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THE USE OF ECONOMICS IN AGROFORESTRY

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1. *Introduction*

Agroforestry has become a rather popular subject amongst agricultural scientists in the past decade or so. This may have been caused partly by the frequent failures of some traditional approaches to stimulate agriculture and forestry, partly by a genuine belief that agroforestry is a superior land use system but also because of a tendency to jump on the band wagon.

Whatever the reason, the ultimate test of agroforestry's usefulness will be its acceptance by the farmers. Various traditional agroforestry systems can be seen throughout the world and these have obviously passed this test already. Adaptation of these systems to reflect changes in farming systems and/or environments as well as development of new technologies is expected to take place in the next decade and it is precisely these systems/technologies which have to be put to the test to prove their usefulness.

Design and development of new or modified agroforestry systems/technologies should therefore be done with the ultimate users in mind so as to avoid disappointment at the end.

In this paper, the role of economics in the design and development of agroforestry land use systems/technologies is discussed.

Since economics deals with helping people to make decisions in a rational way, first and foremost, the type of decisions to be made in agroforestry as well as the information required to make decisions are briefly looked into. The role of economics in the diagnostic, design and development phase and its interrelationship with other disciplines are then briefly discussed, culminating into a review of the methods of economic analysis.

In dealing with the economic analysis of agroforestry systems/technologies, emphasis has been put on the farmer's point of view.

because his/her acceptance of this form of land use is the key to its widespread introduction. However in the last section of this paper some attention is also given to the analysis of agroforestry from a society's point of view.

Since many good economic textbooks exist already, no detailed description of the economic principles and methods of analysis is included in this paper; instead, examples are used to demonstrate the agroforestry application of such principles or methods as well as to highlight some of the specific aspects of agroforestry land use systems.

Finally, this paper has dealt with the economics of agroforestry and, in particular, the analysis of it in a rather sketchy manner so as to provide some general guidelines to individuals interested in the design and development of agroforestry. This paper may in future perhaps be expanded but it is felt that emphasis in the first instance should be put on the application and publicising of the actual use of economics in the design, development and appraisal of new and existing agroforestry systems. This would not only help to view agroforestry more objectively, but it would also scress the role economics has to play in developing this form of land use.

2. *What decisions*

The main contribution of economics to the design and development of agroforestry is to facilitate decision making and it seems therefore useful to start identifying the type of decisions that have to be made. The following broad categories are identified:

Should an agroforestry type solution be used to solve a particular problem or are there other non-agroforestry type solutions?

For example, if a soil fertility problem has been diagnosed, should it be solved by buying and applying the appropriate artificial fertilizer or should it be solved by for example introducing hedgerows of *Leucaena leucocephala*, which will be lopped regularly to provide green manure.

What type of tree/shrubs should be used to solve a particular problem?

For example, to plant a shelterbelt, should *Pinus halepensis* or *Eucalypthus camaldulensis* be used?

How and where should the tree component be planted?

This category involves a number of decisions such as: planting method, plant spacing, inter-cropping versus monocropping, plant location, time of planting, etc. For example, growing *Calliandra calothyrsus* to solve a diagnosed fuelwood problem on a farm could be done by direct seeding or with seedlings; plants could be spaced 1 meter or 2 meters apart; they could be grown in a pure stand or inter-cropped with annual crops or planted on benchrisers or farm boundaries.

What husbandary and harvesting system should be adopted?

This decision category deals with weeding, fertilizing and harvesting time. For example, when *Cassia siamea* is grown for mulch, should it be lopped two, three or four times a year?

3. *Information required for decision making*

To enable an economist to make decisions, information on the following aspects is required:-

i) the farmer's objectives;
ii) resources and constraints to production;
iii) potential agroforestry system/technologies.

3.1 The farmer's objectives

In subsistence and semi-commercial farming, the farmer's short-term objectives are usually to satisfy the basic household needs as well as to produce as much cash as possible to buy "non-essentials" to improve the quality of life.

In the long run, most farmers also aim at maintaining the level of output they have reached, but preferably to increase it.

Trying to achieve this longer-term objective may conflict with the short-run objective, especially if resources and/or farming technology are insufficient to satisfy basic levels of food, energy and cash requirements. In such situations, farmers, quite naturally, give priority to the present rather than the future and therefore over-exploit their resources which results in a gradual destruction of their productive capacity. However, observing the gradual destruction of world's resources should not be interpreted as a lack of long-term objectives on the farmers' side.

ICRAF (1) is in the process of developing a methodology for diagnosing the problems at farm level with the aim of designing the appropriate agroforestry activities (research and/or development). Satisfying the diagnosed needs will become the objective of the proposed interventions in the farm system. However, it should be emphasised that not all needs can be fulfilled, while certain needs may be best fulfilled with non-agroforestry interventions.

The first step after determining the farmer's needs should therefore be to screen them with a view to determining whether or not they are capable of being solved with the help of agroforestry. To facilitate this process, ICRAF prepared a list of such needs.

i) supply of food (crops as well as livestock products);
ii) supply of energy;
iii) supply of shelter;
iv) supply of raw materials for home industry;
v) supply of cash.

The first category offers a particularly broad potential for agroforestry either in a direct way, i.e., production of edible fruits, or in an indirect way, i.e., fodder production for livestock, conservation of moisture, maintenance or improvement of soil fertility, etc.

3.2. *Resources and constraints to production*

Resources and constraints constitute the limits to production; in other words a feasible farm plan is one which takes into consideration the resources and constraints in which the farm has to operate.

According to Carpenter (2), resources and constraints for a farm can be sub-divided into three categories, namely:-

i) farm family resources;
ii) physical resources and environment;
iii) government/social environment.

Family resources are an aggregate of several factors which together constitute the farm, i.e.:

i) family size, age, labour force;
ii) management skills, education
iii) farm size, quality;
iv) location, distance, access;
v) disease hazards.

The government/social environmental factors represent predominantly the body of policies and institutions which have tried to "influence", "encourage" through "incentives" or "direct and regulate" the interactions of farm family and physical environmental factors to achieve "development", i.e.,

i) policies
   - prices
   - trade
   - bank/credit
   - subsidies

ii) infrastructure
   - extension/education
   - research
   - transport
   - supplies/markets

iii) industrialisation
   - inputs available
   - by-product demand

iv) other (tenure, cultural habits, etc).

3.3. *Potential technologies/systems*

Although the emphasis in the selection of appropriate interventions would be on agroforestry technologies, non-agroforestry interventions should be considered as well.

The determination of appropriate agroforestry technologies is part of ICRAF's diagnosis and design methodology. Some of the technologies thus identified may be more or less ready for direct application while others will be of a notional nature, requiring research.

Because of the fairly recent emergence of agroforestry as a science, very little input/output data on different technologies are readily available and appraisal of existing systems as well as monitoring newly established systems will be required to obtain data for a thorough *ex ante* analysis of alternative technologies.

"Activity budgets" have to be prepared for each agroforestry system/ technology to be considered for research and/or development. Ideally, these budgets should contain the following information (3).

i) a list of the demands placed on farm-resources per unit level of the activity;

ii) quantification of any inter-relationship between the special activity and other possible activities (i.e. grazing requirements of livestock, rotational attributes of crops);

iii) a list of any non-resource constraints on the level of the activity either alone or in combination with other activities (i.e. marketing constraints or constraints reflecting the personal preferences of the farmer);

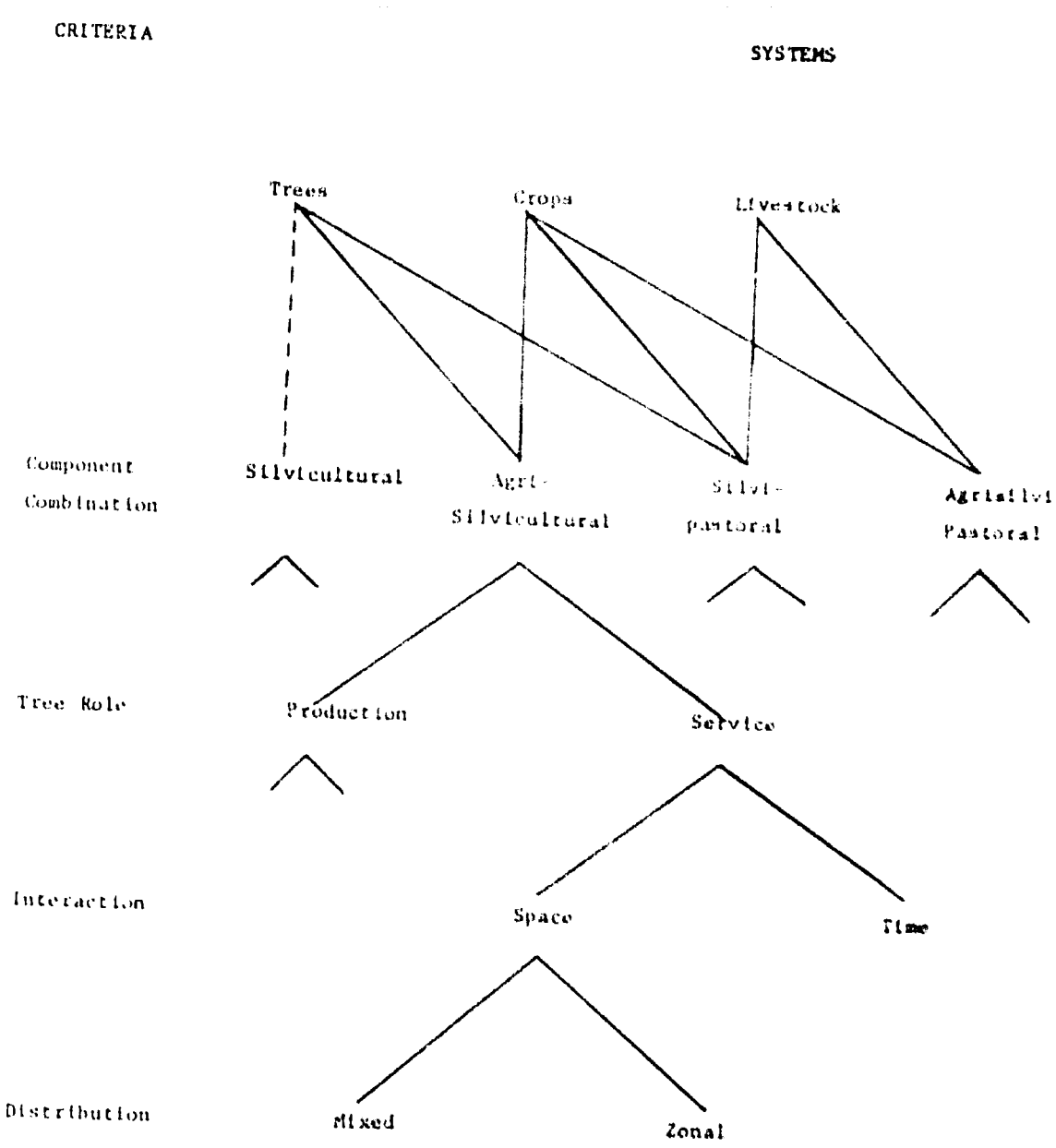
iv) a listing of variable cost per unit level of activity;

v) a statement of the output produced per unit level of the activity and if the output is sold an estimate of the net price received.

Because of the multi-period nature of almost all agroforestry systems, all of these data should be plotted against a time scale.

The different agroforestry systems have been summarised in a diagram by Torres (4).

Diagram: 3.3.1. *Agroforestry systems*



4. *Use of economics in diagnosis, design and development of agroforestry technologies/systems.*

Before discussing the different aspects of economic analysis in an agroforestry context it seems useful to first of all outline the role of economics in the different phases of generating appropriate agroforestry technologies/systems.

4.1 Diagnostic phase

In the diagnostic phase of the whole planning process, economics should be used to define the "boundaries" in which any new system/technology has to operate (see 3.2.) as well as to analyse the existing systems so as to identify bottlenecks in the present farming system. These can then in turn become the focal point (s) for designing appropriate agroforestry as well as non-agroforestry solutions.

The latter bottlenecks are commonly displayed with the help of weekly, monthly or seasonal profiles, e.g.

- *Labour profile* : depicting supply and demand of labour over time.
- *Cash flow* : showing cash inflows and outflows including loans and debt servicing over time.
- *Food profile* : showing food production (its storage and food consumption) over time (for the main products only). A more sophisticated form of a food profile is a nutrition profile.
- *Energy profile* : showing the consumption of energy as well as the supply of energy products over time.

Traditionally these profiles have been substantiated on the basis of studies providing detailed quantative information. Although such detail seems to be ideal, in rapid rural appraisal where little time and/or data are available, obtaining a rough qualitative picture identifying critical periods may be all that is possible or necessary.

4.2 Design phase

The *ex ante* analysis of a new technology may either be based on an *intuitive* or an *analytical* approach (5).

In the very early stages of the design process, emphasis will most likely be on the intuitive approach with only a few simple economic analyses whenever data are available. Later on in the design phase when the original ideas have gone through some form of testing (on-farm or on-station), the emphasis may gradually shift to the analytical approach as more data on the technology become available.

Part of the early design process will be to decide as to where certain desired tree functions are best located. For example, if fruits have been identified as having a potential for solving the diagnosed cash or food problems, several potential planting sites are feasible.

To facilitate this decision making process, the following steps are suggested:

List all candidate tree functions for the study areas as well as all potential planting sites.

Tree functions may be sub-divided on the basis of the tree component performing a productive and/or a service role.

A *tree product* will here be defined as all material output which is harvested/collected irrespective of whether it is an end or intermediate product or whether it is sold or consumed.

The most common products are: fuelwood, fruits, timber, poles, craftwood, charcoal, fodder, leaf litter (mulch).

A *tree service* will here be defined as all immaterial output which is obtained from the individual trees, and/or derived from the spatial arrangement of the trees within a system, e.g. trees to provide shade to humans and/or animals, a living fence to keep out animals, a row of trees for demarcating a boundary, a shelterbelt to protect crops and/or dwellings against the wind, scattered trees or rows of trees to control erosion.

While tree service functions are more or less site-specific, trees with productive functions are not and can be planted almost anywhere, including sites identified for service functions, e.g. a fruit tree which also provides the required shade in the home compound.

Distinctions between planting sites are made on the basis of their present use and potential for performing a tree service role. The most common ones are:

arable land - sub-divided on the basis of present and/or potential use (terrain characteristics, soil properties, distance to farm house, irrigation facilities, etc)

grazing land - sub-divided on the basis of present and/or potential use (see arable land)

- boundaries.

home compound including boundaries

woodlots/orchards.

Match tree functions and sites

Since no detailed economic analysis of different function/site alternatives is envisaged at this stage, deselection of sites for certain functions should be based on some simple comparative methods. The following procedure is suggested.

Construct a matrix with tree functions and planting sites in the axis and enter all "site specific" service functions in the matrix.

Then, the "non-site-specific" productive functions should be entered one by one. It is important in this respect to examine the feasibility of combining the productive function with the service functions. This, to a certain extent, will be determined by technical factors and requires amongst others considering possible alternative designs to fulfill a service role, since different "service role" designs

may accommodate different tree products. For example, a single row shelterbelt would more or less exclude tree products which require the harvesting of the whole tree, a multiple row shelterbelt, on the other hand, could possibly include such tree products.

At the same time, sites not identified for a service role may also be considered for producing tree products. In order to get an appreciation of possible differences in cost and benefits between individual sites it may be useful to study the existing spatial distribution of trees in a given area and to find out why certain trees (functions) are found in particular locations. A number of factors can usually be synthesised from such an exercise, e.g. difference with regard to: labour, (distance, soil, etc.) protection against animals or theft, potential use of land, etc.

The end product of such an exercise would be a matrix which links the different tree functions and planting sites. If a location has been identified as being suitable for several tree functions, multi-purpose trees may be considered as well as combinations of mono-purpose trees (see example of tree decision matrix).

Example of tree function decision matrix

location / function	arable land			grazing land		home compound	
	1	2	3	1	2	1	2
shelterbelt						X	
erosion cont.	X						
fence					X		
shade				X		X	
fuelwood	X	X	X		X		
fodder		X		X			
fruits	X					X	X
mulch	X		X				

arable land 1 - contour lines
2 - waterlogged area
3 - boundaries

grazing land 1 - general
2 - boundaries

home compound 1 - general
2 - boundaries

Having narrowed down the choice of candidate agroforestry land use systems/technologies on the basis of the location, narrow down the choices with regard to components and practices.

It should be noted that although this sequence in steps should be followed in principle, in practice, steps often have to be taken simultaneously.

Several methods of economic analysis, briefly described later, may be used to decide about different components and management practices. However, in the absence of "hard" data in the early stage of the design process, a more intuitive approach may be called for. The intelligent observation of existing tree species and management practices in the study area may in such cases provide the best clue to the most appropriate choice.

Having identified several potential agroforestry systems/technologies in this way, make final selection of only the most promising ones

In this deselection process, several factors should be taken into account.

i) The amount required of a specific tree product. For example planting trees for fuelwood in a woodlot in a waterlogged section of a farm may not satisfy the present or projected needs for fuelwood and a second less profitable alternative should also be considered.

ii) The *mutually exclusive* nature of some technologies with regard to the use of a specific scarce resource. For example, a rocky area of the farm may have been identified as being suitable for fuelwood production as well as fruit production. If multipurpose trees don't appear to have a potential and if the whole area would be required to satisfy the demand for either fuelwood or fruits, only one of the activities can be selected to the exclusion of the other.

In the more advantaged stage of the design process, when ideas have to be tested, another important use of what is generally considered to be part of farm management comes into focus, i.e. *monitoring* inputs and outputs.

4.3. *Development phase*

This final phase in the generation of new technology deals with the integration of the newly developed technology and/or existing technology into the farms. The major task for an economist at this stage is to find the best possible combination of technologies so as to solve for each farm type the diagnosed problems in the most economic way and at the minimum of risk.

Emphasis in this final phase is on the analytical approach and the different aspects of such analysis are the subject of the rest of this paper.

5. *Economic analysis applied to agroforestry*

5.1. *Benefits and costs*

In analysing different agroforestry land use systems from a farmer's point of view, only *direct* costs and benefits are taken into account, while the *indirect* costs and benefits (also referred to as *externalities*) are excluded.

Indirect benefits are those which result from the introduction of an agroforestry land use system, but are not received by the farmer, while indirect costs are those inputs required for the introduction of the system but not paid for (in full) by the farmer.

An example of an indirect benefit is the reduced rate of siltation in an irrigation water reservoir downstreams resulting from an agroforestry land use system aimed at preventing/reducing soil erosion upstreams.

An example of an indirect cost is the damage caused on neighbouring farms by an increased bird/insect population because of the inclusion of trees on a farm. A special category of indirect costs is also the "uneconomic" pricing of certain inputs, this aspect will be dealt with in section 6 of this paper.

Benefits from a farmer's point of view are the physical outputs multiplied by the *market price* received for a unit sold or the *opportunity price* the farmer would have to pay to acquire an additional unit of the products for his/her consumption.

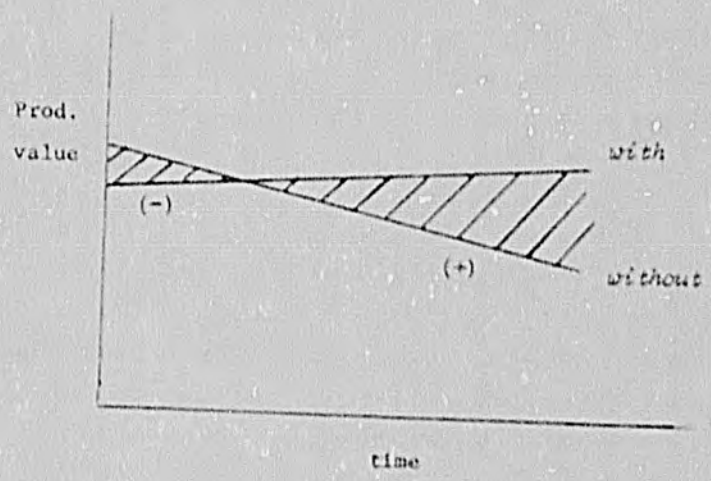
However, many products from agroforestry activities are in fact not marketable and in such cases different methods of valuation are suggested. Fodder from browse trees may, for example, be valued on the basis of its energy content and digestible protein content and the per unit prices for these measures derived from commercial feeds (6). Fuelwood may be valued according to the value of substitute fuels(7).

Attention should be drawn to the fact that this valuation method of benefits may be inadequate to determine the real benefits to the farmer, especially in subsistence farming. If, for example, a farmer is unable to purchase fodder either because there is no market or he does not have the cash, the benefits of an agroforestry system producing fodder should be measured in terms of livestock production.

Certain agroforestry benefits can only be measured by a comparison with other land uses, including non-agroforestry uses. This brings into focus the concept of added benefits from a *with* and *without* agroforestry comparison.

The following example on soil degradation illustrates this method. When land is cropped continuously without adequate soil conservation and fertility measures, the productive capacity of such land will gradually decline. A hedgerow cropping system with tree species lopped regularly for leafy mulch may help to maintain soil fertility. The gross benefits of such a system would, therefore, be the difference in production value between the *with* and *without* hedgerow cropping situation as demonstrated in figure 5.1.1.

Fig. 5.1.1. Benefits hedgerow cropping system



Costs from a farmer's point of view are the inputs multiplied by the *market price* paid for each unit of purchased inputs and the opportunity return (*opportunity costs*) of the farmer's own resources in their next best use. The latter inputs only need to be costed in case of a partial budget analysis (see also 5.3.)

Hired labour may therefore be costed at the going market price if it can be added easily to existing hired labour usage. Family labour or hired labour withdrawn from its use on the farm has to be costed according to the opportunity cost principle. This valuation will usually differ according to season and/or the existence of off-farm employment opportunities. If there is a real opportunity of being employed as a casual labourer, family labour is normally valued at the net wage received in such employment. If no such opportunities exist the opportunity cost of labour is estimated at 50 - 75% of its market price in the off-season and 125% of its market price in the peak season (8).

The costing of land will depend on whether the farmer owns or rents it. In case he/she rents, the rental price may be taken, while the opportunity cost principle has to be used in case the land is owned.

The opportunity cost of land is mainly determined by its present use and its potential productive capacity. When designing agroforestry land use systems, it is important to differentiate between locations having different opportunity costs, since it will affect the attractiveness, and hence the spatial arrangements, of the agroforestry activities on the farm (see also section 4.2.)

Raw materials, such as fertilisers, seedlings and chemicals, which are usually not produced on the farm, are costed at purchase price.

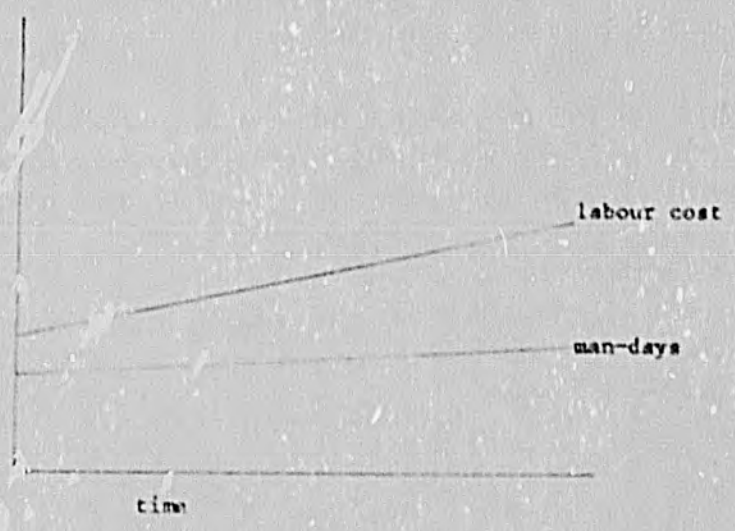
The costing of what is called the farm's own physical capital resources, i.e. buildings, breeding stock, perennial crops and machinery, has to be based on the opportunity cost principle.

Since the opportunity cost of each owned farm resource may be difficult to ascertain separtely, they are often combined by computing only the overall net returns to family resources (gross production value minus purchased inputs).

This approach is used in the previously mentioned *with* and *without* agroforestry comparison. The returns to family resources in the *without* situation can be considered as the opportunity cost of the farm resources committed in the *with* situation. In case there are differences in family resource use between the *with* and *without* situation, the opportunity returns to such lower or additional resource use, on or off farm, have to be assessed using the opportunity cost principle mentioned earlier.

The net benefits between two alternatives may consist of the net value of additional output and/or the opportunity returns of the reduced inputs required to obtain the same amount of output. An example of the latter benefits is the introduction of a labour-saving fuelwood activity. It is envisaged that in view of the fact that fuelwood in many countries is becoming scarcer, the labour involved in collecting fuelwood in the *without* situation will increase over time. Further, the opportunity returns per unit of labour will rise with an increased labour demand and for collecting fuelwood because increasingly labour will have to be withdrawn from other productive uses on the farm. (see Fig. 5.1.2.).

Fig. 5.1.2. Development fuelwood collection labour input and cost per farm



5.2. *Discounting*

Due to the multi-period nature of agroforestry land use systems, valuation of costs and benefits over time has to be considered. Economics deals with this aspect through a technique called *discounting* which is the process of adjusting future costs and benefits so as to express its present value. The adjustment factor, commonly called *discount rate* is derived from the accepted time value of consumption. This may be explained in simple terms as follows. If we ask a thirsty farmer whether he prefers a glass of beer now, or two glassed of beer later, the answer would depend on his degree of thirst. In an extreme case, a farmer who is so thirsty that he believes he will not survive another hour will take a glass of beer now, irrespective of the amount offered later (9). In such a case the discount rate would be very high. If the farmer, on the other hand, has just finished a glass of beer and presumably his degree of thirst has been reduced, he might forego the extra glass of beer now for two glasses of beer later, i.e. he has a lower personal discount rate.

As is clear from this example, the personal rate of discount is rather difficult to determine since it varies from one commodity to the next, depending on the level of risk aversion and the relative scarcity of the commodity which in turn is determined by the scarcity of production resources. According to Flinn (10) it is likely, however, that:

i) poor farmers have higher discount rates than rich farmers;

ii) farmers with profitable investment alternatives, or stringent necessities, have higher discount rates than others; and

iii) farmers who live in a natural environment that imposes high risks on them will have greater discount rates than others.

Any rate will, therefore, be subject to discussion and most economists either use of several discount rates, from which the user can select, or use the internal rate of return (see also 5.3.).

It would be interesting, however, to examine whether or not agroforestry land use systems have a similar discount rate as non-agroforestry land use systems. In a recent paper by Harou (11) it is argued that there is a lower risk attached to agroforestry systems as compared to mono-cropping systems and therefore farmers may more easily forego present consumption than with non-agroforestry interventions. Another factor which will perhaps result in a lower discount rate for agroforestry, is the general awareness for a need for tree planting created by international as well as national bodies.

On the other hand, insecurity of tenure in many small farming situations may strongly discourage farmers from planting trees, and indirectly cause a higher rate of discount.

The formula for discounting future costs and benefits is presented below:

$$V_o = V_n (1 + r)^{-n}$$

In which V_o = present value

V_n = future value in year n

r = discount rate

n = number of years until future value occurs

5.3. *Measure of economic worthiness*

To compare alternative technologies/systems, three different measures of economic worthiness may be considered.

Present value costs (P.V.C.)

$$P.V.C. = \sum_1^n C_n (1 + r)^{-n}$$

In which C_n = costs in year 1.

This measure is used to compare alternative technologies/systems which have the same benefits but a different cost structure, also referred to as the *least cost analysis*.

Net present value or worth (N.P.V.)

$$N.P.V. = \sum_{1}^{n} B_n (1 + r)^{-n} - \sum_{1}^{n} C_n (1 + r)^{-n}$$

In which B_n = benefits in year n.

This measure is used to compare alternative technologies/systems with different flows of cost and benefits.

N.P.V. is usually expressed per unit of land but may also be expressed per unit of any other production factors.

Because of the absolute nature of this measure, it cannot be used to compare alternatives which are not mutually exclusive.

Internal rate of return

That r where N.P.V. = 0

This measure is also used to compare alternative technologies/systems with different flows of costs and benefits. However it is less useful when the net benefit flow has no negative value or when the rate is higher than 50% or when comparing mutually exclusive alternatives (12).

5.4. Decision-making principles.

Three bio-economic relationships form the basis for design and analysis in general as well as in agroforestry (13), i.e.

1. Input/output relationships
2. Input/input relationships
3. Output/output relationships

While the first function forms the basis for deciding *how much* should be produced, the second function addresses the question of *how* to combine inputs to produce a certain amount of output and the third one deals with *what* combination of outputs should be produced given a certain amount of inputs.

General principles for decision making in each of these cases are outlined below and illustrated with some agroforestry examples.

5.4.1. How much production

Production functions curves are commonly used to illustrate the relations between the level of input and the resulting output.

To determine the optimum level of output, the physical production function as well as the unit prices of inputs and outputs have to be known.

Ideally, the quantity of inputs should be increased to such a level that the value of the last added unit of input equals the value of the resulting output; i.e. marginal costs equal marginal benefits.

Care should be taken , however, with the application of this principle where costs and benefits occur over a period of more than one year. An example of how to determine the optimal harvesting age of a tree may illustrate this.

Assume the following cost/benefit relation for a hypothetical tree.

Table 5.4.1.1. Flow of costs and benefits hypothetical tree.

Year	0	1	2	3	4	5	6	7	8
Accumulated benefits (1)	-	-	30	60	120	170	210	230	234
Annual costs	20	5	5	5	5	5	5	5	5
Harvesting costs (1)	-	-	2	3	4	6	6	7	7

(1) if harvested in that year.

Applying the undiscounted version of the *equi-marginality* principle to determine the optimum harvesting time of the tree would lead to a decision to harvest this hypothetical tree after 7 years, since in year 8, marginal costs (=5) exceed marginal benefits (=4). However, such method ignores the fact that the benefits *accrued* in the previous years reduce in present value if *realised* only at the end of year 7. Therefore the decision has to be based on a year-to-year comparison of the present value of the accumulated benefits minus the sum of the present value of the annual costs. That year which gives the highest N.P.V. is selected as the optimum harvesting time.

The N.P.V. of a tree at the end of year 6 would, for example, be computed as follows:

Table 5.4.1.2. Computation N.P.V. of hypothetical tree harvested after 6 years.

	Year							
	0	1	2	3	4	5	6	*Total*
Discount factor (12%)	1.0	0.89	0.8	0.71	0.64	0.57	0.51	-
Benefits	-	-	-	-	-	-	210	-
Discounted benefits	-	-	-	-	-	-	107.1	107.1
Establishment costs	20							
Annual costs	-	5	5	5	5	5	5	
Harvesting costs	-	-	-	-	-	-	6	-
Discounted costs	20	4.4	4.0	3.5	3.2	2.9	5.6	43.6
Net present value (discounted benefits minus discounted costs)								63.50

Because of the multi-output nature of most agroforestry systems, a slight modification of this approach may be required if part of the desired benefits are realised on an annual basis, e.g. fodder, fuelwood. Benefits in such cases should be subdivided into those realised only at

the time the whole tree is harvested and those realised on an annual basis. The latter benefits will have to be discounted on an annual basis, similar to the annual costs, and added to the former accumulated benefits discounted over the time period up to harvesting.

Several other decisions which have to be taken in designing agroforestry systems/technologies can be based on the marginal costs and benefits principle, e.g. plant spacing, level of labour input for weeding and fertilising, etc.

However, data will usually be insufficient to determine the optimum level of inputs and therefore it is common to compare only two or three different levels of inputs and select the one which shows the highest N.P.V. The following example illustrates this method.

A farmer considers planting *Calliandra calothyrsus* for fuelwood production. Two systems are feasible, i.e. planting 2 meters apart and harvesting once a year, and planting 1 meter apart and harvesting twice a year. Assuming that both systems will last for about 5 years, the following costs and benefits are projected:

Table 5.4.1.3. Flow of costs and benefits in respect of two planting distances (hypothetical)

		Years					
1-meter spacing		0	1	2	3	4	5
Costs:	land	-	200	200	200	200	200
	labour	30	20	20	20	20	40
	seed	50	-	-	-	-	-
	Total cost	80	220	220	220	220	240
Benefits		-	-	450	450	450	500
2-meter spacing							
Costs:	land	-	200	200	200	200	200
	labour	8	12	12	12	12	25
	seed	13	-	-	-	-	-
	Total costs	21	212	212	212	212	225
Benefits		-	-	360	360	360	400

Assuming a discount rate of 12%, the N.P.V. of 1-meter spacing is 364 and of 2-meter spacing is 206. Provided the opportunity costs and the discount rate were correctly chosen, the 1-meter spacing method appears to be the better method.

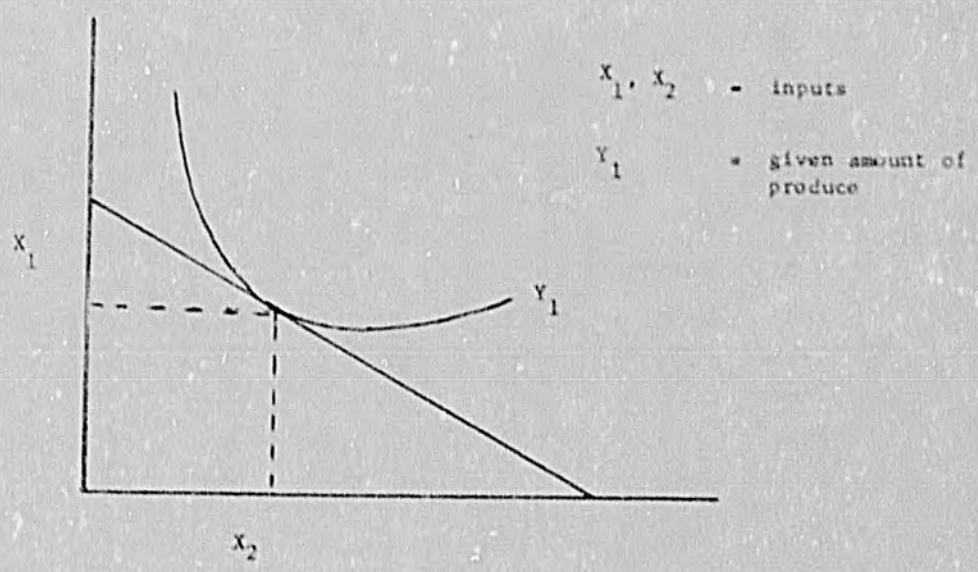
5.4.2. *How to combine inputs*

To produce a given amount of output , a decision has to be taken as to how to combine two or more inputs for its production.

The general principle is to replace an input (x_1) with another (x_2) until the marginal values of the inputs are equal.

Iso product curves (all possible combinations of two inputs resulting in the same amount of output) and *iso costs lines* (all combinations of two inputs which can be purchased for a given cost) are used to illustrate this point (see Fig. 5.4.2.1.).

Fig. 5.4.2.1. Best economic combinations of x_1 and x_2 to produce y_1



To satisfy many of the identified needs such as fuelwood, shelter and often food, the farmer's objective will be to produce a given amount at the least risk and therefore the above outlined principle is very much applicable in the design and development of agro-forestry systems/technologies.

Similarly, with regard to the question of how much to produce, discussed earlier, data are often insufficient to determine the optimum combination of inputs to produce the required output and therefore most decision making in this field deals with comparing the present value cost (P.V.C.) of only two possible combinations of inputs. An example is given below.

Assume the same situation as in the last example, with the exception that the farmer requires an annual supply of 30 m^3 of fuelwood using either the 1- or 2- meter spacing (price of fuelwood 15/m^3).

Table 5.4.2.1. Cost flows in respect of two planting distances to produce 30 m^3 of fuelwood annually (hypothetical)

	Year					
1-meter spacing	0	1	2	3	4	5
Land (1 hectare)	-	200	200	200	200	200
Labour	30	20	20	20	20	40
Seed	50	-	-	-	-	-
Total	80	220	220	220	220	240
M^3 fuelwood	-	-	30	30	30	33.3
2-meter spacing						
Land (1.25 hectares)	-	250	250	250	250	250
Labour	10	15	15	15	15	30
Seed	16	-	-	-	-	-
Total	26	265	265	265	265	280
M^3 fuelwood	-	-	30	30	30	33.3

Assuming a discount rate of 12%, the present value cost of the 1-meter spacing method is 884 and of the 2-meter spacing is 990 and, therefore, the 1-meter planting distance/biennial harvesting appears to be a cheaper method, provided, of course, that the opportunity costs of land and labour are correctly chosen.

It should be noted that similar costs in both alternatives could have been omitted from the comparison since they would have balanced each other out.

5.4.3. *What to produce*

A distinguishing feature of an agroforestry land use system is that resources are used to produce multiple outputs. A theoretical model dealing with decision making in such a situation was developed around 1920 by Edgeworth-Bowley using a box diagram. Since then, the theory has been further developed and is presently described in many (agricultural) economics textbooks and articles (14, 15, 16, 17).

The general principle with regard to decision making in multiple output production systems is to increase input to any one component so that the marginal value products of this input is the same in each alternative.

To illustrate this optimisation procedure so called *iso cost* and *iso revenue* curves are used. An iso cost (also called production possibility) curve shows all possible combinations of outputs of two components using the same amount of inputs (costs). Different curves are therefore possible, depending on the levels of inputs assumed or available.

Three types of output/output relationships are usually identified i.e. complementary, supplementary and competitive.

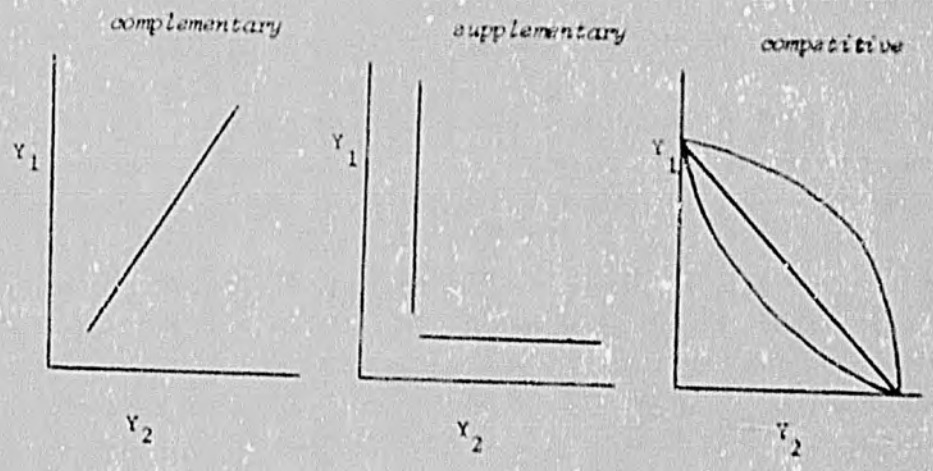
In *complementary* relationships, increasing the output of one component results in a corresponding increase in the other (see Fig. 5.4.3.1.).

In *supplementary* relationships, an increase in the output of one component does not affect the output of the other (see Fig. 5.4.3.1.)

In *competitive* relationships an increase in the output of one component decreases the production of the other (see Fig. 5.4.3.1.).

In reality, production possibility curves are often composed of a combination of these three relationships.

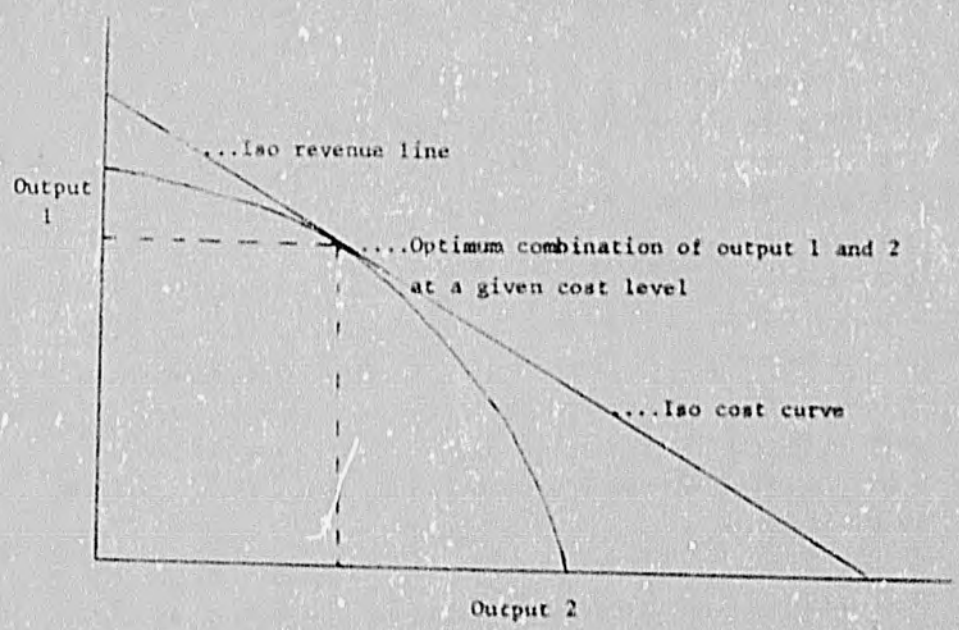
Fig. 5.4.3.1. Complementary, supplementary and competitive output/output relationships.



Iso revenue curves, on the other hand, represent all possible combinations of outputs of two components which have an equal value. If constant prices are assumed for both products, each iso revenue curve would be a straight line with an angle equal to the reciprocal of the price ratio between the two products.

The point of tangency of the iso revenue and the iso cost curves determines the optimum combination of two products at certain cost level. Value marginal increase in the output of one equals the value marginal loss in output of the other (see Fig. 5.4.3.2.).

Fig. 5.4.3.2. Optimum combination of outputs



An example of the application of the allocation of scarce resources in a multiple output agroforestry land use system is given below.

Assume a farmer wants to introduce a hedgerow system of *Leucaena leucocephala* on his cropland, where he has been growing two crops of maize every year. He intends to harvest the rows twice a year to supply organic fertilizer to his maize crops as well as to produce some fuelwood.

He considers two possible hedgerow spacings, i.e. one at 3-meters between the rows taking up 25% of the cropland and one at 1.5-meter between the rows taking up to 50% of the cropland (width hedgerow assumed to be 0.75m).

The following assumptions are made with regard to the inputs and outputs of such a land use system.

Leucaena production is estimated at 1 kg of dry leaves/meter/year, (starting year 1) containing a nitrogen content of 3.5%. The 3-meter spacing method will therefore result in a production of 117 kg of organic nitrogen per year (half per crop) while the 1.5-meter spacing will produce 233 kg of organic nitrogen (per intercropped hectare). Based on data by Kang et al (18) it is computed that on average, 1 kg of organic nitrogen produces 6.3 kg of maize* and hence annual maize production will be increased by 734 kg using the 3 meter spacing and 1,468 kg using the 1.5 meter spacing. These increases are gross since the per hectare production will be reduced because of a loss in acreage, occupied by the hedgerow.

The annual fuelwood production of leucaena is estimated at 2 and 4 m^3/annum for the 3- and 1.5-meter spacings respectively.

The following additional assumptions were made with regard to inputs and outputs of maize and leucaena.

Table 5.4.3.1. Annual inputs and outputs per hectare 2 maize crops

Production	1,000 kg
Seeds	50 kg
Labour (excluding harvest)	100 man-days
Harvesting labour (0.04 x production)	ma-days.

* It should be noted that at a high rate of application of organic nitrogen, it is unrealistic to maintain the same 6.3. conversion rate.

Table 5.4.3.2. Flow of inputs 1 hectare of leucaena

	Years								
	0	1	2	3	4	5	6	7	8
Labour (man-days)	50	50	150	150	150	150	150	150	150
Seeds (kg)	3	-	-	-	-	-	-	-	-

Prices

Maize	1.5/kg
Fuelwood	15/m^3
Seed maize	5/kg
Seed leucaena	300/kg
Labour	8/man-day

Based on these data, flows of costs and benefits were made for the two proposed land use systems (see Table 5.4.3.3. and 4).

Assuming a 12% discount rate, the net present value per hectare of the cropping system with the leucaena hedgerows spaced at 3 meters resulted in a net present value of 2,513 while the 1.5 meter spacing resulted in 2,956. The latter spacing, therefore, seems to result in the more beneficial land use.

5.5. *Methods of analysis*

The method of analysis demonstrated in the example in section 5.4. is commonly referred to as *multi-period budget* comparison or *cost benefit* analysis.

Most of the comparisons made were *partial* in nature in that they dealt only with part of a whole farm system. Although this method may be used for analysing mutually exclusive agroforestry technologies/systems it should be kept in mind that rather large partial budgets may be required to fully analyse the impact an agroforestry intervention has on the whole farm system. In particular, the evaluation of

Table 3.4.3.3. Annual flow of costs and benefits leucaena/maize cropping system (hedgerow at 3 meter intervals).

	Years								
Benefits	0	1	2	3	4	5	6	7	8
Maize (0.75 hectares)									
- base	-	1,125	1,125	1,125	1,125	1,125	1,125	1,125	1,125
- increment	-	-	1,105	1,105	1,105	1,105	1,105	1,105	1,105
Fuelwood (0.25 hectares)	-	-	30	30	30	30	30	30	30
Total benefits	0	1,125	2,260	2,260	2,260	2,260	2,260	2,260	2,260
Costs									
Maize (0.75 hectares)									
- labour (excluding harvesting)	-	600	600	600	600	600	600	600	600
- labour harvesting	-	240	476	476	476	476	476	476	476
- seeds	-	187	187	187	187	187	187	187	187
Leucaena (0.25 hectares)									
- labour	100	100	300	300	300	300	300	300	300
- seeds	225	-	-	-	-	-	-	-	-
Total costs	325	1,127	1,563	1,563	1,563	1,563	1,563	1,563	1,563

Table 3.4.3.4. Annual flow of costs and benefits leucaena/maize cropping systems (hedgerows at 1.5 metern intervals)

	Years								
Benefits	0	1	2	3	4	5	6	7	8
Maize (0.5 hectares)									
- base	-	750	750	750	750	750	750	750	750
- increment	-	-	2,202	2,202	2,202	2,202	2,202	2,202	2,202
Fuelwood (0.5 hectares)	-	-	60	60	60	60	60	60	60
Total benefits	-	750	3,012	3,012	3,012	3,012	3,012	3,012	3,012
Costs									
Maize (0.5 hectares)									
- labour (excluding harvesting)	-	600	600	600	600	600	600	600	600
- labour harvesting		160	630	630	630	630	630	630	630
- seeds	-	125	125	125	125	125	125	125	125
Leucaena (0.5 hectares)									
- labour	200	200	600	600	600	600	600	600	600
- seeds	450	-	-	-	-	-	-	-	-
Total costs	650	1,535	1,955	1,955	1,955	1,955	1,955	1,955	1,955

silvipastoral systems may prove to be difficult using the third method, because of its many linkages in the farm systems.

A disadvantage of partial budgeting in general is the fact that it is rather difficult to determine the relative scarcity of the farmer's own production resources, since the scarcity does not only depend on the availability of farm resources and the demand made upon them by the alternatives considered to satisfy a particular objective, but also by the demands made upon them by other alternatives considered by the farmer which are not mutually exclusive. This has its repercussions on the selection of activities, since a wrong judgement of the relative scarcity reflected in the opportunity cost of the resources may easily lead to selecting the wrong alternative. To avoid such a situation, ordinary budgeting may be complimented by computing *net benefits per unit of a scarce production resource.*

By computing the N.P.V.'s for several potentially scarce resources, a researcher can test whether or not the choice made, based on the initial budgeting method, would change if the scarcity of production resoruces were different from what was originally assumed.

The following example may clarify this procedure:

Assume a farmer has to select the most appropriate plant spacing and harvesting frequency similar to those given in the example in section 5.4.1. However, in this case he/she is not quite sure about the relative scarcity of the three production factors involved, i.e. land, labour and seeds. Therefore the discounted net benefits per unit of a scarce resource are computed in the following way:

per hectare:	discounted net benefits plus discounted opportunity value land;
per unit of labour:	discounted net benefits plus discounted valu labour opportunity costs, divided by the number of man-days (1 man-day = 5 monetary units)

Per unit of seed : discounted net benefits plus discounted value seed cost, divided by the physical seed units (1 seed unit = 25 monetary units).

Using the data presented in Table 5.4.1.3. the followng N.P.V.'s are computed:

Table 5.5.1. N.P.V. per unit of scarce resource at 12% discount rate

	1-meter spacing	*2-meter spacing*
N.P.V./hectare	1,085	927
N.P.V./man-day	15.9	16.4
N.P.V./seed unit	207	436

While one criterion (N.P.V./hectare) favours the 1-meter spacing method (at 12% discount rate), the N.P.V. per unit of seed and the N,P.V. per man-day favour the 2-meter spacing, which means that if land is not the scarcest resource, it seems advisable to select the 2-meter spacing.

Whole-farm budgeting takes into account all activities to be undertaken by the farmer. To compare different whole farm plans there is, therefore, no need to compute the opportunity cost for each of the farm's own resources since the combined discounted returns to these resources constitute the correct measure for comparing the attractiveness of each of these plans to the farmer concerned.

To ensure, however, that each of the proposed plans does not exceed the availability of the farmer's own resources it is common to prepare profiles of the periodical use of land, labour and cash (see also section 4.1.).

Although partial and whole farm budget comparison are the most frequently used methods in farm analysis, a disadvantage of the method is that it does not optimise the use of scarce farm resources. It merely selects the best alternative from two or more feasible technologies/plans.

Methods which select and combine activities into a farm plan which is at once optimal have a *programming approach* to farm planning.

Simplified programming (s.p.) is a method of selecting a farm plan in which the required calculations are performed by hand. For this reason, the application of the method is confined to relatively simple planning problems involving only a few activities and constraints. If the real planning problem involves many activities and contraints, as is usually the case, the planner must use his judgement to eliminate all but a few of the activities and to restrict the constraints to be considered to a few crucial ones (3). If this involves too great an abridgement of reality, s.p. may have to give way to the computer based technique of *linear programming*.

No detailed description of these two methods is given here since it can be found in appropriate textbooks (19,20). Attention should be drawn however, to the fact that the agroforestry application of such methods again calls for a multi-period approach bringing into focus discounted costs and benefits as well as the definition of resource availability and resource demand by different activities in time (21,22,23).

5.6. *Risk and uncertainty*

So far, the analysis has been wholy *deterministic* in nature, i.e. inputs and outputs were assumed to have fixed values. However, in practice, many of these parameters are *stochastic* in nature, i.e. they have a probability of having a certain value (5)

This brings into focus *risk* and *uncertainty* which, in a small farmer's decision making, is a very important consideration. It is therefore necessary to subject the first results of the analysis to a *sensitivity* test to evaluate the validity of the conclusion in the light of changes in costs, benefits or discount rates.

Different approaches may be taken for the sensitivity test. The most common one is to change the benefits, costs or discount rates rather arbitrarily and examine the effects on the profitability as well as

ranking of the alternatives. The following example illustrates this method:

Two sets of net present values, at 12% and at 30%, are computed on the data earlier presented in Table 5.4.1.1. Selecting 12% as the appropriate discount rate would result in choosing the end of year 6 as the optimum harvesting time of the hypothetical tree; however, a 30% discount rate would favour harvesting the tree after 5 years.

Table 5.8.1. N.P.V.'s hypothetical tree at different times of harvesting

	Discount rate	
Year	12%	30%
2	-6.93	-10.20
3	8.56	3.14
4	38.53	9.78
5	55.03	14.69
6	62.80	9.05
7	58.06	1.53
8	46.84	-6.80

Another approach to the sensitivity analysis is to calculate *break even* points for the technologies/systems selected. For example, at which discount rate would the optimum harvesting time of a tree change from one year to the next? Such a question may be answered with the help of the *marginal rate of return* (M.R.R.), which is computed as follows:

$$\frac{(B_{(x+1)} - C_{(x+1)} - H_{(x+1)}) - (B_x - H_x)}{(B_x - H_x)} \times 100$$

in which

B_x = accumulated benefits year x

C_x = annual cost year x

H_x = harvesting cost if harvested in year x

If the discount rate exceeds the M.R.R., the optimum harvesting time would be year x, if it is below the M.R.R. it would be year x+1.

Applying this formula to the data presented in Table 5.4.1.1. yields the following M.R.R.'s or break-even discount rates.

Table 5.6.1. M.R.R.'s hypothetical tree.

Year	1	2	3	4	5	6	7	8
M.R.R.	-	-	86	95	37	21	7	-

When dealing with an agroforestry tree, which usually has some annual benefits, this formula should be modified to.

$$\frac{(B_{(x+1)} + b_{(x+1)} - c_{(x+1)} - H_{(x+1)}) - (B_x - H_x)}{(B_x - H_x)}$$

in which

B_x = benefits of annually harvested produce

Another possible break even analysis is to determine, in respect of the leucaena/maize hedgerow system example used in section 5.4. at which lower average conversion rate (caused, for example, by the high rate of application) the 1.5-meter hedgerow system would lose its advantage over the 3-meter alternative.

The following formula may be used to compute the reduced annual increment (γ) for years 2 to 8.

$$(N \times \Delta C \times P_m) - (N \times \Delta C \times C_h \times P_l)$$

N = annual production organic nitrogen 1.5 meter hedgerow (233)

ΔC = assumed change in the conversion rate

P_m = price maize (1.5)

C_h = harvest labour coefficient (0.04)

P_l = price labour (8)

It can be computed that the sum of the discounted value of Y_2 to Y_8 ($\sum_1^n Y_n (1 + r)^{-n}$) equals 112 for $\Delta C = 0.1$

Since at the break even conversion rate $\sum_1^n Y_n (1 + r)^{-n} = 443$ (difference in N.P.V.'s between the 3- and 1.5-meter spacing at 12% discount rate). The break even conversion rate is computed to be $6.3 - 443/112 \times 0.1 = 5.9$.

5.7. *The use of computers in economic analysis*

Cost benefit analysis coupled with sensitivity analysis is a rather tedious undertaking and computerisation may facilitate the analyst's task.

Recently the Australian National University and ICRAF collaborated in the development of MULBUD. This micro computer software is 'user-friendly' and performs cost benefit and sensitivity analyses for multi-period multicrop agroforestry land use systems to be modelled with the help of this program.

At present, the program is further developed to include livestock enterprises as well.

ICRAF is also developing/collecting other small programmes to assist in the analysis, e.g. cost benefit analysis, optimal harvesting age trees, surface computation, crop livestock budgeting programme (developed with the help of the Centre for Research in Economic Development, University of Michigan).

6. *Project analysis aspects of agroforestry*

Emphasis in this paper has so far been put on viewing agroforestry from a farmer's perspective, which, among other things, limits the scope of benefits and costs attributed to agroforestry as compared to viewing agroforestry from a *higher* point of view.

In project analysis, usually two types of cost benefit analysis are identified, i.e. the financial and the economic. Brown (12) defines the *financial analysis* as an evaluation in terms of its attractiveness to the farm family or other entities participating in a project, while he defines the *economic analysis* as an evaluation in terms of the most efficient use of available resources to produce national income.

Farm analysis, in this context, is therefore one of the financial analyses conducted within the project analysis framework. Similarly, for example, a financial analysis may be conducted from the forestry service point of view in case of the taungya system. While the farmer would conduct such an analysis by evaluating costs and benefits to produce a foodcrop (including labour he/she has to provide to the forest service to allow him to use the land, the forest service would evaluate their cost and benefits to produce timber (including cost of marketing facilities or input services provided to the taungya farmer but excluding cost of labour provided free of charge by some farmers).

In an economic analysis, indirect costs and benefits (from the farmer's point of view) have to be included in the analysis since society as a whole is interested in total resource use and aggregate production as a result of the agroforestry project.

Furthermore, market prices used in the financial analysis have to be adjusted for *imperfections* in the free market mechanism to reflect the true economic value of inputs and outputs. This adjustment of prices, commonly referred to as *shadow* pricing, is described in all textbooks on project analysis (24, 25, 26, 27, 28, 29) and is therefore only briefly described here using Brown's approach (12).

Adjusting transfer payments.

These include various taxes and duties, subsidies and grants, as well as loan instalments and repayments. While these are included in the financial analysis, they should be excluded from the economic analysis.

Adjusting the price of foreign exchange

The official rate of exchange (O.E.R.) used by the Central Bank and for a financial analysis should be replaced by a shadow rate of exchange (S.E.R.) when the currency is either over - or under- valued.

Adjusting price of inputs

Four different input categories are distinguished:

Non-produced inputs

For land and labour, the opportunity cost principle has to be used.

Locally produced inputs

Depending on whether or not such inputs would be exported if there was no project and whether or not there is excess capacity in the producing industry, the opportunity cost of such inputs could be foreigh exchange losses valued at S.E.R. or prices paid by alternative users (adjusted for transfer payments) or cost of variable resources used to produce it.

Imported inputs

The S.E.R. should be used in the economic analysis to value imported inputs while tariffs and subsidies should be excluded.

Mixed component inputs

Mixed component inputs are inputs which are produced locally but which contain some costs attributable to imported raw materials. A distinction should be made between foreign and domestic components and the previously explained rules should be applied to each one of them.

Adjusting the price of outputs

Five major categories are identified.

Exported outputs

The border price (f.o.b.) multiplied by the S.E.R. should be used to compute the *export parity* price.

Imported substitutes

The *import parity* price is computed by multiplying the c.i.f. value of the foreign exchange earnings valued at S.E.R.

Locally consumed products

The general rule is to value these products at farm-gate prices or at the point of first sale after deducting subsidies and other transfer payments.

Intangible benefits

Benefits which have a true value but are difficult to measure. They may be ignored or subjectively assessed if they only form a small fraction of the total benefits. If they form the main part of the benefits the *least cost analysis* (P.V.C.) may be used to determine the most efficient method to produce them.

Intermediate products

Products which are used as inputs in other farm enterprises are not valued, since their value will be part of the gross production value of the end product.

Society as a whole may want to achieve other objectives with the project e.g. to have an impact on the distribution of regional income, employment, saving and investment. Arnold (30) mentions in his paper that agro-forestry projects should in fact be based on groups with shared economic objectives and situations, and a measure of socio cultural homo-genity.

To incorporate these additional objectives into the more traditional economic analysis, a *social cost benefits* analysis has to be conducted.

The common procedure is to first compute a measure of economic profitability for different project alternatives and to adjust them to take account of each alternative's contribution to the social goals of society.

Hosier (7) in applying this procedure for a fuelwood project describes a step-wise approach by first accounting for effects on savings, then for income distribution and finally a weighing of products which are either beneficial or detrimental to society using a so-called *merit want* adjustment.

In practice this may be very difficult to implement, however, and only a subjective discussion of some of those social benefits may be feasible.

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