PART I

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).

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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.

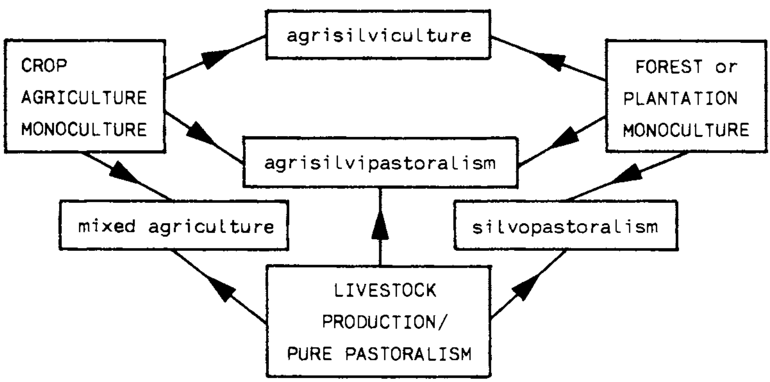


Figure 1. A continuum of land use systems involving agroforestry. (from Wood & Burley, 1989)

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 (Bojö, 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.

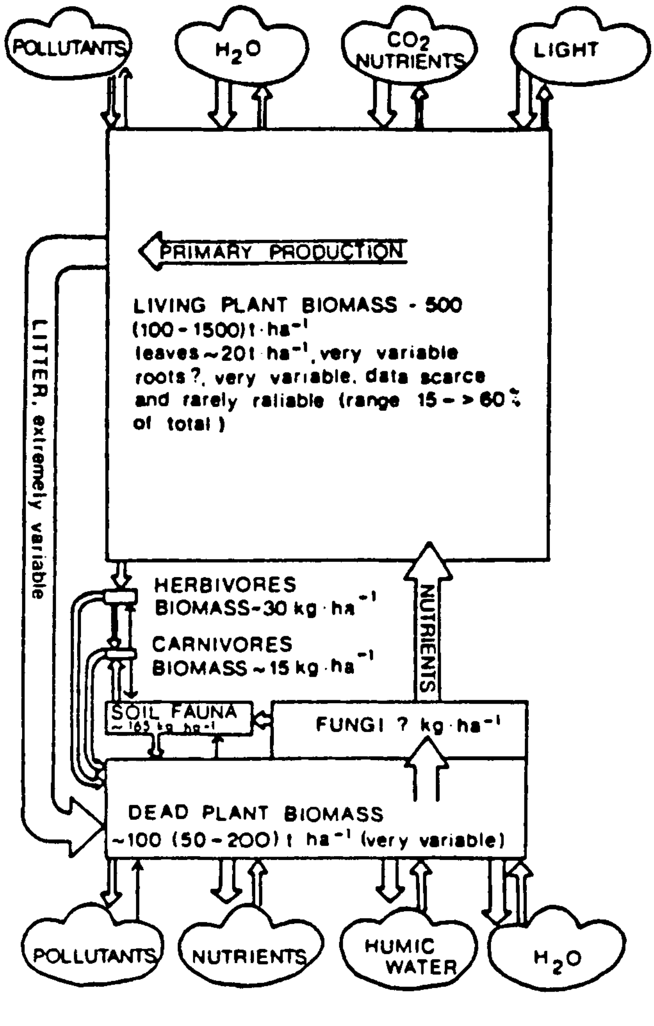


Figure 2. A model of a mature, humid, tropical equatorial, mainly evergreen, lowland forest. Note the variation and range in stocks and flows of phytomass which reflects uncertainty in the working of the system. (Source: Brunig, 1982).

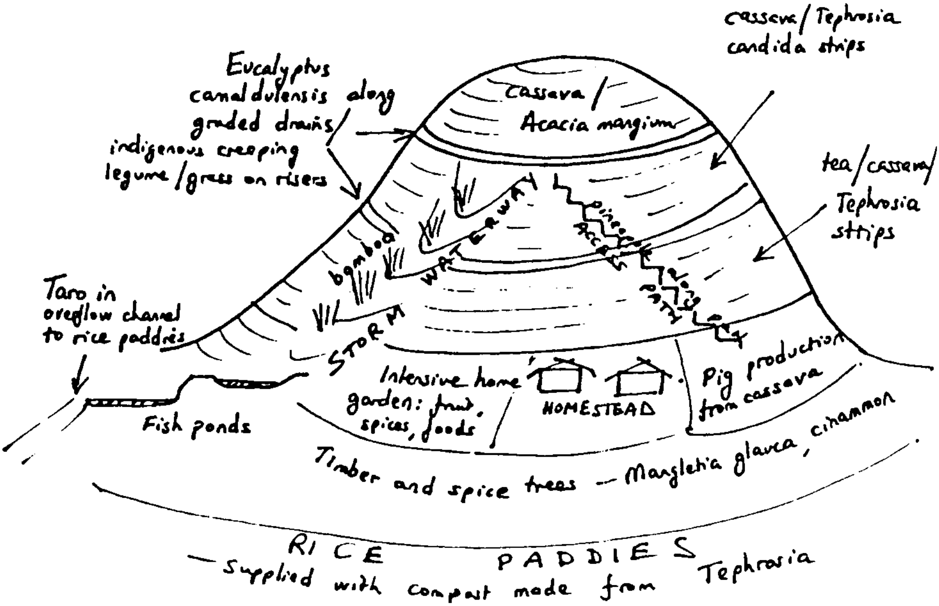


Figure 3. A simplified model of an household agroforestry production system in northern Vietnam. Note: cassava, tea, rice and homegarden outputs stand as before. External environmental benefits not taken as a benefit to the household.

INPUTS	OUTPUTS
[additional to previous paddy rice/cassava system]	
Tree seedlings bought in: <u>Acacia mangium</u> <u>Eucalyptus camaldulensis</u>	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.

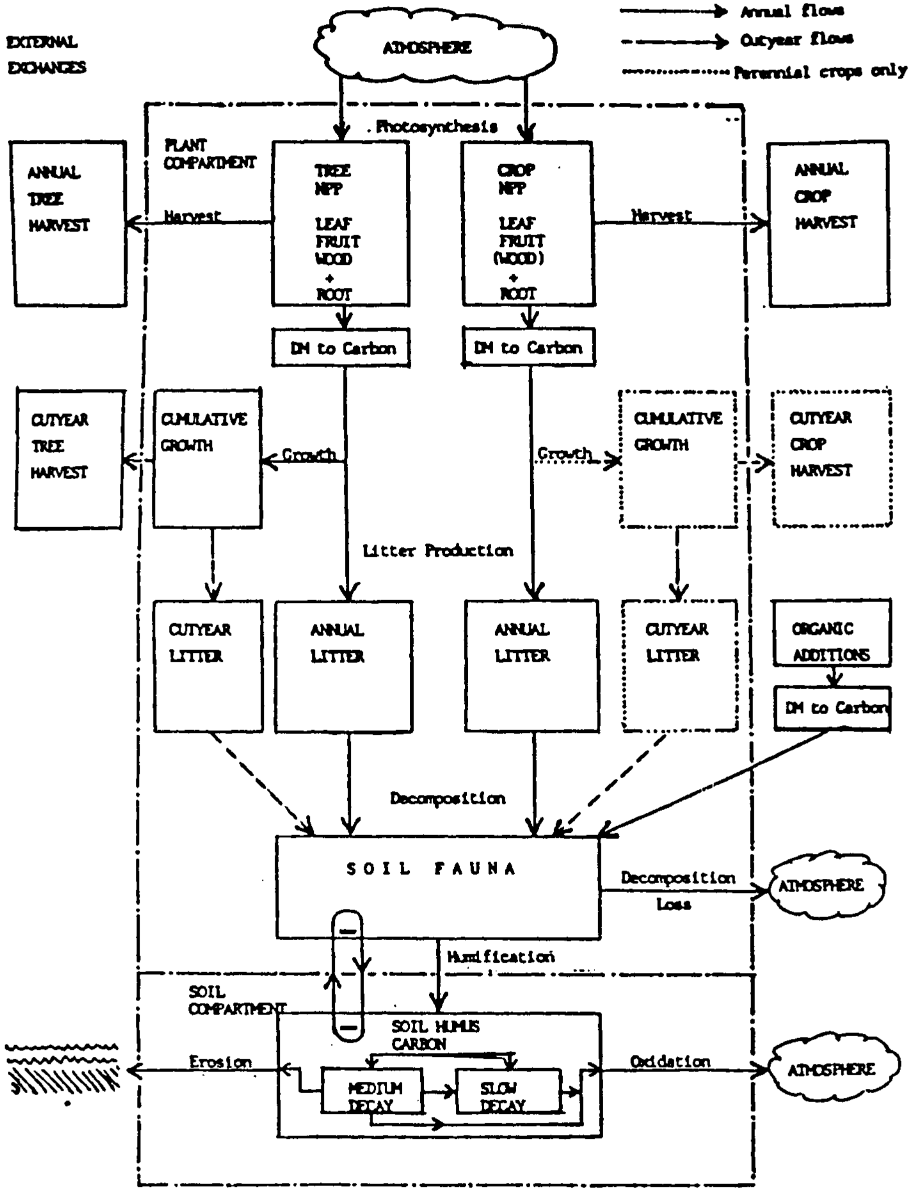
Soil Changes Under Agroforestry, SCUAF. This model incorporates erosion prediction, but extends the prediction to changes in soil organic matter and nutrients over time given different combinations of trees and ground cover. The following is a brief synopsis taken from the ICRAF Working Paper on SCUAF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

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

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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