minerals. Wehmeyer (1966; quoted by Campbell, 1988) observes that local fruits tend to have a higher Vitamin C content than exotics, while other constituents are comparable. Because of the storage properties of certain indigenous fruits, they can be made available as food at any time of year. However, drying is likely to affect their nutritional and digestion qualities.

The economics of an indigenous fruit tree: a case example

The *Mupfura* tree, (*Scelerocarya birrea*) is one of the most desired indigenous fruit trees. Table 1 of preliminary returns shows quite clearly that this tree is in high demand. The demand is due to its multiplicity of uses (cf preference ranking results). The *mupfura* tree provides, at the peak of its production season, fruits which can provide a kind of wine which can be sold or used for work parties (*humwe*); the bark on the other hand can be used to cure a number of stomach ailments, while the trunk (if the tree is male) is used to make drums, stools and mortars, *Mupfura* trees are also thought to have a positive effect on crops. The fruits are cracked open to produce a nut that is highly desired and has a ready market, both locally and in the urban areas. The cash value of the *mupfura's* by-products is well recognised, but like most of the fruit trees in the project area it faces a number of taboos which will have to relaxed if any commercial value is to be realised.

It is often wrongly assumed that labour is not a constraint in the rural areas. In Mazvihwa a limited study indicated that each rural household had on average two full time adult working residents in the home, in addition to part-time assistance from children. A majority of such households experience labour problems during the peak periods of ploughing, weeding and harvesting. In some households, however, the labour issue is resolved by hiring people to do the work either on a part-time or full-time basis. Where employed full-time, such persons will be paid between $45 to $60 per month (Gumbo and Mukamuri 1988). This is a common feature in those households where remittances are received. In families where labour is scarce, and with no means of paying for the labour, the best way out is to use work parties (*humwe*). Labour is provided on a goodwill basis, but people need to be given refreshments while they work. These refreshments take a variety of forms from tea for the followers of the Zionist Church (an indigenous Church) through home brewed beer to *mukumbi*, an alcoholic drink made from the *mupfura* tree (Gumbo and Mukamuri 1988).

The making of *mukumbi* is a special art which not every woman in the rural areas knows. Those families that use *mukumbi* in general cannot raise sufficient labour to carry out all the agricultural tasks in their homes. Work parties whose source of refreshment is *mukumbi* usually do meaningful work. If the charges for labour quoted above are taken as a baseline, the earning rate of labour under rural conditions in Mazvihwa, it would mean that labour is charged at the rate of $1.75 a day or 22c per hour for an 8 hour day. *Mukumbi* takes about three days to reach maturity and in that time 1.5 days will have been spent by the woman making it. Using the mean earned per day this will mean that the woman will have put in $2.64 worth of work. (This takes into account the fact that the total fermentation process will take close to 1.5 days during which time little if any work will be expected from the brewer concerned). Once the brew is ready the woman calls for a work party. Between 10 and 16 people will come, but it should be noted that some of these may not drink *mukumbi* and that none of these will arrive early as they have to work in their fields first before joining the work party.

Most people will aim to arrive around 11.00 am and thus just in time for *chifemba* (the first serving of the brew) and by the time of the *chisayino* at approximately 4.30 pm they will have put in close to 4.5 hours of work with an hour's break for lunch. In that time they will have got an extra two servings of *mukumbi*. Thus for 16 people coming to such a *humwe* will in total contribute close to 72 hours of work. A total of 72 person-hours will mean potential earnings of $15.84 or work worth that much if valued at 22c/hour (see above). If the *humwe* is meant to be for weeding the actual amount of work done will depend on the type of the crop and also as to whether it is the first or second weeding. Here is a situation whereby the *Mukumbi* will have played a positive role in helping a family to carry out meaningful and purposeful work.

Some families, especially immigrants, do also sell *mukumbi*. This is only so because taboos do not mean much to them. These people belong to groups that are not under the strict control of local ruling lineages. On average 8 litres, of *mukumbi* are brewed and sold for a single brew. The *mukumbi* is sold in 100ml cups at 10 cents a cup and will after small losses experienced through *nzwisa* (tasting) the family will gross about $32. Considering that a total of 12 hours (1.5 work days) will have been spent making the *mukumbi* this is equivalent to $2.64 and thus a profit of $29.36 is realised. This is another way in which *mukumbi* is of use to rural households. The potential annual output of a single mature tree is difficult to estimate, but between 3-4 such brews are potentially possible.

An equally important source of income for some households is the by-product of the *mukumbi* making process: *shomwe*. *Shomwe* are nuts found in the *mupfura* fruits. These are cracked manually and the *shomwe* are sold in small 3 gram containers for 20 cents in the local areas. The same container can fetch up to 30 to 40 cents in the urban areas. The production of the *shomwe* is very labour intensive and for better returns, whole nuts must be produced. In order to be able to do this the dry fruits are often boiled. The nuts are usually stored in 800 gram tins and to fill a tin of this size will require a total of 24 working hours. The revenue works out to a gross of $53.33 and if the labour time of 24 working hours is deducted then then such a venture would realise $48.05. The off take estimated here is very small in relation to the full potential annual production of a mature tree. If fully exploited and successfully marketed the returns could be huge.

Throughout the project area, farmers preferentially retain *mupfura* in their fields (see Figure 1). They value it for shade and for the perceived positive benefits that the leaf litter provides for improving soil nutrient content and structure. This reduces the need to apply fertiliser in the area of the tree (Wilson, 1989;CSC, 1988).

The bark of *mupfura* is used for a number of medical purposes. These include the treatment of stomach ailments, eye complaints and backache which are commonly known. The availabilty of such products reduces the requirements for purchased medication. Specialists know further medical uses and these are usually available at a cost.

Another type of industry also thriving on the *mupfura* tree is that of stools and drum making. Both the drums and the stools are made from the thickest part of the tree and so there is a necessity for the tree to be cut completely. Trees used in this regard are the ones the people classify as male in the sense that they do not produce fruit, and also those felled by wind and lightning. Drums sell for about about \$6, while a mortar will cost about \$5 and a stool \$3. A mature tree will produce about 2 to 3 mortars and the upper ends of the tree trunk will produce a couple of stools. A tree that has been felled by the wind will only realise about \$24 depending on where the artefacts produced are marketted. The making of a mortar will take on average about 12 hours with the carving done in between the more profitable labour tasks like weeding. The labour involved in the carving of a single mortar can be valued at \$2.64 and the profit made will therefore be \$2.36.

Harvesting of the mature tree for the wood is therefore not as profitable as the returns realised from *mukumbi* or *shomwe*. This provides an economic rationale for why people do not cut and are keen to plant the *mupfura* tree. The potential returns discussed above are realised from mature trees. These take 20–30 years to reach full production, although fruits are available from age 4–5. Therefore the planting of a *mupfura* is a long term investment for the home as people expect returns only over a long time horizon. From the data on farmers' planting priorities in the project areas it can be seen that people regard that the long term returns are worth it.

Conclusion

The economic basis for understanding why people in the project area want to plant fruit trees is complex. Many factors are involved and these differ between project areas. It is important to take a local, farmer perspective on economic issues to investigate planting priorities. Our understanding of these interacting factors is at an early stage and the ENDA project intends to pursue research into the determination of the economic value of fruit trees and potentials for further commercial exploitation (Muzondo, 1989).

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Appendix 1: Trees planted in the project area (1988/9 season)

Total: 47 tree species; 24 fruit tree spp.

Local name	Fruit	Scientific name
Mubvumira		*Kirkia acuminata*
Muchakata	*	*Parinari curatellifolia*
Muchecheni	*	*Zizyphus mucronata*
Mudohonya	*	*Ficus soldanella*
Mudziyavashe		*Combretum apiculatum*
Mufuti		*Castor oil*
Mukamba		*Afzelia quanzenzis*
Mukusi		*Teak*
Mukwakwa	*	*Strychnos madagascarensis*
Munhunguru	*	*Flacourtia indica*
Munyii	*	*Berchemia discolor*
Muonde	*	*Ficus sycamorus*
Mupani		*Colsphospermum mopane*
Mupanda		*Lonchocarpus capassa*
Mupfura	*	*Sclerocarya birrea*
Mupfuti		*Brachystegia boehmii*
Mupwezha		*Combretum collinum*
Murovamhuru		*Combretum hereroense*
Musasa		*Brachystegia spiciformis*
Musekesa		*Piliostigma thonningi*
Mushavi	*	*Ficus spp.*
Mushuku	*	*Uapaca kirkiana*
Musuma	*	*Diospyros mespilliformis*
Musvimwa	*	*Lannea stuhlmanni*
Mususu		*Terminalia sericea*
Mutamba	*	*Strychnos spinosa*
Mutobwe	*	*Azanza garckeana*
Mutondo		*Julbernardia globiflora*
Mutondochuru		*Schotia brachypetala*
Mutsviri		*Combretum imberbe*
Muvora		*Albizzia amarra*
Muvuyu	*	*Adansonia digitata*
Muzumi	*	*Strychnos cocculoides*

[**Appendix 1** – Continued]

Rukato		*Acacia ataxacantha*
–		*Acacia polycantha*
Flamboyant		
Guava	*	
Gum		
Jacaranda		
Lemon	*	
Leucena		
Mango	*	
Mulberry	*	
Naartjis	*	
Orange	*	
Paw paw	*	
Peach	*	

Trees not planted but mentioned in the text:

Dhorofia	*	*Opuntia sp.*
Dzvirimombe	*	*Vangueria sp*
Muhubvu	*	–
Mukosvo	*	*Artabortrys brachypetalus*
Mukute		*Syzygium sp.*
Mutarara		*Gardenia spatufolia*

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AGROFORESTRY AND HOUSEHOLD FOOD SECURITY

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CONTENTS

Introduction

"Food security" has the ring of a new buzz word in development circles. The subject of household food security, however, includes a number of issues of central importance for the economics of agroforestry. The problem of household food security is not restricted to issues such as agricultural outputs, crop prices, or international debt, but encompasses all factors affecting a household's access to an adequate year-round supply of food. Thus, it is likely to involve not just the household's production of next season's rice crop, but can also include factors as diverse as deforestation, the availability of income with which to purchase other foods, the seasonal variations in food supply and income, the nutritional quality of the foods available, shifts from subsistence to the cash economy, and even the timing of other cash needs such as school fees.

In many rural areas, forests, fallow and farm trees play an important role in household food security. In many tropical and sub-tropical landscapes, forests and woodlands may protect the land against erosion, flooding and desertification. Throughout the agroforestry literature the protective functions of farm trees are emphasized; trees can protect the soil and crops against damage from wind, rain and the sun. And in many tropical regions tree cover provides the only means of restoring soil fertility, through systems of intercropping or forest fallow. Many rural households depend on forest fallow and farm trees for food, medicines, fuel with which to cook and process foods, for livestock fodder and products which can be sold for cash income. This discussion focuses on the socio-economic aspects of agroforestry's role in household food security. (It synthesizes the findings of a longer study conducted for the FAO, see Falconer and Arnold, 1989).

The Relevance of Food Security for Agroforestry Economics

While few would question the importance of food security issues, some may still wonder about their relevance here in a book on economic methodologies for agroforestry. As household food security is an important goal and concern of many rural people, examining the links between agroforestry and food security

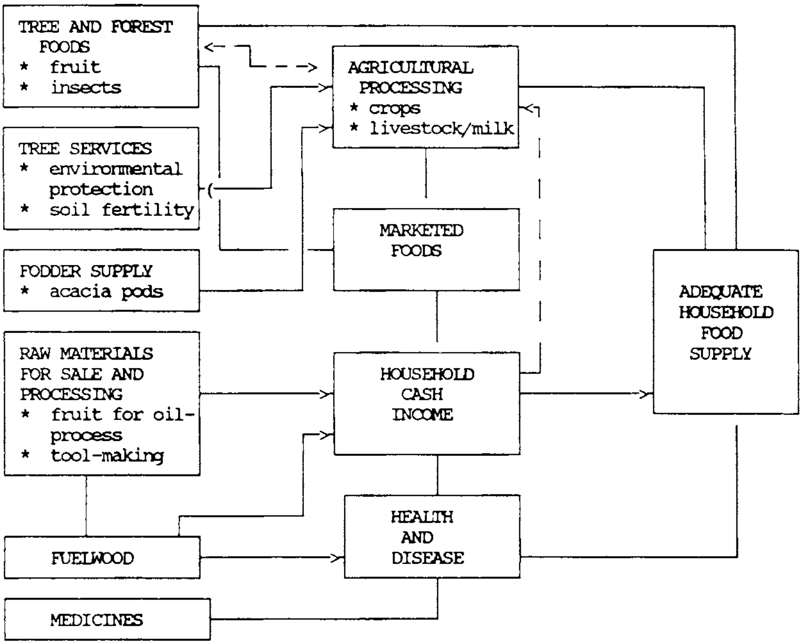

Figure 1 Agroforestry and Food Security

problems will help focus the discussion on issues of central concern to farmers and other rural people and may highlight some of the factors affecting their choice for or against tree-growing.

Assessing agroforestry systems and designs in light of household food security expands the discussion beyond that of benefits and costs of a particular intervention or practice and places it in the dynamic realm of the household economy.

Agroforestry practices are often seen as systems which bring the benefits of forests onto farms. Consideration of the contributions of forests to food security illuminates some important limitations of agroforestry systems in terms of rural development. Most notably, forests have provided resources (land, foods, fodder, medicines, and products for cash income) to those with least access to other resources. Poorer people, especially the landless, have thus been able to exploit the forests for food, fuel and marketable products. While forest gathering activities are not restricted to the poor, they do depend on these activities to a great extent. The poor, and especially poorer women, often dominate forest product gathering and processing activities, both for household products and income. Forests have also provided resource buffers during emergencies. On farm agroforestry systems cannot provide the buffer resources of forests, nor can they address, to any great extent, the needs of the landless poor.

The goal of many agroforestry programmes is to improve the productivity and sustainability of existing farming and agroforestry practices. There is a need to examine these systems in the light of farmers' production goals which may (or may not) be revealed in examining household food security. Focussing on food security should direct the discussion to one aspect of people's well-being - their nutrition.

The Links Between Agroforestry and Household Food Security

The main links between agroforestry and food security are illustrated in Figure 1. Products such as tree foods, fodder and environmental benefits (such as ameliorating soil conditions) all

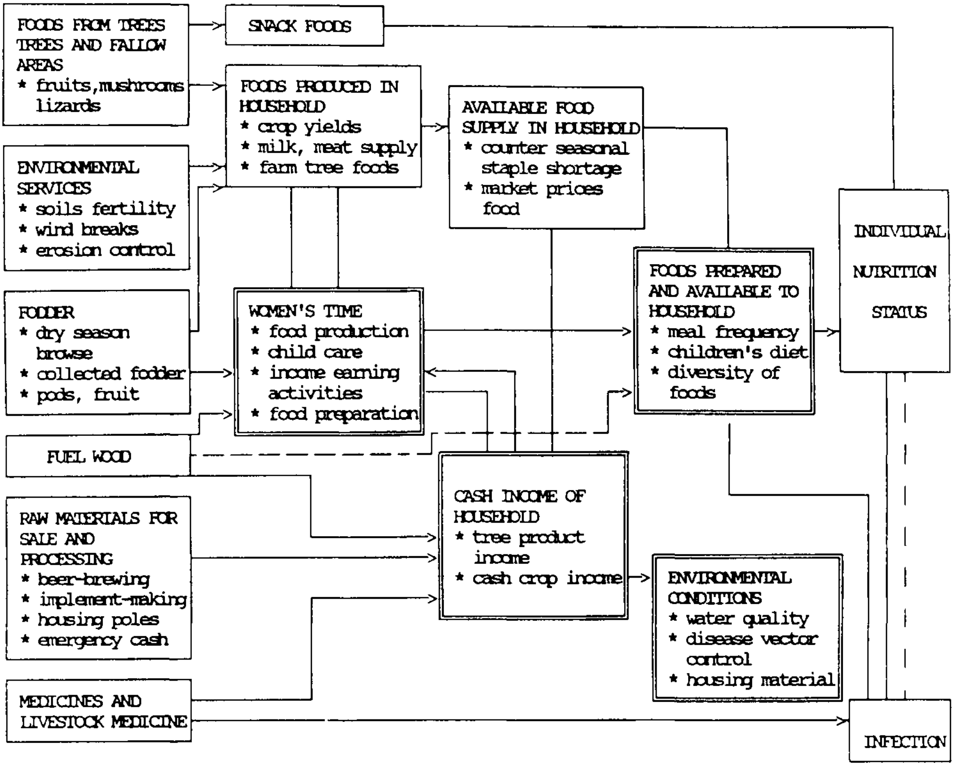

Figure 2 Agroforestry and Household Food Security: Some Key Factors

contribute directly to the quantities of foods available to the household. In addition to these products, fuelwood and raw materials for processing provide cash income for food purchasing. Finally, tree products such as fuelwood and medicines may have an impact on people's health and therefore on their nutritional well-being (while the links between health and nutrition can be quite complicated, a few nutrient-related health problems are described in Table 1).

The boxes on the far left represent tree products and benefits on which agroforestry projects often focus (e.g. fuelwood production and windbreaks). Moving to the right, some major links between tree outputs and a household's food situation are suggested. Most agroforestry programmes and designs focus on measuring the outputs of tree products, rather than examining the impact of these products and services on the household food situation.

The second diagram (Figure 2) adds a few more details- illustrating some key elements of household food security - or more specifically, individual nutritional status. It emphasizes the links between household income, women's work loads and the household availability of food as well as environmental conditions (in highlighted boxes) - all are factors which agroforestry activities can influence.

Cash income earned from tree/forest dependent activities (e.g. palm oil production, fuelwood sales) may be spent directly on food purchases or may be invested in agricultural assets such as livestock, land, farm implements, or seeds; thus it contributes to a household's future food situation, by improving its production potential.

Consideration of the **available household food supply** incorporates factors such as seasonal fluctuations in food supplies and food diversity. It is generally assumed that farm trees provide foods during the seasonal hunger periods and produce during droughts and other emergencies. While this is true of some tree species, it is not necessarily the case with all of them. A clear understanding of the fruiting and leafing periods of species in particular environments is important. Also valuable are species which "hold" their fruit or seed over long periods or whose produce survives on the ground (Becker, 1983).

Table 1 Some common nutrition problems and the potential role of forest food

Nutrient-related problems	Forest food with potential for combatting deficiencies.
Protein-Energy malnutrition: due to inadequate food consumption causing reduced growth, susceptibility to infection, changes in skin hair and mental facility.	Energy rich food which is available during seasonal or emergency food shortages, especially, nuts, seeds, oil-rich fruit and tubers; e.g. the seeds of *Geoffroea decorticans*, *Ricinodendron rautanenii*, and *Parkia* sp.; oil of *Elaeus guineensis*, babassu, palmyra and coconut palms; protein-rich leaves such as baobab (*Adansonia digitata*); as well as wild animals (e.g. snails) incl. insects and larvae.
Vitamin A deficiency: in extreme cases causes blindness and death; responsible for blindness of 250,000 children/yr.	Forest leaves and fruit are often good sources of Vitamin A; e.g. leaves of *Pterocarpus* sp., *Moringa oleifera*, *Adansonia digitata*, the gum of *Sterculia* sp., palm oil of *Elaeus guineensis*, bee larvae and other animal food; in addition fats and oils are needed for the synthesis of Vitamin A.
Iron deficiency: In severe cases causes anaemia, weakness and susceptibility to disease; especially women and children.	Wild animals including insects such as tree ants, mushrooms (often consumed as meat substitutes), as well as forest leaves such as *Leptadenia hastata*, *Adansonia digitata*.
Niacin deficiency: common in areas with a maize staple diet; can cause dementia, diarrhoea, and dermatitis.	Forest fruit and leaves rich in niacin such as *Adansonia digitata*, fruit of *Boscia senegalensis* and *Momordica balsamina*, seeds of *Parkia* sp., *Irvingia gabonensis* and *Acacia albida*.
Riboflavin deficiency: common throughout southeast Asia; among those with rice diets causes skin problems.	Forest leaves are especially high in riboflavin, notably *Anacardium* sp., *Sesbania grandiflora*, and *Cassia obtusifolia*, as well as wild animals, especially insects.
Vitamin C deficiency: common to those consuming monotonous diets; increases susceptibility to disease, weakness.	Forest fruit and leaves often supply the bulk of Vitamin C consumed, especially good sources include fruit of *Ziziphus mauritiana*, *Adansonia digitata* and *Sclerocarya caffra*, leaves such as *Cassia obtusifolia*, and the gum of *Sterculia* sp., are also good sources of this vitamin.

Women's work has been closely linked to household nutrition. In many regions women play an essential part in food crop production. Women are generally responsible for food preparation processing and preservation. In addition, several researchers have found that women's cash income-earning is also directly linked with the household food situation (Cecelski, 1987). For this reason, their labour was chosen as a variable to illustrate the links between physical tree outputs and household resources (in this case, labour) and household nutrition. Thus, rather than measuring the benefits and outputs from an agroforestry system in terms of fuelwood produced, palm fruit available for processing, or additional fodder, an analysis of the impact (of an agroforestry intervention) on lessening women's time pressures might be a more significant measure in terms of the impact on household food security.

The links between agroforestry, nutrition and medicine are extremely important. Many intestinal diseases, for example, cause malnutrition by preventing the absorption of foods by the body. Disease also debilitates and can affect food production by reducing labour efficiency during peak periods of the agricultural year. Forests, bush fallows and farm trees provide the main supply of medicines to the majority of rural people in developing countries. While the effectiveness of many traditional treatments are under considerable dispute, their importance in combatting at least some illnesses is widely recognized.

Environmental conditions are also important factors influencing infection - the quality of water resources and housing conditions are two areas where agroforestry activities can have an impact. Some trees have properties which can directly affect the quality of water supplies. The seeds of the Moringa trees, for example, are used in Sudan and Egypt to clarify turbid water. They contain coagulants which can clear water to near tap quality in a few hours (which is accompanied by a 98% elimination of indicator bacteria) (Jahn, 1986). The fruits of *Balanites aegyptiaca* and *Swartzia madagascariensis* contain saponins which are lethal to both the snails which act as host to bilharzia and to the water flea which harbours guinea worm. Planting these species along irrigation banks might help prevent these diseases (Wickens, 1980).

By focusing on food security issues such as those illustrated above, assessments of agroforestry systems will examine factors which are more closely linked to rural people's well-being, and thus their development potential.

The Contribution of Forest Fallow and Farm Tree Products to Household Food Security

In terms of household food security, fallow and farm tree resources serve to supplement existing food resources and income, fill in seasonal shortfalls of food and income as well as provide seasonally crucial agricultural inputs, and help reduce risk and lessen the impact of droughts and other emergencies. In addition, farm trees and forests can be especially important for the rural poor, as frequently they must rely on off farm employment opportunities and forest (and fallow) resources to help meet their household needs (Table 2 summarizes some important roles of trees).

Supplementary Role of Farm Tree Products:

For the majority of rural people, and especially the rural poor, forest and farm tree foods add variety to diets, improve palatability, and provide essential vitamins, minerals, protein and calories. Although the quantities consumed may not be great in comparison to the main staple foods, they often form an essential part of otherwise bland and nutritionally poor diets. Diet diversity is an extremely important element of nutritional well being, in part because more vitamins and minerals are consumed, and also because it improves the taste of staple foods - thus encouraging greater overall consumption. Some species are noteworthy as particularly rich sources of vitamins, minerals, proteins and fats.

Few studies focus on the nutritional importance of tree and forest foods. While information is available on the nutrient value of different foods, few studies have assessed the frequency and extent to which they are consumed or the nutritional value they impart. The most common supplementary foods are leaves and wild animals, both of which are generally added to sauces and soups which accompany staple foods. For example, the leaves of *Boscia senegalensis* are consumed year-round by the Peuhls in Senegal, where they are added to sauces which accompany their grain staple (Becker, 1983). This combination is important because, in addition to increasing nutritional value, these wild leafy vegetables add flavour to bland staple foods, thereby encouraging greater food consumption. Little attention has been paid to the importance of improved palatibility provided by wild foods, yet it may have significant nutritional implications.

Trees are often left or planted on farms for the food and fodder they provide. For example, home gardens (intensively managed farm systems combining tree and herbaceous crops) supplement food production from other sectors of the farm. The few studies which have examined their nutritional impact show that home gardens increase the total quantities of foods consumed by households (Soemarwoto 1985, Immink, 1981). In addition, trees may be maintained or planted to provide wild animal habitat. In Thailand, for example, trees are left in paddy fields and on dikes, in part to provide a habitat for commonly consumed wild animals such as lizards, birds and tree ants (Grandstaff, 1985).

Fallow and farm tree products are also valued throughout the year as snack foods. Fruits and nuts are the most common snack foods, especially for children. They are commonly eaten on the job, while working in fields, while herding and gathering fuelwood. There is little information on the consumption of snack foods and their nutritional significance, as most nutrition studies focus on meals or food markets. However, some authors suggest their role is important: a study in Swaziland, for example, estimates that wild fruits are a major source of vitamin C (Ogle and Grivetti, 1985).

Tree foods such as fruits can be used to combat nutrient-related health problems. For example, many tree fruit and leaves are good sources of vitamin A; vitamin A deficiency is a common cause of blindness in many developing countries. Table 1 illustrates some of the ways in which tree foods might be used to combat specific nutritional problems.

Trees and forests also contribute to the food supply indirectly - providing fodder for livestock, thereby helping maintain a supply of milk, blood and meat. In addition, where available, trees and woody shrubs are the main source of energy used for cooking and food processing. Some foods such as beans cannot be consumed without cooking and many others are difficult to digest or unpalatable, or may carry diseases if eaten raw or partially cooked. Fuelwood is also used to process many foods such as fish, seeds, and oil, which are generally smoked, dried or cooked. Processing serves to extend food supply and, in some instances, provides a source of cash income.

While there is little concrete evidence linking fuelwood supply to nutrition, some researchers have noted that its supply may influence the **amount** and **quality** of foods cooked, as well as the quantities and quality of processed foods. Fuelwood shortages could also indirectly affect household food security, forcing women to spend more time collecting fuelwood leaving less time for income-generating activities.

Tree and forest fallow resources also provide supplemental sources of income for many rural households. Many gathering and processing activities are undertaken as part-time activities to provide supplemental income. These activities are especially important for the poor as they may have access to fewer income-earning alternatives.

In many rural communities where poor farmers cannot raise enough to be self-sufficient in food, and are forced to earn cash for food purchases, trees grown as cash crops may provide a low input alternative land use. In addition, products collected from fallow and farm lands such as fruit, fuelwood, or building materials may provide supplemental sources of income. The burgeoning fuelwood trade for example, illustrates farmers' ever-growing need to supplement their farm income as well as the growing demand for fuelwood (e.g. Kamara, 1986).

Seasonal Importance of Forest and Farm Trees

Forest and farm trees are most extensively used to help meet dietary shortfalls and to supplement household income during particular seasons in the year. Many agricultural communities suffer from seasonal food shortages generally known as "hunger periods". They commonly occur at the time of year when stored food supplies have dwindled and new crops are only just beginning. During this period the consumption of tree foods increases. In many areas the consumption of wild animals and fish is also highly seasonal. Forest fallow and farm tree produce are also valued during the peak agricultural labour period, when less time is available for cooking and people consume more snack foods.

In many arid regions, trees provide an important source of dry season fodder, ranging from nil to 100% of the livestock diet. In the Sahelian region, browse represents an estimated 30-40% of the dry season feed (Le Houerou, 1986).

Home gardens are widely designed to make use of variations in the timing of the harvest of different component tree crops; in this way, they supply foods and saleable produce during the period between harvests of staple crops. Another important feature of such gardens and other systems incorporating trees is that work on the latter can often be undertaken during the slack season, thus helping to even out the peaks and troughs in the demand for farm labour.

For example, in Northern Brazil, babassu palm kernels are gathered and processed during the agricultural slack period. During this period the income earned from these activities represents more than a third of the family's overall budget (May **et al**, 1985). In Sierra Leone, the collection of fuelwood for the market closely mirrors the work requirements for agriculture; during the slack months, fuelwood collection increases (Kamara, 1986). This income is of particular importance as it is available at a time when food supplies are at their lowest.

In other cases tree-based activities may be dictated by seasonally induced cash needs such as loan payments or school fees. As the markets for many locally processed tree products are dependent on rural people's purchasing power, they too are tied to the cyclic nature of agricultural incomes. Several authors have remarked that income earned from tree products is often used to purchase inputs such as seeds, needed for the

Table 2 Farmer Responses based on Tree-Growing Components

Tree subsystem	Changes in Resources	Farmer responses	Contribution of tree subsystem
Home gardens, Java	1. Declining landholding size, minimal or no rice paddy, minimal capital	Increase food and income output from home gardens component of the farming system	Highest returns to land from increasing labour input, flexibility of output in face of changing needs and opportunities
	2. Further fall in landholding size below level able to meet basic food needs	Concentrate on low management tree crops to release labour to off-farm employment	Most productive stable use of land with reduced labour input
Compound farms, Nigeria	Declining landholding size and site productivity, minimal capital	Concentrate resources in compound area, raise income-producing component and off-farm employment	Improves productivity, highest returns to labour, flexibility
Home gardens, Kerala, India	1. Declining landholding size, minimal capital	Bring fallow land into use, intensify home garden management	Multipurpose trees maintain site productivity and contribute to food and income
	2. Capital input substantially increased	Transfer land use to high value cash crops, substitute fertilizer and herbicide for mulch and shade	Trees removed unless they are high value cash crop producers
Farm woodlots, Kenya	Farm size falling below basic needs level, minimal capital, growing labour shortage	Low input low management pole cash crops, off-farm employment	Lower capital input than alternative crops and higher returns to labour
Farm woodlots, Philippines	Abundant land, limited labour	Put land under pulpwood crop	Expands area under cultivation increases returns to family labour

following agricultural season (Engel 1984, May **et al** 1985). In these cases, forest-based income is quite closely linked to the agricultural production cycle.

Forests, Farm Trees and Risk Reduction

Traditionally, in Africa at least, trees have been important in emergency periods, especially in times of droughts, famines, floods and wars (Becker 1983, Campbell 1986, Irvine 1952, Turton 1977). In times of crop failure they may provide emergency foods as well as products which can be gathered for sale. These emergency foods often differ from resources exploited in other periods. In famine periods, roots, tubers, rhizomes and nuts are most sought after. They are characteristically energy rich, but often require lengthy processing. For example, in Zimbabwe the stems of *Encephalartos poggei* are soaked in running water for three days, sun-dried and crushed into a fine powder before being consumed (Malaisse, 1985). In many regions, the increasing commercialisation of rural markets and the advent of food aid have led to a decline in use and knowledge of these emergency foods (Turton, 1977).

Trees are also valued by farmers as insurance. They are planted where drought threatens; or they are planted in order to help diversify farm production, increasing the variety of crops available and guarding against the risk that a crop may fail. Trees may also be viewed as a form of savings which can be drawn upon when needed, or as providing more flexibility in planning expenditures. For poor farmers who have access to few resources, trees may provide one of the few assets they can liquidate in emergency periods (Chambers and Leach 1987).

Dynamics of the Rural Household Economy: the Changing Uses of Forest and Farm Tree Resources

Rural people, especially the poor, employ a diversity of means to help meet basic needs: food crop production, forest and tree product gathering, consumption, processing and sale, cash crop production and income-earning enterprises both on and off the farm. Changes in the physical, social and economic environment will affect people in different ways, depending on their available resources and opportunities.

The following section focuses on two aspects of change: the diminishing forest resource base and the implications of the growing importance of the cash economy in rural areas.

Impacts of Diminishing Forest Resources

Throughout the developing world, forest resources are rapidly being logged, degraded, cleared for agriculture and cordoned off for private or government use. In many regions, the result is that an ever-expanding rural population must rely on decreasing forest and land resources. In terms of household food security, this trend implies diminishing availability and use of forest food resources as well as diminishing knowledge about their utility, fewer income earning opportunities for the rural poor, and increased burdens on households in their efforts to meet their basic needs. People's responses to these changes depend to a large extent on whether there are any available substitutes; what constitutes an available substitute depends on its associated costs (e.g. labour) and social acceptibility (e.g. taste).

In many areas, forest food consumption is declining - a result of the decline of forest resources, changing tastes, and commercial markets. The impacts on household food security are unclear: in many areas the diversity of the diet has declined as people rely increasingly on purchased foods. Perhaps the worst impact of the loss of forest foods is that poorer people's food options will be further reduced during seasonal and emergency hardship periods.

The trend is not universal, however. In some areas forests still supply foods and fodder. In addition, commercialisation and rapid migration have led to expanded markets for some forest foods. In other instances they are sought after for their traditional social value, while in still other cases they are valued for their medicinal qualities.

As the availability of land and forest resources decline, some communities are facing problems of fuelwood shortages. As was illustrated in Figure 2 above fuelwood supply can influence the time women have for childcare, food production and income earning, the quality of cooked food, and possibly the prices of processed foods. As women are forced to spend longer collecting fuelwood they may have less time to spend on food production or income earning activities.

Incorporation of Trees into Farming Systems

Throughout history, farmers have protected, planted and managed trees on their land in order to maintain supplies of sought after products no longer readily available from forests. Generally, trees are incorporated into these systems for a variety of products and overlapping motivations. Thus, while trees may be planted for marketable fruits or poles, these products and many others are also valued for consumption and use by the household. For example, in Zimbabwe, farmers in severely deforested regions selectively maintain their favourite fruit species on farms. As a result, Campbell (1986) found that in this study region, the frequency of consumption and availability of the most popular forest fruit species was not affected by the conditions of the forest resource.

The intensification of management of farm and fallow lands for a combination of tree and annual plant products can be seen as a response to the changing availability of resources (including forest and land, labour and capital) and opportunities for the farmer. Analysis of tree-growing practices of farmers facing a range of resource situations reveals some important factors which encourage (and discourage) farmers to adopt agroforestry techniques as a major component of their farming practices. These are summarized in Table 2.

It has often been argued that cultivation of trees is something that is possible only for wealthy farmers. This assumption is based on the premise that the main objective of poor farmers is the production of staple foods. Hence the assumption that as farm sizes decline farmers will be forced to abandon tree crops for staple food production. However, the evidence suggests that in many cases poor farmers' resources are too limited for them to meet their basic food needs, so that income generation becomes increasingly important.

Contributions of Tree Products to Household Food Security - Summary

Supplementary role:

* farm tree and forest fallow foods add diversity to the diet increasing palatability and in some cases increasing overall food consumption;
* they also contribute essential minerals and nutrients to diets;
* these foods are often consumed as snacks contributing added energy and nutrients;
* supplement fodder supplies thereby helping to maintain year round milk, meat and blood supplies;
* farm and fallow trees are important sources of fuel used for most cooking and processing;
* income earned from the sales of tree products (or processing) may supplement the household budget - especially important for poorer households who must supplement food production with cash income earning in order to meet their food needs;

Seasonal importance:

* forest and farm trees provide food during the "hungry season" common in many seasonal agricultural systems;
* farm trees may provide snack foods during the planting season when there is little time for cooking;
* trees and fallow areas provide sources of dry season fodder;

* integration of trees on farms helps insure a year round supply of food;

* farm and fallow tree products provide seasonal cash income; in some cases this income may be invested in the following agricultural season, for fertilizer, implements, seed, or livestock.

Risk reduction:

* farm trees provide insurance: assets which can be liquidated during hard times, diversifying crop production, as well as spreading harvests across seasons.

* foods from farm trees, fallow and forest areas provide a buffer food source for emergencies: these foods are different from those garnered in other periods-- they are characteristically energy rich but may require lengthy processing, taste unpleasant or be difficult to collect;

* gathering and processing forest and tree products may provide a source of cash during emergency periods.

Increasing Dependence on the Cash Economy

As the physical resources (both agricultural and forest lands) available decrease, farmers are forced to rely increasingly on the cash economy. In many cases, diminishing size and productivity of farm holdings force farmers to rely on off-farm cash earning opportunities. The resulting decline in labour available for farming forces them to plant low input cash crops on their farms.

In some cases farmers increase the value of production from farm land by processing higher value products such as coconut sugar, and making more products from the same area such as fuelwood and charcoal, both by-products of land clearing. In a farming study in rural Sierra Leone, many farmers noted that non-agricultural activities such as fuelwood collection, hunting, fishing, oil processing, craft production and palm wine tapping are of major importance for them, both in terms of their time and the benefits for their households (Engel, 1984).

As farm productivity decreases to a point where farmers must turn to earning cash income, trees may be grown as cash crops in order to take advantage of growing markets for forest products. For example, in Haiti, where trees are being planted by farmers for the pole and charcoal markets, they are often chosen over other cash crops as they tend to entail low establishment costs and require less labour, minimal costs throughout the year, less water after establishment and thus lower susceptibility to drought (Conway, 1987). For poor farmers, the possibility of accumulating capital through tree growing may also be important.

In situations where land rather than labour is the limiting factor, joint tree/crop/livestock systems may give better returns than monocrops. Trees are also planted by the poor to help maintain the productivity of their land when the cost of alternatives such as fertilizer, herbicide, and irrigation are beyond their means (Lagemann 1977, Soemarwoto and Soemarwoto 1984, World Bank 1986).

The Impact of Cash-cropping on Household Food Security

While it is generally assumed that increases in cash income will improve the well-being of rural households, some studies suggest just the opposite-- that increases in cash income can have a negative impact on household nutrition. In some cases, overall household nutrition conditions decline with increasing reliance on cash crops (Longhurst 1987, Hassan 1985). The quality and diversity of purchased foods may not compare to those traditionally gathered and cultivated (Hassan, 1985). In other instances, reliance on the cash economy introduces different risks - in terms of market availability of foods as well as changes in purchasing power.

Production for cash crops may lead to increasing food prices as land is transferred from food production. Reliance on cash crops makes households dependent on the vagaries of market prices for these products: a drop in cash crop prices will mean a household has less cash with which to purchase foods. Farmers are especially vulnerable if they are dependent on a narrow range of cash crops and market outlets. Cash crop income is likely to be "lumpy" with periods of little income. Finally, a shift to cash crops may reduce employment opportunities as frequently they require less labour than food crop production.

In situations where the shift from food to cash crop production entails a shift in control of household income from women to men, household nutrition may be affected as women are most closely involved with provision of the household's food. There are some studies which indicate that women are most concerned with subsistence needs, while others suggest that they are equally involved and interested in cash earning. Obviously these factors vary greatly, depending on the culture, economy, available opportunities for women, and the household situation. Nonetheless, some nutrition studies indicate that where women have control of household income, overall family nutrition may improve.

Potentially, therefore, tree crops could have a negative impact on household food security. Tree growing can transfer land from food crop production with a loss of employment; tree promotion services are concentrated on male farmers; often there is only one marketable product; and trees take years to mature.

However, in many cases the potentially negative aspects of cash crop production may be offset by other features of tree growing. As was discussed earlier, the transfer of land from food to tree crops is often a response to changing conditions, such as increasingly scarce land and labour, which make food crop cultivation impracticable. Thus the shifting emphasis from food to cash crops may be unavoidable.

The impact of tree-growing on household food security depends on the species grown and the ways they are managed. Most trees provide other products in addition to those for cash sale. Virtually all species will produce some fuelwood. Fruit, fodder, shade, mulch, soil amelioration are all positive features of tree production which can contribute to food supplies as well as household income especially during seasonal shortfalls. These features, however, apply only to multipurpose agroforestry systems.

The more narrowly focused single- species (or product) tree crops, such as eucalyptus, rely on their efficiency in using available household land labour and capital resources to generate income. Such tree monocrops provide "lumpy" income flows. They are feasible options only if the household has alternative sources of food or income. This does not, however limit their effectiveness to large farmers. Poor farmers dependent on off-farm income often rely on tree crops to keep their land in productive use with minimum labour.

The lumpiness of income flows from tree crops needs to be balanced against the magnitude of that income and the flexibility it provides. Tree crops can be harvested when the farmer most needs them, i.e. for emergencies and to meet lump sum cash needs. For these reasons, they may be most appropriate for poor households.

Agroforestry Development: Building from the Food Security Needs of Rural Households

Agroforestry's contribution to household food security must be viewed in perspective. Farm trees (and forest fallow) are components of complex rural environments. Forestry efforts alone cannot substantially alter fundamental social, economic and political factors at the root of many food supply inequalities. Nor would it be correct to conclude that the answer to declining availability of foods, income or employment from forest based sources necessarily lies in forest and tree based interventions. Alternatives to forest and tree foods, fuels and products exist or could be made available in nearly every situation.

However, forest and tree resources have played an important role in household food security, especially during seasonal and emergency hardship periods. Incorporating household food security concerns into agroforestry analyses and programme development requires an understanding of the dynamics of the rural household economy, an understanding of people's food security goals, as well as the particular nutritional problems they face. Focusing on household food security problems will require a dynamic approach; one which accounts for the changing uses and roles of tree products within the household economy, as well as the variations in their importance from community to communities as well as between households and household members within communities.

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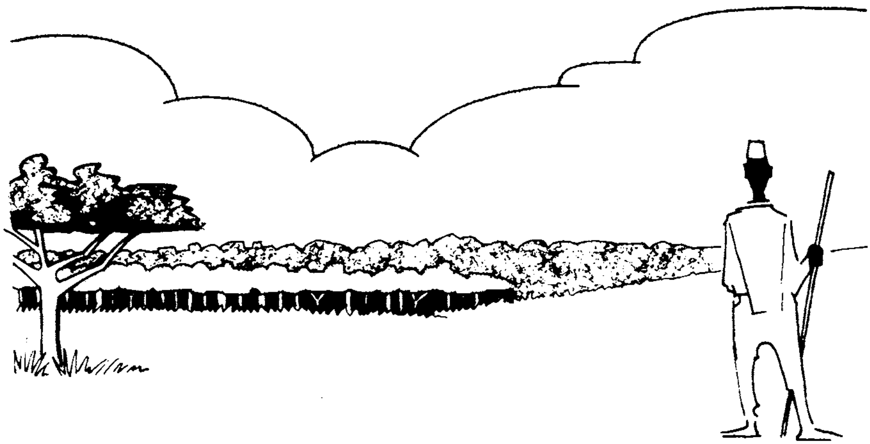
CHAPTER 2

TECHNICAL INPUTS TO ECONOMIC ANALYSIS



THE ROLE OF TREES IN MAINTAINING AND IMPROVING SOIL PRODUCTIVITY - A REVIEW OF THE LITERATURE

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CONTENTS

INTRODUCTION

The role of trees in maintaining and improving soil productivity is considered central to the sustainability of many agroforestry systems. Do we know enough about the effects of trees on soils to quantify and value this role?

By reviewing some of the evidence for enhancement and maintenance of soil fertility by trees and by examining our current understanding of the mechanisms involved, we can start to consider how the benefits from trees might be evaluated in economic terms. The importance of selecting components of the system which might be used as parameters in the measurement of improved soil productivity is clear in this respect.

DEFINITION AND MEASUREMENT OF BENEFITS

Appropriate agroforestry systems, as well as many natural tree based ecosystems, are perceived to improve or maintain soil fertility and soil productivity, to promote soil conservation, reduce soil degradation and achieve sustainable production. These benefits are often attributed to the tree component of the system. Before examining the evidence it is necessary to understand what is meant by these concepts. Only through definition and understanding will it be possible to quantify and measure the beneficial effects of trees on soils.

Soil fertility can be simply defined as the capacity of the soil to support growth of plants. It is common therefore to consider it in terms of soil constraints to plant growth. Using nutrient content alone to indicate fertility is too restricted since crop nutrient responses are interactions between soil chemical constituents and the effects of soil condition on movement of nutrients and their uptake by plants. Soil chemical, physical and biological properties all contribute to soil fertility and should be equally considered in fertility assessment.

Despite our understanding of what contributes to soil fertility we generally limit its measurement to single soil properties such as % Base Saturation or more commonly to soil macro-nutrient

(NPK) status. The latter can be interpreted and valued in terms of crop fertiliser requirements. Soil nutrients data however can only point to excess or deficiency problems and only where correlation from crop trials have been established can fertiliser or management recommendations be usefully made.

Soil fertility is only one of a number of factors that determine the magnitude of crop yield.

Soil productivity is a broader concept relating to the ability of the soil to support crop growth on a sustained basis. It might be considered (and perhaps measured) as the soil's ability to maintain fertility over time. Crop yield, both amount and variability with time, can give some indication of the soil's productive capacity although productivity is not alone in determining crop yield response. Monitoring soil changes over time can be used to assess the maintenance of soil productivity. Land productivity includes soil productivity and all other land factors which influence crop growth.

Soil conservation in its broadest sense is the maintenance of soil physical, chemical and biological properties for which the prevention of soil loss by erosion is one condition. Erosion control can be measured as reduction in the rate of soil loss in units of tonnes/ha/year. With a knowledge of typical soil organic matter (SOM) and nutrient contents (kg/ha) of the topsoil which have been retained by conservation, some indication of conservation of fertility can also be made (Stocking 1986).

Degradation is defined as the 'results of one or more processes that lessen the current and potential capacity of a soil to produce, quantitatively and/or qualitatively, goods or services' (FAO 1977). It commonly arises from pressure of land use on resource. Recognised forms of degradation are erosion; acidification; lowering of nutrient content; biological degradation, which is linked to soil physical properties and nutrients; and physical degradation, which all lead to the lowering of soil fertility and productivity. It can be expressed by measuring changes in individual soil properties but is commonly reflected in decline of crop yields and reduced response to fertilisers.

Young (1987) distinguishes degraded soils which were once fertile and those which are inherently infertile, the former having more potential for improvement.

A **sustainable agricultural** system is one which can maintain productivity over a prolonged period of time without depleting renewable resources. Such systems are characterised by high efficiency of internal resource use.

Yields, both in terms of amount and stability over time, can be used to indicate sustained productivity. The time scale might be considered in planning terms, Young (1987) suggests 20-50 years for farmers and planners, or over a longer time frame; for example Dumanski (1984) suggests sustainable production can be measured as 'average output over an infinitely long time period'. Sustainable systems are also believed to maintain stable yields in equilibrium with the environment, with little variation in response to typical environmental fluctuations. It is possible therefore to assess sustainability by measuring yield variation in response to environmental fluctuations over time.

Conservation of soil organic matter and efficient nutrient cycling are fundamental to sustainability of both natural and agricultural systems. Natural systems achieve this by internal regulation whereas agricultural systems are dominated by large inputs and outputs with little internal regulation. In addition to monitoring soil and yield changes over time to assess sustainability, we might also look to an understanding of the processes of internal regulation, by measuring nutrient storage and transfer and compiling budgets.

Clearly many variables need to be considered when assessing the fertility, productivity or sustainability of an agricultural system. Methods and units of measurement of such benefits need to be established before any attempt is made to evaluate the role of trees in agricultural systems in economic terms.

REVIEWS TO DATE

A number of reviews are available which provide a synthesis of the current information on soil productivity aspects of agroforestry and are valuable in highlighting gaps in research data (Mongi and Huxley (1979); Sanchez (1987); Nair (1984); Young (1987)).

These conclude that although the potential of trees for soil improvement is recognised, evidence from rigorous scientific studies of agroforestry systems by which trees affect soils is not yet complete. Attempts to understand the processes and to validate the concept of soil improvement are however now being made in soils research in agroforestry based on guidelines outlined in the above reviews (CSC, 1987).

EVIDENCE FOR THE IMPROVEMENT OF SOILS BY TREES

Many of the perceived benefits of trees in agroforestry systems are still hypothetical with much of the evidence observational or extrapolated from natural, plantation or annual cropping systems. Whilst much of the enthusiasm for agroforestry is for its value in marginal areas, the main documented work to date comes from areas of fertile, base-rich soils, specifically from two areas: experimental studies of hedgerow intercropping at IITA, Nigeria on pH6 Entisols and Alfisols, and from nutrient cycling work in cocoa and coffee plantations of Latin America on Alfisols and Andisols (Sanchez and et al 1985; Young 1987). Sanchez et al (1985) in their review, found little scientifically sound evidence that agroforestry systems improve soil properties in marginal areas and found it hard to adapt data from the above studies to acid base poor tropical Oxisols and Ultisols.

The evidence available to us in support of the proposition that trees improve soils comes from a number of sources, namely:

* Comparison of soils under natural tree based eco-systems and agricultural systems

* The effects of forest clearance on soils

* The restorative powers of fallow

* Observations of soil enrichment and improved crop growth under individual trees and shrubs

* Experimental agroforestry systems

* Reclamation of problem soils through afforestation

* Soils under plantations

Much of the evidence is indirect. For example, stable structures, good moisture holding capacity, resistance to erosion and good fertility with nutrients bound up in organic molecules of soils which have developed under natural woods or forests are often used to support the premise that trees improve soils. Similarly the deterioration of soil properties following forest clearance and their consequent improvement with bush fallow systems has often been used to demonstrate the benefits of trees. Studies on soil dynamics under shifting cultivation are numerous and evlauated by Nye and Greenland (1960); Sanchez (1976); Young (1976).

The success of reclamation forestry in improving fertility of some problem soils is used as further evidence for the value of tree cover. The potential ameliorating effect of trees on soils degraded by erosion and salinity in India is discussed by Tejwani, (1979); Gill and Abrol, (1986); Khanduja et al, (1986).

This discussion is restricted to reviewing the more direct evidence from some indigenous and experimental agroforestry systems.

THE EFFECTS OF INDIVIDUAL TREES AND SHRUBS ON SOILS AND CROPS BENEATH THEM

Introduction

Many tree species are valued by farmers and play an important role in traditional agroforestry systems. Some trees have conspicuous effects on crop growth beneath them and this phenomena has prompted studies to compare yields and soil properties under individual canopies with those outside the canopy. The following is a brief review of some of these studies and their results.

Acacia albida

This tree, which has the advantage of shedding its leaves at the start of the rainy season, is valued by farmers in semi-arid zones of W Africa and subhumid zones of Senegal, Malawi and Ethiopia. It has been the subject of a number of studies because of the apparent promotion of crop yield and soil fertility beneath its canopy.

Radwanski and Wickens (1970) quote Blair (1963) in his observation of irrigated wheat at Nyertete, Sudan - he recorded plants near *A. albida* trees of 80 cm height with 8 ears per plant, each with 32g rains compared to plants away from the tree which were only 30cm tall with 3 ears per plant and an average of 22 grains per ear.

Charreau and Vidal (1965) found the yield of *Pennisetum* millet growing near *A. albida* 2.5 times more than the yield away from the tree and the protein yield of the crop 3.5 times greater than outside. This yield increase correlated with a several fold increase in soil nitrogen and organic matter. Soil water holding capacity and structure under trees were also improved compared to outside.

Felker (1978) in his review concluded that, in the infertile sandy soils of the peanut basins in Senegal, yields of peanuts and millet increase from 500 ± 200 kg/ha under *A. albida* foliage (Dancette and Poulain 1969; Charreau and Vidal 1965).

Young (1987) comments that yield increases are reported to be more pronounced under conditions of low fertility.

Radwanski and Wickens (1967) compared soil profiles under *A. albida* and under *Balanites aegyptiaca* on the mantle soils of lower pediments in Zalingei, Sudan. These gravelly soils have a small clay content, low water holding capacity, little structural stability when wet, and low resistance to erosion. *A. albida* was observed to modify these adverse physical soil conditions with more organic matter (shown by darker and thicker surface layer) and more stable structural aggregates found in soil under canopies. They suggested that improved moisture conditions under *A. albida* (8%) compared to *B. aegyptiaca* (4%) (measured just before the rainy season) were partially the result of these improved physical conditions and reduced evaporation, although *A. albida* naturally occurred on moister soils than *B aegyptiaca*. (Schoch (1966) explained reduction in potential evapotranspiration under *A. albida* as due to full leaf canopy in the dry season).

Contents of organic carbon, nitrogen and phosphorus differed significantly between the two soils with the uppermost horizon of *A. albida* profiles containing more carbon, nitrogen and phosphorus but less potassium (Table 1)

Table 1 Comparison of Soil Nutrient Content under and outside *Acacia albida* Canopies (after Radwanski and Wickens, 1967)

Profile	Under *A. albida*			No *A. albida*		
	1	2	3	4	5	6
Organic carbon (%)	0.78	1.43	1.78	0.76	0.42	0.81
Total nitrogen (%)	0.15	0.39	0.73	0.07	0.05	0.08
Total phosphorus (mg/100 g)	35.0	35.0	35.0	26.0	20.0	23.0
Total potassium (mg/100 g)	164.0	252.0	172.0	300.0	220.0	284.0

Bernhard-Reversat (1982) comparing soils under *A. albida*, *B aegyptiaca* and *Adansonia digitata* with those outside the canopies on sandy lithosols in semi-arid N Senegal, found a gradient in SOM (Soil Organic Matter) and total nitogen away from the trees, decreasing both with depth and distance from the trunk.

Prosopis

This genus (43 species) is considered to have great potential for soil improvement in semi-arid and arid zones.

In Indian arid zones there is a long tradition of growing pearl millet *(Pennisetum glaucum)* under *P. cineraria* (Khejri) which supports better growth of this crop as well as a large number of forage species (Mann and Saxena 1980). Farmers in W Rajasthan are reported to maintain *P. cineraria* trees in densities as high as 150 trees/ha in pearl millet fields (Radwanski and Wickens 1981). Soil studies show an increase in SOM, nitrogen content, Zn, Mn, Cu and higher moisture availability in the surface layers under *P. cineraria* compared to open fields or *P. juliflora* (Aggarwal 1980) (Table 2).

Table 2 Soil nutrient content beneath Prosopis spp.. North-west India (Aggarwal, 1980).

	Depth (cm)	Available nutrients (kg/ha)		
		N	P	K
Prosopis cineraria	0-15	250	22.4	633
Prosopis juliflora	-	250	10.3	409
Open field	-	203	7.7	370
Prosopis cineraria	15-30	193	10.3	325
Prosopis juliflora	-	212	4.5	258
Open field	-	196	4.0	235

A considerable amount of work has been carried out on *Prosopis* shrubs, (mesquite) in USA deserts to investigate the effects on soils and and vegetation beneath. Tiedemann and Khemmedson (1973) found herbage yield was four times greater in growth chambers using soil from beneath *Prosopis* shrubs in Arizona compared to the open grown control.

Felker (1981) quotes figures for nitrate content of soil saturation extract under *P. glandulosa* var. torreyana in Californian desert for a 30cm sample of 400 mg/kg under the tree compared to 100 mg/kg away from the tree. This 1200 kg nitrate/ha is only possible because of low rains eliminating leaching loss.

Barth and Klemmedson (1978) tried to characterise spatial patterns of soil and plant dry matter, nitrogen, organic carbon and pH as influenced by velvet mesquite and blue palo verde (*Cercidium floridum Benth*) in the Arizona desert. The weight of under storey vegetation and shrub litter declined with distance from the shrub centre for all shrubs, while soil nitrogen and organic carbon declined from the shrub centre with distance from canopy and with soil depth. These shrub - induced horizontal gradients were most obvious in surface soils with surface nitrogen declining by 50% from tree bole to outside, and surface C by 50-60%.

Other examples of microsite enrichment under tree/shrub canopies.

Soil samples from under 3 dominant shrubs, *Acacia gregii* (legume), *Cassia armata* (legume) and *Lannea divaricata*, of a desert wash plant community on gravelly sand loams showed a decrease in nitrogen with depth and lateral distance from shrub centres (Garcia-Moya and Mckell 1970).

Kellman (1979) found that 5 broadleaf species native to neotropical savanna in the subhumid zone of Belize preferentially enriched the soil around them. Mineral nutrient (N, P, K, Ca) enrichment was essentially superficial, rising from low levels in the open to high levels under trees where levels were equal or sometimes greater than nearby rainforest soils.

In miombo woodland in Zimbabwe, Campbell et al (1988) found that soil properties were related to proximity to the tree trunk. In areas of closed woodland, organic matter, extractable P and nitrate N were significantly higher in soils at the base of tree trunks compared to a few metres away.

There are many other examples of trees valued as soils or crop improvers which are part of the farmed landscape. For example, in Natural Regions III–IV (m.a.r 400–800mm) in Zimbabwe, *Parinari curatellifolia*, *Ficus sur* and *Ficus sycamorus* are retained in arable fields primarily for fruit and shade. Maize growth beneath these tree canopies is often observed to be enhanced, particularly in drier seasons. Preliminary investigations suggest that position under the canopy does influence maize cob size for all species with the highest volumes obtained at midcanopy and edge positions. Farmers recognise the benefits of the trees on yields and often reduce fertiliser application under the canopies (Abel et al 1988).

Gerakis and Tsangarakis (1970) looked at the influence of *A. senegal* fallow on soil fertility and crops in central Sudan. Trial results for sorghum on Goz sands show that first year yields after 12 year fallow are better on soils where *A. senegal* trees had been uprooted than away from them. Soil samples taken in radii away from uprooted tree centres showed increases in *nitrogen* (at 0–20cm) and organic C which was higher for all soil layers but particularly the top. No difference however, in pH, available phosphorus, exchangeable potassium or texture were detected.

Radwanski (1969) working in Nigeria, compared Neem (*Azadirachta indica)* fallow with abandoned farmland fallow on red, acid 'problem' soils which are leached, have little organic matter and no structural aggregation. This soil has even been observed to deteriorate with the natural regenerative fallow employed in shifting cultivation because erosion occurs before a ground cover is established.

Results from the study are presented for 0–7.5cm composite soil samples (Table 3). pH, organic carbon and total nitrogen were all greater under Neem but phosphorus was greater under fallow. Total cations, Base Saturation and CEC are all considerably higher under the Neem fallow. Sampling was in the dry season and the farmland soil was dry throughout although lower horizons of Neem soil were reported to be still moist.

Table 3 A Comparison of Soil Properties in Nigeria under Neem Fallow as Compared with Abandoned Farmland Fallow

	Abandoned Farmland	Neem fallow
pH	5.4	6.8
C%	0.12%	0.57%
Total N%	0.013	0.047
CEC(me/100g soil)	1.70	2.25
%Base Saturation	20%	98%
Total cations(me/100g soil)	0.39	2.40
Avail P(ppm)	195	68

Interpretation of all the above evidence must be treated with some caution. All these studies assume that soils inside and outside tree/shrub canopies were initially the same and that any differences now observed could be explained in terms of the effect of the tree. It may however be differing conditions in the soil to start with which explain tree establishment and distribution. For instance in the Jebel Marra Highlands of Sudan, *A. albida* dominates on ash soils with relatively high nutrient reserves, CEC and Base Saturation (Miehe 1986). Similarly increased clay contents reported beneath *A. albida* (Jung 1966) and *P. cineraria* (Mann and Saxena 1980) may explain the trees' presence, rather than be a result of the tree. The need for well designed studies and soil characterisation when investigating the effects of trees on soil is clear.

AGROFORESTRY SYSTEMS RESEARCH

Young (1987), Nair (1984) and Sanchez (1987) have reviewed results from agroforestry systems research in raltion to soil productivity, and species which have potential as soil improvers within agroforestry systems have been proposed (Young 1987; Nair 1984). One alley cropping study, which monitors soil changes with time, is that of *Leucaena* intercropped with a maize-cowpea rotation (annual) on sandy soil at Ibadan (Kang et al 1981; 1985). Table 4 shows soil condition, before and after hedgerow intercropping and compares the effects of retaining or removing prunings. The application of prunings led to higher SOM, potassium, calcium and magnesium and improved AWC, but there was no change in phosphorus. SOM was maintained over the six years compared to a decline when prunings were removed.

Table 4 Soil changes under hedgerow intercropping with *Leucaena*, Ibadan, Nigeria. Values are for unfertilized plots, soil depth 0–15cm. Source: Kang et al (1981, 1985).

Treatment	pH	Org.C	Exchangeable (meg/100g) K	Ca	Mg	Bray P ppm
Before H.I	6.2	0.98	0.25	2.63	1.02	25
After 3 yr H.I, prunings removed	5.7	0.96	0.16	5.07	0.35	19
After 6 yr H.I, prunings removed	6.0	0.65	0.19	2.90	0.35	27
After 3 yr H.I, prunings retained	5.7	1.47	0.16	5.33	0.43	22
After 6 yr H.I, prunings retained	6.0	1.07	0.28	3.45	0.50	26

The following is a selection of some of the evidence available from various land use systems. The potential of trees as soil improvers is apprarent but clearly more quantitative evidence from research in agroforestry systems in required. Work on soil dynamics under tree plantations suggests that a decline in soil fertility can result (Lundgren 1978) and it is important to remember that trees have adverse effects on soils as well as beneficial ones. The value of well designed experiments and full characterisation of soils is obvious.

PROCESSES BY WHICH TREES AFFECT SOILS

The evidence for soil improvement under trees can be summarised as follows:

- Increase in SOM (% organic carbon)
- Increase in nutrients (predominantly total nitrogen and exchangeable bases)
- Improved physical structure (more stable aggregates, increased AWC, reduced bulk density, improved infiltration)
- Reduced erosion and runoff (tonnes/ha/year)
- Improved moisture status (% moisture content, improved AWC)
- Crop improvement (yield kg/ha, height, ears per plant, grains per ear, protein content)

The available evidence allows us to postualte how these changes might be brought about. The following discussion concentrates on the role of the tree and the mechanisms by which it affects the soil rather than the converse. It is not possible to consider fully the processes whereby crop growth is enhanced under trees since microclimatic effects are beyond the scope of this review.

Processes can be discussed under the following headings:

- Protection
- Conservation and increase of SOM
- Increase in nutrient status
- Nutrient cycling
- Improved moisture status

Protection

Protection of soil against erosion, runoff and compaction is considered one of the principle roles of trees. Both canopy and litter can protect the surface from the impact of erosive rains and dampen extreme moisture/temperature fluxes. The effectiveness of different tree covers varies. It is generally considered that tree canopies in communities of bush fallow with different strata are more effective than artificial fallow or monoculture plantation crops, although runoff and erosion recorded from soil under plantation crops can be comparable to that under natural forest (Sanchez et al 1985).

Litter has been shown to be of more value than canopy cover. In a study of an *A. auriculiformis* plantation in Java the effects of tree canopy removal, undergrowth and litter on soil erosion were compared. While the canopy alone had little effect on soil erosion, and the undergrowth effect was small, litter reduced erosion by 95% compared to bare ground (Wiersum 1985). Mulch used in cropping or agroforestry systems plays a similar protection role.

It is questionable that trees are any more efficient at protection than annual crops which can cover soil far quicker. When mulched or managed with low tillage annual crops give the same results for soil loss as do secondary forests (Lal 1977). Trees can take more than two years to close canopy in humid tropics during which time the ground is bare, as litter is still insufficient to cover it. This contrasts with annual crops which can provide adequate cover within 30-45 days and pastures within 2-6 months (Sanchez 1987).

Trees and shrubs can also protect the soil against wind erosion by retarding the movement of soil particles, as observed in deserts (Garcia-Moya and McKell 1970). Capture of clay particles during dust storms might also explain the higher proportions of clay found under *A. albida* and *P. cineraria* canopies (Jung, 1966; Mann and Saxena, 1980). Tree roots are also valuable in anchoring unconsolidated soils. Another aspect of protection that is afforded by a ground cover of litter (or mulch) is a reduction in temperature and moisture flux.

Conservation and Increase of Soil Organic Matter (SOM)

The increased supply of litter (above and below ground residues) in tree based systems is considered responsible for maintenance or increase of SOM. SOM is a major component in the plant-soil nutrient cycling system, and its maintenance or increase is fundamental to many soil improving processes. In addition to the increased supply of residues to the soil there may also be a coincident increase in the rate of humus mineralisation due to reduced cultivation and lower temperatures under trees.

(i) **Sources of organic matter**

The two main sources of litter are below ground (roots) and above ground (leaves, branches, twigs, fruit).

a) Below ground biomass and litter

Roots make a constant contribution to SOM through decay. They can represent 20-25% of the total living biomass of trees (Armson 1977) although this proportion will vary in different environments. Roots are thought to make a relatively small contribution to tropical forest systems where many of them are concentrated at the surface whereas in semi-arid and arid regions the proportion is greater. For example, at the end of the fallow period at sites in Sri Lanka and Sarawak, root biomass was 17% and 13% of total biomass respectively (Andriesse 1987); whereas roots of *Acacia gregii* and *Cassia armata* in desert wash plant community were found to be 55% and 41% of dry weight of the plant respectively (Garcia-Moya and McKell 1970). In moist savanna areas typical figures are 35-40% total plant biomass (Young 1987).

Table 5 shows root biomass for a range of land use systems compared to leaf biomass (Ewel 1982).

Table 5 Leaf and Root Biomass in Nine Land Use Systems (Ewel 1982)

	Agricultural systems			Forest Systems		Agroforestry Systems			
	Young maize	Mature maize	Sweet potato	Gmelina plantation	Secondary forest	Coffee-Erythrina	Cacao-Cordia	Tree garden	Planted fallow
Leaf biomass, kg/ha	300	1000	1070	3120	3070	2720	2040	2450	2480
Root biomass, kg/ha (to 25cm)	390	1150	410	1280	2170	2350	2720	3070	4220
Ratio, roots to leaves	1.18	1.15	0.38	0.41	0.71	0.86	1.33	1.25	1.70

These are estimates of root proportions at any one time but turnover of feeder roots by sloughing off, rapid decay and exudation can increase the contribution of roots to SOM substantially. In addition it is suggested that there is formation of SOM directly from root tissue without intervention of soil microfauna. Martin (1977) suggests that a steady release of carbohydrate-rich organic material from actively growing roots represents a high energy input into soil ecosystems capable of supporting a substantial microbial population.

Unlike above ground biomass, root residues are rarely removed from the soil and therefore play a central role in SOM maintenance. Root residues are particularly important in shifting cultivation systems where above ground material is lost in burning.

b) Above ground biomass and litter

There have been many estimates of total above ground biomass and its distribution amongst the different components of natural forest ecosystems. Nair (1984), Young (1987) and Sanchez (1979) present summaries of this material.

The potential contribution of organic matter addition that can be expected from an ecosystem according to climatic zone is indicated in the following summary of figures for net primary production of above ground dry matter.

Humid tropics (no dry season): 20 000 or more kg/ha/yr
Humid tropics (short dry season): 20 000 kg/ha/yr
Subhumid tropics: moist 10 000 kg/ha/yr
Subhumid tropics: dry 5 000 kg/ha/yr
Semi-arid zones: 2 500 kg/ha/yr (Young 1987)

Table 6 present figures for biomass of different components of fresh vegetation at the end of the fallow period in Sri Lanka and Sarawak. The critical factor, however, is which of these components will reach the soil as litter. In this respect it is interesting to note that leaf biomass is only 8.8% and 9.9% of total above gound biomass in Sri Lanka and Sarawak respectively.

Litterfall is the major recognised pathway of organic matter addition to the soil. Figures for rates of litterfall are available from a number of studies and summarised in Table 7. The amount of litter in the system at any one time is also an indication of the contribution from litter fall. Andriesse (1987) sampled litter in the dry season in Sri Lanka and during the least wet part of the year in Sarawak. The former amounted to 3 360 kg/ha compared to 9 800 kg/ha in the latter. It was felt that the large amount in Sarawak was a reflection of the high biomass regeneration and turnover.

Table 6 Oven-dry weights in kg/ha and as % of total living above-round biomass at Sri Lanka and Sarawak (Andriesse 1987)

	trunk	small wood	twigs	leaves	fruit	total
Sri Lanka						
tree	24600	11000	6000	2400		44000
bush	10000	7000	5000	2000		24000
shrubs	-	5000	5000	2000		12000
herbs	-		500	500		1000
Total	34600	23000	16500	6900		81000
% of total	42.7	28.4	20.4	20.3		
Sarawak						
trees and shrubs	21606	4589	1945	2079	28	30247
lianas	-	431	194	70		695
ferns and grasses	-		159	1027		1186
Total	21606	5020	2298	3176	28	32128
% of total	67.2	15.6	7.2	9.9		

Biomass production from tree components in agroforestry systems can approach that of natural vegetation systems. In one alley cropping system at Ibadan (moist subhumid/humid), total biomass production of the system reached some 15 000 kg/ha/yr when the crop net primary production of about 10 000kg/ha/yr from two crops was added (Young 1987). The *Cordia-Erythrina* component in coffee or cocoa plantations in Central and South America can typically supply some 10 000 kg/ha/yr above ground biomass (Young 1987).

Table 7 Rate of Litter Production (per annum) (Nye and Greenland, 1960)

Vegetation	Place	Little fall(kg/ha)	Nutrients in litter (kg/ha)					Authority
			N	P	K	Ca	Mg	
Forest (Namanja dominant)	Congo	14800 (dry matter)	139	4.6	103	127	38	Laudelout (1985)
Mixed forest	"	12500 (dry matter)	228	6.8	48	105	46	"
Mixed high forest	Ghana	10720 (oven dry)	203	7.3	64	205	40	Nye (Unpublished)
Rain forest	Colombia	10500 (oven dry)						Jenny (1950)
" "	"	10600 (oven dry)						"
" " (Sub-tropical mixed app.)	Queensland	6000 (oven dry-leaf only)	107	6.8	34	75		Webb (1956)
Temperate	New York	3100 (dry matter)	18	3.3	15	74		Chandler (1941)

Typical leaf yield values (dry weight) for alley cropping shrubs at IITA are presented below (Table 8).

Table 8 Leaf yields from leguminous woody shrubs at IITA, Ibadan, Nigeria

Shrubs	Leaf yield dry weight kg/ha/yr
Gliricidia sepium	2300
Tephrosia candida	3067
Cajanus cajan	4100
Leucaena leucocephala	5000 - 8000

Source: Kang et al (1981); Wilson and Kang (1981)

Young (1987), considering only topsoil carbon and assuming it all belongs to the labile fraction (half life of about 3 years in tropical soils) estimated the amounts of plant residues needed to be added to the soil to maintain SOM. Results suggest that to maintain SOM the in the humid tropics, 8 000 kg dry matter above ground residues ha/yr are needed to return to the soil while 4000 kg and 2000 kg are required for subhumid and semi-arid areas respectively. Comparing these figures with those available for biomass production from agroforestry systems, he concluded that SOM can be maintained only if total tree biomass is added to the soil. If woody material or foliage is harvested, a deficit results. In considering the amount of biomass needed to maintain SOM it is important to distinguish between the different tree components (litter, roots, wood, fruit) which might reach the soil or might be removed in harvest.

This represents a method for assessing the potential of different systems and component species to conserve SOM and therefore allow some quantification of requirements for a sustainable system.

(ii) **The value of SOM**

The build up of SOM is associated with both chemical and physical changes which are intimately linked. The following are the recognised benefits of SOM conservation or improvement:

a. improved/maintained soil physical properties
b. improved ion exchange material
c. improved substrate for microbes
d. improved source of inorganic nutrients
e. moderating effect on extreme soil reactions.

SOM is not a homogeneous material. Recent work using isotope labelling has enabled the identification of at least 3 pools or fractions which are distinguished by their turnover rates in soil. For example, Parton et al (1963) define three such functional pools:

Active SOM	- turnover 0-3 years
Slow SOM	- turnover up to 25 years
Passive SOM	- about 1000 years

Most of the immediate source of nutrients comes from the active pool but the slow and passive pools are equally important in promoting soil structure and providing a source of slow-release nutrients. What is clear is that SOM is one of the most important of soil properties but is also the least measurable because of our limited understanding of these functional pools. Analysis for % organic carbon in soil gives an estimate of total SOM, whereas methods of separating microbial, light and heavy fractions are necessary to determine the extent and the dynamics of the functional pools under trees or agroforestry systems.

a. Improvement or maintenance of soil physical properties

The physical properties of soil depend on the degree of aggregation between particles and the volume and size distribution of pores which determine available water holding capacity and root penetration.

Although these are influenced primarily by texture and clay type, organic gums and fungal mycelia can bring soil particles into aggregates resulting in structural stability and good pore size distribution, which in turn provides good water holding capacity, favourable permeability and aeration, a good rooting environment and resistance to surface erosion. The value of SOM in this role is evident when loss of SOM brings about capping, compaction and surface crusting and pan formation.

The importance of physical structure cannot be overlooked. Available nutrients may be useless if soil properties do not favour proper root development to tap them. Declining yields during cropping periods of shifting cultivation sometimes cannot be revived by fertiliser application alone (Ahn 1979). Some tropical soils however are not so easy to degrade, due to stable microaggregation and the value of organic matter to these is less (Ahn 1974).

Sanchez et al (1985) note the importance of tree roots in promoting good structure in soils beneath plantations by loosening topsoil by radial growth - improving subsoil porosity when roots decay.

b. Ion exchange material

Cation exchange capacity (CEC) is known to be enhanced by the clay-humus complex in soil. Raising humus levels, where clay minerals have low CEC, such as kaolinite, can be particularly valuable. Higher CEC results in improved nutrient retention and enables a greater efficiency of nutrient utilisation.

Juo and Lal (1977) compared *Leucaena* and bush fallows on Alfisols in W Nigeria. After 3 years CEC was significantly higher in the soil receiving *Leucaena* prunings compared to the bush fallow.

c. Substrate for microbes

Improvement of SOM status can result in an increase in activity of favourable microorganisms in the root zone. Such microorganisms can contribute to nutrient release and may also produce growth promoting substances.

Jung (1966, 1967) compared microbial changes under and away from *A. albida* and found an increase in invertase, dehydrogenase, asparaginase and respiratory CO_2 under the canopy. Bacteria counts were the same at the two sites but there was a marked increase in fungi and actinomycete population under *A. albida* which he took as an indication that the soil would be able to degrade leaf litter and release nutrients more quickly. However, slow decomposition of surface litter/mulch is associated with no till systems and this has been related to a higher proportion of fungi (Holland and Coleman 1987).

It has also been suggested that good SOM status provides a favourable soil environment for nitrogen fixation.

d. SOM as a nutrient source

The decomposition of raw organic residues and the mineralisation of SOM will result in nutrient release. Young (1987) recognises the following favourable aspects of SOM as a nutrient source:

- supply is balanced across the range of primary, secondary and micronutrients

- nutrients in the form of organic molecules are protected from leaching

- there is a slow release of nutrients in an available form through mineralisation

In addition, there will be a blocking of phosporous fixation sites by organic complexes, and complexing results in improved availability of micronutrients.

Above ground litter

Amounts of nutrients returned in the soil litter can be estimated with a knowledge of typical nutrient contents of tree components and the extent to which they contribute to litterfall.

For fallow sites in Sri Lanka and Sarawak, Andriesse (1987) found that leaves contain the highest amounts of all nutrient elements (being notably high in nitrogen and potassium) except sometimes calcium which is higher in bark; and that the relative nutrient accumulation is found in the sequence trunks < branches < leaves. He also found the high calcium values of litter in Sri Lanka were reflected in the calcium levels found in the living vegetation.

Table 7 summarises data for amounts of nutrients added to soil in litter for a range of forest systems. Table 9 presents the total macronutrients stored in the litter at the Sri Lanka and Sarawak sites.

Table 9 Total of major nutrients stored in litter for Sri Lanka and Sarawak sites in kg/ha; oven-dry basis (Andriesse 1987)

	N	P	K	Ca	Mg	Total Litter
Sri Lanka	38	1	10	71	7	3.360 kg/ha
Sarawak	137	4	20	152	19	9.800 kg/ha

Similar estimates can be made for agroforestry systems. *Erythrina, Inga* and *Cordia* which are combined with cocoa and coffee in Latin America, produce large amounts of biomass and there is a large potential to contribute significant amounts of nutrients to the soil (Table 10).

Large nitrogen returns can be explained partly by nitrogen fixation however non-N-fixers can still contribute substantial amounts of nitrogen.

Juo and Lal (1977) in comparison of *leucaena* and bush fallow found that the *Leucaena* plot receiving prunings for 3 years had a significant increase of calcium and potassium compared to the bush fallow. Kang et al (1985) found higher nutrient status in a plot (pH6 Entisol) receiving *Leucaena* prunings for 6 years compared to that receiving no prunings (Table 4).

Table 10 Return of nutrients to soil in litter and prunings for some agroforestry species.

		N	P	K	Ca
			(kg/ha/yr)		
Glover and Beer (1986) (Fertilised)	Coffee	148	8	88	87
	Trees	183	14	74	241
Russo and Budowski (1986)	*Erythrina poeppigiana*	330	32	156	319
Yamoah et al (1986)	*Gliricidia sepium*	238	14	152	
	Flemingia congesta	78	8	57	
	Cassia siamea	186	20	100	
Keerakoon and Gunasekera	Leucaera *leucocephala*	105	5	37	

After Young (1987)

It should be noted that whatever the potential of litter/prunings, large amounts of biomass may be needed to achieve sufficient nutrient returns.

Below ground litter

Below ground litter represents another major source of SOM and therefore a potential source of nutrients. There is little data available for nutrient content of root residues or on rates of addition of residues to the soil, but, given the amount of root mass in proportion to the total plant the contribution of nutrients from this source should not be ignored.

Nutrients in the root system at the end of the fallow period in Sri Lanka and Sarawak are given in Table 11 (Koopmans and Andriesse 1982):

Table 11 % of plant biomass nutrients in root system

	N	P	K	Ca
Sri Lanka	16	9	13	17
Sarawak	13	28	18	12

For nitrogen-fixing perennials, roots may be expected to be the main source of nitrogen however the distribution of fixed nitrogen within the plant will depend on a number of factors including species, stage of development etc. Studies with mature cowpea found only 5-6% nitrogen in roots and nodules (Minchin et al 1978). Figures for nitrogen content of perennial legume leaves suggest that nitrogen is translocated in large amounts to leaves although Andriesse (1987) found that leguminous plants were effective at storing nitrogen in all tree components. Nitrogen-fixing roots however can still contribute nitrogen by decay and slough of nodules, decay upon plant senescence and perhaps by nitrogen excretion from nodules as demonstrated by Eaglesham et al (1981) for annual nitrogen fixes.

Garcia-Moya and Mckell (1970) found nitrogen content of soil under non-leguminous desert shrubs followed the pattern of root distribution with contrasting patterns of root growth giving rise to different patterns of soil fertility. Barth and Klemmedson (1978) noted abundance of roots near non-nodulating shrub centres in USA desert and near the surface which coincided with patterns of soil nitrogen and carbon.

Factors affecting SOM decomposition and mineralisation

We have established that large amounts of litter/prunings can be returned to the soil in both natural and agroforestry systems and that these can contain substantial amounts of nutrients.

It is the process of decomposition however that regulates the rate of nutrient supply from these residues and the process of mineralisation which determines the rate of nutrient release from SOM. In simple terms, the rate of decompostion is a function of resource quality of the litter (C:N, lignin content etc) and of soil environmental conditions (temperature and moisture). Factors influencing mineralisation, although less understood, are believed to be the same.

The range of litter qualities from tree-based ecosystems (wood, leaf, twig, root, fruit) have different decomposition rates and this helps to distribute the release of nutrients over time.

Barth and Klemmedson (1978) proposed that differences in C:N suggest a more favourable decompostion environment under mesquite canopy than beyond. Similarly Radwanski and Wickens (1967) found a low C:N ratio under canopy of *A. albida* and suggested that SOM composition was such that available nitrogen could readily be released to the sorghum crop.

The soil environment, particularly moisture, influences the microbial activity, and therefore the rate of decomposition and mineralisation. In seasonal climates, decomposition and mineralisation of litter is also seasonal, with decomposition halting or slowing down in the dry season. This has been demonstrated in miombo woodland in Zimbabwe where nitrification rates show a strong correlation with soil moisture and marked seasonality (Swift and Hatton, unpublished).

Radwanski and Wickens (1967); Charreau and Vidal (1965); Jung (1966; 1967) and Dugain (1960) all attribute increase in crop yield under *A. albida* to the fact that leaf litter is provided at the start of the rainy season when it can be readily and rapidly be decomposed allowing crops to benefit from increased available nutrients.

Bernhard-Reversat (1982) observed two peaks of nitrogen mineralisation in semi-arid savanna of Senegal which were related to rainfall distribution. Mineralisation occurred mainly at the beginning of the rainy season and was shown to be a function of the number of days in which the soil was wet, for a given temperature and nitrogen content.

With a knowledge of factors that influence decomposition rates such as litter quality and soil moisture, it is possible within agroforestry systems to manipulate them by management, with the aim of synchronising release of nutrients with periods of crop nutrient demand. There is also potential for managing organic matter as a nutrient store. The value of nitrogen being held in organic form in SOM or immobilised by microbial biomass is that it is protected from loss from the system by leaching.

Increase in nutrient status

Trees have the ability to augment the nutrient status of soils by various mechanisms. Most important is the potential for some trees to nodulate and fix atmospheric nitrogen.

i) **Nitrogen fixation**

The role and potential of woody perennial legumes as N-fixers in agroforestry is well documented. Allen and Allen (1961) estiamte that about 1000 species of woody legumes form nitrogen fixing nodules. The ability to nodulate, however is not universal to all members of the legume family. The *Caesalpinoideae* subfamily nodulate less frequently than *Mimosoideae* and *Papilionoideae*. In addition, a few non legumes such as the genus *Casuarina* can fix N.

The amount of nitrogen fixed will depend on cultivar, species, number of nodules, their size, longevity and bacterial strain, the conditions of growth and management of the crop, soil available water and soil nutrient status and reaction. Amounts of fixed-nitrogen recorded for agroforestry tree species are reported by Dommergues 1987; Nair 1984 and Young 1987. These can range from 500kg/ha/yr for *Leucaena* to 21kg/ha/yr for *A. albida* (Felker 1978).

It is difficult to predict both the ability to nodulate and the amount of nitrogen fixed as this depends on many environmental factors as well as plant characteristics.

Habish (1970) in his work with *acacias* found 15% soil moisture, pH 6.5–7.0 and soil temperatures up to 35½C as optimum for growth and nodulation. All *acacias* he studied nodulated effectively at 7.5% soil moisture which was equivalent to 30% of water holding capacity of the sandy soil he used. Dry season low moisture in arid soils might explain the relatively poor nodulation on roots of *A. albida* and *B. aegyptica* reported by Radwanski and Wickens (1967) in Sudan, where soils had 8% and 4% soil moisture respectively.

Nodulation is greater in conditions of low soil nutrient status, whilst nitrogen fertilisers are known to inhibit nodulation. The phenomenon of more pronounced yield increase under *A. albida* canopies in low fertility conditions might therefore be attributed to greater N–fixation. However an increase in nodule biomass and function in *Inga jinicuil* was found to correlate positively with increasing phosphorus applications to coffee (Young 1987).

For many legume trees field evidence for nitrogen fixation is still confused. Some workers report nodulation and nitrogen fixation on roots of *Prosopis* and *Acacia* (Habish and Khain 1970; Felker et al 1980). Felker (1978) proposed that the increases in nitrogen and crop yields under *A. albida* were due to nitrogen fixation and estimated that 21 kg N/ha/yr was fixed, although generally few nodules are observed. Gerakis and Tsangerakis (1970) similarly attribute higher fertility under *A. senegal* in Sudan to nitrogen fixation.

Evidence available for *Prosopis* suggests that although they can nodulate they may not do so under extreme environmental conditions, and that even when nodulated, active nitrogen fixation occurs only when water is available (Sprent 1986).

Jung (1967) concluded that although nitrogen fixation is possible in *A. albida* it is not essential as these trees create a good nitrogen regime through normal microbial processes. Garcia–Moya and Mckell (1970) found no difference in the amounts of vegetation and soil nitrogen between legumes and non–legumes in a desert wash plant community, and concluded that the importance of the shrubs was more as a reservoir rather than for nitrogen fixing. Bath and Klemmedson (1978) found no evidence of nodulation in legume shrubs in Arizona.

Non symbiotic nitrogen fixation

Free living nitrogen fixing bacteria are known to be heterotrophic and therefore dependent on organic C for energy. It is possible that an increase in organic C can create a favourable environment for proliferation of these bacteria and explain the nitrogen rise around non nitrogen fixing plants such as Neem (Radwanski and Wickens 1981).

It is clear that nitrogen fixation offers great potential for augmenting the nitrogen status of soils. It is important however to be aware of the environmental and plant limitations to nodulation and nitrogen fixation.

ii) **Atmospheric deposition**

Atmospheric deposition of nutrients dissolved in rain or contained in dust represents another mechanism whereby trees can capture nutrients.

Kellman (1979) could not explain enrichment of soils under common savanna trees and shrubs on Ultisols in Belize by increased CEC under canopies or by deep rooting. He proposed that atmospheric deposition in rain was a major source of nutrients and that there was a gradual accumulation of mineral nutrients over time by perennials.

Andriesse (1987) suggested that atmospheric inputs or deep groundwater inputs by brackish water might explain high levels of Ca and Mg in vegetative components in Sri Lanka where soils were inherently infertile. Table 12 shows amounts of nutrients added to soil in rainfall compared to litter for a plantation in Brazil.

Table 12 Nutrient inputs and outputs in a high-yielding 17-year-old cacao plantation, shaded by *Erythrina fusca*, on a fertile Typic Tropadalf in Itabuna, Brazil (mean of 2 years) (Calculated from Santana & Cabala-Rosand 1984)

		Input or Output ($kg ha^{-1} yr^{-1}$) of N	P	K	Ca	Mg
Inputs	Rainfall	23	3	21	18	12
	Litter	112	13	25	162	53
Outputs	Harvest 1 t ha^{-1} of beans +1 t ha^{-1} of pods	44	10	20	1	3
	Leaching	68	0.5	2	38	63
Balance		+ 23	+ 6	+24	+141	-1

The extent of the contribution from atmospheric inputs is demonstrated by Russel (1983) whose balance between atmospheric deposition and leaching shows virtual absence of net nutrient losses from rainforest, mature pine plantation and even from an 18 months old second rotation in Brazil. In some forest sites in Latin America, potassium additions through rainwash were more than twice the amount added through litter decomposition (Fassbender 1977; De las Salas 1978).

The capture of nutrients in windblown fine soil particles around tree shrub bases represents another process of atmospheric deposition. In the same way accumulation of windblown seeds near trunks can increase herb growth and lead to greater organic matter accumulation under the canopy.

iii) Stemflow and throughflow

Throughflow, the process of rain dropping from canopy leaves; and stemflow, rain flowing down tree stems, represent another source of nutrient input although there is a distinction between leaching of nutrients from leaves, which is recycling, and washing atmospheric deposits from leaves, which is nutrient capture.

iv) Animal dung

Another input of nutrients, as yet not fully explored, is the accumulation of animal dung (mammal and bird) under trees. Large amounts of dung and urine observed under *A. albida* might explain increases in soil nitrogen and carbon recorded under the canopy (Radwanski and Wickens 1967) although the same increases were achieved when grazing animals had been excluded for 19 years (Charreau and Vidal 1965). The Fur people in Sudan ascribe fertilisation under *A. albida* to animal droppings rather than to any effect of the tree itself (Miehe, 1986).

v) Root exploitation

It is generally believed that tree roots can exploit deep soil layers (below 2m) beyond the reach of annual/pasture crops where fresh weathering products (potassium, phosphorus, bases and micronutrients) are available. The effect of nutrient capture at depth, and translocation into the plant system is known as nutrient pumping. This concept, although still hypothetical, is supported by the high concentration of nutrients found in forest topsoils compared to subsoils.

Tree rooting habits, however, differ with genetics and environment and different patterns and functions will develop in tree communities compared to individuals.

Kerfoot (1963) and Jenik (1977) indicate that for many woody species in the tropics, the largest number of roots and majority of fine roots are in the uppermost fertile portion of the profile. In constrast in arid systems trees can develop roots capable of reaching the water table, enabling them to continue growth through the dry season when surrounding surface rooting herbaceous plants become dormant. Figures for root biomass as a percentage of total plant biomass have already demonstrated differences in climatic zones. Kellman (1979) on excavation, found trees in neotropical savannas in Belize to be shallow rooting and could not explain soil enrichment under canopy by efficient nutrient pumping.

Soil analytical results from Neem and abandoned farm fallow suggest that Neem can extract considerable quantities of nutrients from inherently poor leached soils (Radwanski 1969).

Some examples of rooting patterns are given below:

Prosopis chilensis	- shallow and spreading (Nair 1984)
Lannea divaricata	- shallow and spreading (Garcia-Moya & Mckell 1970)
Prosopis juliflora	- very deep >3m (Philips 1963)
Prosopis	- deep (Sprent 1986) commonly >20m down to water table (Solbrig and Cantino 1975)
Acacia gregii	- Garcia-Moya and Mckell (1970)
Cassia armata	- Garcia-Moya and Mckell (1970)

Nutrient cycling

Tree based natural systems are characterised by efficient nutrient cycling and more efficient utilisation of nutrients already in the soil or those added from outside. This is achieved through the maintenance of a relatively closed nutrient cycle in the soil-forest system.

The soil-plant system is partitioned into several compartments. Most nutrients are stored in the biomass or topsoil, although the distribution of nutrients between these compartments varies between sites. A constant cycle of nutrient transfer operates from the different compartments through physical and biological processes of rainwash, root decomposition and plant uptake (Nair 1984).

The amounts of nutrients lost from such a system are negligible. Studies of phosphorus and potassium cycles in Panama reveal total gains and losses make up only 5% of phosphorus and potassium in the internal cycle, showing that this forest can maintain a nutrient cycle that is 95% closed (Golley et al 1975). In contrast annual cropping sytems are open. They experience large losses of nutrients in harvest, erosion and leaching, consequently relying on large inputs.

Research also indicated that plantation crops have the ability to cycle nutrients efficiently. Santana and Cabala-Rosand (1984) demonstrated outstanding nutrient use efficiency in a high yielding, mature 17 year old cocoa plantation with leguminous tree shade on fertile Alfisols in Bahia, Brazil. They found the balance between inputs (atmospheric and litter) and outputs (harvest and leaching) to be positive for nitrogen, phosphorus, potassium and calcium, and neutral for magnesium (Table 12).

Nutrient cycling processes are particularly relevant to agroforestry systems because tree components have a similar effect to those in natural systems. The extent to which an agroforestry is open or closed will depend on the factors which determine the amount of nutrients exported in harvest and the amount of nutrients returned to the soil in residues.

The mechanism by which tree-based systems can maintain efficient nutrient cycling is believed to be through the capture of nutrients in soil solution by tree roots that would otherwise be lost by leaching. Tree roots exploit greater depth and volume of soil, followed by translocation of these nutrients through the plant system and the return, via litter, to the soil surface where they become available to coincident or subsequent surface rooting plants.

i) **Efficient nutrient cycling** in tree-based systems is characterised by a large root absorbing zone and a large increase of nutrients stored in the plant and topsoil compartments.

a) It is accepted that the extent of root proliferation or the volume of soil occupied by tree roots (the system sorption zone) will be larger than in herbaceous plants. Trees have longer to develop an extensive rooting system.

Different nutrient absorbing zones of complementary species can lead to greater efficiency in resource sharing. Ahn (1979) suggests that this is one of the features of a natural fallow that explains its greater efficiency over monoculture artificial fallow. Reduced root competition and greater use of rooting zone should also be the aim of agroforestry mixes.

Mycorrhizae associated with roots expand the plant root system and assist in extraction of nutrients from the soil, increasing uptake ralative to leaching. They are particularly valuable in improving plant uptake of phosphorus.

Sanchez et al (1985), in their review of soil dynamics under plantation crops, explained the magnitude of increase of exchangeable calcium and sometimes exchangeable magnesium recorded in topsoils in the fallow enrichment stage at some sites, by establishment of a nutrient cycling mechanism capable of returning quantities of bases to the soil which are released from decomposing trunks, roots and stumps of cleared former forest. It was also noted that nutrient levels do not appear to decrease under tree crops implying prevention of leaching loss. Evidence suggests that when the tree canopy is established, nutrient cycling can begin. Russel (1983) measured negligible losses of phosphorus and measureable losses of K, Ca and Mg under rainforest, *G. arborea* and *P. caribea* plantation on sandy Ultisol at Jari, Brazil. He recorded lower leaching losses during mature growth stage at 1.5 years into second rotation than those under rainforest.

b) In forest systems large amounts of nutrients are stored in the vegetation and the topsoil, although the proportion of different nutrients stored in biomass and soil is known to vary. Andriesse (1987) shows how bases are concentrated in the biomass compared to nitrogen and available phosphorus, which predominate in the soil (Fig 1). A similar distribution has been recorded in tropical forests in Latin America (Sanchez 1979). In contrast, budgets for a tropical forest in Panama found 144 kg/ha phosphorus in the vegetative store (leaf, wood, fruit) compared to 22 kg/ha in the soil store (Golley et al 1975).

Bernhard-Reversat (1982) concluded that *A. albida* and *B. aegyptica* trees of Senegal increased the magnitude of fluxes between soil and vegetation as a result of organic matter and nitrogen accumulation in the soil and nutrient cycling through litter from root zone to below canopy, although the main flux occurred via herbaceous strata. Similarly, Kellman (1979) attributed preferential nutrient capture by savanna species to ability of the trees to establish enlarged plant-litter-soil nutrient cycles due to prolonged persistence at one site, enabling herbaceous biomass and litter beneath the canopy to increase.

The extent of topsoil enrichment by nutrient cycling is not only a function of the efficiency of cycling but also of the inherent fertility of the soil. Improved topsoil fertility through additions of nutrients via tree residues is only a reflection of what is in the soil to start with.

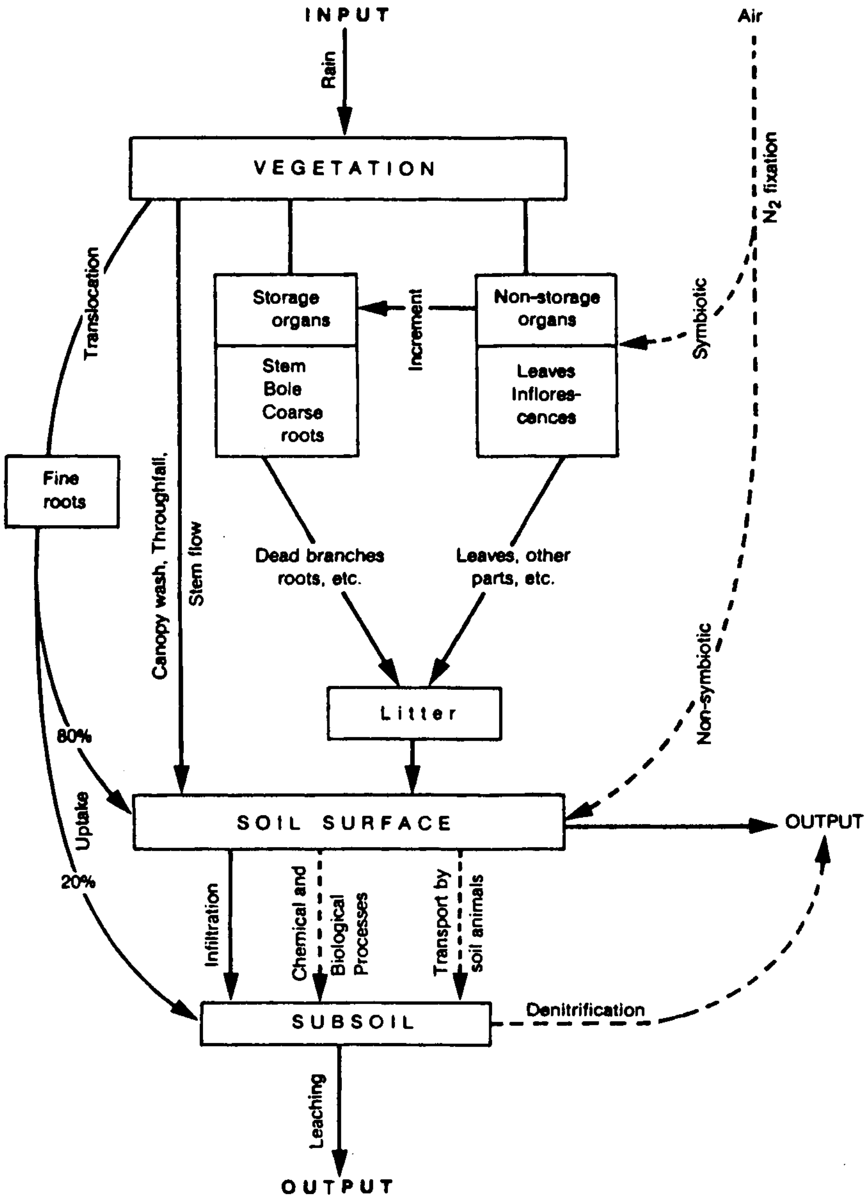
Some trees have shown potential for selectively accumulating certain nutrients. Sanchez et al (1985) report that litter and detritus from *Gmelina arborea* contained twice as much calcium as that of virgin forest or mature pine plantation while the magnesium content of litter was three times as much as in *Pinus* litter. Chijoke (1980) reports 117 and 161 kg Ca/ha/yr were returned in *G. arborea* litter for two plantation sites in Brazil. Trees that produce base rich litter have potential for checking soil acidification.

Other examples of nutrient accumulation are:

Palms and palm litter	- rich in potassium (Folkes et al 1976)
Tree ferns	- nitrogen (Mueller-Dombois et al 1984)
Cecropia spp	- Ca and phosphorus on acid soils (Odum and Pigeon 1970)
Dendrocalamus	- potassium (Toky and Ramakrishnan (bamboo India)(1982)
Heliconia spp	- available phosphorus (Tergas and Popenoe 1971)
Grass fallow	- potassium (Laudelot 1961, Lal et al (1979)
Legume fallow	- nitrogen (Pushparaja 1984) (Malaysia)

Nitrate can be taken up by some plants in excess of immediate requirements when it is freely available in soil solution and stored as free amino acids. Comparable amounts of K^+ and Ca^{++} to NO_3 will also have to be absorbed to maintain electrical neutrality (Huck 1983).

Figure 1 Relative distribution of active amounts of main nutrients over the soil–biomass–litter compartments in Sri Lanka and Sarawak (after Nair, 1984)



ii) Nutrients stored in plants are returned to the soil through two pathways: **litter and plant cycling** (Nair 1984).

a) Litter

The amounts of nutrients returned in natural forest litter and agroforestry prunings has already been discussed in section 4. However the value of litter as a pathway for the return of nutrients can only really be appreciated from nutrient budget figures such as those prepared by Santana and Cabala-Rosand (1984) (Table 12).

b) Plant cycling

This represents the part of the total uptake of nutrients which is again leached out from vegetative parts through crown washout, canopy drip and stemflow. The amount will depend on nutrient content of leaves, frequency of rain, tree age and arrangement of leaves (Nair 1979).

Increased CEC recorded in soils under trees as a consequence of increased SOM can also improve efficiency of nutrient utilisation.

Further aspects of improved nitrogen ecnomy with trees is the possibility of reduced loss of nitrogen by denitrification and volatilisation under canopies where the environment is less favourable for these processes.

Efficient nutrient cycling is probably the key to explaining why herbaceous cropping systems cannot achieve the same benefits as tree based systems. Sanchez (1987) points out that although herbaceous plants might be able to fix camparable amounts of nitrogen and can cover the ground more quickly than tree crops, and sometimes more effectively under certain management, they cannot achieve the extent of exploration of the soil that tree roots achieve, nor contribute litter in such large amounts. The latter is a feature of time, since tree stands are still increasing, in biomass and storing nutrients long after herbaceous plants have stopped.

Nutrient budgets can be used to determine the efficiency of nutrient cycling within systems. These can simply be balances of inputs and outputs to determine net loss or gain, the size of gains and losses of nutrients compared to those in the internal cycle, or become more detailed studies of amounts of nutrients in the plant-soil storage compartments and involved in transfer in the soil-plant system. Understanding of nutrient dynamics through modelling introduces a predictive capability.

Improved moisture status

Improved moisture status under trees is achieved through canopy shade reducing evaporation and evapotranspiration and by canopy, litter or mulch dampening soil moisture flux. Resulting uniform moisture conditions favour decomposing flora and fauna.

Indirectly increased SOM will promote better structure and good pore size distribution which improve moisture holding capacity of soil. Improved surface structure and reduced runoff also favour infiltration.

TREE SELECTION AND MANAGEMENT

Given our understanding of the role of trees and processes which occur enabling soil improvement we have a good idea of what makes a tree a soil improver and therefore know what to look for in selecting trees for this purpose.

Young (1987) lists properties likely to make a woody perennial suitable for soil fertility maintenance or improvement.

1. A high rate of nitrogen fixation
2. A high above-ground biomass production
3. A dense network of fine roots, either with abundant feeder roots or a capacity for mycorrhizal association
4. The existence of some deep roots
5. A moderate to high, balanced, nutrient content in the foliage
6. An appreciable nutrient content in the root system

7. **Either** rapid litter decay, where nutrient release is desired **or** a moderate rate of litter decay, where soil cover for protection against erosion is desired
8. Absence of toxic substances in the foliage or root exudates
9. For soil reclamation or restoration, a capacity to grow on poor soils.

The potential of trees as soil improvers can only be achieved under appropriate management. Management should aim to balance gains and losses to the system by minimising loss of nutrients and biomass in harvest of tree (and crop) components and retaining those components with high proportions of nutrients, ensuring these and adequate biomass are returned to the soil. There are also opportunities to manipulate timing, state and location of residues to synchronise release of nutrients from decomposition with times of crop nutrient demand, and so improve efficiency of nutrient utilisation. The principle of maintaining a relatively closed nutrient cycle and a positive or zero nutrient balance is fundamental to cropping system sustainability. Large harvests of tree or crop components represent large exports of nutrients, and such systems which exploit tree efficiency in extracting and storing nutrients are effectively mining the soil.

Some of the adverse effects of trees listed below can result from inconsiderate management or exploitation.

Adverse effects of trees on soils

- Loss of organic matter and nutrients in tree harvest
- Nutrient competition between trees and crops
- Moisture competition between trees and crops
- Production of substances which inhibit germination or growth
- Acidification by trees which produce mor-type humus

(After Young 1987)

CROP RESPONSE

The processes described above obviously interact to achieve soil improvement although in some circumstances certain processes might dominate.

Some workers have attempted to explain improved crop growth associated with trees by single variables. Dancette and Poulain (1969) explain yield under *A. albida* by increased nitrogen content in soil and Tiedemann and Klemmedson (1973) similarly attribute greater herbage growth under *Prosopis* compared to outside the canopy to nitrogen.

It is clearly easier to look for easily measurable soil variables or short term changes to explain crop response rather than to the less tangible long term improvements of structure or reduction of insidious sheet erosion.

As defined earlier soil fertility or soil productivity is just one factor which determines crop response. Fig 2 (Huxley 1983) illustrates how many external influences at a tree-crop interface need to be considered.

Relationships between trees and understorey crops are viewed as supplementary, complementary or competitive and that which predominates depends on the growth factors that are limiting. Raintree (1983) notes a significant interaction between soil fertility and other growth factors. In some cases the effect of improved soil fertility on crops may be counteracted by competitive effects such as shade resulting in net supplementarity.

Research comparing fertilised and unfertilised soils has shown greater water use efficiency of crops when nutrients are not limiting (Hanks and Tanner 1952). Felker et al (1980), in their review, estimated that plant productivity in semi arid zones may be ten times more limited by nitrogen than by available water. Similarly research using artificial shade on cocoa plantations in Trinidad revealed that where there were adequate nitrogen, phosphorus and potassium levels in the soil, the highest yields were obtained in full sunlight but when soils were of a low nutrient status the highest yields were achieved under shade

(Murray and Nichols 1966). Similar results have been achieved from tea and coffee plantation work (Wight 1958; Willey 1975). Clearly soil fertility as a growth factor does not operate alone to determine crop response.

These examples all serve to illustrate that crop yield response does not necessarily reflect soil productivity alone.

TIME

Any assessment of soil fertility maintenance and improvement must be considered in the context of time. Perennial trees have great advantages over annual crops in terms of more time available to accumulate biomass, store nutrients and develop an effective rooting sytsem. The effect of single trees acting as nutrient reservoirs can be attributed to the processes of accumulation of nutrients and SOM over time (Kellman 1979).

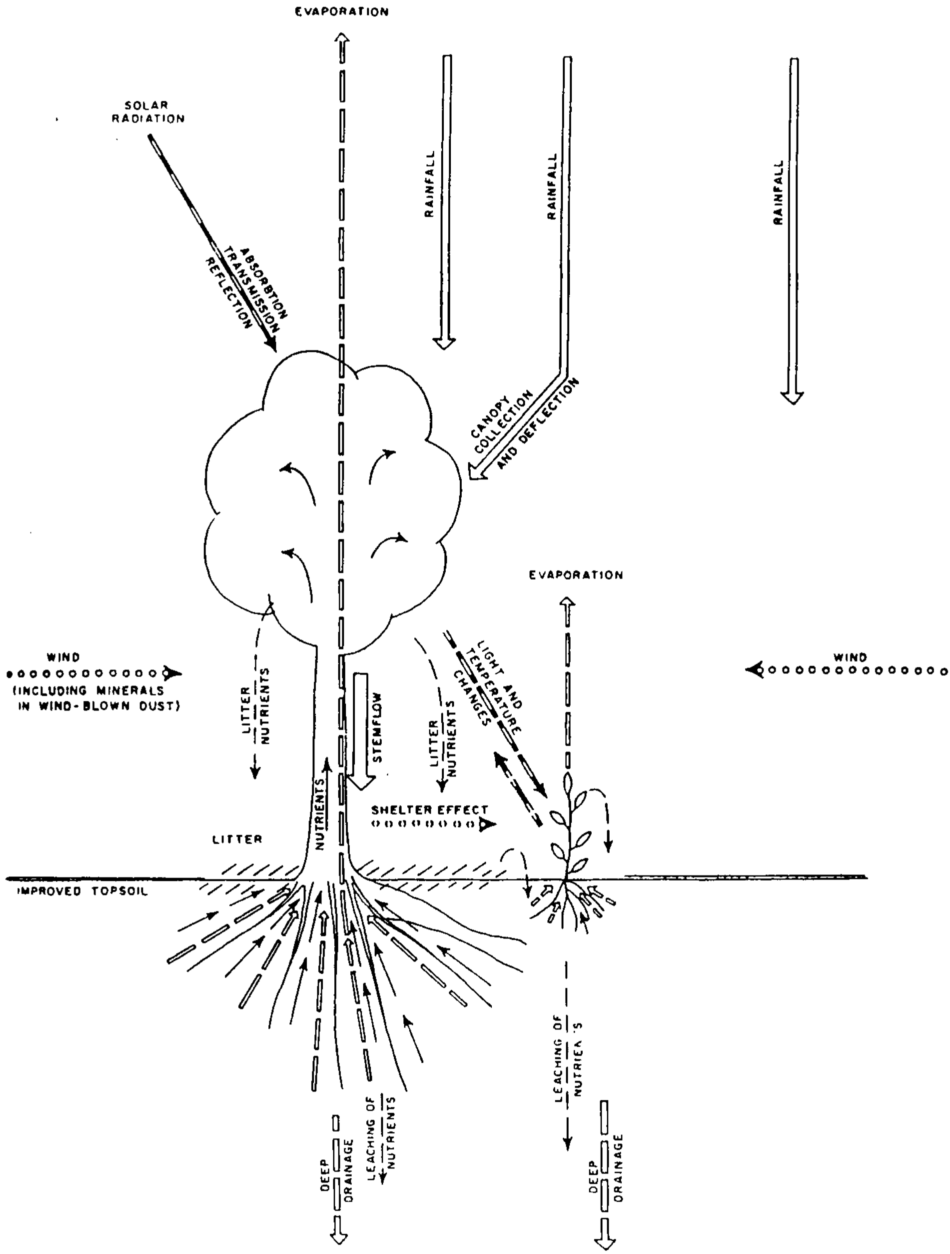
We need to consider three aspects of the time in terms of soil improvement, particularly with a view to economic analysis: how long does it take for soil improvement to become effective? How long does it continue? What are the patterns of change with time and what influences these patterns?; is equilibrium achieved? These are important both with regard to sustainability and opportunity cost considering the definitions given earlier.

Only results from those studies monitoring soil change over time at the same site can help to answer these questions. In evaluating the amount of fallow time required to restore soil fertility, the relative lengths of cultivation and fallow, expressed in terms of the R factor, are used. The R factor is defined as follows:

$$R\% = \frac{\text{years under cultivation}}{\text{years under cultivation and fallow}} \quad X \ 100$$

R values necessary to maintain soil fertility for rain forest and Savanna (burnt) have been suggested as 17–33% and 5–11% respectively.

Figure 2 External influences at the tree-crop interface (after Huxley 1983)



Okigbo and Lal (1979) state that under fallow, fertility improves with age; Ahn (1979) however argues that a fallow will have an optimum length, after which time soil improvement will stabilise.

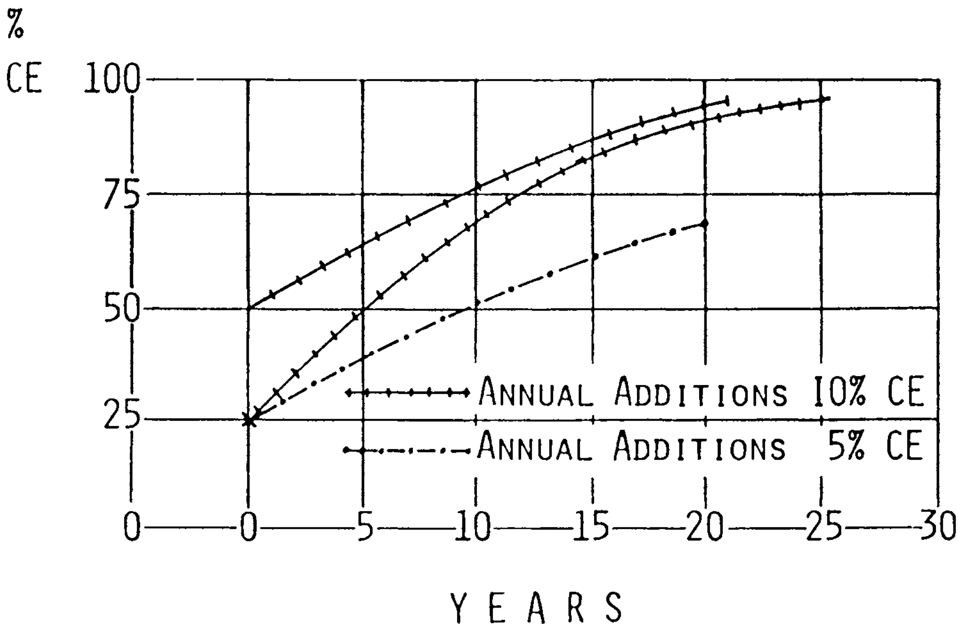
The main factors affecting the optimum length of a fallow in terms of soil improvement are environmental ones of soil, vegetation and climate which regulate rate and efficiency with which fallow brings about change. Since increases in physical, chemical and biological changes are all related to increase in humus, Ahn (1979) proposes that humus is a useful parameter which reflects changes that together increase productivity.

He suggests that optimum fallow length is the point when increase in SOM reaches equilibrium (ie when gains = losses). On the basis that the rate of humus increase depends on how far present levels are below the humus equilibrium level, additions of raw organic matter will have different effects on SOM content, depending on its initial content in relation to equilibrium. This is why Ahn (1979) explains the initial rate of SOM increase is high in fallow (when SOM is below equilibrium) and then becomes progressively lower as equilibrium is approached (see Fig 3)

The optimum fallow time, therefore, is the point when increase in SOM flattens out, reflecting the progressive reduction in size of the annual increment of humus addition. As the increment gets smaller, justification for keeping land out of production is less. Six-eight year fallow is suggested as a practical minimum for many areas although longer is required in savanna areas. It is interesting to consider opportunity costs of leaving land in fallow, particularly for the periods beyond optimum length.

Estimates have been made of the capacity of certain indigenous agroforestry systems to maintain soil productivity over time. Guilloteau (1954) suggested that 1 year's fertilisation by grazing animals of a stand of 15 *A. albida* trees/ha every 80 years was sufficient to maintain fertility for the land to be continuously cultivated without recourse to fallow. Ferguson (1949) reported that sorghum is grown continuously under *A. albida* year after year in the same areas of the Sudan and in some cases up to 30 years continuously.

Figure 3 Graphs showing calculated humus contents during fallow periods for soils with initial humus contents at 25% and at 50% of equilibrium level, receiving annual additions of humus carbon equivalent to 5% and 10% of humus carbon at equilibrium level (Ahn 1979)



The question of immediate versus long term benefits should be introduced here. Agroforestry systems, although they offer long term productivity and ecological stability, cannot compete with the immediate results of artificial fertilisers. It is quite difficult to evaluate long term, less tangible benefits commonly associated with low input systems.

LEVELS OF IMPACT

So far we have considered soil fertility improvement within a single field or forest plots. It is important to view the different levels of impact these benefits have:

Level	Effect	Immediate Beneficiary
Field	Improved yields	Farmer
Farming system	Improved sustainability	Farmer
Catchment	Hydrological benefits	Community
Ecosystem	Ecological stability	Community

Nair (1984) argues that inclusion of trees in farmland can have considerable impact by changing a farming system from one of decline to one of sustainability because improved productivity and introduction of multi-purpose trees brings stability to the system.

Felker (1978), in considering the combined effect of all increases which result in increased fertility and crop yields on smallholdings in the Sahelian zone, postulated that the presence of *A. albida* on a farm could increase carrying capacity from 10–

20 to 40–50 persons/km^2. It would be interesting to consider the effects on farm sustainability of removal of *P. cineraria* in W Rajasthan where they occur at densitites of 150/ha in pearl milet fields.

Secondary benefits of improved soil productivity under trees can be accrued to the community as a whole. There is evidence that hydrological characteristics of catchment areas are favourably influenced by the presence of trees while the benefits of trees in soil conservation and erosion are extended to the whole ecosystem.

CONCLUSION

Improved soil fertility, soil productivity or soil conservation and reduced soil degradation are often attributed to the beneficial effects of trees on soils. The importance of defining these improvements and standardising methods and units of their measurement, particularly with regard to preparing for economic evaluation, has been discussed.

The improvement of soils by trees is service rather than product orientated, making conventional economic assessment difficult. Furthermore these benefits are not yet fully proven for agroforestry systems and are known to vary under different conditions of environment and management.

Despite the obvious potential of trees as soil improvers, the evidence is mostly indirect and some of this should be viewed with caution, particularly in interpretation and extrapolation to agroforestry systems in differing environments. Similarly our understanding of the processes involved, although advanced, is still hypothetical and further work is needed to validate the hypotheses. Modelling of these processes will introduce a predictive capacity and the opportunity to investigate the economic consequence of introducing certain agroforestry interventions.

The benefits associated with tree cover and methods of measurement are summarised in Table 13. We must explore whether it would be desirable to assign economic value to improvements in

Table 13 Summary of benefits associated with tree cover and standard methods of measurement.

Benefits	Measurement
Increased or maintained SOM	Total organic carbon Functional pools - light fraction, heavy fraction, microbial carbon Biomass produced by tree components Loss of topsoil C by oxidation or erosion
Improved structure	Bulk density Infiltration capacity Aggregate stability and size Pore size and distribution SOM AWC
Increased nutrient status	Total nitrogen Available phosphorus Exchangeable bases Micronutrients
Erosion control	Erosion tonnes/ha/yr Nutrient loss kg/ha/yr SOM loss kg/ha/yr Surface structure Infiltration capacity
Improved moisture status	% moisture AWC
Efficient nutrient cycling	Net gains or losses Nutrient returns in biomass kg/ha/yr Nutrient losses in harvest Nutrient losses in leaching/erosion Net gains and losses in relation to internal nutrient cycle
Improved productivity	Soil changes over time Yield
Improved sustainability	Yield stability or degree of variation over time.

soil characteristics and qualities or to the effect of these improvements ie improved sustainability or yield increase.

Assessing the degree of SOM conservation and efficiency of nutrient cycling are two methods that allow some evaluation of internal regulation and sustainability. Interaction of growth factors at the tree-crop interface, however, complicate the use of crop yield as a reflection of soil productivity.

It is important to remember that the farmers' aim is food production and that a productive and perhaps equally sustainable system might be achieved by use of manures/inorganic fertilisers and appropriate tillage in other cropping systems. Clearly some method of comparing relative benefits for farmers is needed.

Finally we can look to the farmer as being the most experienced economist for his farming system. However, whilst he might have adopted the most economically viable system for given resource constraints, this may be targeted towards immediate productivity at the expense of long term economic and ecological stability.

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FOLIAR NITROGEN LEVELS OF SOME DRY ZONE HARDWOOD SPECIES IN MALAWI.

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CONTENTS

Abstract

Foliar nitrogen levels were determined as an index for screening tree species for a project investigating the effects of trees on soils.

Mid crown leaves of *Leucaena leucocephala, L. diversifolia, Albizzia caribaea, A. guachepele, Gliricidia sepium, Enteralobium cyclocarpum, Crescenta alata, Senna atomaria, Guazuma ulmifolia, Acacia farnesiana* and *A. deamii* were analysed for foliar nitrogen by the wet digestion method.

The results indicate *Leucaena diversifolia, Crescenta alata, Enterolobium cyclocarpum* and *Gliricidia sepium* as the top four with values above 2%. However these values need to be linked to foliage biomass production. Field observations indicate that *G. sepium* produces more foliage than any of the other ten species. It is therefore considered the most appropriate for use in the soil amelioration project which aims at understanding processes of tree-crop-soil interactions where woodlots are used to contain land shortage and address lowered soil fertility and wood resource scarcity.

Introduction

Malawi has a population of almost 8 million people spread over a land area of 94,270 square kilometres. This works out to almost 85 persons per square kilometre, which is among the highest in Africa.

The country heavily depends on rainfed agriculture whose smallholder subsector accounts for just over 80% of total production. This subsector meets the national requirement for basic foodstuffs and a little surplus for export (Malawi Government, 1984).

Steady growth of the subsector due to high population growth has meant converting forestland to agricultural land. Consequently, wood resource is a scarce commodity and it is largely the marginal land that is available for afforestation. This marginality means poor rainfall, stoney or massive lateritic soil, waterlogged sites and lowered soil fertility due to overcultivation.

Suitable species are, therefore, required for planting on these difficult sites. Screening species on the basis of their adaptability to the sites as indicated by survival rates, diameters at breast height and tree heights have been the concern of a Fuelwood and Polewoood Research project for the Rural Population of Malawi. This Project was funded by the International Development Research Centre (IDRC). In addition to the above parameters, foliar nitrogen levels were determined as an index for the tree species' ability to ameliorate soils through litter fall.

Materials and Methods

Mid crown leaves of *Leucaena leucocephala, L diversifolia, Albizzia caribaea, A. guachepele, Gliricidia sepium, Enterolobium cyclocarpum, Crescenta alata, Senna atamaria, Guazuma ulnifolia, Acacia farnesiana* and *A deamii* were sampled in February 1989 from 2 year old trees growing on a fairly acidic sandy loam soil which is deficient in total nitrogen as indicated in Table 1.

The leaves were oven dried at 80°C overnight, ground and subsamples digested with concentrated sulphuric acid. The digests were distilled into Boric acid which was back titrated with N/70 solution of hydrocholoric acid.

Table 1 Soil properties of topsoil (0–20 cm layer) at Naminyanga dry zone hardwood elimination trial as at planting.

Sand, %	67
Silt,%	12
Clay,%	21
Bulk density, g cm^{-3}	1.37
Waterholding capacity, cm cm^{-3}	1.37
pH	5.5
Organic matter, %	12
Total nitrogen, %	0.10

Results and Discussion.

Leucaena diversifolia, Crescenta alata, Enterolobium and Gliricidia sepium are the top 4 tree species in foliar nitrogen as indicated in Table 2.

Table 2 Foliar nitrogen leaves of dry zone hardwood species growing at Naminyanga

Species	N% (oven dry mass) ± Std
Leucaena diversifolia	2.19 ± 0.80
Crescenta alata	2.66 ± 1.42
Enterolobium cyclocarpum	2.64 ± 1.70
Gliricidia sepium	1.97 ± 0.98
Albizzia caribaea	1.93 ± 1.38
Albizzia guachepele	1.76 ± 0.32
Acacia farnesiana	1.76 ± 0.32
Senna atomaria	1.72 ± 0.34
Guazuma ulmifolia	1.49 ± 0.16
Leucaena leucocephala	1.36 ± 0.48
Acacia deamii	1.01 ± 0.47

The foliar nitrogen levels serve as a crude index for screening species ability to ameliorate soils and provide good fodder. However the index needs to be linked to foliage production. The importance of this linkage can be demonstrated by *Gliricidia sepium* which is ranking fourth in Table 2. Field observation indicate that *G. sepium* produces more foliage than any of the other species in the table. It is therefore expected to rank first on total foliage nitrogen when the foliage biomass data is taken into account.

The data in Table 2 together with information on growth (Ngulube, 1986) provide background information to a Commonwealth Science Council project on 'Amelioration of Soils by Trees'. This project aims at understanding the processes involved in the tree-crop-soil interactions where woodlot agroforestry practice is used to contain land shortage and address lowered soil fertility and wood resource scarcity (CSC 1987). The collaborating partners are the Forestry Research Institute of Malawi (FRIM), a smallholder farmer in Malawi, Department of Soil Science at the University of Reading (UK) and the Department of Biological Sciences at the University of Exeter (UK). Cost benefit analysis will be done to compare this situation against one without the woodlot.

Conclusions

Foliar nitrogen levels need to be linked to foliage biomass production in order to improve their role as an index for screening tree species for use in amelioration of soils by trees programmes. Although *Leucaena diversifolia* ranks high on foliar nitrogen per cent, *Gliricidia sepium* (fourth on the per cent scale) produces more foliage than any of the other ten tree species investigated in this study.

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ECONOMIC CONSIDERATIONS OF ALLEY CROPPING FOR FOOD PRODUCTION IN SEMI-ARID AREAS

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Introduction

Kenya's arid and semi-arid areas cover approximately 83% of the country. The semi-arid areas with marginal to medium agricultural potential comprise about 21% of the total land area (Braun and Mungai, 1981).

In the past two decades, because of population pressure, there has been considerable human migration from the high potential areas to the medium and more recently to the low potential ones. this trend is likely to continue at an increased rate and calls for an effort to both increase and stabilize food production in these areas. According to Government policy, one third of the projected increase in agricultural production in Kenya is expected to come from new acreage largely in the semi-arid areas (Government of Kenya, 1983). Thus, it would seem these areas will play an important role in human settlement as well as in the production of subsistence food as people in the more favoured areas opt for food and also cash crops.

The major environmental factors limiting crop and animal production in the semi-arid areas of Kenya are rainfall and soil fertility. The average annual rainfall is low and in much of the country it is divided into two rainy seasons of short duration. The seasonal rainfall is not only unrealiable but also has poor distribution. The climatic problem is especially enhanced by the high evaporation rates occurring in the semi-arid areas. The intense and most erosive rainstorms occur in the first few days of the rainy season when the vegetative cover is low which gives rise to high erosion rates (Moore 1978). The high intensity storms not only reduce the quantity of water available to crops, but also lead to reduced plant nutrients in the top soil through leaching. The net result of this is land degradation and reduced productivity from the land. However, the soil fertility problems in the semi-arid areas are not only related to the loss of top soil but also to the relatively low turnover of organic matter in the soil.

Apart from these environmental problems, the farming enterprises in the semi-arid areas have been dominated by repetitive maize/bean (or other legumes) intercrops and low agricultural inputs. This crop management system is risky in the face of unfavourable conditions such as weather vagaries and disease and pest attacks. Failure of crops has often necessitated expensive Government intervention in the form of famine relief. With the increasing population and low and unsustainable yields in the semi-arid areas, it would appear that a practice of mixed **sustainable** cropping is a more viable alternative even though yields may be lower than those in the high potential areas.

A major response to these problems has been the introduction of agroforestry (various interventions) as a low input technology to sustain crop production as well as offer other benefits to the farmer. The Kenya Forestry Research Institute (KEFRI), in conjunction with the Machakos Integrated Development Programme (MIDP) and other relevant Government and Non-Governmental organisations, are involved in a major research effort in alley cropping in the semi-arid areas of Machakos district. Alley cropping is essentially an agroforestry system in which food crops are grown in alleys formed by hedgerows of trees or shrubs (Kang et al 1981; Wilson and Kang, 1981; Kang et al 1984). KEFRI is interested in the potential of alley cropping for soil nutrient increase and other improvements of growing conditions for small-scale farmers in the semi-arid areas, as well as other benefits eg fodder and fuelwood (Arap Sang and Hoekstra, 1986).

The aim of this paper is to give a preliminary technical evaluation of the biological potential of alley cropping in semi-arid areas based on ecophysiological research carried out at the National Dryland Farming Research Station, Machakos, during 1987 and 1988 as well as to suggest relevant variables for a cost-benefit analysis of the system. Since a strict definition of economics is not easy (Todaro, 1977), the economic evaluation of a farming system, such as alley cropping, should take into account changes of the principle economic components which may result from changes in the system's management. This is because a change in the management aspects of the system could radically alter the principle components used in its evaluation. For example, the production of useful wood from an alley cropping system might be a different economic component compared to the possible impact the mulch input might have on crop production in the crop and this change in the principle economic component has been brought about by a change in the management of the system. A great temptation when discussing agroforestry interventions from an abstract economic view is to extend, unreasonably, the concept of multipurpose trees. Great care must be excercised in applying the "multi-purpose" tree concept to all climatic conditions, especially in semi-arid areas. The underlying problem is that the potential uses of a tree may vary depending on the rainfall and the management of the proposed intervention. Without serious consideration of the biological aspects it is very tempting to fall into the "designer tree" syndrome (Coulson 1989). You can't get everything for nothing!

The reported ecophysiological data were gathered under the umbrella of the TTMI-Project, the University of Nairobi and the National Council for Science and Technology. The TTMI- Project also operates in the Sudan and Tanzania investigating diverse agricultural research problems of critical relevance to small scale subsistence-oriented farmers. The project is based at the Agricultural University, Wageningen and is funded by DGIS (The Netherlands).

Overview and the experiments

The experimental site belongs to the National Dryland Farming Research Station which is about 7km from Machakos town (approximately 1½ 30'S, 37½ 15'E; altitude 1560m). The average annual rainfall and potential evaporation are about 700mm and 1800mm respectively. The average seasonal rainfall for each of the so-called "long-rains" and "short rains" is about 300mm. The soils of the experimental site are Luvisols; they are well drained and deep (80-120cm) with friable clay over murram. The top soils have low (< 1%) organic matter content.

The established experimental layout is a randomised design with two treatments (excluding the control) replicated four times. *Cassia siamea*, which is non-leguminous, had been previously selected as the tree species for the hedgerows. Within each plot, except in the controls, four hedges have been established since November 1983, at between - row spacing of 3.6m. In row spacing of *Cassia siamea* is 0.25m for treatment 1 and 1m for treatment 2. In between two hedgerows, three rows of Katumani

Composite B maize are planted parallel to the hedgerows at a spacing of 90cm by 30cm. In the control plots, each hedgerow is replaced by a row of maize. The established practice is to incorporate the loppings of *Cassia siamea* into the soil at the beginning of the season. The experiments described here were done in the 0.25m spacing and the controls.

From the early work of the Dryland Agroforestry Research Project (1903-1985), it appeared that during the development period of the alley cropping system, the maize rows adjacent to the hedgerows outperformed the centre rows perhaps due to improved availability of moisture, light and nutrients. When the hedge was better developed, a negative impact was noted on the maize rows closest to the hedges most likely due to competition for soil moisture and nutrients between the hedges and the maize (arap Sang and Hoekstra, 1986).

In an integrated quantification approach, the "Traditional Techniques of Microclimate Improvement" Project began in late 1986 involving collaborative research with the various institutions. The TTMI - Project has three main aims (Mungai et al, in prep) i.e:

a) to train local scientists though working on local problems

b) to demonstrate the need to study the interactive relationships between micrometeorological (aerial and soil) and plant parameters in agroforestry systems, as they relate to yield sustainability and the conservation of the environment.

c) to develop appropriate methodologies and equipment for environmental quantification of AF on-station and on-farm conditions.

In this paper, we will deal with objectives (a) and (b). Some aspects of (c) are discussed by Coulson and Taylor (1984), Couslson and Stigter (1988), Coulson et al (1988) and Coulson and Musyoki (in press).

Preliminary results and implications for cost-benefit analysis

Of all the parameters being quantified, soil moisture as determined by amount and distribution of rainfall and nutrient availability, appears to be the most important in determining the growth and yield of Katumani Composite B maize in Machakos.

"Long rains", 1987

The seasonal rainfall (March-May) was below the long term average. Gravimetric soil moisture measurements indicated higher percentage moisture in the top soil of treatment plots compared to the controls - a treatment effect due to mulch incorporation in the *Cassia* plots. However, the sub-soil in the controls was wetter that in the *Cassia* plots. Transpiration and photsynthetic rates were higher in the controls than in the *Cassia* plots. The control plots lost slightly more maize plants than the treatment plots but the differences were not statistically significant. No statistically significant differences were found for the grain yields.

"Short rains", 1987

The rains were late, low in amount and poorly distributed. Because of this, there were marked contrasts in the performance of the maize. The percentage number of dead plants was higher in the *Cassia* plots than in the controls. This difference, which was reflected in the grain yield data, was statistically significant at the 95% level. The differences in the survival rates of the maize plants were largely due to competition for water. Soil moisture measurements, using gypsum blocks, indicated wetter conditions in the controls. A recent preliminary study of the root distribution of *Cassia siamea* indicated that at a distance of 75cm from the trees, 56% of the roots occurred in the top 40cm of the soil. At 40cm from the tree 63% of the roots were found in the top 40cm of the soil. This surprisingly shallow rooting depth of the *Cassia siamea* seems to explain the competition for both water and possibly nutrients that were observed during this season.

"Long rains", 1988

The rainfall this season was above the long term average and also well distributed. This maize grew fast early in the season and quickly surpassed the height of the *Cassia siamea* hedgerow. Thus compared to the previous seasons, soil moisture was not a major limiting factor. Based on the total planted area, the mean grain yield of the *Cassia* plots was 2.6 t/ha compared to 2.8 t/ha for the controls. The difference in the mean grain yield was not statistically singificant at the 95% level.

Discussion

From these results, it appears that competition for growth resources eg space, water, light and nutrients etc between the annual crop and trees or hedges in an alley cropping system obviously has implications for the productivity of the crop. When the perennial part of the system over-competes with the crops, the crop yields will be reduced. If we consider competition for water within the sytem then this will obviously be a function of rainfall. If water resources are plentiful, then competition between the crop and the hedge will be minimal or non-existent. With a reduction in the available water, competition will start to occur between the two parts of the system. The degree of competition will depend on the density of component plants and, importantly, on the soil horizons from which they predominantly extract their water. The experiments described here strongly suggest that the productivity of the maize crop in the alleys relative to that not in the alleys is very much influenced by rainfall. In seasons of good rainfall, the productivity of the maize in the alleys (fewer maize rows) is not statistically different from that in the controls. This is probably the result of increased soil fertility due to mulching. During poor rainfall seasons, however, the productivity is reversed in that the maize in the controls is more productive than the maize between the *Cassia*. This would seem to suggest that in the alleys, the *Cassia* 'won' and the maize 'lost' when water was limited. This raises the idea that as rainfall declines, the alleys becomes less productive and at some rainfall figure, the maize in the *Cassia* plots has the same productivity as the maize in the controls. Further rainfall reduction makes the productivity of maize in the controls greater than that in the alleys where, under such limited rainfall, the competition by *Cassia* for water is too great. A 'break-even' rainfall could be typical on all alley cropping systems though the actual rainfall value would be expected to vary depending on various factors eg soil moisture retention and release characteristics, duration and distribution of the seasonal rainfall, and rooting patterns of the component plants (Coulson, unpublished).

One of the important factors that will influence the degree of competition between the hedges and maize will be the depth of rooting of these two components. If the rooting depths are similar, then we would expect appreciable competition. The observations on maize yield and *Cassia* rooting seem to confirm this.

The relationship between the shoot and root mass in plants has been studied for many years. Such studies indicate that within a species, there is a relationship between the mass of the shoot and that of the root. Although to some extent, this relationship is plastic it is probably true to say that the greater the extent of the shoot, the greater is that of the root. It is conceivable that reduction of the shoot system of some trees reduces the root system in such a way that water extraction takes place from the upper parts of the soil profile. This situation would encourage or increase competition between the *Cassia* and the maize for both water and nutrients. The continous lopping of the *Cassia* down to 50cm in the experiments described above could be the reason for the apparent shallowness of the rooting system of the *Cassia* and the competition patterns at low rainfall. To avoid or at least to reduce such competition, the tree component of the alleys should preferably extract water from a lower soil depth than the maize. To engender the situation, it may be profitable to consider a reduced lopping regime to increase the shoot mass thereby increasing the root mass, allowing water extraction from deeper soil layers. This principle would be more applicable to hedge trees/shrubs which tend to develop tap root systems. However, it must be realised that an increased shoot mass could lead to increased lateral root growth and perhaps greater competition of the tree with the maize. One concept is that in semi-arid regions, alley cropping which involves heavy pruning may be counter productive (taking all production functions into account) and a reduced pruning regime coupled with a reduced density of the tree component may be a better solution. This concept could be approximated by the following:

Pruning Height Regime = f(1/rainfall and tree density)

If this concept (Coulson, unpublished) leads to a viable management practice, the question then arises as to the effect on the economics of the system. Presently under the heavy pruning regime of the *Cassia* hedges, the pruned material is used as mulch to increase soil fertility and to improve other growth conditions. An economic benefit would be expected to be a reduction in the chemical fertilizer input. If the rainfall is such that it is better to have larger and fewer trees, this economic benefit of the system may change. Under these circumstances, the production and monetary value of poles or wood would probably be higher. Some mulch from natural litter fall may still be expected to occur and indeed the deeper roots of the trees could bring nutrients to the rhizosphere which might otherwise, because of shallower roots, be lost to the system.

Other relevant economic considerations

a) Opportunity costs for land and labour. These should be assessed according to the constraints and production objectives of given farmer categories.

b) The economics of relevant training. With good training based on local problems, it would be expected that well directed research would be carried out in the many 'grey areas' of agroforestry to understand cause-effect relationships or to develop relevant methodologies. Perhaps the aspirations of national research priorities do not show sufficient emphasis on the fact that the skills required for agroforestry research are not normally available in the scientific pool, particularly in the developing countries. Thus, the cost of providing a good manpower base for AF research is underestiamted and the long term implications not fully appreciated.

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THE TECHNICAL COSTS AND BENEFITS OF AGROFORESTRY TO THE CATCHMENT AS A WHOLE. UPSTREAM–DOWNSTREAM RELATIONSHIPS

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Introduction

All interventions in the management of areas within a catchment will have implications for the environment elsewhere in that catchment. Specifically, land management programmes in the upstream zone may have profound impacts on the areas downstream. These impacts may be beneficial or deleterious, but either way should be included in any environmental impact assessment or economic review of the upstream programmes. All too often they are ignored. This may well be largely due to technical constraints; it is very difficult to predict upstream-downstream reactions in terms of altered runoff or sedimentation amounts or distributions. This is because the processes involved are extremely complex. Most of the computer models which exist for predicting catchment scale discharges or sediment yields rely on calibration of parameters for an **existing** situation. To reliably predict the impact of a proposed catchment management change is almost impossible.

Because these types of question have only just begun to be considered by the technical world, especially with respect to the tropics, there is a dearth of data on which to base any hypotheses. This lack of data, and the complexity of the physical processes involved, mean that we are often unable to give economists estimates of the wider scale effects of intervention on which they can base a cost-benefit analysis.

There is also the question of the time scale of effects. Does it matter if sediment yields to a downstream reservoir decrease, if there is already enough sediment in the river valley to fill the reservoir anyway? In this case the benefits of upstream catchment protection will have no effect on the reservoir in the short-term. If the sediment stored in the valley is only a fraction of that needed to fill the reservoir, it is still likely that the reservoir will continue to fill at a rapid rate until the valley sediments are exhausted. Only then will the reservoir benefit from the upstream management changes. These benefits in the future are, in economic terms, of less worth than any immediate benefit. But, what if there are no alternative sites for reservoirs, and the water from the reservoir is important for power generation or irrigation? Then maybe there is an argument that protection of the reservoir should be worth more than the simple discounted value of benefits in the future. This, however, is a question of economics rather than a technical one!

In this paper I am aiming to review what is known of the technical costs and benefits of agroforestry to the catchment as a whole. I will augment this with experience we have gained in Africa and Asia on the movement of sediment through the catchment, and the effects of different land management techniques in reducing runoff and soil loss.

What are the impacts of agroforestry, in terms of supply of sediment and water to areas downstream?

A review of the role of agroforestry as a means of soil conservation (ie reduced soil erosion) carried out by Young (1986) shows that there is little data specific to agroforestry. An exception is the work by Wiersum (1984), who reviews various measured rates of soil erosion by water under agroforestry systems. Much other work assesses the likely impact of agroforestry, by considering it as a hybrid, somewhere between forest and cropped land. In this paper I am not going to attempt to put values to the soil erosion or water yield from different agroforestry systems. I am instead going to look at the trends that may exist, and try to show how the effect of these trends can be evaluated for the catchment as a whole. In other words, I am going to present important concepts and relationships, which must be understood if impact on the catchment is to be successfully assessed.

There is a general feeling that agroforestry is good in terms of reducing soil erosion. This may not always be so, being dependent on the type of agroforestry that is implemented. Pereira, quoted in Hamilton and King (1983), cites a demonstration of agroforestry in which maize and pineapple were planted between rows of pine trees, straight up and down 20% slopes - this cannot be expected to reduce soil erosion! On the other hand if properly implemented, with due consideration to sensible soil conservation practices, there is evidence that soil losses may be comparable with those under forest. Recently the idea of converting forest to agroforestry use has gained in popularity. If properly managed the impact on runoff and soil loss may be dramatic, but it must always be remembered that the potential for disaster is there, when a stable eco-system is disturbed. The effect of the conversion also depends on the way in which it is carried out. So, we must look at downstream impacts in terms of either an increase or a decrease in eroded soil from the agroforestry site.

The effect of agroforestry on runoff is just as unpredictable. Hamilton and King (1983) discuss a case in Kenya, where forest was changed to tea plantation plus shade trees. Here, although the total annual yield of water was not changed, both low flows and peak flows were increased. This redistribution of flows, and especially any increase in peak discharge, has profound implications in terms of the sediment carrying capacity of rivers. This point will be pursued later.

It is likely that if agroforestry replaces a previous unstable agricultural use, both total annual runoff and peak discharge will be reduced. With this scenario low flows are also likely to be reduced, due to the higher consumptive water use of trees, and indeed of intensive agriculture. Again this redistribution of flow frequencies has implications for river sediment transport.

Confirmation of these relative values of discharge, and the potential reductions in soil loss comes from a comparative catchment study in Malawi (Amphlett, 1986). The results are summarised in Table 1 and Figures 1, 2 and 3. Although none of the catchments are under agroforestry, the completely managed catchment at Bvumbwe which combined both physical and biological conservation techniques, shows the benefits which can be obtained. This catchment encompasses the one thing that is often quoted as the most important factor for agroforestry systems in reducing erosion, namely a high percentage of soil cover. This good soil cover was also present in the plantation catchment at Mphezo. Perhaps the results for agroforestry would lie somewhere between these two catchments. Physical conservation alone is not nearly so effective (Mindawo II catchment), although it gives vast improvements when compared with the traditionally farmed, Mindawo I catchment.

Table 1

Summary of results from the catchment study in Malawi

	SEASON	BVUMBWE (full land use plan)	MINDAWO (traditional cultivation)	MINDAWO II (physical conservation)	MPHEZO (plant-ation)
Rainfall	1981/82	957	890	-	-
(mm)	1982/93	822	910	975	951
	1983/84	836	865	914	923
	1984/85	1334	1191	1207	1137
Runoff	1981/82	29.7	81.0	-	-
(mm)	1982/93	19.0	156.7	54.8	7.7
	1983/84	6.7	42.0	17.4	4.2
	1984/85	62.2	154.5	85.6	8.4
Soil loss	1981/82	0.12	10.06	-	-
(t/ha)	1982/93	0.21	13.70	2.31	0.092
	1983/84	0.03	4.44	1.18	0.028
	1984/85	0.13	14.32	5.11	0.058

Further similar work in the Philippines, on two small reforested catchments at Dallao, gave similar low values of runoff and soil loss (Table 2). Again good soil cover is the primary reason for the decrease in erosion.

The magnitude of effect which agroforestry has on the catchment as a whole, depends on the percentage of the catchment which is under agroforestry. If 2% of the catchment area, somewhere up in the mountains has agroforestry applied it is probable that little effect will be noticed at the outlet of the larger catchment. But, if the percentage under agroforestry is 98%, changes at the catchment outlet may well be very distinct. Pitman (1978) in a study of trends in streamflow due to upstream land use change shows mean annual runoff decreasing almost linearly with increasing forest area (Fig. 4). A similar picture may be expected for agroforestry, which also shows fairly high evapotranspiration rates.

Table 2

Summary of results from reforested catchments at Dallao, Philippines

	Year	Rainfall (mm)	Runoff (mm)	Soil loss (t/ha)
Catchment B	1984(J-D)	937.85	70.53	0.082
	1985	2035.02	336.18	0.995
	1986	1791.92	245.47	0.199
	1987	1179.55	129.36	0.171
Catchment C	1984(J-D)	864.42	71.36	0.111
	1985	1833.64	341.41	0.770
	1986	1615.86	203.77	0.390
	1987	1076.12	-	-

Figure 1 Cumulative runoff records for 1981/82 & 1982/83 seasons

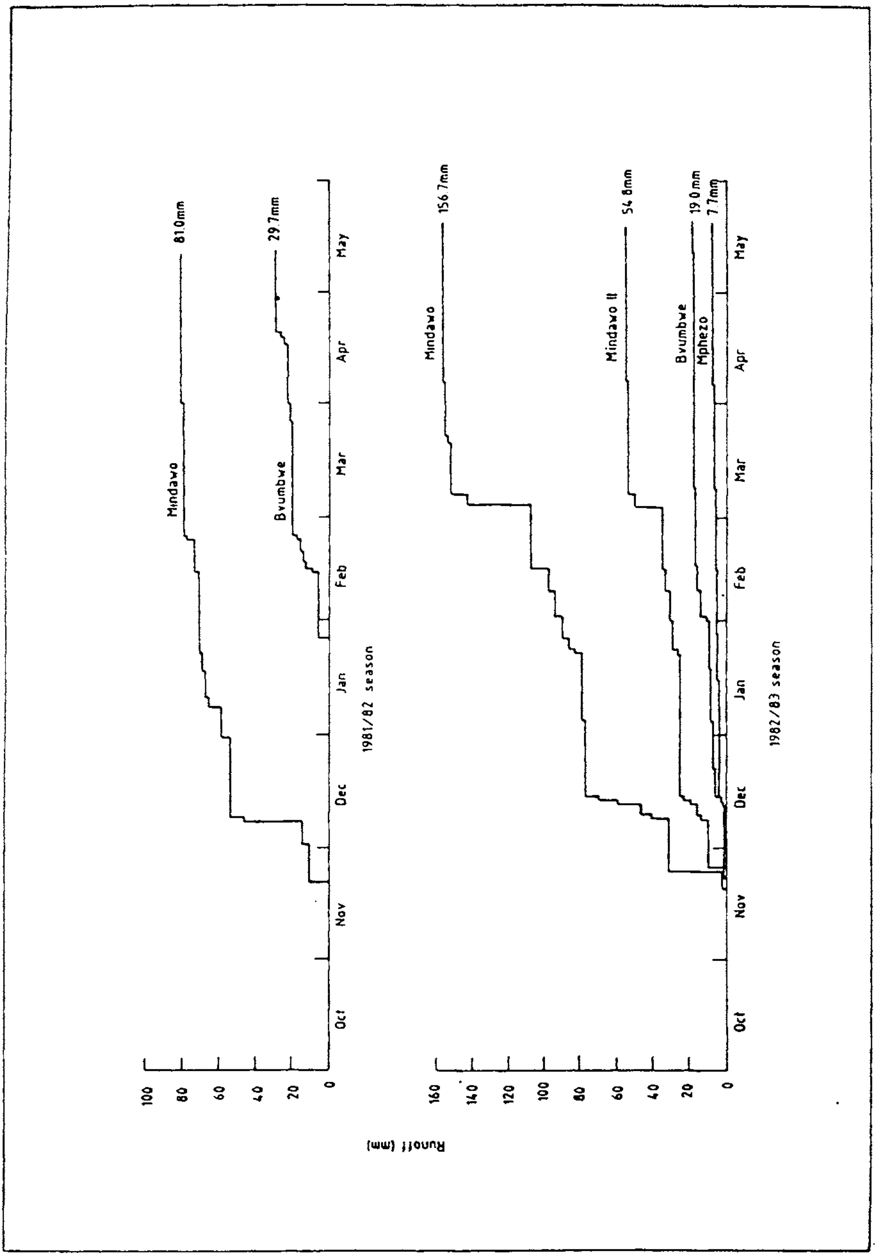
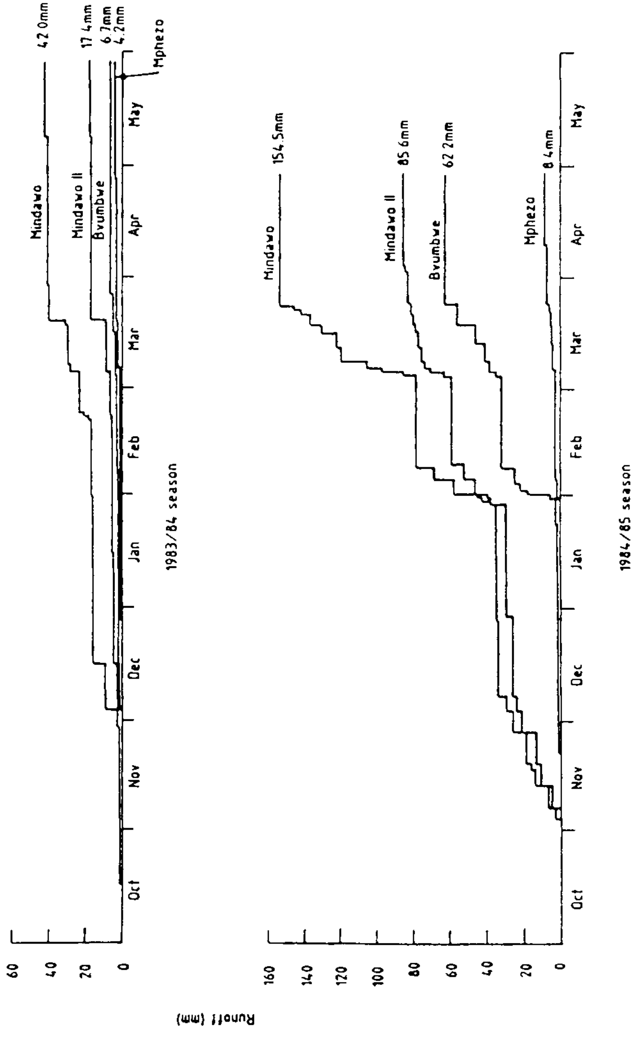


Figure 2 Cumulative runoff records for 1983/84 & 1984/85 seasons



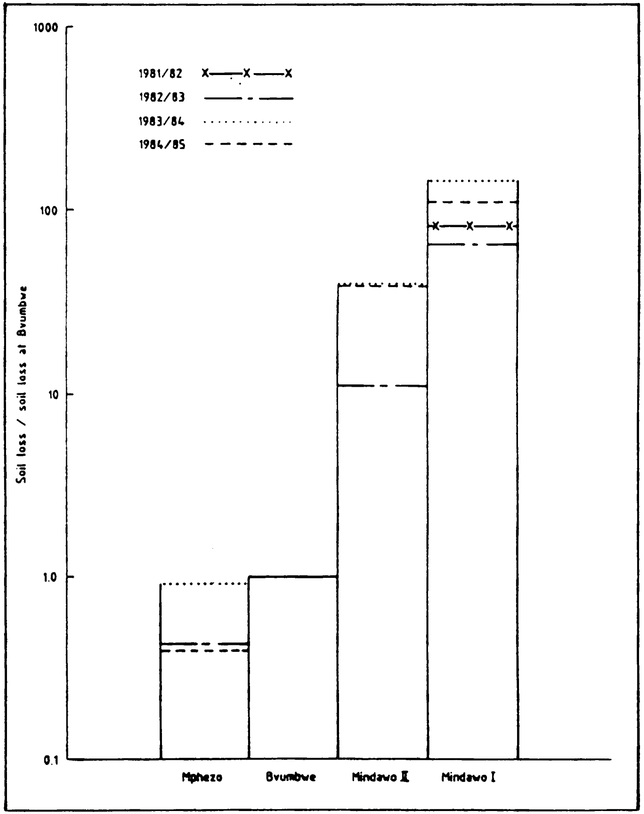


Figure 3 Ratio of soil loss to that in the Bvumbwe catchment

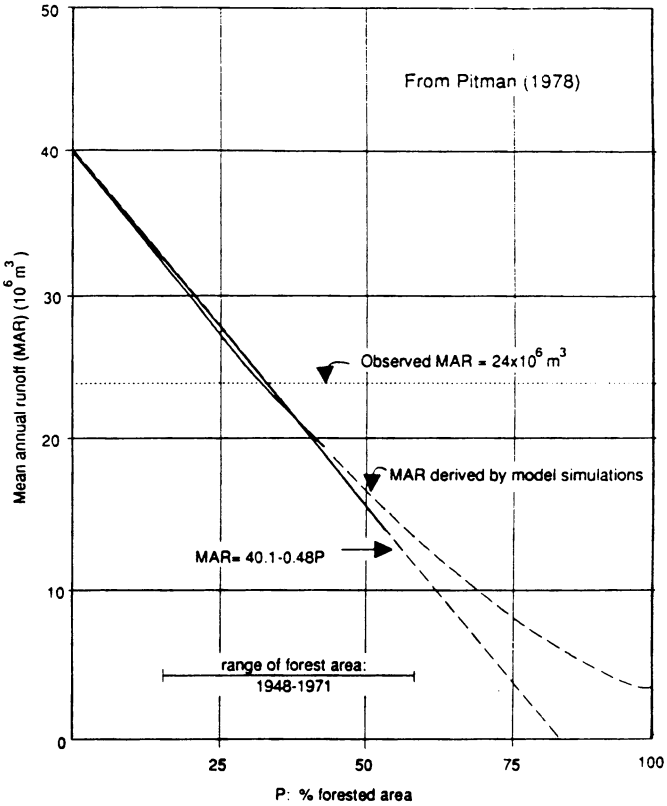


Figure 4 Relationship between mean annual runoff and forested area

Implications of changes in soil erosion rates, runoff rates, amounts and distributions

The movement of sediment downstream is highly influenced by high discharge events. This is because the relationship between suspended bed material concentration and discharge is a power law, ie:

$$\text{Concentration} = a * \text{Discharge}^{b}$$

where a and b are constants for a given river site, and $b > 1$.

This means that the total amount of suspended bed material transport is a power law with an exponent of b+1, ie:

$$\text{Transport} = a * \text{Discharge}^{b+1}$$

In areas where sediment supply is not restricted (ie. high erosion rates even on limited areas of the catchment, sediment deposits in the river valley, erodible river bed and banks) changes in the discharge pattern can thus have a major effect on the downstream sediment supply. Because of the form of the relationship, there is a much higher price to pay (in terms of increased sediment yield) for increased flood discharges, than any benefit that may accrue from reduced annual runoff volume. These concepts are illustrated in Figures 5 to 10.

Let us first imagine a situation where annual discharge is not greatly changed by the implementation of agroforestry, but both peak and low flows are increased. This situation was reported to have happened in the case described by Pereira in Kenya, which was previously mentioned. Figure 5 shows an idealised distribution of discharges before and after agroforestry has been developed. If we now assume a relationship of the form given above, between sediment transport and discharge, it is possible to calculate sediment yield for each group of discharges, and hence estimate annual sediment yield from the different discharge distributions. For all calculations in this paper, we will assume constant $a = 0.005$, and $b = 2.0$, values which have been found from our work in the Philippines. Figure 6 shows the

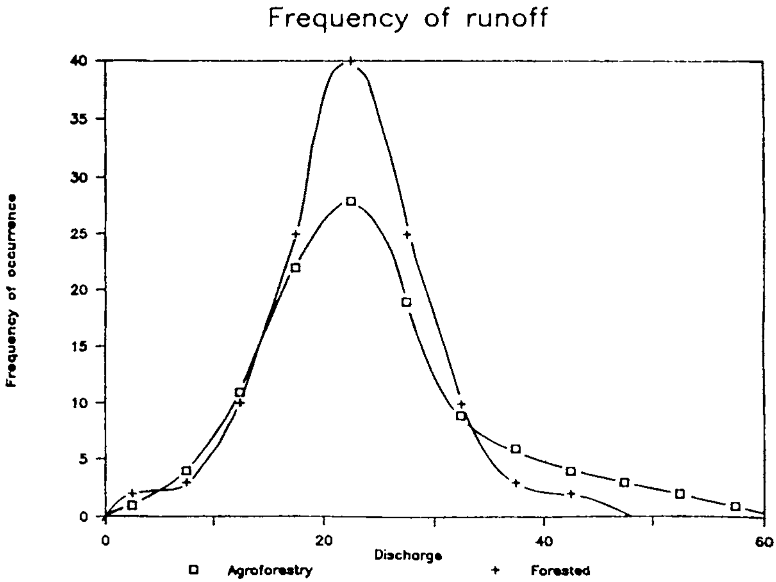


Figure 5 Hypothetical changes in runoff frequently due to land use change from forest to agroforest

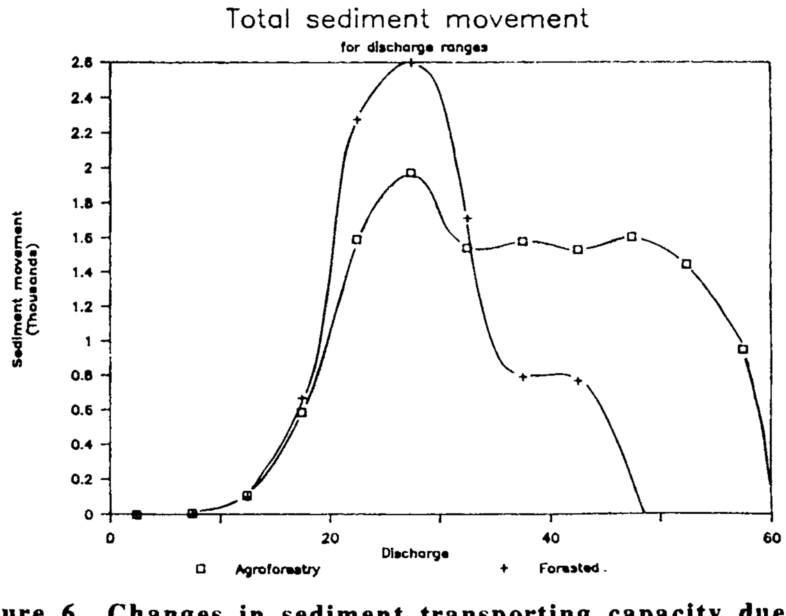


Figure 6 Changes in sediment transporting capacity due to hypothetical discharge frequency changes (forest to agroforest)

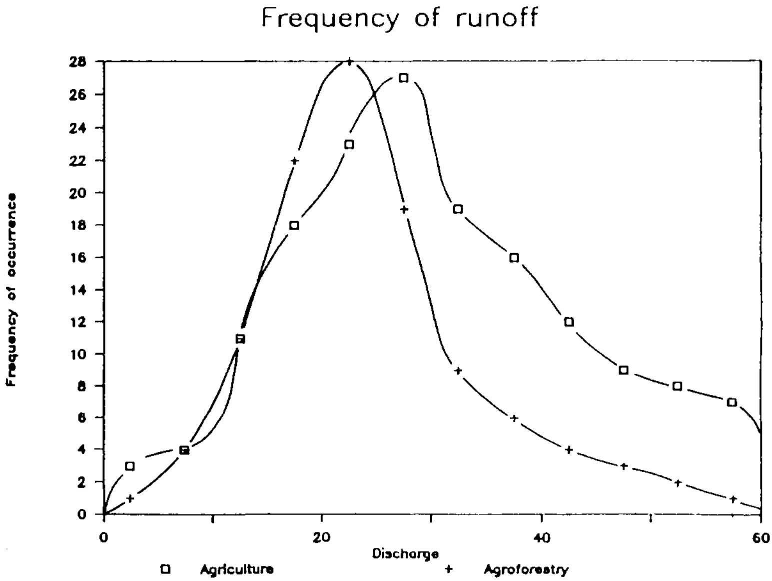


Figure 7 Hypothetical changes in runoff frequency due to land use change from agriculture to agroforest

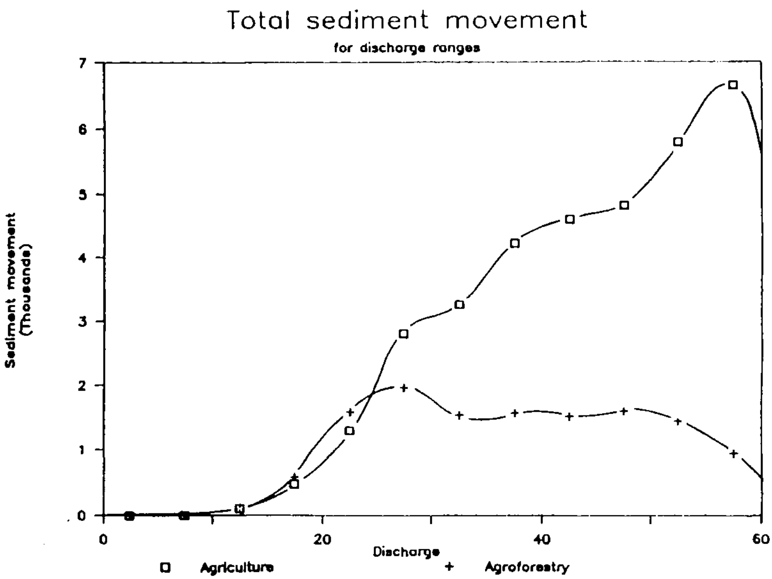


Figure 8 Changes in sediment transporting capacity due to hypothetical discharge frequency changes (agriculture to agroforest)

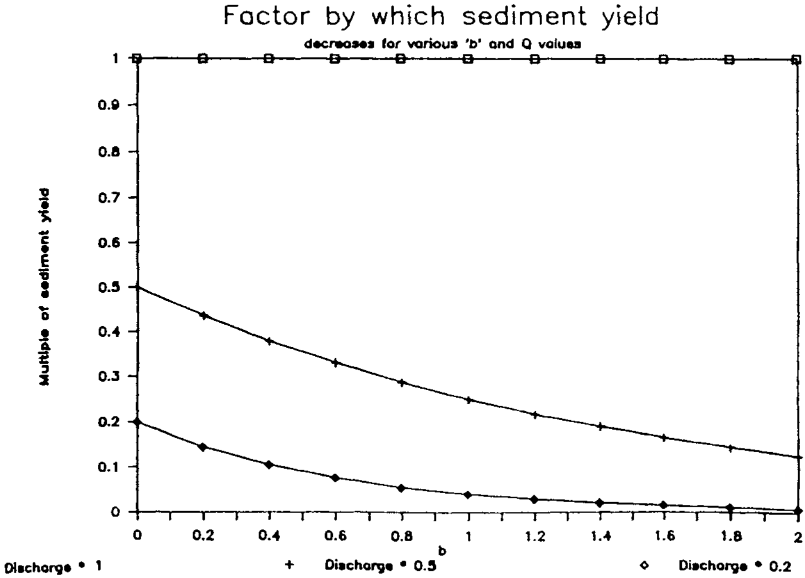


Figure 9 Potential decreases in sediment yield for reduced instantaneous discharge frequency changes

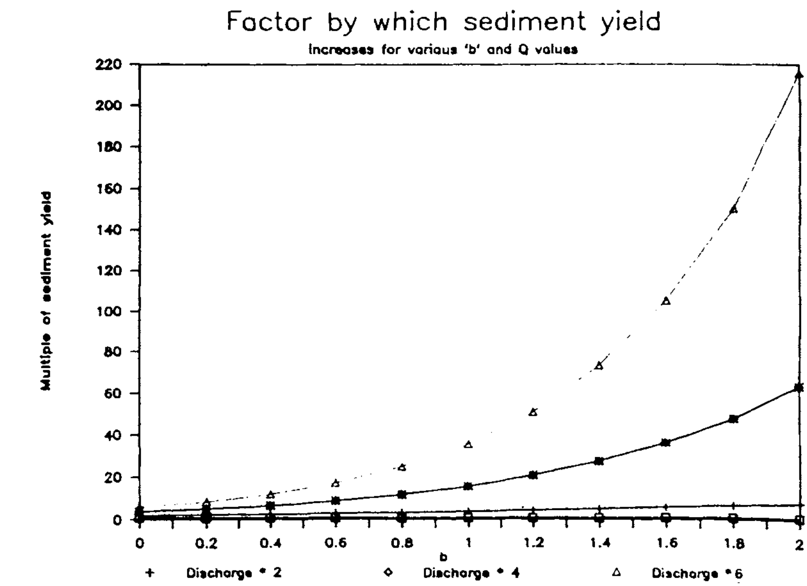


Figure 10 Potential increases in sediment yield for increased instantaneous discharge

result of these calculations in pictorial form. The data and calculations are given in Table 3.

A similar calculation can be done for a situation where peak and low flows together with annual discharge are reduced. Idealised distributions for this situation are shown in Figure 7, with corresponding sediment yields on Figure 8. These calculations are summarised in Table 4.

It can be seen from these two series of calculations, that simply shifting the distributions of discharge to higher flows, can dramatically increase sediment yield. In the first example we only increased peak discharge by 35%, without any increase in annual runoff. This caused a 45% increase in the capacity of the river to transport sediment.

If we can in some way reduce both annual discharge and peak flows, then corresponding reductions in the downstream sediment yield will result. This is what was shown by the second example, where annual discharge was reduced to 0.51 of the previous value, peak discharge was reduced by 0.79 and the sediment yield decreased to only 0.28 times its former value.

Although these examples are hypothetical, the point to bear in mind is that in terms of sediment yield, the important parameters are sediment availability and both the distribution and amount of discharge. Figures 9 and 10 show the factors by which sediment yield would be multiplied for certain values of the exponent 'b' in our power law equation and various multiples of instantaneous discharge. So for a 'b' value of 1.5, if we double the discharge for the peak flood event, the sediment yield will increase, for that storm, by a factor of 6.25. Similarly if we halve peak discharge we reduce sediment yield to 0.177 times its previous value. These calculations assume that sediment supply is not restricted. Typical values for 'b' are between 1 and 2.

A further complication is that there is some evidence that the concentration of sediment in a river may tend towards a maximum limit at extreme flows. This in part depends on sediment availability, but also on the size grading of that sediment. Any review of sediment concentrations in the major Chinese rivers will confirm that if sufficient fine material is available, then

Table 3

Flow and sediment distribution for forested catchment

Mean discharge	Number of storms	Total discharge	Sediment conc.	Sediment movement per event	Total sediment movement
2.5	2	2	0.03125	0.078125	0.15625
7.5	3	21.5	0.28125	2.109375	6.328125
12.5	10	525	0.78125	9.765625	97.65625
17.5	25	437.5	1.53125	26.79687	669.9218
22.5	40	900	2.53125	56.95312	2278.125
27.5	25	687.5	3.78125	103.9843	2599.609
32.5	10	325	5.28125	171.6406	1716.406
37.5	3	112.5	7.03125	263.6718	791.0156
42.5	2	85	9.03125	383.8281	767.6562
Totals	120	2700			8926.875

Flow and sediment distribution for catchment under agroforestry

Mean discharge	Number of storms	Total discharge	Sediment conc.	Sediment movement per event	Total sediment movement
2.5	1	2.5	0.03125	0.078125	0.078125
7.5	4	30	0.28125	2.109375	8.4375
12.5	11	137.5	0.78125	9.765625	107.4218
17.5	22	385	1.53125	26.79687	589.5312
22.5	28	630	2.53125	56.95312	1594.687
27.5	19	522.5	3.78125	103.9843	1975.703
32.5	9	292.5	5.28125	171.6406	1544.765
37.5	6	225	7.03125	263.6718	1582.031
42.5	4	170	9.03125	383.8281	1535.312
47.5	3	142.5	11.28125	535.8593	1607.578
52.5	2	105	13.78125	723.5156	1447.031
57.5	1	57.5	16.53125	950.5468	950.5468
Totals	110	2700			12943.12

Ratios for agroforestry/forestry

Annual discharge	1
Peak discharge	1.352941
Annual sediment load	1.449905

NB: For this example sediment concentration = 0.005 * Discharge^2

Table 4

Flow and sediment distribution for catchment under agricultural use

Mean discharge	Number of storms	Total discharge	Sediment conc.	Sediment movement per event	Total sediment movement
2.5	3	7.5	0.03125	0.078125	0.234375
7.5	4	30	0.28125	2.109375	8.4375
12.5	11	137.5	0.78125	9.765625	107.4218
17.5	18	315	1.53125	26.79687	482.3437
22.5	23	517.5	2.53125	56.95312	1309.921
27.5	27	742.5	3.78125	103.9843	2807.578
32.5	19	617.5	5.28125	171.6406	3261.171
37.5	16	600	7.03125	263.6718	4218.75
42.5	12	510	9.03125	383.8281	4605.937
47.5	9	427.5	11.28125	535.8593	4822.734
52.5	8	420	13.78125	723.5156	5788.125
57.5	7	402.5	16.53125	950.5468	6653.828
62.5	5	312.5	19.53125	1220.703	6103.515
67.5	3	202.5	22.78125	1537.734	4613.203
72.5	1	72.5	26.28125	1905.390	1905.390
Totals		5315			46688.59

Flow and sediment distribution for catchment under agroforestry

Mean discharge	Number of storms	Total discharge	Sediment conc.	Sediment movement per event	Total sediment movement
2.5	1	2.5	0.03125	0.078125	0.078125
7.5	4	30	0.28125	2.109375	8.4375
12.5	11	137.5	0.78125	9.765625	107.4218
17.5	22	385	1.53125	26.79687	589.5312
22.5	28	630	2.53125	56.95312	1594.687
27.5	19	522.5	3.78125	103.9843	1975.703
32.5	9	292.5	5.28125	171.6406	1544.765
37.5	6	225	7.03125	263.6718	1582.031
42.5	4	170	9.03125	383.8281	1535.312
47.5	3	142.5	11.28125	535.8593	1607.578
52.5	2	105	13.78125	723.5156	1447.031
57.5	1	57.5	16.53125	950.5468	950.5468
Totals	110	2700			12943.12

Ratios for agroforestry/agriculture

Annual discharge	0.507996
Peak discharge	0.793103
Annual sediment load	0.277222

NB: For this example sediment concentration = 0.005 * Discharge^2

the river will carry it! The tendency to a maximum sediment concentration is not seen everywhere, and so far there is no method of predicting in which rivers it will occur. To err on the side of safety, one would normally assume no concentration limit.

Increasing sediment yield to a downstream area, which by definition will have lower river channel slopes and a corresponding lower ability to transport sediment, may well cause aggradation. This may be in the river, or in downstream engineering works such as irrigation schemes or reservoirs. These all have associated management problems and costs. Aggradation in the river may well mean increased flooding and less predictable river locations. The latter makes the siting of offtakes extremely difficult, and often results in offtakes which are stranded laterally.

A decrease in sediment supply to the downstream area may well be thought of as a good thing, but it again has associated problems. If sediment supply is reduced, but discharge remains the same then it is possible that the river will begin to erode the river banks and bed in order to supply itself with sediment. This can again result in stranded irrigation or water supply offtakes, this time above the level of the river.

Changes in the discharge patterns and amounts have more obvious implications for the downstream zone. Increasing peak discharge will result in a greater risk of flooding downstream, with a lower risk of flooding being due to lower peak discharges. But lower peak flows may well go hand-in-hand with reduced low flows and annual discharge, both of which mean reduced water abstraction is possible. Reductions in low flows may even result in periods of critical water shortage for water supply or irrigation schemes.

So, the upstream-downstream relationships are not simple, and are not even reliably predictable at present. Changes in flow distributions and the assessment of sediment availability are two areas where it is particularly difficult to make reliable predictions. It is probably true to say that most downstream benefits have an associated downstream cost and vice versa. But this does not mean that they can be ignored. Much research is needed in this area, if successful development, in terms of the catchment as a whole, is to occur.

The prediction of changes in downstream discharge and sediment transport due to upstream land use change

The prediction of the hydrological effect of various conservation techniques, especially in terms of sediment yield, is something which is at present very difficult to carry out. This is particularly true in the tropics, where little data on soil loss or sediment movement downstream have been collected. There are predictive models available, both for estimating soil loss under various land uses, and for predicting sediment yield. Most of these have been developed in the USA, and are not transferable to the different climatic, topographic, soils and agricultural conditions found in the tropics. Many of the models fall down on the constituent parameters which have to be estimated en route to prediction. An example of this is the EI30 parameter representing rainfall erosivity in the Universal Soil Loss Equation (Wischmeier and Smith, 1978). It is now well reported that EI30 overestimates erosivity at the high rainfall intensities found in the tropics.

Many of the sediment yield and discharge prediction models that are available, are extremely data hungry, demanding inputs such as twenty years of continuously recorded rainfall data, or cross-sections every 100 metres down a river profile (eg. Beasley, 1977; Li, 1977; Crawford and Linsley, 1966; Holtan et al, 1975). Collection of this sort of detailed data is obviously out of the question when one is just trying to assess the impact of a small land management plan for a fraction of the catchment; realistically, it is not even going to happen for assessment of major projects. Models which do show some promise in terms of predicting the parameters of interest have rarely been tested in the tropical environment, partly because of data availability problems. Many of them are, in any case, based on the Universal Soil Loss Equation which has been shown to be lacking outside of the USA. The work of Moore and Clarke (1981 and 1983), using a statistically based runoff and sediment yield model, was tested on data from the study in Malawi, but was not very successful. This was possibly because the model was developed on data from

Europe, and did not transfer well to African conditions. It is hoped that further work to adapt the model to non-European conditions will take place.

The alternatives to these data hungry, sophisticated computer models are a few very simplistic prediction techniques, which take a limited view of the causal and restrictive factors in the runoff-erosion process (eg. Fournier, 1960; Fleming, 1969; Al Kadhimi, 1982). These models also present difficulties for inclusion of limited land use change. At best they give order of magnitude answers.

Another favoured technique for sediment yield prediction is the use of a sediment delivery ratio, in conjunction either with data or predictions of soil erosion at the small scale. There are several different versions of the sediment delivery ratio, all empirical (eg. Roehl, 1962; Williams, 1977; Renfro, 1975). Some are based on catchment area, whilst others rely on topographic relationships (Fig. 11). All of them purport to do the same thing, which is to use soil erosion figures for the whole catchment (divided into small areas and assessed individually) and then to scale these down to allow for the temporary and permanent deposition of sediment on its way downstream from the fields to the river. The basic concept is sound in that soil may be eroded many times on its way down hill, but will only once be part of the sediment yield of the catchment. However, thinking that a simple reduction factor can represent the complexity of sediment erosion and transport is not realistic, and more research is needed to better explain the processes involved. It will not be possible to model the overland sediment movement phase throughout a catchment, because of the complexity of the system. We only have to remove one tree from a hillside to alter both the local erosion and the movement of sediment which previously got stuck behind the tree! It would simply be impossible to incorporate all the detailed information that would be needed for such modelling, and even if we could it would be impossible to keep up with the changes to the system which happen every day. So, we must settle for some sort of 'lumped' approach to modelling. At Hydraulics Research (HR) we are convinced that the best way to pursue this subject is to monitor the effects of various land uses at the catchment scale, rather than on a plot

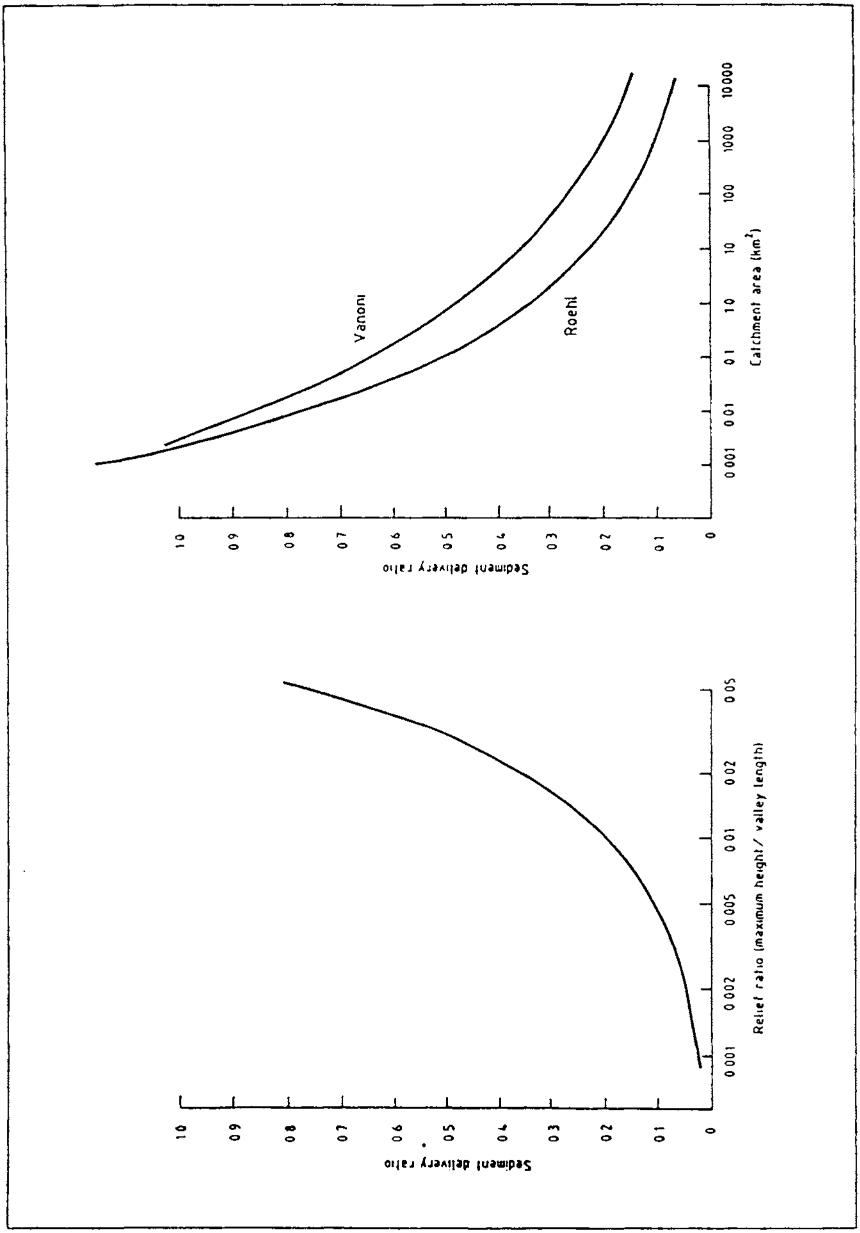


Figure 11 Sediment delivery ratio as a function of catchment area and relief ratio

scale. Plots, of course are useful for quantifying on-site benefits, but are of little use to the off-site questions.

The research of the soil erosion group of the Overseas Development Unit (ODU) at HR is focused on improving prediction techniques for sediment yield in the tropics. This involves, by default, modelling discharge patterns and soil erosion, and changes in them due to alterations in land use. At present our research is in the early stages, but we believe that we can now produce more realistic estimates of sediment yield than has previously been possible. Our approach is a modular one, looking at sediment supply, sediment transport, distributions of rainfall, runoff and flood events separately, so that different aspects can be updated or improved without changing the way that the final predictions are done. To carry out this work we must look at catchments in terms of several smaller sub-catchments which we can study in some detail, and about which we can make reasonably reliable estimates. This approach gives us the flexibility to assess the effect of changed land use on a small area of the catchment, on water or sediment yield at some point downstream.

In the meantime we are carrying out measurements at the small catchment scale (10's of hectares) (Amphlett, 1986; Amphlett and White, 1986; Dickinson, 1988) as well as at larger scales. Our major research project for the last four years has focused on the measurement of discharge and sediment transport for a 4123 square kilometre catchment in the Philippines (Amphlett et al, 1987; Wooldridge, 1986). This study is aimed at investigating the way in which sediment moves through the catchment, by monitoring at a series of nested sites, with areas increasing by a factor of 10, as one moves to the next site downstream. A similar project was initiated in Botswana (Amphlett and Hare, 1988; Blyth, 1989a). This latter project has unfortunately given little data, in part due to a one in fifty year flood which removed the bridge from which we were monitoring. We hope to find another site for a further nested catchment study shortly.

However, the monitoring of discharge and sediment yield forms but a part of the work that is needed on the prediction of catchment sediment yield in the tropics. A further part of our study has been aimed at learning from the data, and developing predictive techniques which address both the lack of models available for the tropics, and the need to assess the catchment implications of changes in land use at whatever scale. The basic concept was to look at a catchment in terms of several small sub-catchments. This is partly because much more work has been done at the smaller scale, both in terms of monitoring and predictive techniques, and we thus feel more confident about estimating sediment yield at the small scale. The use of small catchments also limits the variability of soils, land use and rainfall within the area which we are considering as a unit in terms of sediment yield. Each of our sub-catchments has a defined stream outlet, meaning that from the outlet of the sub-catchments downstream we are routing discharge and sediment in a river rather than overland. We are thus detaching the two processes which the sediment delivery ratio inherently considers together, namely overland flow and river discharge routing. The desirability of this split has long been recognised (Pacific Southwest Interagency Committee, 1968; Walling and Webb, 1983, Fleming, 1984) and is incorporated in some of the more sophisticated predictive models.

The estimation of sediment yield at the small-scale is done by use of an erosion prediction technique in combination with a sediment delivery parameter to represent the amount of eroded sediment which reaches the stream. This means that we must consider erosion from areas even smaller than the sub-catchments. This is achieved by use of a micro-computer based Geographical Information System. Variation of parameters is considered for each pixel of the catchment. The area which a pixel represents depends on the scale at which one works. For our 4123 square kilometre catchment each pixel represents an area of approximately 150x150 metres. This enables realistic application of the field or plot scale erosion predictors. We have so far used the SLEMSA (Soil Loss Estimator for Southern Africa, Elwell (1980)) in combination with a sediment delivery factor due to Hession and Shanholtz (1988). This work is reported in White (1989a). We are going on to test both modified versions of the Universal Soil Loss Equation, and the AGNPS model (Hession and Young, 1988).

Potential erosion can be calculated for each pixel throughout the catchment in much the same way recommended by Stocking (1987).

This goes on to be lumped together on a sub-catchment basis to give a figure for sediment yield. For the Philippines project we can obviously compare the output from our model with the measurements we are making in the river network. It is almost certain that some degree of calibration against measurements will be necessary. This is likely to always be the case, and our recommendations for sediment yield prediction will therefore always include a limited monitoring programme.

A limited set of measurements is unlikely to cover the full range of events that may occur at a site, and so some way of putting the period of measurement into context in the long term is needed. This forms the third aspect of our study, which looks at statistical distributions of rainfall and runoff events, changes in land use that have happened or may occur in future, and any other factors which have implications for change in the rainfall, runoff or sediment supply patterns (Blyth, 1989b).

Table 5

Multiples of sediment movement caused by variation in discharge

Sediment concentration = a * Discharge^{b}

Peak discharge *	0.2	0.5	1	2	4	6
Value of b	Factor by which sediment yield increases or decreases					
0	0.2	0.5	1	2	4	6
0.2	0.144955	0.435275	1	2.297396	5.278031	8.585814
0.4	0.105061	0.378929	1	2.639015	6.964404	12.28603
0.6	0.076146	0.329876	1	3.031433	9.189586	17.58093
0.8	0.055189	0.287174	1	3.482202	12.12573	25.15777
1	0.04	0.25	1	4	16	36
1.2	0.028991	0.217637	1	4.594793	21.11212	51.51488
1.4	0.021012	0.189464	1	5.278031	27.85761	73.71621
1.6	0.015229	0.164938	1	6.062866	36.75834	105.4856
1.8	0.011037	0.143587	1	6.964404	48.50293	150.9466
2	0.008	0.125	1	8	64	216

Research needs

It is apparent from what has been reported here that there is much work to do on the prediction of the downstream effects of upstream land use change, particularly in the tropics. It is not even easy to model a catchment with no land use change - but at least then we have the option of measurement! These shortcomings in modelling are not specific to agroforestry, although the lack of data on the on-site effects of agroforestry do not ease the situation. Research needs are therefore twofold.

First there is a need for more data on the effect of agroforestry on soil erosion and runoff amounts and distributions. This is of course not a simple task, as the term agroforestry covers such a wide range of cropping patterns and management techniques. It is therefore vital that where measurements do occur, they, and the agroforestry system to which they apply, must be comprehensively reported. Furthermore, these data must be made available. It is surprising how much measurement of erosion rates is done and then not reported outside of the organisation where it was carried out. Measurements on the implications of agroforestry need to be done at both plot and small catchment scales. As stated before the plot studies are not of much use for catchment scale prediction, although being useful for on-site assessment.

The second research area which needs to be further investigated is the movement of sediment and water through the catchment. This is where our work at HR is concentrated, although as part of this work we are monitoring at the small catchment scale. We think this is best done by measurement in a series of nested catchments, whilst at the same time some fundamental thinking about sediment delivery is done. The latter has commenced at HR with some ideas, and order of magnitude calculations for a cyclone affected area such as the Philippines (White, 1989b).

Apart from the technical questions, we feel that some thought must be given to the economic analysis of land management plans. Often the implications of such projects are far reaching and long lasting, with some benefits or costs not happening for several years. With current cost-benefit analysis and existing discounting rates, benefits 20 to 25 years in the future are of virtually no value. Of course any change in economic analysis is dependent on reliable technical predictions being made, so it makes sense to work together in a multi-disciplinary team - something which happens infrequently today, but which would seem to be vital for future progress.

Acknowledgements

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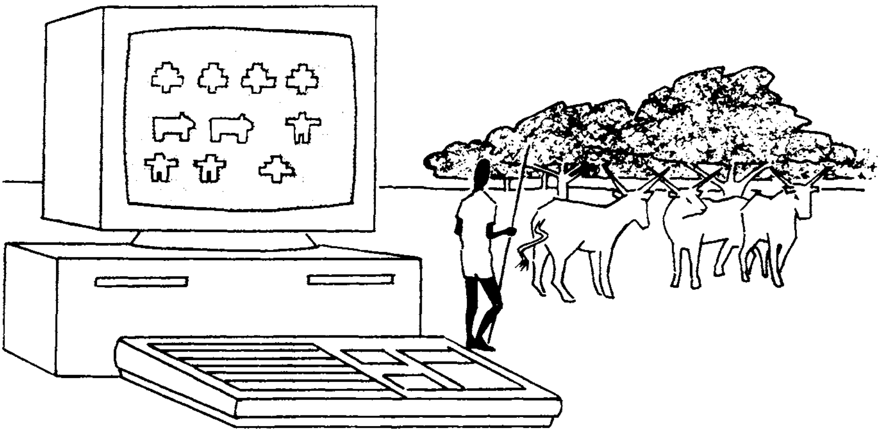
CHAPTER 3

ECONOMIC MODELLING FOR AGROFORESTRY SYSTEMS



A SPREADSHEET APPROACH TO THE ECONOMIC MODELLING OF AGROFORESTRY SYSTEMS

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CONTENTS

Introduction

This paper is divided into two parts. Section A is concerned with methodological aspects of the economic evaluation of a system of multiple land use in which agricultural and forestry enterprises are undertaken on the same area of land. It begins by describing the general approach and assumptions adopted and then proceeds to outline in detail key components of a computerised spread sheet model embodied within the VP - Planner package. This allows a large number of parameters, both technical and economic, to take on a range of possible values thus enabling an assessment of the sensitivity of profitability to changing technical and economic conditions. Section B presents the results of applying this methodology to a poplar, cereals and sheep agroforestry system, primarily to demonstrate its flexibility. Finally some conclusions are drawn as to the proper context within which a spreadsheet model such as this can operate.

SECTION A

1. The General Approach

The approach adopted here has been for both forestry and agricultural components to:

a. Identify relevant inputs.

b. Quantify their levels for assumed output levels consistent with specified site conditions.

c. To simulate 1) The growth of physical timber volume
2) The decrease in physical agricultural output consistent with this growth.

d. To calculate costs and revenues associated with both activities on an annual basis using input and output prices applying in a specified year.

e. To use Discounted Cash Flow Analysis for the purpose of calculating the Net Present Value (NPV) from:

(i) All Forestry
(ii) All Agriculture
(iii) Agroforestry on equivalent areas of land.

2. **Assumptions relating to the approach adopted**

(i) This analysis is confined to 1 ha 'cells' of land apportioned to varying fractions between agriculture and forestry. The fractional area occupied by agriculture is determined at the outset by assumed tree planting and inter row widths.

(ii) The analysis is conducted for a specific rotation length, though this of course can be varied to determine optimum rotations.

(iii) It is assumed the actual area of agroforestry within the farm is not of a sufficiently large extent to justify an alteration in fixed costs. Practical experience on farms in New Zealand stresses the importance of never planting at any one time an area of trees whose silvicultural needs in terms of thinning and pruning cannot be adequately coped with by the farm staff. By establising uneven age stands to a maximum of round 15% of the farm area this criterion can be met.

(iv) For certain specific operations relating for example to timber felling, cross cutting and extraction, additional capital items may well be required. In order to avoid difficulties associated with depreciating farm and forestry mixes of equipment, much of which may well already exist on farms, the approach adopted here is to use contractors for these operations.

(v) In the example illustrated in Section B the analysis is conducted throughout 1987, costs and prices at an assumed real interest rate of 3%. Inflation is assumed to affect both components equally in terms of costs and output. Sensitivity analysis enables scenarios which postulate changes in relative product prices and costs to be explored.

3. The Model

A schematic representation of its components is presented in Figure 1. Some additional comments relating to certain components are presented below.

a) Grower

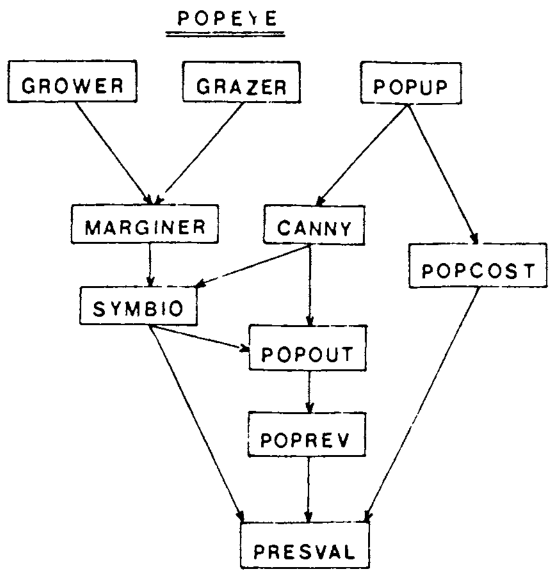
At present this is a user estimate of physical yield based on a visual inspection of the site in conjunction with data relating to soils, geology, topography and bioclimatic data. Input levels are assumed to be consistent with output levels. Eventually 'grower' will comprise a range of response curves which will be selected by the user and reflect differences in production levels according to site capability.

b) Grazer

Similarly what exists at present is a visual inspection of sward type. Dry matter production per ha, consistent with climatic and soil conditions, is assessed, as is its Metabolisable Energy (ME) value per ha. Stocking Density is then calculated on the basis of animal requirements consistent with an assumed level of livestock performance. It should be apparent therefore that site capability is an important element in the sensitivity analysis afforded by the spread sheet.

c) Popup

This is a timber yield model which describes the volumes of timber per ha. as a function of (i) the number of stems per ha.(ii) the diameter, height and form of individual trees. Tree diameter (D.B.H) varies with spacing at a given age and tree height varies with age but is largely invariant with spacing. Using widespread Poplar as an example, it is possible using stand tables to provide a range of values for spacing, age and tree diameter when which analysed by Multiple Regression Analysis can be used to predict both DBH and Tree height as a function of age.



GROWER. Estimates yield on the basis of site characteristics
GRAZER. Identifies sward.Calculates D.M. per ha. Estimates ME values of swards. Calculates stocking rate.Estimates performance level.
POPUP. Estimates Stem Diameter and height from spacing and age.
POPCOST.Details inputs and factor prices required for all planting. Silvicultural and harvesting operations. Calculates timber costs per ha. per year for any specified planting regime.
MARGINER. Converts Grower and Grazer to equivalent Gross Margins (£/ha).
CANNY. Estimates crown diameter from stem diameter and crown depth from POPUP for any specified pruning regime
SYMBIO. Reduces agricultural gross margins per ha. with increasing crown development. Alters annual basal area increment as required.
POPOUT. Estimates timber volume on the basis of Buttlog Volume and Toplog volume per ha.
POPREV. Includes grants, all product prices and calculates revenues per ha. per year of rotation for any specified planting regime.
PRESVAL.Calculates net cash flows per annum and uses these to give Net Present Values (NPV) per ha. for a range of real discount rates 'All Agricultural', All Forestry and Agroforestry' options are compared.

<u>Notes</u> All input and outputs are include as variables in both physical and financial forms. Th s changes in technical input/output coefficients, factor and product prices can be examined in terms of their impact on NPV.

Figure 1 Popeye: A Schematic Representation

This yields equations of the general form

$$D = a + b \ln (A.S) \qquad (1)$$

where

D = diameter at breast length (1.3m)
A = age of tree in years
a&b = constants
ln = natural logarithm
S = tree spacing in metres

and

$$H = a + b(A) + C(A^2) \qquad (2)$$

where

H = Dominant Tree height in metres
a,b&c are constants
A = Age of Tree in years.

d) **Popout**

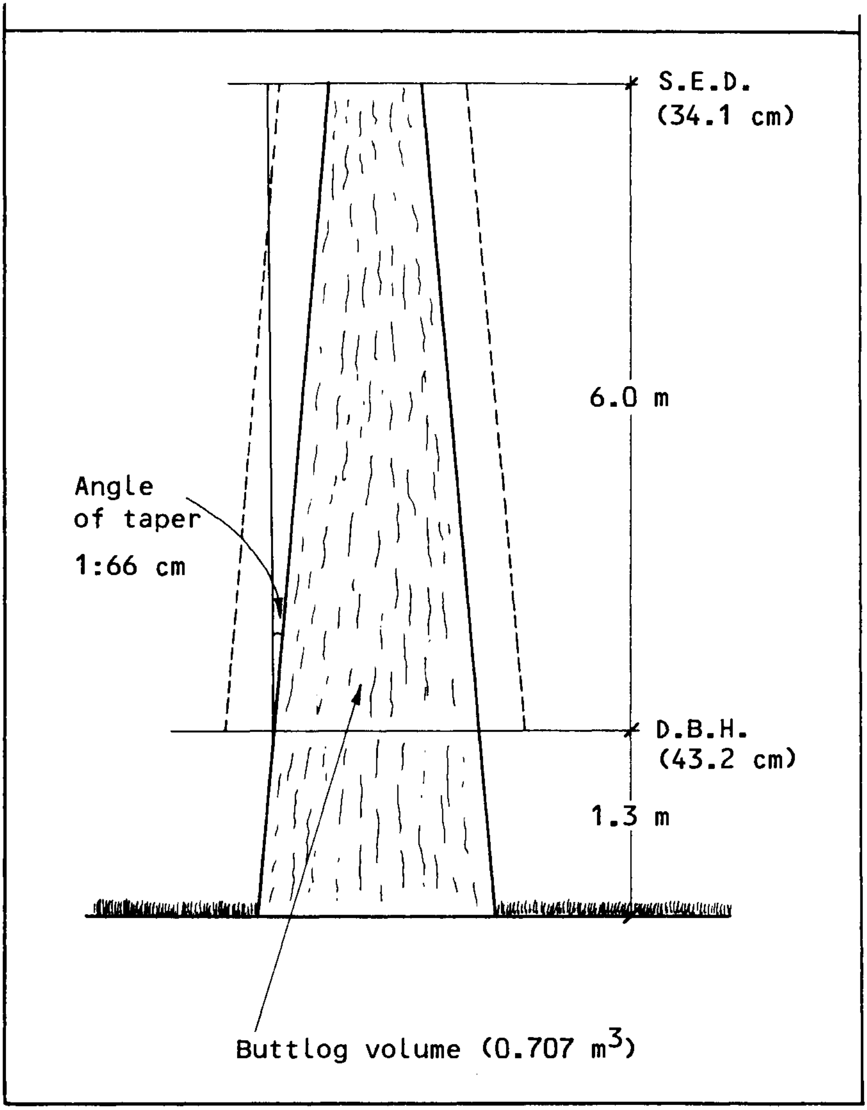
This component adjusts individual tree volume by a) introducing a range of 'taper' functions, b) calculating ' small end diameter' (SED) at any specified pruned height, and c) distinguishing between 'buttlog' and 'top log' volume. These features are illustrated in Figure 2.

'Butt log' volume is considered to be represented by the 'frustram of a cone' whose volume is given by

$$B = \frac{\pi}{12} (D^2 + Dd + d^2)\ h. \qquad (3)$$

where

B = butt log volume measured in cubic meters
D = diameter at Breast Height (1.3m)
d = 'small end' at 'top' diameter at a given height
h = dominant tree height in metres



KEY

—— Dimension in period t.

--- Dimension in period t+1.

Figure 2 The Form Characteristics Predicted by the Model Poplar (22 Years)

Top Log Volume is assumed to be represented by a 'cone' whose volume is given by:

$$T = \frac{\pi d^2 h}{12} \qquad (4)$$

where

T = Top log volume measured in cubic metres
D = diameter measured in metres
h = dominant tree height measured in metres

Form characteristics are an important aspect of open grown trees since these tend to produce greater taper and thus a loss in volume with increasing tree height. Pruning can reduce this effect by effectively pushing the cylindrical component further up the stem. It is obviously essential to achieve as high a volume of timber production from the buttlog as possible since pruned timber carries a much higher price premium. This can also be achieved by breeding. Certainly the latest Belgian poplar clones can have form factors as high as 0.5 (Van Slycken pers. com. 1989) when compared with a 'conical' form factor of 0.33. The Spreadsheet allows tree form to be altered across a range of taper functions.

Finally, top log and bottom log volumes are multiplied by their appropriate prices depending on their final end use. Within a market economy, price quotations for sawlogs based in larger diameter classes are obtainable, though precision in terms of a price size relationship varies enormously from country to country. It is particularly poor in the UK, better in Europe and much better in Australia, Chile and New Zealand where greater emphasis is placed on larger diameter logs (Thomas et al 1989). However, a subsistence economy presents greater problems in terms of product valuation.

e) **Canny**

This component uses an acknowledged relationship between crown diameter and stem diameter to simulate the dynamics of canopy development. The theoretical basis for this relationship can be found in the 'stove pipe' theory of plant growth (Franco 1987). Dawkins (1963) distinguished between a range of tropical species in terms of their ability to tolerate competition from other crowns whilst still maintaining diameter growth. More recently Kalibala (1988), Pryor (1985), Garson (1988) and Saville (1988) have determined crown diameter:stem diameter equations for a range of common British species following the general form:

$$D = A + B(DK) \qquad (5)$$

where

D = diameter at breast height measured in centimetres
DK = crown diameter measured in centimetres
a&b = constants

In this spreadsheet model the causal relationship is reversed so as to predict tree crown diameter from tree stem diameter in (1). However the nature of 'fit' is normally so good between these two variables this is not statistically a problem.

Crown diameter, and indeed crown depth are important information. Crown depth is predicted from tree height less any adjustment for pruning as and when it occurs.

f) **Symbio**

This component deals with positive and negative interactions between tree and agricultural activities. Dealing with negative interactions first, agricultural output declines as a result of tree growth and its associated increase in shading. This can be coupled with underground effects concerned with reduction in soil nutrients and water availability through increased root competition, for example Castellani and Prevosto (1967), (Atkinson 1988). Additional negative interactions may be concerned with bark stripping, browsing of young trees and increased parasitic infestation in animals.

Secondly, considering complementary effects, these may be manifested in an increased tree basal area increment of up to some 40% due to fertilising effects of grazing animals and reduced understorey competition (Knowles and West, 1987). Agricultural livestock productivity may be increased by up to 20% as a result of shelter or shade effects as reflected in higher lambing percentages or increased stocking rates (Reid and Wilson 1985). Similarly, trees may actually prolong pasture productivity within a season due to an amelioration of land drying by wind or direct sunlight. Variations undoubtedly exist between tree, grass, and animal types in terms of the nature of these interactions. For example not all trees are damaged by livestock and neither do all livestock damage trees. Similarly not all trees benefit from livestock grazing, indeed for poplar for example some evidence suggests the opposite (Anon 1986). By contrast, for the same genus light cultivations can significantly enhance the mean annual increment of timber volume (Anon 1977). Trees vary in terms of their ability to withstand heavy pruning regimes and maintain diameter growth. Evidence suggests however that price premia for clear wood (Price 1989) at least match in total revenue terms the reduction in volume which can arise, and grazing revenues are maintained.

Other differences in tree species with respect to the seasonal timing of their leaf development when compared with understorey development will significantly effect reduction in pasture production. Moreover seasonality of pasture production is itself likely to be site specific, at least in regional terms. In Wales for example, leaves tend to emerge when grass production is already well underway. The duration of the canopy is short and opacity of the canopy much lighter than when compared with, let us say, sycamore.

All of these aspects suggest a complex mix of positive and negative interactions which ultimately may result in a positive net effect on the side of agroforestry in terms of total production.

This very brief review of the real world 'black box' of interactions which is conceptually encompassed by SYMBIO serves to illustrate the likely complexity of interactions. There are also many gaps in the information available and many compartments needed to accommodate known and potential effects on output levels. As time progresses and information becomes available the relative importance of these various interactions under a range of topographic and climatic conditions will be better understood and estimates of technical parameters will be improved. Once a spreadsheet exists, however, it becomes easier to accommodate such progress within it.

This spreadsheet currently encompasses two broad types of interaction. Firstly negative interactions caused by shading out of the understorey with increased canopy development through time. Secondly, complementarity, or competition as reflected in the rate of annual change in timber volume per ha.

Taking the latter first the effect on timber volume can be accommodated by adjusting equation (3) as follows:

$$C_B \quad \sum_{t=1}^{r} \left[\frac{\pi}{12} (D^2+Dd+d^2)h\right] c \qquad (6)$$

where

C_B = the total increase in timber volume per butt log

t = the start of the period over which the effect is assumed to occur

r = the end of the period over which the effect is assumed to occur

c = the complementarity or competition factor expressed as a decimal with appropriate sign attached

Such evidence as exists, for example (Knowles 1988) suggests that complementarity of this type occurs in the period prior to canopy closure though the effects of cropping and grazing may be quite different. The above equation effectively allows for a partitioning of the rotation into whatever periods are thought to be appropriate, with associated values for the complementarity or competition factor.

Considering now the matter of simulating the decline in agricultural production over time, a number of approaches have been used. In New Zealand for example, it has been observed that decreases in annual dry matter production appear to correlate well with green crown length and the number of crowns per ha This approach makes intuitive sense in that in higher latitudes, conical and columnar shapes cast longer shadows hence the importance of crown diameter and crown depth as variables. Alternatively, more fundamental approaches utilise light interception models. Some are forestry orientated in terms of planting designs, (eg Kauluvainen and Pukkala 1982). Others require information describing the opacity of the canopy as measured by leaf area index and crown dimensions at wide spacing (Jackson and Palmer 1979), (Slatterlund 1983). The latter in particular give rise to difficulties associated with spatial arrays of trees, a paucity of information existed until recently of the crown dimensions of trees and the horizontal distribution of shade associated with direct as opposed to diffuse sunlight.

Given these limitations, two approaches are currently available in this spreadsheet. The first can best be described as a sensitivity approach. The pasture component when viewed in general terms, follows a well developed pattern of declining productivity. There is an initial period of shade free years during which the level output is unaffected and can be characterised as a plateau, or may well increase. This is followed by a rapid decline in output, offset to varying degrees by thinning and pruning operations, before a lower plateau is reached as a result of canopy closure. The researcher effectively uses whatever sources of information are available to him to locate the upper plateau in horizontal space, ie. thereby defining the shade free period. The lower plateau has also to be located in vertical and horizontal space. These two plateaux are then linked by mathematical functions which best describe the rate of agricultural output decay through time. In Fig. 3 we see both plateaux located and representing an initial shade free period of two years and a lower plateau level of some 30% of open grazing. Both are connected with a combination of cereal and pasture decay functions derived by fixing equations to data pertaining to a poplar, cereals and sheep system found in the West Midlands of England (Beaton 1987).

The grazing decay function fits the data well and is represented by an equation of the form:

$$Y = A+Be^{-Kt} \qquad (7)$$

where

Y = a coefficient of decay expressed as a decimal
A,B and K are constants
t = time

The crop decay function also fits the data well and is represented by an equation of the general form

$$Y = \left(A \frac{100}{P(T+T^2)}\right) \qquad (8)$$

Where

Y = a coefficient of decay expressed as a decimal
A and P are constants
T = time

In Equation (7) and Fig. 3 the initial (shade free) plateau is represented by A+B, the final plateau by A and the proportional rate of decline by K. Provided A and B can be defined, it is possible to estimate how changes in the value of K influence yield at chosen times in the period of change. Moreover different scenarios relating to the difference between the temporal position of the upper plateau and horizontal position of the lower plateau can be examined in terms of their impact on agricultural output for a given tree species and planting regime.

There may of course be no secondary sources of data available since the system may have never been operated. Some form of biological modelling must then be necessary. Current work on light interception under ash trees in Southern England (Newman pers. comm.) suggests that a diffuse light situation falling vertically on opaque tree crowns is likely to approximate conditions prevailing there for over sixty percent of the time and particularly so in the period in which understorey growth is most pronounced. A similar situation might conceivably exist in the tropics. Provided that crown diameter can be predicted from stem diameter, the proportion of unshaded area at any point in time in any tree planting grid can be calculated and agricultural production adjusted accordingly. The logic of this approach is presented in Fig. 4 which illustrates canopy development with triangular planting designs. The spreadsheet enables the user to vary the spacing of trees thus increasing or decreasing the proportion of unshaded area.

The user may of course wish to crosscheck the results of both approaches. Indeed, using the sensitivity approach in the Poplar example discussed earlier, the lower plateau represented some 30% of open pasture grazing productivity, a fact confirmed by short term grazing rentals under trees being approximately one third of those of open pasture. By contrast, applying Newman's diffuse light model to the same planting configuration puts the lower plateau at approximately 10 percent higher. Immediately the researcher is looking for factors which have been omitted and here the answer very probably lies in the area of underground effects, whatever these may eventually prove to be. The important thing we as economists are doing is setting upper and lower boundaries to the position of the lower plateau and assessing their significance in terms of economic effects.

g) Pop cost

This component is basically an inventory of all input requirements for planting, protecting, weeding, silvicultural operations and harvesting. All inputs are expressed in physical terms and multiplied by factor prices to give cost per unit area. Estimates can be readily made, for example, of labour requirements for pruning by observation. Less easy to determine would be an appropriate labour wage rate. Such calculations are important however in agroforestry systems which are relatively labour intensive and farm based due to the potentially very high value productivity of farm labour in agricultural operations at

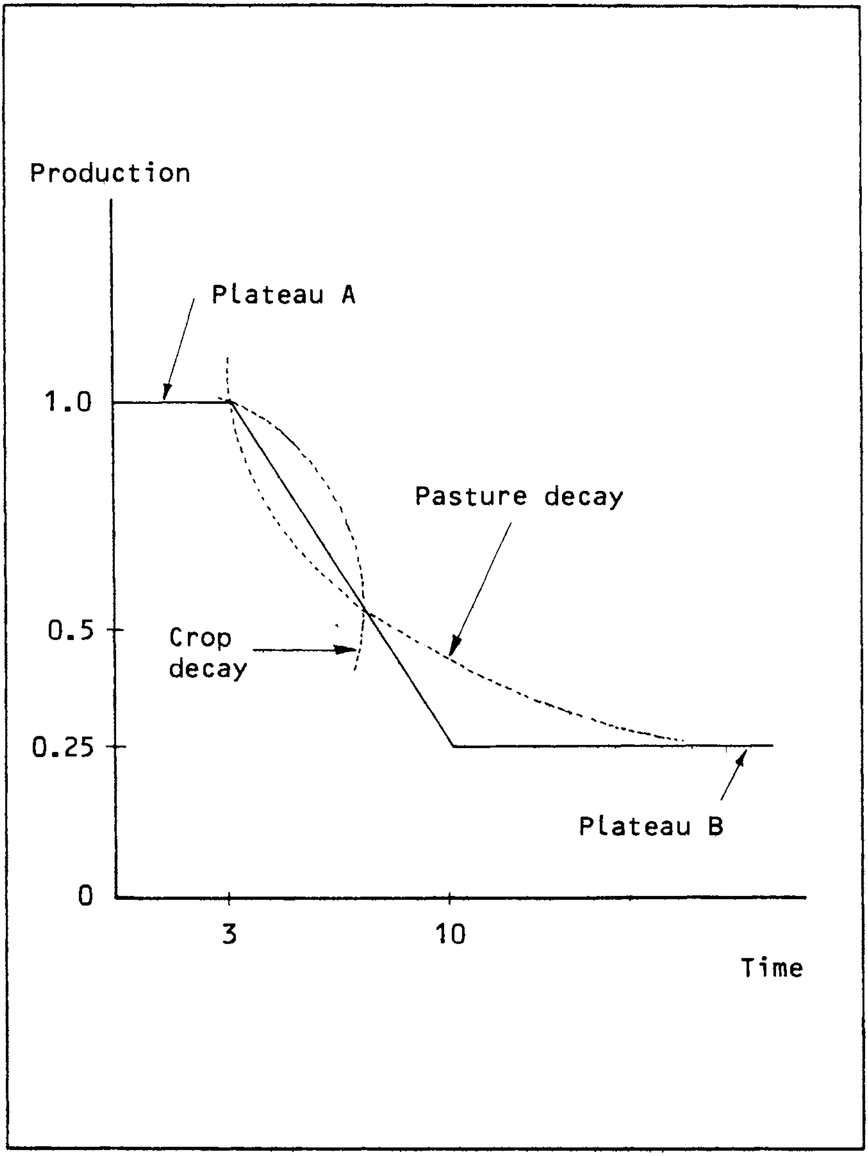
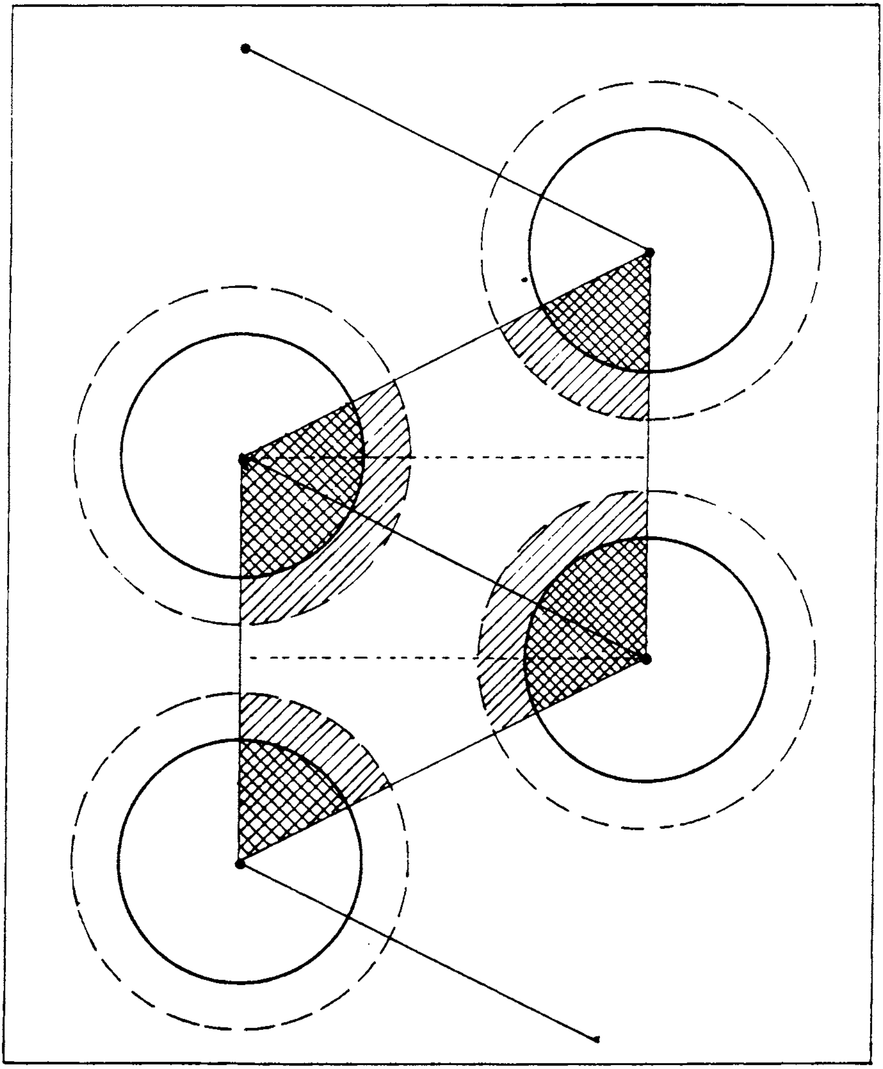


Figure 3 Agricultural Decay Functions used by the Model Poplar, Cereals (7 years) Sheep Grazing to 22 years



Key:

——— Measurement at t | Shaded pasture in t

— — — Measurement at t+1 | Shaded pasture in t+1

Figure 4 Shading Effect: Diffuse Light Model, Triangular Spacing

certain times of the year. The spreadsheet allows the researcher to employ a range of factor prices within this component.

h) **Presval**

Discounted Cash Flow Analysis is used to reduce future income flows from both components to a Net Present Value per ha. The user has the facility to use either a single real discount rate for both components which would imply that a given set of price changes for agriculture and forestry would be assumed to occur at the beginning and end of each rotation respectively. Alternatively the user has the facility to employ separate real rates of discount for each component which will simulate a gradual divergence of price trends through time.

SECTION B

An application of the model

The Site

This example relates to a site in the Midlands of England. Detailed information relating to soils, climate, geology and existing land use are presented in Table 1. A range of observed agricultural land uses are evident within the site : permanent pasture, grass leys, rough grazing for sheep and beef cattle; together with arable enterprises comprising spring barley, sugar beet and swede turnip. A number of agroforestry plantations using poplar can be found within the vicinity though all are now approaching the end of their first rotation and are generally of Yield Class 14.

Table 1 Site Characteristics

ITE LAND CLASS 15 SQUARE 436

Context

Farm type: Lowland livestock (cattle and sheep)

Soils	Group/sub-group	pH	Texture
Plots 1	Gley	6.2	
2	Gleyed brown earth	6.4	Loam
3	Gley	6.7	
4	Gleyed brown earth	6.2	Loamey silt
5	Gleyed brown earth	5.1	Loam

Climate

Mean daily max Jan	7°C
Mean daily max July	20.5°C
Mean daily min Jan	1.5°C
Mean daily min July	12°C
Average annual rainfall	700 mm
Average daily sunshine	5.5 hours

Geology

Ashgill and Caradoc; Pre-Cambrian; drift-glacial gravel

The System

This is one in which poplars are planted into cultivated land in rows at 8m triangular spacings giving an initial and final tree stocking density of 180 st. per ha. Two agricultural components are postulated. The first is one which crops cereals for a period of up to 7 years and is then undersown with a rye grass clover mixture to provide grazing for the remainder of the rotation. The second is a silvopastoral system using sheep from the outset with trees planted into permanent swards and protected by electric fencing.

System Parameters and Initial Values

Those relating to agriculture are presented in Table 2 and are self-explanatory. Input levels are consistent with output levels under these sorts of conditions when combined with factor prices, revenues, and flock investment requirements these data can be used to calculate gross margins for both cereal and livestock components, expressed per ha of agriculturally utilised land.

Those relating to forestry are presented in Table 3. The objective is to produce a 42cm DBH peeler buttlog in 22 years. All timber prices are 'ride side' so that net returns are very much a function of site location in relation to the harvest sawmill or peeling plant. All trees are assumed to be pruned to 6m, some 50% of which will be veneer quality. Some 10% of the stand volume is considered as wastage and allocated to the pulping market.

Results

Forestry and Agricultural Production

The forestry stand model and its components are shown for information in Table 4. Computed values relating to final volumes, revenues, silvicultural, harvesting and transport costs are presented in Table 5. The reduction through time in both agricultural components is illustrated in Table 6.

A Sensitivity Analysis

The sensitivity analysis concentrates on 5 key areas of interest. These are:

* Changes in prices and price trends of agricultural and forest products.
* Changes in factor prices, particularly that of labour.
* Changes in location in relation to sawmills.
* Changes in complementarity and competition assumptions.
* Changes in land types.

Table 6 presents a 'best scenario' analysis for this system on better quality land within the site. A comprehensive coverage of their scenarios can be found elsewhere (Thomas 1988). It is fairly obvious that a rather unlikely combination of factors would be needed to make this form of land use an attractive option when compared with monocultural agriculture. The picture changes significantly however when lower productivity land within the site is evaluated. This land is unable to produce cereals has a lower productivity in terms of Dry Matter production and therefore can support lower stocking at the same level of animal performance. These factors are reflected in Table 7 when compared with Table 2. A best scenario analysis for this land quality is presented in Table 8.

Finally, a scenario of opposing price trends in agricultural and timber products over the period of the next 22 years is evaluated in Table 9. This is achieved by using separate discount rates for the agricultural and forest component. In our case in the UK, the general concensus is that food prices are likely to fall in real terms whilst timber prices are likely to rise. The degree of divergence can be seen to significantly effect the viability of agroforestry when compared with monocultural land use systems.

Table 2 Agriculture - System parameters and initial values (Good Quality Lowlevel Grazing land)

int rate	3								
(real)									
seed	175kg/ha	wheat yld	5.9 t/ha	shade	2	DM yld	4100 kg/ha	lmb price	40.5
seed price	220 £/t	wheat prc	100 4/t	free yrs		ME val	10 mj/kg	wool val	3.2
fert rate	200 kg/ha	straw yld	2.5 t/ha	tree	8 m	lambing %	135	ram pchse	190
fert price	120 £/t	straw prc	20 £/t	spacing		ME req	4824 mj/ewe	cull ram	40
pest cost	70 £			tree				cull ewe	30
twine cost	9 £			strip width	2 m	concs	15 kg/ewe	repl rate	
				forest		con prc	140 £/t	ewes	22
		yrs of	7	rotation	22 yrs	vet & med	2.3 £/ewe	rams	33.3
		cereals				mktg cost	.9 £/ewe	ewes/ram	40
		% usable	.7113164			misc	.8 £/ewe	mortality	
		for ag				fert/ewe	10 £/ewe	ewes	3
		cereals		rotation in absence				lambs	9
		var csts	141.5	of forestry:		forage			
		revenue	640	cereals %	25	seed	21 £/ha		
		(unadjusted)				sprays	24 £/ha	stocking	8.499171
								rate (unadjusted)	
								livestock	16.1
								costs (unadjusted)	
								rev unadj	45.86694

Table 3 Forestry Inputs, Factor Prices and Product Prices

planting		strnr gap	25 m		
grant	£560 /ha	activator	£62	% fenced	50
		row lngth	100 m	wastage %	10
price/plt	£ 1	wire prce	£.03/m	pricescubic metre	
pltg lab	16 hrs	post prce	£.6	pulp	£ 15
lab cost	£3 /hr	strnr prc	£.04	firewood	£ 10
sprays	4 litres	year of thinning		veneer	£ 30
spray prc	£15 /ltr	first	99	sawlogs	£ 25
spray lab	2 hrs	second	99	taper	66
thinning lab	0 hrs	third	99	butt lgth	600 cm
Harvesting		year of pruning		veneer %	50
logging cost		first	3	thinnings	0
buttlog	£4 /cu.m	second	5		
toplogs	£6 /cu.m	third	7	COMPLEMENTARITY	% + or -
mill mles	30	fourth	9	cereals	0 %
cost/mile		year of spraying		livestock	0 %
buttlogs	£.2 /cu.m	first	1		
toplogs	£.3 /cu.m	second	2		
pruning hours/ha		third	99		
first	15 hrs	fourth	99		
second	18 hrs	fifth	99		
third	20 hrs				
fourth	23 hrs				

Table 4 Timber Yield Model Popup

Butt length (cm)	600	Pruning years		thinning years	
rotation (yrs)	22	first	3	first	99
taper	66	second	5	second	99
veneer proportions	5	third	7	third	99
tree spacing (m)	8	fourth	9	fourth	99
stems/ha	180,4273 (calculation)				

Tree Age	D.B.H	Top Height	Basal Area	Basal Area/ha	Crown Diam	Crown Height	MCL/ha	Top Diam	Buttlog Vol/tree	Toplog Vol/tree	Buttlog Vol/ha	Wastage Vol/ha	Toplog Vol/ha	Volume Thinns
							.00							
0	.00	.000	.0000	.00	.00	.000	452.48	.00	.0000	.0000	.00	.00	.00	.00
1	.00	2.508	.0000	.00	2.25	2.508	724.63	00	.0000	.0000	.00	.00	.00	.00
2	3.65	4.016	.0005	.08	2.83	4.016	724.63	00	.0021	.0000	.38	.04	.04	.00
3	10.35	5.490	.0038	.68	4.14	4.016	984.37	1.25	.0910	.0000	3.44	.34	.34	.00
4	15.08	6.930	.0080	1.44	4.99	5.456	984.37	5.99	.0556	.0009	10.03	1.00	1.16	.00
5	18.77	8.335	.0123	2.23	5.59	5.456	1231.70	9.68	.0985	.0057	17.78	1.78	2.81	.00
6	21.77	9.706	.0167	3.01	6.04	6.827	1231.70	12.68	1431	.0156	25.83	2.58	5.40	.00
7	24.32	11.042	.0208	3.75	6.39	6.827	1466.62	15.23	.1875	.306	33.83	3.38	8.91	.00
8	26.52	12.344	.0247	4.46	6.66	8.129	1466.62	17.43	.2308	.0505	41.65	4.16	13.27	.00
9	28.46	13.612	.0285	5.14	6.87	8.129	1689.12	19.37	.2729	.0748	49.23	4.92	18.42	.00
10	30.20	14.845	.0321	5.78	7.05	9.362	1905.42	21.11	.3135	.1032	56.56	5.66	24.28	.00
11	31.78	16.044	.0355	6.40	7.19	10.561	2115.51	22.69	.3527	.1353	63.63	6.36	30.78	.00
12	33.21	17.208	.0388	6.99	7.31	11.725	2319.39	24.12	.3905	.1707	70.45	7.05	37.85	.00
13	34.75	18.338	.0419	7.56	7.40	12.855	2517.07	25.44	.4270	.2091	77.04	7.70	45.43	.00
14	35.75	19.434	.0449	8.11	7.48	13.951	2708.54	26.66	.4623	.2501	83.40	8.34	53.46	.00
15	36.89	20.495	.0478	8.63	7.54	15.012	2893.80	27.80	.4964	.2933	89.56	8.96	61.88	.00
16	37.96	21.522	.0506	9.14	7.60	16.039	3072.86	28.87	.5294	.3386	95.51	9.55	70.65	.00
17	38.96	22.514	.0533	9.62	7.64	17.031	3245.71	29.87	.5613	.3857	101.28	10.13	79.72	.00
18	39.90	23.472	.0559	10.09	7.68	17.989	3412.35	30.81	.5923	.4342	106.87	10.69	89.04	.00
19	40.79	24.396	.0585	10.55	7.72	18.913	3572.78	31.70	.6224	.4841	112.30	11.23	98.57	.00
20	41.64	25.285	.0609	10.99	7.75	19.802	3727.01	32.55	.6517	.5349	117.58	11.76	108.27	.00
21	42.45	26.140	.0633	11.42	7.77	20.657	3875.04	33.35	.6801	.5866	122.72	12.27	118.11	.00
22	43.21	26.960	.0656	11.84		21.477		34.12	.7078	.6389	127.71	12.77	128.05	.00

Table 5 Computed Values for the Forestry Component (Status Quo)

Complementarity					
cereals	0%	dbh	43.21299 cm		
livestock	0%	cls dbh	24.31830 cm		
		net comp	0 x 100 %	rows	15,43418
planting costs	228,4273 £/ha	stems/ha	180.4273	canopy closure	
thinning costs	0 £/ha	values in end year		occurs yr	30
		adj dbh	43.21299 cm	wire mtrs	1507,852
spraying costs	66 £/ha	top ht	26.9602 m	figs if all forestry	
logging costs		basl area	.0656200 sqm	basl area	.0656200
buttlogs	10 £/cum	sed	34.12208 cm	sed	34,12208
toplogs	15 £/cum	volumes/ha		volumes/ha	
		buttlogs	127.7121 cu.m	buttlogs	127,7121
tot.logging & transport costs		toplogs	115.2755 cu.m	toplogs	155,2755
buttlogs	1149,409 £/ha	revenue/ha		revenue/ha	
toplogs	1920,701 £/ha	pulp	£1920.701	pulp	1920,701
		sawlogs	£1436.761	sawlogs	1436,761
		peelers	£1724.113	peelers	1724,113
fencing cost	142,0207 £/ha	thinnings	£0	thinnings	0
			5081.575		5081575

Table 6 The Viability of a Poplar, Cereals and Livestock Agro Forestry System. A Best Scenario Analysis on Good Land

	Net Present Value (£/ha)		
	Agro Forestry	Forestry	Agriculture
Best Scenario:			
Distance from mill - 10 miles			
Wood prices + 50%			
Labour £0 per hour			
Cereals complementarity + 10%			
Livestock " + 5%			
Fencing cost 0			
Agricultural prices unchanged	5024.86	3434.43	4741.16
As above with fencing 50%	4886.98	3434.43	4741.16
As above with cereal prices -50%	4230.04	3434.43	4741.16

Table 7 Agriculture - System Parameters and Initial Values (Medium Quality Lowland Grazing Land)

Int rate	3						
(real)							
seed	175 kg/ha						
seed prc	220 £/t						
fert rate	220kg/ha						
fert prc	120 £/t						
pest cost	70 £						
twine cst	9£						
wheat yld	5.9 t/ha	shade	2	DM yld	2100kg/ha	lmb price	40.5
wheat prc	100 £/t	free yrs tree	8m	ME val	10 mj/kg	wool val	3.2
straw yld	2.5 t/ha	spacing tree		lambing %	135	ram pchse190	
straw prc	20 $/t	strip wdth	2m	Me req	4824 mj/ewe	cull ram	40
		forest rotation	22yrs	cocs	15 kg/ewe	cull ewe	30
				conc prc	140 £/t	repl rate ewes	22
yrs of cereals	0			vet & med	2.3 £/ewe	rams	33.3
% usable	.7113164			mktg cost	.9 £/ewe	ewes/ram	40
for ag cereals				misc	.8 £/ewe	mortality(%)	
var csts	141.5			fert/ewe	10 £/ewe	ewes	3
revenue	640	rotation in absence				lambs	9
(unadjusted)		of forestry:		Forage:			
		cereals %	0	seed	21 £/ha		
				sprays	24 £/ha	stocking rate	4.8
						(unadjusted)	
						livestock csts	16.1
						(unadjusted)	
						rev unadj	45.86694

Table 8 The Viability of a Poplar, Cereals and Livestock Agroforestry System. A best Scenario Analysis on Medium Quality Land (No Cereals)

	Net Present Value £ (ha)		
Best Scenarios	Agro Forestry	Forestry	Agriculture
1. Timber price +50% Everything else as status quo	2149	1680	2065.14
2. Timber price +25% Lamb price -25% Labour cost £0/hr Everything else as status quo	2164.66	1876.55	1319.22
3. Timber price +10% Lamb price -25% Labour cost £0/hr	1661.81	1373.70	1319.22
4. Timber price +10% Lamb price -25% Labour cost £3.0/hr	1420.15	1132.04	1319.22
5. Timber price unchanged Lamb price -25% Everything else as status quo	1167.73	880.86	1319.22
6. Timber price unchanged Lamb price -25% Labour cost 0 Complementarity +5% Everything else as status quo	1466.16	1178.05	1319.22
7. Timber price unchanged Lamb price -25% Labour cost £0/hr Complementarity 5% Distance from mill 10 miles	2125.80	1837.69	1319.22
8. As above with 20 miles distance from mill	1795.98	1507.87	1319.22

Table 9 The Viability of a Poplar, Cereals and Livestock Agroforestry System. Sensitively to Opposing Term Prices for Agricultural and Forest Components

(i) Better Quality Grazing land

Price trend scenario	Net Present Value (£)/ha Agro Forestry	 Forestry	 Agriculture
Status Quo	2471.29	880.86	4741.16
Agro price rise 2% < inflation Forest price rise 2% > inflation	2844.09	1422.27	3915.94
Agro price rise 5% < inflation Forest price rise 5% > inflation	4207.80	2982.96	3034.68

(ii) Medium quality Grazing land

Status quo	1348.20	880.86	2065.14
Agro price rise 2% < inflation Forest price rise 2% > inflation	1825.02	1422.27	1705.69
Agro price rise 5% < inflation Forest price rise 5% > inflation	3312.41	2982.96	1321.84

Conclusions

The spreadsheet provides a framework within which the various components listed in Figure 1 can be linked together. So far the components themselves reflect requirements for the sort of system currently envisaged under Northern European conditions.

Popup and Popout for example simulate the production of pruned timber buttlogs. Similarly, the agricultural components and site conditions described here are Western European in character.

It should be apparent however that the incorporation of, for example, fruiting components, or coppice for biomass or fuel can be achieved without undue difficulty. Moreover the constant stream of income from this sort of tree component would significantly affect Net Present Values.

Similarly, beause the model works from initial conditions which reflect site productivity (provided relevant bioclimatic and topographical information is available, and key parameters relating to the performance of whatever components are being considered are known with reasonable accuracy), it should be possible to adopt the approach presented here for a range of site conditions and systems. Moreover, if changes in site productivity are envisaged to occur through time these can be reflected in the initial values of system parameters or built in to the respective decay functions.

The quality of information is obviously important to the reliability of the results. Some of the information, for example land capability and bioclimatic data may well exist for potential sites, as will data relating to input requirements and site productivity to serve as initial values and system parameters. Less easy questions may well relate to the valuation of inputs and outputs, the dynamics of tree and crown development at wide spacing and the effects of interactions in terms of increased or decreased output levels of the various components.

None of these aspects need necessarily be a problem when the analytical framework is incorporated within a spreadsheet. Indeed, not only can the spreadsheet indicate the sensitivity of a solution to a change in factor or product prices but it can also demonstrate the likely financial magnitudes of impact on the system as a whole of for example particular pruning regimes, improving the form characteristics of trees or perhaps a supplementary forage establishment programme using legumes late on in the course of a rotation. Using a model in this context can actually point the researcher in the direction in which greatest potential source of economic benefit from further research is likely to be.

Experimental Research need not be the only source of technical information employed. Delphi sessions should be able to establish ranges of estimates of key parameters which could be cross checked with the results of rapid rural appraisal techniques in the field. Farmers can be interviewed and their existing husbandry practices examined. Economic values such as for example grazing rentals under trees can provide suitable proxies for the purposes of assessing stocking capacities until experimentation based on light interception and root competition research yields better data. In an economic context the current situation is tending more towards one of assessment rather than optimisation. The resolution required of data should reflect this.

Finally, this model is currently based on a unit of area, rather than a farm. It avoids difficulties such as cash flow problems and capital items. It nevertheless provides a unit which can be aggregated upwards to both farm and regional level. At these higher levels of aggregation new and additional sets of issues emerge. The availability of labour and capital to farmers, their training and education, the provision of suitable infrastructures for transport, harvesting and processing, together with the communality of ownership in respect of system components are all important "grey areas". The establishment and management of uneven aged stands, the determination of farmers' needs, and their attitudes to agroforestry in relation to regional and national objectives also need to be determined.

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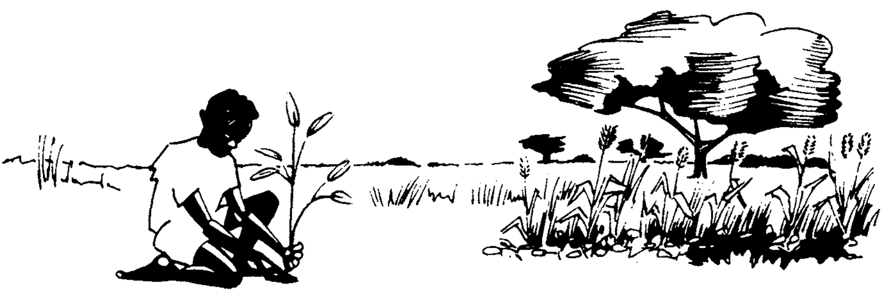
CHAPTER 4

ECONOMICS FOR SUSTAINABLE DEVELOPMENT



ECONOMICS FOR SUSTAINABLE PRODUCTION

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CONTENTS

Abstract

Although many definitions of sustainable development abound, from the point of view of the sustainability of production a potentially operational definition is maintaining the constancy of natural capital. This definition compares favorably with the ecological concept of 'resilience'; however, in the presence of natural resource degradation or depletion, the objective of economic efficiency may require modification. The paper demonstrates how a 'weak' and 'strong' sustainability criterion can be incorporated into cost-benefit analysis. Such an approach has important implications for the economic analysis of agroforestry projects, and may facilitate proper assessment of their net benefits in terms of sustainable development.

Introduction

The term 'sustainability' has become recently in vogue. Attention is now focussing on what economics has to say about sustainability, how it compares to more conventional economic criteria, such as economic efficiency and Pareto optimality, and how the economic view of sustainability differs from that of other disciplines. Only by clarifying what our concepts and objectives are when we talk about the sustainability of production can we then proceed to operationalize it at the applied level, such as in the design of agroforestry systems, projects and even policy options. The following paper aims to develop an operational definition of sustainability, based on both economic and ecological perceptions of the term.

The Sustainability Criterion

A review of the literature on 'sustainable' economic development suggests that two interpretations of that concept have emerged: a wider concept concerned with sustainable economic, ecological **and** social development and a more narrowly defined concept largely concerned with 'environmentally sustainable development', i.e. with optimal resource and environmental management over time (Barbier 1987, 1989, Pearce & Barbier & Markandya 1988, 1989, World Commission 1987).

From the point of view of the sustainability of production, it is more useful to concentrate on the 'narrower' interpretation – the relationship between environmental quality and sustainable economic activity. The latter is interpreted as that level of economic activity which leaves the environmental quality level intact, with the policy objective corresponding to this notion being the maximization of net benefits of economic development, subject to maintaining the services and quality of natural resources over time (Barbier 1988, Pearce, Barbier, Markandya 1988, 1989).

The term 'natural resources' is used broadly. It includes **renewable** resources, such as water, terrestrial and aquatic biomass; **non-renewable** resources, such as land in general, minerals, metals and fossil fuels; and **semi-renewable** resources, such as soil quality, the assimilative capacity of the environment and ecological life support systems.

Consequently, maintaining the services of a natural capital stock does not necessarily imply maintaining this physical stock of composite resources intact, which in any case, may not be desirable or feasible for non-renewables. On the other hand, keeping the level of **environmental quality** intact implies caution in assuming that an irreversible loss of the natural capital stock is justified if it results in the formation of more manmade capital. Some of the functions of the environment are not replicable by reproducible capital, such as complex life support systems, biological diversity, aesthetic functions, micro climatic conditions and so forth. Others might be substituted but not without unacceptable cost. In addition, degradation of one or more parts of a resource system beyond some threshold level may lead to a breakdown in the integrity of the whole system, dramatically affecting recovery rates and resilience of the system. The total costs of the system breakdown may exceed the value of the activity causing the initial degradation. Examples where this may be the case include extensive deforestation of tropical forests, such as is occurring in Amazonia, upper watershed degradation through inappropriate upland farming and even the global warming induced by greenhouse gases. For further discussion of the economic aspects of these 'system breakdowns' see (Barbier 1988, Pearce, Barbier, Markandya 1989).

Thus 'constancy' of the natural capital stock, or more precisely constancy of the level and quality of services that this stock provides, can take on different meanings - interpretations in terms of both constant **physical** capital stock and constant **economic value** of that stock are common (Bishop 1978, Page 1977, Pearce, Barbier, Markandya 1988, 1989). These interpretations are fundamentally equivalent, provided that the presumption is that 'sustainability' has something to do with non-depreciation of the natural capital stock, in terms of providing a valued level and quality of services, and provided that proper economic valuation of any depreciation in this stock has taken place.

In short, without too much loss of interpretation, the necessary environmental condition for sustaining production can be conveniently summarized as ensuring non-depreciation of the natural capital stock. More strictly, the requirement is for non-negative change in the stock of natural resources such as soil and soil quality, ground and surface water and their quality, land biomass, water biomass, and the waste assimilation capacity of receiving environments (Barbier 1989, Pearce, Barbier, Markandya 1988). Not only is this criterion consistent with the literature on sustainability but, as will be discussed further below, it is also operational: the criterion of 'sustainability' can now be introduced into cost benefit techniques of project appraisal by setting a constraint on the depletion and degradation of the stock of natural capital. Such an approach is exceedingly important to the economics of agroforestry and other multi-functional resource systems.

Sustainability as Resilience

However, economics is not the only discipline grappling with the concept of sustainability. One useful approach taken by some ecologists is to view agricultural production units as 'systems' interacting with their surrounding natural environments. Such an approach allow a specific definition of 'sustainability' to be applied to these 'agro-ecosystems', which is drawn from the ecological concept of the 'resilience' of natural ecosystems (Holling 1973).

For example, **sustainability** is defined by Conway 1987 as the ability of an agro-ecosystem to maintain productivity when subject to stress or shock. **Productivity** is the output of valued product per unit of resource input, with common measures of productivity being yield or income per hectare, or total production of goods and services per household or nation. **Stress** in this context would be a regular, sometimes continuous, relatively small and predictable disturbance on agricultural productivity over time, for example the effect of salinity, toxicity, erosion, declining market demand or indebtedness. **Shock** on the other hand would be an irregular, infrequent, relatively large and unpredictable disturbance to the agricultural system, such as a rare drought or flood, a new pest or a sudden rise in input prices, like oil in the mid-1970s.

Sustainability can thus be compared to other indicators of agricultural performance - productivity, stability and equitability. This approach has been broadened further to take into account the international constraints on sustainable and equitable development, the necessary national policies, and the needs of rural households (Conway and Barbier, 1988, 1989). It therefore has become a powerful tool for re-thinking strategies for agricultural development.

However, a major obstacle to explicitly incorporating Conway's definition of sustainability in economic analysis is the difficulty in evaluating the multitude of social, economic and environmental variables that might at any time act as stresses or shocks on a given agricultural system. On the other hand, it may be possible to operationalize a more narrow concept of agricultural sustainability if we initially limit our economic analysis solely to the **environmental** stresses and shocks. This does not trivialize the concept of agricultural sustainability. For example, it is self-evident that agro-ecosystems are directly dependent on environmental resources and essential ecological functions for 'sustainability'. Thus the unchecked abuse of resources within an agro-ecosystem, whether as a result of the inappropriate use of agro-chemicals and fertilizers, the overcropping of erodible soils, poor drainage, etc., not only directly affects the sustainability of the agro-ecosystem but may also increase its susceptibility to other external stresses and shocks, such as changes in market conditions, prolonged dry seasons, changes in land tenure, and so on. As a consequence, a crucial component of sustainability, as defined in terms of the resilience of an agricultural system to external stresses and shocks, is maintaining the environmental resources and ecological functions upon which the system depends.

In essence, the economic and ecological interpretations of sustainability are the same: the necessary condition for environmental sustainability is non-depreciation of the natural capital stock.

Productivity, Efficiency and Sustainability

There still remains the crucial issue in economics of how the notion of sustainability compares with the criterion of 'economic efficiency'. It is important to distinguish between **private efficiency** - the efficiency of the production system from the point of view of its users - and social efficiency - how the production system affects the allocation of resources to society as a whole. The latter falls under the 'Pareto optimality' criterion; that is, resources are allocated efficiently when it is not possible to change the allocation of resources without making someone worse off.

For the users of a production system, economic efficiency is achieved through maximizing their discounted net **private** returns or benefits, i.e. ensuring that the users' discounted flow of private benefits less costs from exploiting the system is at a maximum. For society as a whole, the objective is to maximize discounted net **social** returns or benefits - the benefits less the costs accruing not just to the users of the production system but to all individuals whose welfare is affected by that system.

For example, assume a simple upland agricultural system producing an annual crop such as cassava for a single household's subsistence and income needs. It is very much a low-input system, i.e. the household cannot afford or gain access to modern inputs such as inorganic fertilizers. Suppose that production from this system can be sustained indefinitely, except for the environmental stress imposed on the system from prolonged soil erosion. That is, the impact of continuous annual cultivation on the upland soil under tropical climatic conditions is to cause erosion and eventually declining soil fertility. As a result, future cassava yields will decline and the system may collapse. This is the **user costs** of soil erosion - the loss of future soil productivity through the erosion caused by current use of the resource for crop production. As the farming household will incur these user costs over time, they are part of the overall private costs that the household attempts to minimize in its quest for efficiency in production. Under normal conditions, one would expect that the household would find these user costs so significant that it would have to bring soil erosion under control in order to maximize its discounted net returns. In such instances, the pursuit of private efficiency will also ensure the overall sustainability of the agricultural production system.

But there are also circumstances under which the household may ignore the user cost of soil erosion in its drive for production efficiency. For example, the lack of secure tenure or open access to forests that can be converted to agriculture may make the household less concerned about the future productivity of the land it is using currently to cultivate cassava. Alternatively, some upland soils, such as those based on limestone, may be very poor in quality and have a low regenerative capacity. Under such conditions, the household may find that its discounted net returns are higher not from controlling soil erosion but through exhausting the soil as quickly as possible in order to maximize current yields. This will also be the case if the harvesting cost of cassava is low, or if the price of cassava is high. More often than not, these costs and prices are influenced by government policies, such as the use of input subsidies and procurement mechanisms to increase the producer price of food. For a complete case study of the response of upland farming households to soil erosion see (Barbier 1987).

However, even under conditions where the pursuit of production efficiency by a farming household also ensures the sustainability of production, it does not automatically follow that this outcome is also socially efficient. The existence of **external costs**, costs imposed on other individuals who do not receive compensation or a share of the benefits of the production system, may be a factor. For example, supposing that in order to reduce the user cost of soil erosion to zero, which happens to be consistent with efficient cassava production, our farming household would have only to reduce the rate of erosion to 10 tonnes per hectare (ha) per year. If this were true of all upland farming households, then upland production systems would be efficient and sustainable. Unfortunately, though, the impact of an annual erosion rate of 10 tonnes/ha in the uplands is sedimentation of irrigation canals downstream. The result is a loss of productivity experienced by lowland irrigated farmers, which is the external cost of upland soil erosion. From society's perspective, since individuals - the lowland farmers - are being made worse off, this situation is not (Pareto) optimal. Moreover, it could threaten the sustainability of lowland production. It would be more socially efficient to find some means of compensating upland farmers to reduce their erosion rates further in order to eliminate the external downstream costs to lowland farmers. If such a solution were found, then social efficiency and the sustainability of lowland, as well as upland, production would be complementary.

Once again, though, a socially optimal solution might be found that does not necessarily ensure sustainability of production. For example, society might find that a less costly alternative to compensating upland farmers to reduce erosion further may be to provide affected lowland farmers with off-farm employment opportunities as their yields start declining. Consequently, water supplies and irrigation facilities are allowed to collapse, ending the sustainability of lowland production. But from a social perspective, this loss of sustainability is not crucial to the maximization of overall net returns.

In sum, economic efficiency in production under some conditions may allow the exhaustion of those resources important for sustainability. Even the pursuit of social efficiency does not necessarily lead to the sustainability of renewable resources essential to production. That is why some economists have argued that justifying the conservation of these essential resources requires an additional 'intergenerational equity', or 'sustainability', criterion (Page 1977, Pearce 1977). In other words, ensuring sustainable and secure livelihoods for future generations requires ensuring that these generations have equal access to the natural resource base. Again, the necessary condition for achieving this criterion is non-depreciation of the natural capital stock.

Sustainability and Cost-Benefit Analysis

Cost-benefit analysis (CBA) embodies intuitive rationality in that any course of action is judged acceptable if it confers a net advantage, i.e. if 'benefits' outweigh 'costs'. What constitutes a gain or loss depends on the objective function chosen. Most CBA operates with a function based on economic efficiency, i.e. any increase in total net benefits is desirable irrespective of the distribution of these benefits or the impact of the action on the non-economic objectives. But this is only **one** objective function, and as discussed in the previous section, efficiency may not always be consistent with another desired objective, namely sustainability.

Thus we need to construct a specific sustainability criterion for CBA: essentially, the economic efficiency objective is modified to mean that all projects yielding net benefits should be undertaken subject to the requirement that environmental damage (i.e. natural capital depreciation) should be zero or negative. However, applied at the level of **each project** such a requirement would be stultifying. Few projects would be feasible. At the **programme** level, however, the interpretation is more interesting. It amounts to saying that, netted out across a set of projects (programme), the **sum** of individual damages should be zero or negative. That is, if E_i is the **damage** done by the ith project, we require that:

(1) $$\sum_i E_i \leq 0$$

Such a formulation ignores time. If a time dimension is included, two formulations of the sustainability constraint are possible. Under **weak sustainability** it is the present value

of $\sum_i E_i$, $PV(\sum_i E_i)$, which is constrained to be non-positive.

Under **strong sustainability** each E_i is constrained to be non-positive **for each period** of time.

Since it is not feasible to set $PV(\sum_i E_i)$ to be zero or negative for each project, but it is feasible to set $\sum_i E_i$ to be non-positive, the sustainability constraint amounts to including within any portfolio of investments one or more **shadow projects** the aim of which is to compensate for the environmental damage from the other projects in the portfolio. The shadow project idea is suggested by (Klassen and Botterweg 1976) in what appears to be a neglected paper. The conventional CBA rule would then apply to the **environmentally depleting** projects, i.e.

(2) $$\sum_t d^t[\sum_i(B_{it} - C_{it} - E_{it})] > 0,$$

where B is non-environmental benefits, C is non-environmental costs, E is net environmental costs or benefits, t is time, and d^t is the discount factor.

The **environmentally compensating** project(s), j, would be chosen such that

(3) $$\sum_j PV[A_j] \geq \sum_i PV[E_i]$$

for the weak sustainability criterion, and

(4) $$\sum_j A_{jt} \geq \sum_i E_{it} \quad \text{for all } t$$

for the strong sustainability criterion, where the net environmental benefits of the jth project, $A_{j1}, A_{j2}, \ldots A_{jT}$, compensate for the damage done by the other projects. For the compensating projects, then, the normal CBA decision rule does not apply, although we would wish to minimize the cost of achieving the sustainability criterion.

This approach has been developed further in a formal analysis of sustainability and CBA (Pearce, Barbier, Markandya 1988); it will not be pursued further here.

Relevance to Agroforestry

The above approach nevertheless has important relevance to the economics of agroforestry. Agroforestry is a catch-all term to describe the deliberate mixing or sequential planting of trees and shrubs with crops and/or livestock. One of the perceived advantages of agroforestry is that it provides **multi-functional** economic and environmental benefits. Depending on the type of system, these may include the direct benefits of supplying fuelwood, other wood products (e.g., poles), fodder, fruits and nuts, and the indirect benefits - usually captured through crop and/or livestock productivity - of shelterbelt functions, shade, nitrogen fixation from leguminous trees, and supply of organic matter. Agroforestry can also generate cash income through the sale of wood and other products as well as employment, often during off-season slack periods.

Yet despite these apparent benefits, when compared with the net benefits of some alternative land use systems - e.g., rotation or mono-cropped cultivation of grains - agroforestry projects often appear less attractive. There are usually two reasons:

First, proper economic valuation of all environmental impacts is often **not** conducted for agroforestry projects. The failure to include the net environmental benefits of agroforestry based systems underestimates the NPV of such projects.

Fortunately, this is now changing. For example, an appraisal of rural afforestation programs in the arid zone of northern Nigeria has shown that, if proper valuation of shelterbelt functions and farm forestry is conducted, the prospective economic returns may be substantial (Anderson 1987). Also in Nigeria, a comparison of alternative uses of forest land revealed that a 25-year social forestry scheme that involves farmer clearing, cropping and tree planting in the first few years can yield comparable financial internal rates of return to oil palm plantations and logging if higher valued commercial species are chosen to be planted (Burgess 1989). Similarly, in Sudan, economic analysis has indicated that the total direct benefits to farmers of planting gum arabic trees can be very high. For example, based on a 16-year rotation, the financial internal rate of return from gum, fuelwood and fodder production is estimated to be around 36 percent (Pearce 1988). For a typical bush-fallow system of Northern Kordofan province, consisting of gum trees rotated or intercropped with sesame, groundnuts, millet and sorghum, the financial NPV was calculated to be Sudanese pounds 142.6 per feddan (1 feddan = 4200 m^2), i.e. about US$58 per feddan (1985 prices) (World Commission 1987).

However, many so-called environmental 'rehabilitation' or 'enhancement' projects associated with agroforestry, such as shelter-belt planting, soil conservation projects, afforestation and reforestation to control desertification, etc., are still criticized for yielding a low or even negative NPV under conventional CBA criteria. One major reason is that the environmental benefits of these projects, such as the reduction of off-site sedimentation or nitrogen-fixation by leguminous trees, although widely recognized and accepted, may be difficult to quantify and value due to poor ecological and economic data. Even if these benefits can be estimated, their impacts are often more significant in the long rather than short term. The positive discount factor of a conventional CBA may therefore reduce the importance of these impacts in the project NPV.

Under the sustainability criteria suggested in the previous section, such projects could nevertheless still be accepted as environmentally compensating projects within an agricultural development programme. As indicated by equations (3) and (4), these projects will be accepted not on the basis of their NPV but on whether their stream of environmental benefits compensate for any environmental damages imposed by other projects. A low or negative NPV no longer poses a serious obstacle to the implementation of such projects.

For example, in Sudan, in addition to yielding direct (production) benefits to farmers of gum, fuelwood and fodder, gum arabic planting has indirect (environmental) benefits of reducing soil erosion and water runoff, stabilizing soils and possibly fixing nitrogen, as well as the wider environmental benefits of providing shelterbelts, fixing dunes and acting as a general buffer against desertification. These environmental benefits are difficult to value and, in any case, may be offset by conventional discounting procedures. Thus, following conventional criteria, the **social** NPV of a gum arabic planting project might paradoxically be low or even negative.

However, under the sustainability criteria introduced in the previous section, the gum arabic (re-)planting project could be accepted as an **environmentally compensating project**. As these criteria recognize that the essence of a 'rehabilitation' project is to compensate for environmental damages, such a project could be accepted on the basis of its stream of positive environmental benefits, as suggested by (3) and (4). Thus a gum arabic rehabilitation project could compensate for environmental damage inflicted on the gum belt or on the poor desert soils due to mechanized agricultural projects or overcropping. A low or negative NPV for a gum arabic rehabilitation project no longer poses a serious obstacle to the implementation of such projects.

Conclusion

This paper has set out to operationalize an economic concept of sustainability. To do this required first comparing the economic approach to that of other disciplines, notably the ecological interpretation of sustainability as 'resilience', and secondly, contrasting the sustainability criterion with the standard economic objective of efficiency. Although economists have been reluctant to accept the ecological view of sustainability, they have increasingly recognized that the pursuit of economic efficiency does not always guarantee the sustainability of production. This is particularly the case with the exploitation of the resource base in agriculture.

Thus a straightforward approach to operationalizing sustainability that satisfies both ecological and economic interpretations is to assume that it is dependent on the constancy of the natural capital stock. As long as this stock is not degraded or depleted, then economic efficiency can be safely pursued as the paramount objective. Special sustainability criteria need only be invoked in the presence of degradation or depletion. From these criteria simple 'rules' for project appraisal can be derived. These in turn have important implications for the economic appraisal of agroforestry projects in particular.

However, it must be stressed that the criterion of non depreciating natural capital is only a **necessary** and not a **sufficient** condition for the sustainability of production. Other social and economic factors might easily intervene. One crucial area not discussed in this paper, for example, is the need for appropriate **policy-enabling incentives** focussed on the policy maker and implementing agencies (e.g., institutional strengthening and flexibility, political conditions), **variable incentives** focussed on price changes facing producers and consumers (e.g., altering inputs and output pricing, exchange rate modifications, tax and subsidy reform, adjusting middlemen margins, etc.) and **user-enabling incentives** focussed on the farmer and resource user (e.g., changes in land and resource rights, increased participation in decision making, changing perceptions of risk, changes in income and employment opportunities, etc.) (Barbier 1988). It is clear that the sustainable development of any production system, agroforestry or otherwise, cannot succeed unless distortions in the economic and non economic incentive structure are corrected.

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AGROFORESTRY: TECHNICAL ASPECTS AND COST–BENEFIT ANALYSIS IN THE CONTEXT OF LAND DEGRADATION

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CONTENTS

Introduction

Environmental problems due to development processes are continuing to have undesirable consequences the world over. In little more than 10 000 years, man's impact on his environment has increased enomously, and today about two-thirds of the Earth's land surface is subject to his activities. The need to rethink development strategies is now unavoidable, particularly in the agricultural sector in tropical regions which have experienced unprecedented negative environmental development, illustrated by extreme land degradation. Land degradation has become a problem in many developing countries, and the effects have crippled economies, sometimes with consequent losses in animal and human lives.

The disaster of the Sahel region in the 1970's and the recurrent crop failure due to degraded soils and drought in many countries of Africa, are a persistent reminder of the likely consequences of environmental degradation-desertification. This has received much attention in the international development community which have made determined efforts to find solutions involving sustainable agricultural development and related use of renewable natural resources. The result has been a high turnover of ideas which made available a 'basket' of strategies. These strategies are mere guidelines which need input of relevant knowledge by area or regional specialists. Out of this basket, agroforestry has emerged as a popular strategy which has become something of a buzzword (Steiner, 1988).

This paper briefly reviews agroforestry and land degradation and also examines the use of cost-benefit analysis for natural resource management.

Agroforestry and Land Degradation

Agroforestry

Agroforestry is a practice, as old as man's agricultural activities - growing crops in the midst of trees or along with trees while grazing animals is still common in the tropics (Padoch and Jong, 1987: Godfrey-Sam-Aggrey, 1983; and many others). What is new, is the science of agroforestry. Like many other concepts, it has acquired different definitions in extent and usage. Steppler and Raintree (1983) called it the fledgling interdisciplinary science which has arisen recently to fill the gap created by time-honoured but artificial separation of agriculture and forestry. They further ague that it is a "new name given to the old practice followed by many farmers for generations, of mixing or retaining trees in their crop/animal production fields" Steiner (1988) called it "the old fashioned diversification farm".

In nature, plants of diverse species coexist on the same substrate from which they derive their nutrients, and animals subsist on them, with micro and macro-organisms decomposing dead organic material releasing nutrients to be used again by plants. This sustainable system is interfered with by man's activities which include the propagation of preferred species of plants and animals at the expense of others in a bid to provide food for his ever-escalating populations. This practice, bid to proivide food for his ever-escalating populations. This practice, called agriculture, has developed monoculturally in many parts of the world, with consequent reduction in natural vegetation. Where it has reached intensity beyond what natural nutrient turnover can support, artificial fertilizers have been used with appreciable increase in production, but not without environmmental costs which unfortunately have received little attention until recently.

Agricultural activities largely disturb the balance in a natural ecosystem, and the sustainability of these activities depends on the stability of the system. A stable system can resist disturbance and return to its equilibrium in which production and consumption of all components within the system remain constant even where there is continual change (Richards, 1985). The stability of this type of system differs from place to place, although the basic relationships between components remain similar. Agricultural activities should take account of these relationships, and whatever developments are made to improve productivity, the starting point should be a proper understanding of the natural system.

Agroforestry tries to make agricultural exploitation sustainable by attempting a balance between components as in natural systems. It is this balance which could be achieved by certain combinations of trees/crops and animals that remains a challenge to making agricultural development sustainable. ICRAF (International Council for Research in Agroforestry) (Steppler and Raintree, 1983) has been pioneering the studies of these practices adopted from natural systems.

ICRAF has done a lot of work on identification and diagnosis of some existing agroforestry systems and designing and implementing some tested technology in this area. It has also been exploring analytical techniques to diagnose the performance of basic output subsystems in terms of both their productivity and their sustainability. Multiplicity of outputs in terms of food and animal fodder, fuel, building materials and chemicals (Hall and Combes, 1983), of which there are commonly shortages in developing countries, form the main goals of agroforestry. Other systems with outputs not available for direct consumption, but vital for future production, will need investigation for better designing of agroforestry systems which will conserve and improve environmental aspects of the system. For instance little research is done on soil fauna and microflora which decompose plant and animal residues, releasing nutrients previously bound in the plant biomass, so that they are available for recycling through above-ground portions of the ecosystem (Richards, 1985). A knowledge of the type of organisms involved and how they are likely to be affected by particular designs of agroforestry might be of assistance in designing sustainable systems. Richards (1985) emphasizes a detailed examination of soil biology and biochemistry to be an essential feature of any comprehensive programme of ecosystem analysis.

A case study by Sohlenius, Bostr?m and Sandor (1987) on dynamics of nematode communities in arable soil under four cropping systems for a period of five years found marked differences in species diversity and abundance (Table 1) of nematodes among the different systems. They attributed the differences to changes in the soil environment because the effect of different management practices was small. They also found positive correlation between root production and total nematode numbers ($r = 0.96$, P 0.01), and also cited other case studies of positive correlations between plant production and nematode abundance (Yeats & Coleran, 1982 as quoted by Sohlemius, D S Boström and A Sandor, 1987). In their conclusion, the results indicate, that not only nitrogen fertilisation but also the plant species cultivated can influence the proportions of fungal and bacterial feeding nematodes. This will also affect other organizms which are part of the soil ecosystem.

This case study poses questions of possible research in an agroforestry system:

1. How do soil organisms vary between arable and non-arable soils in type and abundance? What are decomposition rates and seasonal variations?

2. How do soil organisms differ with plant species, and what are the implications in the selection of agroforestry and other species on which processes of nutrient turnover depend.

Agroforestry designs are basically ecosystem transformations in which useful species in terms of desired outputs, (nitrogen fixation, organic matter, increase in yield of crops, soil cover, wood, etc) are grown with the exclusion of other species which may not have these desired outputs, sometimes replacing species otherwise indigenous to the locality. Oldeman (1983) points out the risk of this practice to be the absence of **absolute** ecological identity between the behaviour of organisms, maintaining that small differences exist, hence the balance of the new structure has to be corrected over and over again, until it becomes self-equilibrating. He further observes that many transformed systems turn out to be unstable. Many of the farming systems in the tropics are in fact transformed systems, in which the transformation was not based on a complete understanding of the interrelationships of various components of the whole system.

The success in redressing or improving the existing situation will depend very much on the understanding of changes in the refined biological cycles of apparently simple but durable living systems by (Oldeman, 1983). This can be achieved by more research work on identified existing agroforestry systems and on undisturbed natural vegetation, a very stable system, which may contain possible species which could be cultivated in an agroforestry system. For instance a case study by Tolsma et al (1987) on seasonal variation of nutrient concentrations in a semi-arid savanna ecosystem in Botswana found marked variations. The concentrations of nitrogen and phosphorus in all species studied (8 *Acacia* species, *Dichrostachys cinerea* and *Terminalia sericea*) were higher in young leaves than in mature ones. while Calcium, Sodium and Iron accumulated until leaf fall. The macronutrient elements, nitrogen, phosphorus and potassium, were translocated out of the leaf long before leaf fall. Therefore the most sought after nutrients which are needed for crops are not added to the soil in leaf fall, but are retained in the plants. If these species are to be used for agroforestry, calcium, sodium and iron may accumulate in top soil. To gain nutrients (N, P and K) from them, only young leaves can be used.

Land Degradation

Land degradation in many tropical countries has been well documented (Lewis et al, 1988; Stocking, 1988; Whitlow, 1988; Lal, 1988; and many others too numerous to mention), but there are not many studies on quantitative losses in terms of soil physical characteristics (soil particles), nutrients (elements), organic matter (humus and litter) and soil organisms, due to various processes of land degradation. Some quantitative studies (Lal, 1988) have been done on amount of soil lost through erosion, but mostly through water erosion which is very common in Africa. There are only few studies on quantitative losses due to wind erosion which is very common in sandy areas and trampled soils with little vegetation cover. In New Mexico, wind erosion damaged 357,800 areas of land between November 1983 and May 1981. In most cases wind erosion is just acknowledged and not much attention is given to it, except in the arable Sahel region.

Other losses to arable land may not be easily recognizable, even though they may significantly contribute to land degradation. Lal (1988) estimated nutrients removed in crops to be greater by as much as an order of magnitude compared to the nutrients returned to the soil - a soil mining process. He found that for yields as low as 1.0 ton ha^{-1}, maize and sorghum crops remove as much as 30-40 kg ha^{-1} of nitrogen, 2-10 kg ha^{-1} of phosphorus, and 5–30 kg/ha^{-1} of potassium. In Botswana (and maybe in many other African countries) animals are put in the fields after harvest to feed on crop residue (author's experience). In some cases crop residue is removed from fields and fed to animals outside the field, and other crops are harvested (groundnuts, and certain beans and cowpeas). This type of soil mining by both people and animals has serious implications for agroforestry systems. The analysis of nutrient distribution in various crops will assist in the estimation of nutrient harvested in grains, roots (tubers) and crop residue, hence a better account of nutrient status in arable land.

Cost–Benefit Analysis

When a shifting cultivator finally decides to shift, a decision probably involving some costs and benefits, analysis is used to make a choice. In cost–benefit analysis, alternatives are often evaluated according to their impact on individual welfare, and the principles of this analysis in relation to the valuation of costs and benefits are derived from this premise and the assumption that consumers and producers behave rationally (Aeron–Thomas and Roberson, 1983). Rational behaviour depends on human judgement, but a farmer in the tropics who is at the mercy of the weather and the condition of the soil and faced with a hostile environment on which to make a livelihood (Stocking, 1988), has no luxury of making an irrational decision. Whatever decision is taken or choice of system of production mode is made, it must be based on past experience and thoroughly evaluated.

As a tool for making decisions, informal cost–benefit analysis has always been part of the day–to–day decisions of those investing in a means of making a livelihood in precarious and hostile conditions. It is obviously not as explicit as we know it today with understood discount rates, quantifiable variables, etc. But what is common in the use of this tool, is the time factor which has tended to make it unable to show costs and benefits in the infinite future. In making a decisions to shift, a farmer may be considering the costs and benefits in terms of human welfare in the period of operation of the present system of production. Similarly, in the new technological world, benefits and costs are primarily evaluated on the basis of an individual's willingness to pay for goods and services, marketed or not (Bojö 1986) in terms of monetary units. That is, the willingness is a result of the present decision-making and value attached to the prevailing market prices of the goods. Again willingness implies choice, while a farmer in the tropics may not have that choice if it is a question of survival.

The development or improvement of a tool depends very much on frequency of use, and the type of use determines aspects to be developed or improved. As it is today, cost-benefit analysis reflects frequent use in economic circles, and hence its developed aspects characterise it as a tool for use in those circles, whereas the premise on which it is based intends it to have universal application. Its principles also reflect where it was developed and used mostly, hence its use elsewhere has to take account of the 'new' conditions or requirements for it as a tool to work better. This is particularly true if the new situation no longer uses value in terms of individual willingness, but in terms of individual survival (no-choice situation) and if the monetary unit does not capture fully the importance of benefits and costs. This is likely to be the case when dealing with natural resources where they are used in their natural or semi-natural form and in situ, eg land resources as used in the tropics. Agroforestry is one system which is a semi-natural resource involving agricultural resource use. In applying cost-benefit analysis to agroforestry, the importance of the time factor cannot be overemphasized. The same applies to proper identification of costs and benefits and terms which better show the importance of these.

Costs of Agroforestry

Before looking at costs, a proper identification of the starting point of the analysis will be very important. Starting a new agroforestry system on virgin land will be different from one started on an operated land system. An already running system may have lost the balance between components or have lost/added characters normally present/absent in undisturbed virgin systems of that particular area. A running system is a project which started with initial costs and expected benefits which justified its initiation. For instance a farmer opening a new field on virgin land (uncultivated before) is initiating a project - if a project is taken to be the whole complex of activities in the undertaking that uses resources to gain benefits (Gittinger, 1982).

Operating costs can be very high for a farmer if the field experiences land degradation. Research data from western Nigeria show that yields of maize declined from 5t/ha immediately after forest clearing to 1.5t/ha, and to 0.5t/ha after 2 years and 4 years respectively (Lal, 1988). Lal (1988) has also reported yield losses due to soil erosion in Burkina Faso where the increase in erosion rates from 0.6 to 6 tons per acre caused millet yields to fall from 727 to 352 kg per ha in Burkina Faso, while in the Cameroons maize yield declined by 50% when 2.5cm of topsoil was eroded and complete crop failure occurred when 7.5cm of topsoil were removed.

The costs of starting agroforestry on land already operated by a farmer might start with substantial costs depending on whether the project starts by holding degradation processes, planting new species and addition of fertilizers to make land productive. However the running costs of a sustainable agroforestry system are supposed to decrease as the system becomes established. The success of the system in reducing the running costs to the operator and land depends on the design and management of the system. If it is a "running down" system (not sustainable), the costs of operating will increase.

Benefits

In opening a new field, a farmer has the benefit of woody biomass for fuel, building, even for sale or cash. The expected high yields of crop produce is an important benefit sought after by a farmer. This benefit is supposed to continue as long as the farmer sees it to be profitable, i.e. a return which justifies the further operation of the system. If it is a sustainable system, then benefits are infinite. These initial benefits will be similar to that of an agroforestry system initiated on virgin land which involve among other things, woody biomass for fuel and building. Continuous benefits will depend on its sustainability.

An agroforestry system designed for an already operating system, starts with benefits which are already reaped from the existing system. If it has aspects of improvement, then benefits are expected to increase as the outputs from the agroforestry system increase and add to the already existing benefits. They may be in the form of restitution or improvement of soils, eg by increased addition of organic matter, nitrogen fixing, less soil degradation which reduce the need for additional inputs needed to make a running down system productive. Other benefits will involve products which otherwise were not obtainable in the present system, like wood for fuel and building and browse for animals.

Discussion and Conclusions

There is no doubt that agroforestry remains a viable solution to environmental problems posed by agricultural activities in the tropics because it tries to mimic the natural ecosystem. However, the design of appropriate agroforestry systems should be based on the understanding of the existing natural system and the existing farming system. In many cases, farmers in long-settled parts of the systems that allow sustainable use of the land and respond to the environmental conditions (Stocking, 1988; Waller, 1984). It should be known now that the traditional interference based on the results of research stations not linked to the real world of farmers can be blamed for part of the crisis existing in agricultural activities. Slash and burn activities and shifting cultivation may be viable farming strategies which could form a basis for better technology.

There is no better justification for an agroforestry system than what farmers perceive as making a good return to sustain their livelihoods. The informal cost-benefit analysis farmers use to make decisions which enable them to earn a livelihood in otherwise very difficult environments, has to be credited accordingly. The type of data used may not be 'empirical', as we have come to understand the term, but the decisions were based on the real situation of their existence in terms of their physical world. If non-empirical data were used, then the way they were used would be of vital importance to allow to us to work out or improve relevant aspects of the cost-benefit analysis tool to be useful in such areas where there is no empirical data. It should be noted that although there is a lack of empirical data for us to carry out cost-benefit analysis, farmers have managed to make rational decisions for centuries. We have to make a decision to save land which is losing productivity or restore it to add to the limited area of productive land we have in this world of ever-increasing human population.

However, in a world dominated by the value of quantitative assessment the need for empirical data to carry out a convincing and appreciated cost-benefit analysis cannot be ignored. There is certainly a need for work in many areas. The lack of empirical data in areas of environmental resources which have been used for a long time with increasing depletion/damage, still points to the problem of value which actually determines whether action has to be taken, and if so, what type and to what extent. For instance the problem of land degradation in the tropics has been documented. However, not much effort was put into gathering empirical data because not much value was attached to land as a resource, or alternatively it was seen as an infinite resource. Another aspect of value is type. That is, if value is in terms of money, it may not be easy to place monetary value on natural resources because we may not know enough about the value of the resource to us to estimate its true worth. Hence the losses due to environmental damage often run unattended even in developed countries.

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* economics for sustainable production
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This volume represents the collection of papers presented at the Commonwealth Science Council's meeting on 'Agroforestry for Sustainable Development – Economic Implications' in Swaziland in 1989. The participants of the meeting who contributed to this volume include natural scientists, social scientists and economists so that the approach to the subject is of an interdisciplinary nature.

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