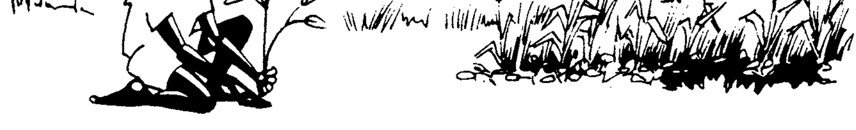
CHAPTER 4

ECONOMICS FOR SUSTAINABLE DEVELOPMENT



ECONOMICS FOR SUSTAINABLE PRODUCTION

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CONTENTS

Abstract

Although many definitions of sustainable development abound, from the point of view of the sustainability of production a potentially operational definition is maintaining the constancy of natural capital. This definition compares favorably with the ecological concept of 'resilience'; however, in the presence of natural resource degradation or depletion, the objective of economic efficiency may require modification. The paper demonstrates how a 'weak' and 'strong' sustainability criterion can be incorporated into cost-benefit analysis. Such an approach has important implications for the economic analysis of agroforestry projects, and may facilitate proper assessment of their net benefits in terms of sustainable development.

Introduction

The term 'sustainability' has become recently in vogue. Attention is now focussing on what economics has to say about sustainability, how it compares to more conventional economic criteria, such as economic efficiency and Pareto optimality, and how the economic view of sustainability differs from that of other disciplines. Only by clarifying what our concepts and objectives are when we talk about the sustainability of production can we then proceed to operationalize it at the applied level, such as in the design of agroforestry systems, projects and even policy options. The following paper aims to develop an operational definition of sustainability, based on both economic and ecological perceptions of the term.

The Sustainability Criterion

A review of the literature on 'sustainable' economic development suggests that two interpretations of that concept have emerged: a wider concept concerned with sustainable economic, ecological **and** social development and a more narrowly defined concept largely concerned with 'environmentally sustainable development', i.e. with optimal resource and environmental management over time (Barbier 1987, 1989, Pearce & Barbier & Markandya 1988, 1989, World Commission 1987).

From the point of view of the sustainability of production, it is more useful to concentrate on the 'narrower' interpretation – the relationship between environmental quality and sustainable economic activity. The latter is interpreted as that level of economic activity which leaves the environmental quality level intact, with the policy objective corresponding to this notion being the maximization of net benefits of economic development, subject to maintaining the services and quality of natural resources over time (Barbier 1988, Pearce, Barbier, Markandya 1988, 1989).

The term 'natural resources' is used broadly. It includes **renewable** resources, such as water, terrestrial and aquatic biomass; **non-renewable** resources, such as land in general, minerals, metals and fossil fuels; and **semi-renewable** resources, such as soil quality, the assimilative capacity of the environment and ecological life support systems.

Consequently, maintaining the services of a natural capital stock does not necessarily imply maintaining this physical stock of composite resources intact, which in any case, may not be desirable or feasible for non-renewables. On the other hand, keeping the level of **environmental quality** intact implies caution in assuming that an irreversible loss of the natural capital stock is justified if it results in the formation of more manmade capital. Some of the functions of the environment are not replicable by reproducible capital, such as complex life support systems, biological diversity, aesthetic functions, micro climatic conditions and so forth. Others might be substituted but not without unacceptable cost. In addition, degradation of one or more parts of a resource system beyond some threshold level may lead to a breakdown in the integrity of the whole system, dramatically affecting recovery rates and resilience of the system. The total costs of the system breakdown may exceed the value of the activity causing the initial degradation. Examples where this may be the case include extensive deforestation of tropical forests, such as is occurring in Amazonia, upper watershed degradation through inappropriate upland farming and even the global warming induced by greenhouse gases. For further discussion of the economic aspects of these 'system breakdowns' see (Barbier 1988, Pearce, Barbier, Markandya 1989).

Thus 'constancy' of the natural capital stock, or more precisely constancy of the level and quality of services that this stock provides, can take on different meanings - interpretations in terms of both constant **physical** capital stock and constant **economic value** of that stock are common (Bishop 1978, Page 1977, Pearce, Barbier, Markandya 1988, 1989). These interpretations are fundamentally equivalent, provided that the presumption is that 'sustainability' has something to do with non-depreciation of the natural capital stock, in terms of providing a valued level and quality of services, and provided that proper economic valuation of any depreciation in this stock has taken place.

In short, without too much loss of interpretation, the necessary environmental condition for sustaining production can be conveniently summarized as ensuring non-depreciation of the natural capital stock. More strictly, the requirement is for non-negative change in the stock of natural resources such as soil and soil quality, ground and surface water and their quality, land biomass, water biomass, and the waste assimilation capacity of receiving environments (Barbier 1989, Pearce, Barbier, Markandya 1988). Not only is this criterion consistent with the literature on sustainability but, as will be discussed further below, it is also operational: the criterion of 'sustainability' can now be introduced into cost benefit techniques of project appraisal by setting a constraint on the depletion and degradation of the stock of natural capital. Such an approach is exceedingly important to the economics of agroforestry and other multi-functional resource systems.

Sustainability as Resilience

However, economics is not the only discipline grappling with the concept of sustainability. One useful approach taken by some ecologists is to view agricultural production units as 'systems' interacting with their surrounding natural environments. Such an approach allow a specific definition of 'sustainability' to be applied to these 'agro-ecosystems', which is drawn from the ecological concept of the 'resilience' of natural ecosystems (Holling 1973).

For example, **sustainability** is defined by Conway 1987 as the ability of an agro-ecosystem to maintain productivity when subject to stress or shock. **Productivity** is the output of valued product per unit of resource input, with common measures of productivity being yield or income per hectare, or total production of goods and services per household or nation. **Stress** in this context would be a regular, sometimes continuous, relatively small and predictable disturbance on agricultural productivity over time, for example the effect of salinity, toxicity, erosion, declining market demand or indebtedness. **Shock** on the other hand would be an irregular, infrequent, relatively large and unpredictable disturbance to the agricultural system, such as a rare drought or flood, a new pest or a sudden rise in input prices, like oil in the mid-1970s.

Sustainability can thus be compared to other indicators of agricultural performance - productivity, stability and equitability. This approach has been broadened further to take into account the international constraints on sustainable and equitable development, the necessary national policies, and the needs of rural households (Conway and Barbier, 1988, 1989). It therefore has become a powerful tool for re-thinking strategies for agricultural development.

However, a major obstacle to explicitly incorporating Conway's definition of sustainability in economic analysis is the difficulty in evaluating the multitude of social, economic and environmental variables that might at any time act as stresses or shocks on a given agricultural system. On the other hand, it may be possible to operationalize a more narrow concept of agricultural sustainability if we initially limit our economic analysis solely to the **environmental** stresses and shocks. This does not trivialize the concept of agricultural sustainability. For example, it is self-evident that agro-ecosystems are directly dependent on environmental resources and essential ecological functions for 'sustainability'. Thus the unchecked abuse of resources within an agro-ecosystem, whether as a result of the inappropriate use of agro-chemicals and fertilizers, the overcropping of erodible soils, poor drainage, etc., not only directly affects the sustainability of the agro-ecosystem but may also increase its susceptibility to other external stresses and shocks, such as changes in market conditions, prolonged dry seasons, changes in land tenure, and so on. As a consequence, a crucial component of sustainability, as defined in terms of the resilience of an agricultural system to external stresses and shocks, is maintaining the environmental resources and ecological functions upon which the system depends.

In essence, the economic and ecological interpretations of sustainability are the same: the necessary condition for environmental sustainability is non-depreciation of the natural capital stock.

Productivity, Efficiency and Sustainability

There still remains the crucial issue in economics of how the notion of sustainability compares with the criterion of 'economic efficiency'. It is important to distinguish between **private efficiency** - the efficiency of the production system from the point of view of its users - and social efficiency - how the production system affects the allocation of resources to society as a whole. The latter falls under the 'Pareto optimality' criterion; that is, resources are allocated efficiently when it is not possible to change the allocation of resources without making someone worse off.

For the users of a production system, economic efficiency is achieved through maximizing their discounted net **private** returns or benefits, i.e. ensuring that the users' discounted flow of private benefits less costs from exploiting the system is at a maximum. For society as a whole, the objective is to maximize discounted net **social** returns or benefits - the benefits less the costs accruing not just to the users of the production system but to all individuals whose welfare is affected by that system.

For example, assume a simple upland agricultural system producing an annual crop such as cassava for a single household's subsistence and income needs. It is very much a low-input system, i.e. the household cannot afford or gain access to modern inputs such as inorganic fertilizers. Suppose that production from this system can be sustained indefinitely, except for the environmental stress imposed on the system from prolonged soil erosion. That is, the impact of continuous annual cultivation on the upland soil under tropical climatic conditions is to cause erosion and eventually declining soil fertility. As a result, future cassava yields will decline and the system may collapse. This is the **user costs** of soil erosion - the loss of future soil productivity through the erosion caused by current use of the resource for crop production. As the farming household will incur these user costs over time, they are part of the overall private costs that the household attempts to minimize in its quest for efficiency in production. Under normal conditions, one would expect that the household would find these user costs so significant that it would have to bring soil erosion under control in order to maximize its discounted net returns. In such instances, the pursuit of private efficiency will also ensure the overall sustainability of the agricultural production system.

But there are also circumstances under which the household may ignore the user cost of soil erosion in its drive for production efficiency. For example, the lack of secure tenure or open access to forests that can be converted to agriculture may make the household less concerned about the future productivity of the land it is using currently to cultivate cassava. Alternatively, some upland soils, such as those based on limestone, may be very poor in quality and have a low regenerative capacity. Under such conditions, the household may find that its discounted net returns are higher not from controlling soil erosion but through exhausting the soil as quickly as possible in order to maximize current yields. This will also be the case if the harvesting cost of cassava is low, or if the price of cassava is high. More often than not, these costs and prices are influenced by government policies, such as the use of input subsidies and procurement mechanisms to increase the producer price of food. For a complete case study of the response of upland farming households to soil erosion see (Barbier 1987).

However, even under conditions where the pursuit of production efficiency by a farming household also ensures the sustainability of production, it does not automatically follow that this outcome is also socially efficient. The existence of **external costs**, costs imposed on other individuals who do not receive compensation or a share of the benefits of the production system, may be a factor. For example, supposing that in order to reduce the user cost of soil erosion to zero, which happens to be consistent with efficient cassava production, our farming household would have only to reduce the rate of erosion to 10 tonnes per hectare (ha) per year. If this were true of all upland farming households, then upland production systems would be efficient and sustainable. Unfortunately, though, the impact of an annual erosion rate of 10 tonnes/ha in the uplands is sedimentation of irrigation canals downstream. The result is a loss of productivity experienced by lowland irrigated farmers, which is the external cost of upland soil erosion. From society's perspective, since individuals - the lowland farmers - are being made worse off, this situation is not (Pareto) optimal. Moreover, it could threaten the sustainability of lowland production. It would be more socially efficient to find some means of compensating upland farmers to reduce their erosion rates further in order to eliminate the external downstream costs to lowland farmers. If such a solution were found, then social efficiency and the sustainability of lowland, as well as upland, production would be complementary.

Once again, though, a socially optimal solution might be found that does not necessarily ensure sustainability of production. For example, society might find that a less costly alternative to compensating upland farmers to reduce erosion further may be to provide affected lowland farmers with off-farm employment opportunities as their yields start declining. Consequently, water supplies and irrigation facilities are allowed to collapse, ending the sustainability of lowland production. But from a social perspective, this loss of sustainability is not crucial to the maximization of overall net returns.

In sum, economic efficiency in production under some conditions may allow the exhaustion of those resources important for sustainability. Even the pursuit of social efficiency does not necessarily lead to the sustainability of renewable resources essential to production. That is why some economists have argued that justifying the conservation of these essential resources requires an additional 'intergenerational equity', or 'sustainability', criterion (Page 1977, Pearce 1977). In other words, ensuring sustainable and secure livelihoods for future generations requires ensuring that these generations have equal access to the natural resource base. Again, the necessary condition for achieving this criterion is non-depreciation of the natural capital stock.

Sustainability and Cost-Benefit Analysis

Cost-benefit analysis (CBA) embodies intuitive rationality in that any course of action is judged acceptable if it confers a net advantage, i.e. if 'benefits' outweigh 'costs'. What constitutes a gain or loss depends on the objective function chosen. Most CBA operates with a function based on economic efficiency, i.e. any increase in total net benefits is desirable irrespective of the distribution of these benefits or the impact of the action on the non-economic objectives. But this is only **one** objective function, and as discussed in the previous section, efficiency may not always be consistent with another desired objective, namely sustainability.

Thus we need to construct a specific sustainability criterion for CBA: essentially, the economic efficiency objective is modified to mean that all projects yielding net benefits should be undertaken subject to the requirement that environmental damage (i.e. natural capital depreciation) should be zero or negative. However, applied at the level of **each project** such a requirement would be stultifying. Few projects would be feasible. At the **programme** level, however, the interpretation is more interesting. It amounts to saying that, netted out across a set of projects (programme), the **sum** of individual damages should be zero or negative. That is, if E_i is the **damage** done by the ith project, we require that:

$$(1) \qquad \sum_i E_i \leq 0$$

Such a formulation ignores time. If a time dimension is included, two formulations of the sustainability constraint are possible. Under **weak sustainability** it is the present value

of $\sum_i E_i$, $PV(\sum_i E_i)$, which is constrained to be non-positive.

Under **strong sustainability** each E_i is constrained to be non-positive **for each period** of time.

Since it is not feasible to set $PV(\sum_i E_i)$ to be zero or negative for each project, but it is feasible to set $\sum_i E_i$ to be non-positive, the sustainability constraint amounts to including within any portfolio of investments one or more **shadow projects** the aim of which is to compensate for the environmental damage from the other projects in the portfolio. The shadow project idea is suggested by (Klassen and Botterweg 1976) in what appears to be a neglected paper. The conventional CBA rule would then apply to the **environmentally depleting** projects, i.e.

$$(2) \qquad \sum_t d^t[\sum_i(B_{it} - C_{it} - E_{it})] > 0,$$

where B is non-environmental benefits, C is non-environmental costs, E is net environmental costs or benefits, t is time, and d^t is the discount factor.

The **environmentally compensating** project(s), j, would be chosen such that

$$(3) \qquad \sum_j PV[A_j] \geq \sum_i PV[E_i]$$

for the weak sustainability criterion, and

$$(4) \qquad \sum_j A_{jt} \geq \sum_i E_{it} \quad \text{for all } t$$

for the strong sustainability criterion, where the net environmental benefits of the jth project, $A_{j1}, A_{j2}, \ldots A_{jT}$, compensate for the damage done by the other projects. For the compensating projects, then, the normal CBA decision rule does not apply, although we would wish to minimize the cost of achieving the sustainability criterion.

This approach has been developed further in a formal analysis of sustainability and CBA (Pearce, Barbier, Markandya 1988); it will not be pursued further here.

Relevance to Agroforestry

The above approach nevertheless has important relevance to the economics of agroforestry. Agroforestry is a catch-all term to describe the deliberate mixing or sequential planting of trees and shrubs with crops and/or livestock. One of the perceived advantages of agroforestry is that it provides **multi-functional** economic and environmental benefits. Depending on the type of system, these may include the direct benefits of supplying fuelwood, other wood products (e.g., poles), fodder, fruits and nuts, and the indirect benefits - usually captured through crop and/or livestock productivity - of shelterbelt functions, shade, nitrogen fixation from leguminous trees, and supply of organic matter. Agroforestry can also generate cash income through the sale of wood and other products as well as employment, often during off-season slack periods.

Yet despite these apparent benefits, when compared with the net benefits of some alternative land use systems - e.g., rotation or mono-cropped cultivation of grains - agroforestry projects often appear less attractive. There are usually two reasons:

First, proper economic valuation of all environmental impacts is often **not** conducted for agroforestry projects. The failure to include the net environmental benefits of agroforestry based systems underestimates the NPV of such projects.

Fortunately, this is now changing. For example, an appraisal of rural afforestation programs in the arid zone of northern Nigeria has shown that, if proper valuation of shelterbelt functions and farm forestry is conducted, the prospective economic returns may be substantial (Anderson 1987). Also in Nigeria, a comparison of alternative uses of forest land revealed that a 25-year social forestry scheme that involves farmer clearing, cropping and tree planting in the first few years can yield comparable financial internal rates of return to oil palm plantations and logging if higher valued commercial species are chosen to be planted (Burgess 1989). Similarly, in Sudan, economic analysis has indicated that the total direct benefits to farmers of planting gum arabic trees can be very high. For example, based on a 16-year rotation, the financial internal rate of return from gum, fuelwood and fodder production is estimated to be around 36 percent (Pearce 1988). For a typical bush-fallow system of Northern Kordofan province, consisting of gum trees rotated or intercropped with sesame, groundnuts, millet and sorghum, the financial NPV was calculated to be Sudanese pounds 142.6 per feddan (1 feddan = 4200 m^2), i.e. about US$58 per feddan (1985 prices) (World Commission 1987).

However, many so-called environmental 'rehabilitation' or 'enhancement' projects associated with agroforestry, such as shelter-belt planting, soil conservation projects, afforestation and reforestation to control desertification, etc., are still criticized for yielding a low or even negative NPV under conventional CBA criteria. One major reason is that the environmental benefits of these projects, such as the reduction of off-site sedimentation or nitrogen-fixation by leguminous trees, although widely recognized and accepted, may be difficult to quantify and value due to poor ecological and economic data. Even if these benefits can be estimated, their impacts are often more significant in the long rather than short term. The positive discount factor of a conventional CBA may therefore reduce the importance of these impacts in the project NPV.

Under the sustainability criteria suggested in the previous section, such projects could nevertheless still be accepted as environmentally compensating projects within an agricultural development programme. As indicated by equations (3) and (4), these projects will be accepted not on the basis of their NPV but on whether their stream of environmental benefits compensate for any environmental damages imposed by other projects. A low or negative NPV no longer poses a serious obstacle to the implementation of such projects.

For example, in Sudan, in addition to yielding direct (production) benefits to farmers of gum, fuelwood and fodder, gum arabic planting has indirect (environmental) benefits of reducing soil erosion and water runoff, stabilizing soils and possibly fixing nitrogen, as well as the wider environmental benefits of providing shelterbelts, fixing dunes and acting as a general buffer against desertification. These environmental benefits are difficult to value and, in any case, may be offset by conventional discounting procedures. Thus, following conventional criteria, the **social** NPV of a gum arabic planting project might paradoxically be low or even negative.

However, under the sustainability criteria introduced in the previous section, the gum arabic (re-)planting project could be accepted as an **environmentally compensating project**. As these criteria recognize that the essence of a 'rehabilitation' project is to compensate for environmental damages, such a project could be accepted on the basis of its stream of positive environmental benefits, as suggested by (3) and (4). Thus a gum arabic rehabilitation project could compensate for environmental damage inflicted on the gum belt or on the poor desert soils due to mechanized agricultural projects or overcropping. A low or negative NPV for a gum arabic rehabilitation project no longer poses a serious obstacle to the implementation of such projects.

Conclusion

This paper has set out to operationalize an economic concept of sustainability. To do this required first comparing the economic approach to that of other disciplines, notably the ecological interpretation of sustainability as 'resilience', and secondly, contrasting the sustainability criterion with the standard economic objective of efficiency. Although economists have been reluctant to accept the ecological view of sustainability, they have increasingly recognized that the pursuit of economic efficiency does not always guarantee the sustainability of production. This is particularly the case with the exploitation of the resource base in agriculture.

Thus a straightforward approach to operationalizing sustainability that satisfies both ecological and economic interpretations is to assume that it is dependent on the constancy of the natural capital stock. As long as this stock is not degraded or depleted, then economic efficiency can be safely pursued as the paramount objective. Special sustainability criteria need only be invoked in the presence of degradation or depletion. From these criteria simple 'rules' for project appraisal can be derived. These in turn have important implications for the economic appraisal of agroforestry projects in particular.

However, it must be stressed that the criterion of non depreciating natural capital is only a **necessary** and not a **sufficient** condition for the sustainability of production. Other social and economic factors might easily intervene. One crucial area not discussed in this paper, for example, is the need for appropriate **policy-enabling incentives** focussed on the policy maker and implementing agencies (e.g., institutional strengthening and flexibility, political conditions), **variable incentives** focussed on price changes facing producers and consumers (e.g., altering inputs and output pricing, exchange rate modifications, tax and subsidy reform, adjusting middlemen margins, etc.) and **user-enabling incentives** focussed on the farmer and resource user (e.g., changes in land and resource rights, increased participation in decision making, changing perceptions of risk, changes in income and employment opportunities, etc.) (Barbier 1988). It is clear that the sustainable development of any production system, agroforestry or otherwise, cannot succeed unless distortions in the economic and non economic incentive structure are corrected.

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AGROFORESTRY: TECHNICAL ASPECTS AND COST-BENEFIT ANALYSIS IN THE CONTEXT OF LAND DEGRADATION

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Agroforestry and Land Degradation

Introduction

Environmental problems due to development processes are continuing to have undesirable consequences the world over. In little more than 10 000 years, man's impact on his environment has increased enomously, and today about two-thirds of the Earth's land surface is subject to his activities. The need to rethink development strategies is now unavoidable, particularly in the agricultural sector in tropical regions which have experienced unprecedented negative environmental development, illustrated by extreme land degradation. Land degradation has become a problem in many developing countries, and the effects have crippled economies, sometimes with consequent losses in animal and human lives.

The disaster of the Sahel region in the 1970's and the recurrent crop failure due to degraded soils and drought in many countries of Africa, are a persistent reminder of the likely consequences of environmental degradation-desertification. This has received much attention in the international development community which have made determined efforts to find solutions involving sustainable agricultural development and related use of renewable natural resources. The result has been a high turnover of ideas which made available a 'basket' of strategies. These strategies are mere guidelines which need input of relevant knowledge by area or regional specialists. Out of this basket, agroforestry has emerged as a popular strategy which has become something of a buzzword (Steiner, 1988).

This paper briefly reviews agroforestry and land degradation and also examines the use of cost-benefit analysis for natural resource management.

Agroforestry and Land Degradation

Agroforestry

Agroforestry is a practice, as old as man's agricultural activities - growing crops in the midst of trees or along with trees while grazing animals is still common in the tropics (Padoch and Jong, 1987: Godfrey-Sam-Aggrey, 1983; and many others). What is new, is the science of agroforestry. Like many other concepts, it has acquired different definitions in extent and usage. Steppler and Raintree (1983) called it the fledgling interdisciplinary science which has arisen recently to fill the gap created by time-honoured but artificial separation of agriculture and forestry. They further ague that it is a "new name given to the old practice followed by many farmers for generations, of mixing or retaining trees in their crop/animal production fields" Steiner (1988) called it "the old fashioned diversification farm".

In nature, plants of diverse species coexist on the same substrate from which they derive their nutrients, and animals subsist on them, with micro and macro-organisms decomposing dead organic material releasing nutrients to be used again by plants. This sustainable system is interfered with by man's activities which include the propagation of preferred species of plants and animals at the expense of others in a bid to provide food for his ever-escalating populations. This practice, bid to proivide food for his ever-escalating populations. This practice, called agriculture, has developed monoculturally in many parts of the world, with consequent reduction in natural vegetation. Where it has reached intensity beyond what natural nutrient turnover can support, artificial fertilizers have been used with appreciable increase in production, but not without environmmental costs which unfortunately have received little attention until recently.

Agricultural activities largely disturb the balance in a natural ecosystem, and the sustainability of these activities depends on the stability of the system. A stable system can resist disturbance and return to its equilibrium in which production and consumption of all components within the system remain constant even where there is continual change (Richards, 1985). The stability of this type of system differs from place to place, although the basic relationships between components remain similar. Agricultural activities should take account of these relationships, and whatever developments are made to improve productivity, the starting point should be a proper understanding of the natural system.

Agroforestry tries to make agricultural exploitation sustainable by attempting a balance between components as in natural systems. It is this balance which could be achieved by certain combinations of trees/crops and animals that remains a challenge to making agricultural development sustainable. ICRAF (International Council for Research in Agroforestry) (Steppler and Raintree, 1983) has been pioneering the studies of these practices adopted from natural systems.

ICRAF has done a lot of work on identification and diagnosis of some existing agroforestry systems and designing and implementing some tested technology in this area. It has also been exploring analytical techniques to diagnose the performance of basic output subsystems in terms of both their productivity and their sustainability. Multiplicity of outputs in terms of food and animal fodder, fuel, building materials and chemicals (Hall and Combes, 1983), of which there are commonly shortages in developing countries, form the main goals of agroforestry. Other systems with outputs not available for direct consumption, but vital for future production, will need investigation for better designing of agroforestry systems which will conserve and improve environmental aspects of the system. For instance little research is done on soil fauna and microflora which decompose plant and animal residues, releasing nutrients previously bound in the plant biomass, so that they are available for recycling through above-ground portions of the ecosystem (Richards, 1985). A knowledge of the type of organisms involved and how they are likely to be affected by particular designs of agroforestry might be of assistance in designing sustainable systems. Richards (1985) emphasizes a detailed examination of soil biology and biochemistry to be an essential feature of any comprehensive programme of ecosystem analysis.

A case study by Sohlenius, Bostr?m and Sandor (1987) on dynamics of nematode communities in arable soil under four cropping systems for a period of five years found marked differences in species diversity and abundance (Table 1) of nematodes among the different systems. They attributed the differences to changes in the soil environment because the effect of different management practices was small. They also found positive correlation between root production and total nematode numbers ($r = 0.96$, P 0.01), and also cited other case studies of positive correlations between plant production and nematode abundance (Yeats & Coleran, 1982 as quoted by Sohlemius, D S Boström and A Sandor, 1987). In their conclusion, the results indicate, that not only nitrogen fertilisation but also the plant species cultivated can influence the proportions of fungal and bacterial feeding nematodes. This will also affect other organizms which are part of the soil ecosystem.

This case study poses questions of possible research in an agroforestry system:

1. How do soil organisms vary between arable and non-arable soils in type and abundance? What are decomposition rates and seasonal variations?

2. How do soil organisms differ with plant species, and what are the implications in the selection of agroforestry and other species on which processes of nutrient turnover depend.

Agroforestry designs are basically ecosystem transformations in which useful species in terms of desired outputs, (nitrogen fixation, organic matter, increase in yield of crops, soil cover, wood, etc) are grown with the exclusion of other species which may not have these desired outputs, sometimes replacing species otherwise indigenous to the locality. Oldeman (1983) points out the risk of this practice to be the absence of **absolute** ecological identity between the behaviour of organisms, maintaining that small differences exist, hence the balance of the new structure has to be corrected over and over again, until it becomes self-equilibrating. He further observes that many transformed systems turn out to be unstable. Many of the farming systems in the tropics are in fact transformed systems, in which the transformation was not based on a complete understanding of the interrelationships of various components of the whole system.

The success in redressing or improving the existing situation will depend very much on the understanding of changes in the refined biological cycles of apparently simple but durable living systems by (Oldeman, 1983). This can be achieved by more research work on identified existing agroforestry systems and on undisturbed natural vegetation, a very stable system, which may contain possible species which could be cultivated in an agroforestry system. For instance a case study by Tolsma et al (1987) on seasonal variation of nutrient concentrations in a semi-arid savanna ecosystem in Botswana found marked variations. The concentrations of nitrogen and phosphorus in all species studied (8 *Acacia* species, *Dichrostachys cinerea* and *Terminalia sericea*) were higher in young leaves than in mature ones. while Calcium, Sodium and Iron accumulated until leaf fall. The macronutrient elements, nitrogen, phosphorus and potassium, were translocated out of the leaf long before leaf fall. Therefore the most sought after nutrients which are needed for crops are not added to the soil in leaf fall, but are retained in the plants. If these species are to be used for agroforestry, calcium, sodium and iron may accumulate in top soil. To gain nutrients (N, P and K) from them, only young leaves can be used.

Land Degradation

Land degradation in many tropical countries has been well documented (Lewis et al, 1988; Stocking, 1988; Whitlow, 1988; Lal, 1988; and many others too numerous to mention), but there are not many studies on quantitative losses in terms of soil physical characteristics (soil particles), nutrients (elements), organic matter (humus and litter) and soil organisms, due to various processes of land degradation. Some quantitative studies (Lal, 1988) have been done on amount of soil lost through erosion, but mostly through water erosion which is very common in Africa. There are only few studies on quantitative losses due to wind erosion which is very common in sandy areas and trampled soils with little vegetation cover. In New Mexico, wind erosion damaged 357,800 areas of land between November 1983 and May 1981. In most cases wind erosion is just acknowledged and not much attention is given to it, except in the arable Sahel region.

Other losses to arable land may not be easily recognizable, even though they may significantly contribute to land degradation. Lal (1988) estimated nutrients removed in crops to be greater by as much as an order of magnitude compared to the nutrients returned to the soil - a soil mining process. He found that for yields as low as 1.0 ton ha^{-1}, maize and sorghum crops remove as much as 30-40 kg ha^{-1} of nitrogen, 2-10 kg ha^{-1} of phosphorus, and 5-30 kg/ha^{-1} of potassium. In Botswana (and maybe in many other African countries) animals are put in the fields after harvest to feed on crop residue (author's experience). In some cases crop residue is removed from fields and fed to animals outside the field, and other crops are harvested (groundnuts, and certain beans and cowpeas). This type of soil mining by both people and animals has serious implications for agroforestry systems. The analysis of nutrient distribution in various crops will assist in the estimation of nutrient harvested in grains, roots (tubers) and crop residue, hence a better account of nutrient status in arable land.

Cost-Benefit Analysis

When a shifting cultivator finally decides to shift, a decision probably involving some costs and benefits, analysis is used to make a choice. In cost-benefit analysis, alternatives are often evaluated according to their impact on individual welfare, and the principles of this analysis in relation to the valuation of costs and benefits are derived from this premise and the assumption that consumers and producers behave rationally (Aeron-Thomas and Roberson, 1983). Rational behaviour depends on human judgement, but a farmer in the tropics who is at the mercy of the weather and the condition of the soil and faced with a hostile environment on which to make a livelihood (Stocking, 1988), has no luxury of making an irrational decision. Whatever decision is taken or choice of system of production mode is made, it must be based on past experience and thoroughly evaluated.

As a tool for making decisions, informal cost-benefit analysis has always been part of the day-to-day decisions of those investing in a means of making a livelihood in precarious and hostile conditions. It is obviously not as explicit as we know it today with understood discount rates, quantifiable variables, etc. But what is common in the use of this tool, is the time factor which has tended to make it unable to show costs and benefits in the infinite future. In making a decisions to shift, a farmer may be considering the costs and benefits in terms of human welfare in the period of operation of the present system of production. Similarly, in the new technological world, benefits and costs are primarily evaluated on the basis of an individual's willingness to pay for goods and services, marketed or not (Bojö 1986) in terms of monetary units. That is, the willingness is a result of the present decision-making and value attached to the prevailing market prices of the goods. Again willingness implies choice, while a farmer in the tropics may not have that choice if it is a question of survival.

The development or improvement of a tool depends very much on frequency of use, and the type of use determines aspects to be developed or improved. As it is today, cost-benefit analysis reflects frequent use in economic circles, and hence its developed aspects characterise it as a tool for use in those circles, whereas the premise on which it is based intends it to have universal application. Its principles also reflect where it was developed and used mostly, hence its use elsewhere has to take account of the 'new' conditions or requirements for it as a tool to work better. This is particularly true if the new situation no longer uses value in terms of individual willingness, but in terms of individual survival (no-choice situation) and if the monetary unit does not capture fully the importance of benefits and costs. This is likely to be the case when dealing with natural resources where they are used in their natural or semi-natural form and in situ, eg land resources as used in the tropics. Agroforestry is one system which is a semi-natural resource involving agricultural resource use. In applying cost-benefit analysis to agroforestry, the importance of the time factor cannot be overemphasized. The same applies to proper identification of costs and benefits and terms which better show the importance of these.

Costs of Agroforestry

Before looking at costs, a proper identification of the starting point of the analysis will be very important. Starting a new agroforestry system on virgin land will be different from one started on an operated land system. An already running system may have lost the balance between components or have lost/added characters normally present/absent in undisturbed virgin systems of that particular area. A running system is a project which started with initial costs and expected benefits which justified its initiation. For instance a farmer opening a new field on virgin land (uncultivated before) is initiating a project - if a project is taken to be the whole complex of activities in the undertaking that uses resources to gain benefits (Gittinger, 1982).

Operating costs can be very high for a farmer if the field experiences land degradation. Research data from western Nigeria show that yields of maize declined from 5t/ha immediately after forest clearing to 1.5t/ha, and to 0.5t/ha after 2 years and 4 years respectively (Lal, 1988). Lal (1988) has also reported yield losses due to soil erosion in Burkina Faso where the increase in erosion rates from 0.6 to 6 tons per acre caused millet yields to fall from 727 to 352 kg per ha in Burkina Faso, while in the Cameroons maize yield declined by 50% when 2.5cm of topsoil was eroded and complete crop failure occurred when 7.5cm of topsoil were removed.

The costs of starting agroforestry on land already operated by a farmer might start with substantial costs depending on whether the project starts by holding degradation processes, planting new species and addition of fertilizers to make land productive. However the running costs of a sustainable agroforestry system are supposed to decrease as the system becomes established. The success of the system in reducing the running costs to the operator and land depends on the design and management of the system. If it is a "running down" system (not sustainable), the costs of operating will increase.

Benefits

In opening a new field, a farmer has the benefit of woody biomass for fuel, building, even for sale or cash. The expected high yields of crop produce is an important benefit sought after by a farmer. This benefit is supposed to continue as long as the farmer sees it to be profitable, i.e. a return which justifies the further operation of the system. If it is a sustainable system, then benefits are infinite. These initial benefits will be similar to that of an agroforestry system initiated on virgin land which involve among other things, woody biomass for fuel and building. Continuous benefits will depend on its sustainability.

An agroforestry system designed for an already operating system, starts with benefits which are already reaped from the existing system. If it has aspects of improvement, then benefits are expected to increase as the outputs from the agroforestry system increase and add to the already existing benefits. They may be in the form of restitution or improvement of soils, eg by increased addition of organic matter, nitrogen fixing, less soil degradation which reduce the need for additional inputs needed to make a running down system productive. Other benefits will involve products which otherwise were not obtainable in the present system, like wood for fuel and building and browse for animals.

Discussion and Conclusions

There is no doubt that agroforestry remains a viable solution to environmental problems posed by agricultural activities in the tropics because it tries to mimic the natural ecosystem. However, the design of appropriate agroforestry systems should be based on the understanding of the existing natural system and the existing farming system. In many cases, farmers in long-settled parts of the systems that allow sustainable use of the land and respond to the environmental conditions (Stocking, 1988; Waller, 1984). It should be known now that the traditional interference based on the results of research stations not linked to the real world of farmers can be blamed for part of the crisis existing in agricultural activities. Slash and burn activities and shifting cultivation may be viable farming strategies which could form a basis for better technology.

There is no better justification for an agroforestry system than what farmers perceive as making a good return to sustain their livelihoods. The informal cost-benefit analysis farmers use to make decisions which enable them to earn a livelihood in otherwise very difficult environments, has to be credited accordingly. The type of data used may not be 'empirical', as we have come to understand the term, but the decisions were based on the real situation of their existence in terms of their physical world. If non-empirical data were used, then the way they were used would be of vital importance to allow to us to work out or improve relevant aspects of the cost-benefit analysis tool to be useful in such areas where there is no empirical data. It should be noted that although there is a lack of empirical data for us to carry out cost-benefit analysis, farmers have managed to make rational decisions for centuries. We have to make a decision to save land which is losing productivity or restore it to add to the limited area of productive land we have in this world of ever-increasing human population.

However, in a world dominated by the value of quantitative assessment the need for empirical data to carry out a convincing and appreciated cost-benefit analysis cannot be ignored. There is certainly a need for work in many areas. The lack of empirical data in areas of environmental resources which have been used for a long time with increasing depletion/damage, still points to the problem of value which actually determines whether action has to be taken, and if so, what type and to what extent. For instance the problem of land degradation in the tropics has been documented. However, not much effort was put into gathering empirical data because not much value was attached to land as a resource, or alternatively it was seen as an infinite resource. Another aspect of value is type. That is, if value is in terms of money, it may not be easy to place monetary value on natural resources because we may not know enough about the value of the resource to us to estimate its true worth. Hence the losses due to environmental damage often run unattended even in developed countries.

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