Assessing the Sustainability of Smallholder Tree Crop Production in the Tropics:
A Methodological Outline

Felix Herzog
Nikolaus Gotsch

ABSTRACT. Tropical tree crops are produced either in commercial plantations or by smallholders. In this article, a methodology for assessing the sustainability of peasant cocoa production in West Africa is outlined. We propose a procedure for testing the hypothesis that shaded and less intensively managed cacao plantings are more sustainable than unshaded, more intensive plantations. The approach is based on ecological, economic and social indicators for sustainability and takes into account the requirements of experimental design to allow for statistical evaluation. [Article copies available for a fee from The Haworth Document Delivery Service: 1-800-342-9678. E-mail address: getinfo@haworth.com]

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INTRODUCTION

Tropical perennial plantation crops occupy about 8 percent of the arable area in developing countries (Nair, 1993). The average export value of the four important tree crops coffee, rubber, tea and cocoa amounted to approximately USS $13 \times 10^9$ in the average of the years 1991-1993 (FAO, 1995). This corresponds to about 14 percent of the total average export value of agricultural commodities of developing countries in the period under consideration. Tree crops are produced either on commercial plantations or on smallholder family farms. This article focuses on cacao (*Theobroma cacao* L.) in West Africa as a perennial commodity crop of primary economic importance in that region. However, many of the considerations apply to other tree crops produced under similar conditions.

Worldwide about $5.7 \times 10^6$ hectares are planted with cacao, of which 23 percent are in Latin America, 60 percent are in Africa and 9 percent are in Asia (FAO, 1996). The West African countries Côte d’Ivoire and Ghana are the world’s largest cocoa producers with over 1.5 and one million hectares, respectively (FAO, 1996). Their economies depend to a large extent on this commodity. For instance, cocoa contributed 29 percent to the total Ghanaian export value of the average of the years 1991-93 and 23 percent to Côte d’Ivoire’s total export value of $632 \times 10^6$ US$ during the same period (FAO, 1995). In 1991 approximately ten percent of the gross domestic product of Côte d’Ivoire resulted from cocoa. As a consequence, these countries are very susceptible to a decline in world market price, as illustrated by Gombeaud et al. (1990) in their report on the “cocoa war.” Cocoa is not only vital for the national economies as a source of foreign exchange but also for the cash income of thousands of farmers. This is due to the predominance of small scale production. In Côte d’Ivoire, 95 percent of the plantings are between 3 and 20 hectares in size, with an average of 7 to 8 hectares (Jarrige and Ruf, 1990). With an average holding size of 5.5 hectares, the structure in Ghana is similar (Hanak Fraud et al., 1996).

Basically, there are two strategies of production (Wessel and Gerritsma, 1993): low input–low yield production over large surface areas (in the following called “extensive”) or high input–high yield production over small areas (“intensive”). Usually, the degree of intensity of production is negatively correlated with the degree of shade. While extensive plantations can be almost completely dominated by shade trees, shade is reduced or absent in intensified plantations. However, as an exception to this general pattern, Ruf (1995a) shows that, due to the so-called forest rent (see below), increased yields at low input level can be harvested on cacao plantings established on cleared virgin forest land, for instance in Indonesia.
SUSTAINABLE COCOA PRODUCTION

Sustainable agriculture has been defined in many ways. Often the term is used for concepts which differ from conventional agriculture (e.g., Neher, 1992). In contrast to this rather narrow understanding of sustainability, the more extensive concept of “sustainable development” is adopted here “...development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). In numerous definitions, this concept has been applied to “Sustainable Agriculture” (Christen, 1996). In the following, the implications of a pragmatic understanding of sustainability for cocoa production will be examined.

Typically, cacao is planted on cleared forest land. After 20-40 years, when the productivity of the cacao-trees declines, the plantings are often abandoned in favor of new plantings established again on cleared forest land. Ruf (1995b) explains the dependence of cacao on virgin tropical rain forest through the concept of “forest rent.” This basically consists of the advantageous biophysical conditions for cacao on cleared forest land (good soil fertility; absence of weeds, pests and diseases; favorable micro-climatic conditions). To transform the forest rent into a “cocoa rent,” no capital is needed. A planting can be established with the resources available to planters emerging from self-sufficiency: land, some simple tools and labor. The forest rent is consumed throughout the economic lifetime of the planting. If the planting is to persist over more than one tree generation, the forest rent must be replaced by inputs and additional labor. This is reflected in the research efforts for replanting (e.g., Ampofo and Onsei-Bonsu, 1987). However, replanting is rarely ever practiced up to now because it has always been cheaper to exploit the rent of a new piece of forest (Petithuguenin, 1995).

On a global scale, the center of cocoa production has shifted from Mexico to Central America in the 16th century, continuing then through the South American continent. It crossed the Atlantic Ocean to West Africa in the early 20th century and recently, in the 1980s, progressed to South East Asia (Ruf, 1995b). Cacao thus contributes to the destruction of tropical rain forest. As the population pressure on the land increases, permanent cropping systems must be developed for cacao, as they are sought for annual crops currently produced in shifting cultivation (e.g., Slaats, 1995).

There is a general consensus that the concept of sustainability has an ecological, an economic and a social dimension (e.g., Schaller, 1993). What would sustainable cocoa production have to be like, in terms of these three dimensions?
Ecological Sustainability

The natural environment is a source of resources and a sink for waste materials. In order to be sustainable, the consumption of renewable resources may not exceed their regeneration and the deposition of degradable waste materials may not exceed the capacity of the environment to absorb them. The management rules for non-renewable resources and persisting waste are more complex and controversial. The functioning of agricultural systems depends to a large extent on soil fertility, which is only partly renewable. Therefore, constant or increasing soil fertility is a key feature of sustainable agricultural systems and hence of cacao plantings. Soil fertility should be maintained or increased; nutrients removed with the harvest must be replaced. This, and the management of the planting in general, should require a minimum of inputs from non-renewable resources (fossil energy, mineral fertilizers, pesticides).

Biologically, the capacity of the environment to react to disturbances increases with the number of genotypes, species and ecosystems within a given area. If this is true for agricultural systems—and there is evidence for it (e.g., Paolletti and Pimentel, 1992; Swift and Anderson, 1994)—polycultures and closely intertwined agricultural and natural ecosystems (in space and/or time) are more sustainable than large-scale monocultures. This is an argument for associating cacao with other crops or trees. Furthermore, agroforestry systems which mimic the structure of the tropical rain forest have been shown to be valuable habitats for wildlife (Thiollay, 1995; Gallina et al., 1996; Lawrence, 1996).

Economic Sustainability

From an economic point of view earlier generations are at liberty to use resources that would thereby be denied to future generations as long as the welfare of future generations remains just as high as that of all previous generations. This condition is fulfilled if the level of investment is sufficient to maintain the value of the capital stock. This capital stock has two components: Physical capital and natural capital. Investments can be made in either or both as long as the value as the aggregate capital stock does not decline. The problem sticks with the limited substitution possibilities between the two types of capital (Daly, 1994). To take this into account and to provide a more operational sustainability criterion Tietenberg (1996) adds the following two alternative interpretations:

- Sustainability as non-declining value of natural capital: The value of the remaining stock of natural capital should not decrease. This defi-
nition places special emphasis on preserving natural capital (as opposed to total capital). It retains the focus on preserving value (rather than a specific level of physical flow) and on preserving an aggregate (rather than on each individual component) of natural capital. This definition treats all natural capital as homogenous.

- Sustainability as non-declining physical service flows from selected resources: The physical flow for selected resources should be perpetually maintained. This definition emphasizes the physical rather than the value dimension and it focuses on individual resources rather than on the aggregate.

According to the latter definition the service flow from critical natural resources would need to be preserved, while other forms of natural capital would remain open to the possibility of substitution. For agricultural production, weak substitutability certainly applies to soil, for which loss of fertility can only partly be substituted by inputs such as fertilizer. This implies that the non-recoverable part of the natural capital (namely soil fertility) must remain intact and that the financial yield should be sufficient to cover the investment in labor and other inputs necessary to replace the forest rent.

Cocoa is amongst the internationally traded agricultural commodities which present a consistently high index of instability (Amin, 1995). This directly affects the economic sustainability of its production. Attempts to stabilize the world market price for cocoa have proved rather ineffective (Herrmann, 1988) and this situation can hardly be influenced by the individual planter. Hence, a high share of household income from cocoa may increase household income variability which renders particularly investment decisions more risky.

Even if environmental quality and economic development are interdependent not all environmental and economic objectives can be simultaneously maximized, and the possible trade-offs for different activities and conditions need to be analyzed. The estimation of the trade-offs (positive and negative) between economic and environmental goals can be achieved by economic valuation of environmental damage and benefits and/or the physical assessment of the environmental consequences of economic activities.

Social Sustainability

Even more than annual crops, a tree crop such as cacao requires security of land tenure to allow for long-term planning. Planters will only invest in their agro-ecosystems if they have reason to believe that they and their
families will be able to take advantage of this investment. Other social issues which must be taken into account are gender problems, health and nutrition issues. The production of cocoa will only be socially sustainable if it does not lead to massive conflicts between different groups within society and if it improves the health situation of the population. This can be illustrated by a possible conflict between genders with respect to the strategy of cocoa production. The gathering of so-called “minor forest products” (Falconer, 1990) is generally part of the women’s obligations. A number of these products can be obtained from the shade trees of cacao plantings (Herzog, 1994). If these trees are removed, the women will no longer be able to gather food, medical products and firewood during their work on the plantings but will have to spend extra time in the forest to obtain them. This will increase their work load whereas they will only indirectly benefit from the intended increase of income from the plantings—if the intensification is successful—the planting being the men’s responsibility.

One of the main features of the concept of sustainability is its orientation towards intergenerational equity. This principle can conflict with intragenerational equity, depending on the way a rural society handles the succession of farm ownership, and in particular of land tenureship. Intragenerational equity is achieved if the inheritance is shared by all descendants. This can lead to a reduction in farm size beyond a minimum which is profitable. Many societies, therefore, have introduced regulations which assign the privilege of inheritance to one of the successors, at the expense of his or her brothers and sisters. In Africa, other forms of land ownership exist where the land is community owned and access is regulated by traditional decision making processes. There, this conflict is partly avoided. However, traditional regulations will increasingly conflict with the modern western-type law systems which are superimposed on the traditional systems.

The consequences of a consistent implementation of the principles of sustainable development would be so radical that the “sustainable society” has to remain “a utopian vision comparable in scope and scale to the earlier utopias such as the liberal and communist” (Månsson, 1994). If utopias can (and should) not be reached, they still indicate a direction to follow. It appears that the vision of sustainable cocoa production, as presented here, is further away from the intensified plantations imagined by the makers of agricultural policy than it is from the actual reality of peasants’ plantings—at least in a number of aspects.
Research Hypothesis

The main reasons why intensified cocoa production has not been successful in West Africa are the susceptibility of unshaded cacao to pests and diseases and the frequent unavailability and elevated cost of necessary inputs (fertilizers, pesticides). Therefore, Beer (1987) and Wessel and Gerritsma (1993) propose reorienting the shade policy towards shading with multipurpose trees, at least for peasant farmers of few resources. Shaded plantings tend to be more stable than “self-shading” cacao—a good example for the stabilizing effect of biodiversity. In unshaded plantations, this effect has to be replaced by management and inputs. This leads to higher production risks. While shade trees have a moderating effect, intensified plantations are more difficult to manage and over the years, their yield shows more extreme variations (Wessel, 1985).

Research on the deliberate association of cacao with other plantation crops has shown that these systems present appealing agronomic, socio-economic and environmental advantages (Alvim and Nair, 1989; Amoah et al. 1995). In the peasant plantings of West Africa, however, the shade trees generally stem from the original forest. Most of them furnish gathering products (food, medical products, wood for construction and combustion). The importance of these products is demonstrated by the farmers’ acceptance of reduced cocoa yield in order to obtain them. Their economic value must be considered when the profitability of shaded and unshaded plantations is compared (Lecomte, 1990; Herzog, 1994).

These arguments lead to the formulation of the following research hypothesis: “In West Africa, shaded and less intensively managed cacao plantations are more sustainable than unshaded, more intensive plantations.” This hypothesis has to be tested against the next-simpler hypothesis (Green, 1979), which in this case is: “With respect to their sustainability, there is no difference between shaded, extensively-managed and unshaded, intensively-managed cacao plantations.”

For complex studies like the one necessary to test these hypothesis, Barnett and Riley (1995) emphasize that “A sampling strategy must be determined which is appropriate for the components to be sampled, whether it be agricultural, climatological, sociological or economic. When mixtures of species and their interactions are of interest, appropriately located samples should be taken at each farm as well as adequate numbers across the farms, so that interactions can be assessed.” The following sections are an attempt to follow these recommendations in order to illustrate how such a study could be carried out.
The Assessment of Sustainability in Space and Time

The assessment of the sustainability of agricultural systems in an experimental setting is not possible because the socio-economic conditions cannot be reproduced in an experiment. Therefore, the data must be gathered in vivo on existing farms and plantations. This may reduce the statistical viability of the data and of any conclusions which are drawn. However, there is no alternative.

The limits in space and time under which the sustainability of a system is to be examined must be specified. In Figure 1, the hierarchical levels of agricultural systems in space are illustrated. Interactions between the different hierarchical levels are indicated by arrows. The intention of this figure is to provide a schematic basis for discussion and to point out the main factors influencing agricultural production at each level. The major limiting factors and the overall objectives of the decision makers depend on the level which is investigated. For the agricultural field, the farmer generally aims to increase productivity over several vegetation periods. Here, agronomic constraints are the main limiting factors. At the farm level, micro-economic considerations dominate. The farming enterprise should persist and provide a living for the farmer and his family.

The next higher level considered in the analysis is the village/watershed level. Faustino (1987, in Müller, 1997) defines a watershed as a dynamic natural system composed of biological, physical and anthropological components whose interaction creates a single, inseparable complex in constant flux. With this definition, a watershed can be understood according to two conceptual approaches: a biophysical framework by which a watershed can be defined and classified, and a political framework for watershed management and use. The latter will in general correspond to the village. Even if village and watershed do not completely coincide, socio-economic factors interact strongly with biological and physical processes to create homogenous patterns of land use. Thus, decisions taken at the village/watershed level have the strongest impact on the landscape (Izac and Swift, 1994).

This level must not be confounded with the "regional" level, which is often proposed in industrialized countries for the assessment of sustainability (e.g., Lefroy et al., 1992) and which consists either of intermediate administrative structures (county, district, etc.) or of regional associations of groups which engage in the planning or promotion of geographic regions. In sub-Saharan Africa, the federal administrative structures are usually not very developed and regional interest groups are scarce (except ethnically motivated ones). The strong actors, with respect to farming practices and landscape, are the central government at the national level
FIGURE 1. Hierarchical levels of agricultural systems. The arrows indicate the major interactions between the levels.

<table>
<thead>
<tr>
<th>Hierarchical level</th>
<th>Main limiting factors</th>
<th>Decision makers</th>
<th>Dominating goals</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global</strong></td>
<td>political-economic (ecological)</td>
<td>international institutions</td>
<td>preventing and solving international conflicts</td>
<td>International negotiations and agreements</td>
</tr>
<tr>
<td><strong>National</strong></td>
<td>micro-economic</td>
<td>national government</td>
<td>food security, government revenue, rural employment</td>
<td>trade, fiscal, agricultural, environmental policy</td>
</tr>
<tr>
<td><strong>Village/Watershed</strong></td>
<td>ecological</td>
<td>local institution</td>
<td>maintenance of ecological functions, employment income</td>
<td>social control, traditional regulations, administrative measures</td>
</tr>
<tr>
<td><strong>Farm</strong></td>
<td>micro-economic</td>
<td>farmer</td>
<td>preservation of the farming enterprise</td>
<td>resource allocation, investment, decisions</td>
</tr>
<tr>
<td><strong>Field</strong></td>
<td>agronomic</td>
<td>farmer</td>
<td></td>
<td>farming practice</td>
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</tbody>
</table>
and the watershed communities at the local level. Therefore, investigations at the village/watershed level are repeatedly recommended (Izac and Swift, 1994; Manyong and Degand, 1995). Studies at this level, however, are hardly ever executed due to the complexity of the task. Difficulties increase as you move up the system’s hierarchy. To assess the degree of sustainability of individual fields, indicators which are relevant for sustainability can be selected from standard agronomic and economic measures. This is still possible to some extent at the household level, but becomes increasingly difficult at higher levels of investigation. In addition to conceptual uncertainties, the effort necessary for data collection will also increase dramatically. By putting the emphasis on lower hierarchical levels, better feasibility can be achieved. It is thus proposed to assess the sustainability of cocoa production at the household or farm level. Management decisions are taken by individual farmers. Within one village, farmers adopting different strategies of production can be compared to each other.

In order to be sustainable, a system must function over “a number” of human generations without degrading. Information on the sustainability of systems, however, must be made available earlier if it is to serve as guidance for decision making. Izac and Swift (1994) argue that by monitoring a system for about a decade it should be possible to decide whether it evolves towards “more” or “less sustainability.” The approach proposed here is even more pragmatic. Instead of monitoring the evolution of a system, it can be sampled in time. Two points of time should be sufficient to yield some early evidence: the starting point (establishment of the plantation) and its characteristics after a time period which allows sustainability indicators to be distinguished (about 2/3 of the lifetime of a cacao-tree). The first point of time is not sampled, but held constant by choosing a research area where the original soil conditions and the vegetation before planting are the same, as are the climatic conditions. This is possible because different management practices co-exist in a close spatial arrangement (plantations with different degrees of shading can be found within one village). Differences in soil and crop characteristics between plantations of approximately the same age can then be attributed to differences in management practices. Their effects on the soil and on the tree crops “accumulate” over the years; it should thus be possible to collect information on the relative degree of sustainability of different strategies of cocoa production in a comparatively short period.

**DESIGN OF INVESTIGATION**

Its inherent interdisciplinarity is a strength of the concept of sustainability because it allows for a more complete understanding of the complex
reality. Research on sustainability therefore depends on interdisciplinary collaboration. A research approach such as the one proposed here can only be implemented by a team comprised of scientists from both the natural and social sciences. Collaboration has to start in the planning phase and must continue throughout the project (same test areas, coordinated data collection, integrated evaluation of results, etc.).

**Sampling**

Samples must be taken at random and with replicates at the watershed/village, the farm and the field level. However, it will not always be possible to respect statistical procedures (random sampling, sufficient repetitions) fully, because working with people requires their agreement. The samples must be large enough to detect correlations, for example, between the characteristics of the household (e.g., farm size, social status of the farmers family in the village) and the strategy of production.

*Watershed/village level:* Villages within the watershed must be chosen within a homogenous ethnic region. The agreement of the communities to conduct research must be obtained. Within the village, all cacao plantations must be classified according to their degree of shading, preferably into three or four classes A, B, C, D. The degree of shading can be defined as

\[ \sum_{c=0}^{n} \frac{Sc}{P} \]

*S being the vertical projection of the crown circumference of individual shade trees c (or of groups of shade trees when the projections of crown circumferences overlap), P being the plantation's surface. The resulting shade classes could be “A” < 20% of shade, “B” 20-40%, “C” 40-60% and “D” > 60%.

*Farm level:* Within each village, households must be selected at random so that an equal number of each class of plantation is represented. The premise here is that the strategy of cocoa production is decided by the farmer and implemented on the majority of his planted surface. Therefore, there would be n households with plantations belonging to the shade class “A,” n with plantations of the class “B,” etc. All plantations must have approximately the same age or, as they are frequently established continuously over a number of years, they must be partitioned into sections established at the same time.

*Field level:* Because the plantations are likely to be very heterogeneous,
an additional stratification with a 10 × 10 m² grid is suggested (Figure 2). For each plot within the grid, the degree of shading is calculated. The plots are assigned to the same classes a, b, c, d as the plantations as a whole. For each plantation, an equal number of plots of each class is selected randomly; incomplete plots are excluded (Figure 3).

**Data Collection**

Basic information on the characteristics of the plantations (age, size, etc.) must be gathered at the beginning of the research. Most of the other data must be collected repeatedly over a number of vegetation periods. Data collection should continue long enough to level out annual variations.

The ecological and socio-economic indicators necessary to judge the systems are presented in Table 1. A major problem is the valuation of goods used for subsistence. Ideally, market prices can be estimated from prices of the same goods or of substitutes in local markets. For food products, this can be done by means of a market survey which takes into account seasonal variations. For medical plants, the monetary assessment is more difficult. Not all of them are sold on markets, and the effectiveness of many of them has not been demonstrated (at least according to western scientific standards).

Data collection has to start at the village level in order to permit sampling and to get an overview of the ecological and social structures. At farm level, the emphasis will be on the economic and social dimensions of sustainability, whereas at the field level, ecological and economic data will be most important. This corresponds to the goals and main limiting factors, as perceived by the farmer (Figure 1). At the plot level, specific agronomic problems can be examined.

Physical/ecological indicators: The degree of shading of the plantations is regarded as the main criterion for differentiating between strategies for cocoa production. At the same time, the number of shade trees and of tree species is an indicator for biodiversity. A frequently used measure to quantify diversity is the Shannon information index (see, for example, He et al., 1994). However, it does not take into account the spatial arrangement of the trees. Other indices may be more appropriate (Magurran, 1988), for example, the index proposed by Li and Reynolds (1993) at the landscape level.

The nutrient balance must be calculated at the field/plantation level from inputs (mineral, organic fertilizers) and outputs (harvested goods, including waste which is removed from the plantation). Soil fertility indicators are sampled at the plot level. The characteristics of cacao-trees and
FIGURE 2. Hypothetical cacao plantation overlaid with a grid of $10 \times 10 \, \text{m}^2$ oriented north-south and east-west (not to scale).
FIGURE 3. Schematic representation of the sampling scheme. The plots selected at random for investigation are marked with an asterisk.

![Sampling Scheme Diagram]

of the soils indicate the accumulated effect of the past management of the plantation which itself is recorded using retrospective interviews. Hailu and Runge-Metzger (1993) list 25 soil parameters related to soil fertility and the sustainability of agricultural land use. The ones appropriate here are: texture, organic matter, aeration and water storage capacity and nutrients. Except for nutrients, which require periodic measurements, a single evaluation is sufficient. On sloped terrain, soil erosion must be monitored.

The pressure on the crop from pests and diseases must be assessed because it is closely related to shade. This information is needed for the interpretation of differences in cocoa yield. Yield per hectare and yield per nutrient input describe productivity. Particular attention must be paid to sucking insects (myrids) and, in less shaded plantations, to grass hoppers (Entwistle, 1985). The dominating disease is likely to be Phytophthora (black pod) (Lass, 1985). The quantity of pesticides applied (in kg active ingredients and according to toxicity) is a proxy measure for the production system stability.

Economic indicators: Economic aspects are related to the plot, farm and watershed/village levels, and may also encompass externalities outside the watershed.

At the watershed/village level land rents paid are supposed to reflect productivity. However, it must be considered that land rents may be biased by speculation or increase due to population growth or immigration
TABLE 1. Indicators for the sustainability of cocoa production. The arrows indicate monetary assessments of physical parameters. Indicators in *italics* have to be measured every season, the other indicators at larger intervals. **Bold** indicators are suited for statistical evaluation.

<table>
<thead>
<tr>
<th>Physical/Ecological indicators</th>
<th>Economic indicators</th>
<th>Social indicators</th>
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<tbody>
<tr>
<td>National level</td>
<td>National level</td>
<td>government policy (migration)</td>
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<td>government policy (costs and prices)</td>
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<tr>
<td>Village / Watershed level</td>
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<td>population</td>
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<td></td>
<td>land use</td>
<td>infrastructure</td>
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<td>Farm level</td>
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<td>land ownership systems</td>
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<td>land use / land resources</td>
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<td>nutritional / health status of the family members</td>
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<td></td>
<td>physical inputs</td>
<td>work study (gender, seasons)</td>
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<td></td>
<td>physical yield:</td>
<td>housing facilities</td>
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<td></td>
<td>- cash crops</td>
<td>formal education</td>
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<td>- food crops</td>
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<td>- gathering products</td>
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<td>- other</td>
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<tr>
<td></td>
<td>expenses for inputs</td>
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<td>monetary income from the farm</td>
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<td>subsistence</td>
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<td>monetary income from outside</td>
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<tr>
<td></td>
<td>the farm</td>
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</tr>
</tbody>
</table>
Field level (plantations)

- shade characteristics
- shade tree species
- cocoa tree characteristics
  plantation density

physical inputs
physical yield:
- cocoa
- products from shade trees

→ expenses for inputs
  monetary income
  subsistence goods

→ work study (gender, seasons)

land ownership

Plot level

- shade characteristics
- shade tree species
- cocoa tree characteristics
- soil characteristics
- cocoa yield
- pests
- diseases

→ monetary assessment of market goods

→ monetary assessment of subsistence goods
(Müller 1997). The comparison of the salaries paid to farm workers in the watershed/village compared to the rest of the country may indicate efficiency, but may also be influenced by the general salary level in the region, employment opportunities and agroecological conditions.

At the farm level, physical indicators are monetarized to calculate the profitability of the farming enterprise, taking into account the subsistence sector. Income from cocoa production as percentage of total farm income may represent a measure for production diversity from an economic point of view. A high share indicates the dependence of the farm-household on cocoa and its vulnerability to changing agroecological and economic conditions (e.g., cocoa price instability, see above). Income per day of family labor indicates efficiency, but is also a social indicator related to the criterion of "satisfaction of needs," since it determines consumption (at least in part). Additional monetary income may come from off-farm activities of family members or additional commercial activities (retail trade). Eventual monetary transfers from family members living outside the village should also be considered as an indicator of economic sustainability.

At the plot level Müller (1997) uses the gross margin per hectare as an indicator for economic efficiency, while the cost of plant protection and its share on total production cost may serve as an approximation for the stability of the system from an economic point of view. High cost for chemical crop protection indicates that the system's ability to cope with weeds, pests and diseases by its own mechanisms is obviously severely depleted; and external input cost increases the vulnerability of the system to changes in input and output prices.

Social indicators: Only the results of the work studies can be monetarized by calculating wages. Health and nutritional status are measured to assess the well being of the family members. The education level of the household members can be understood as an indicator for resilience because it may determine employment alternatives and the capacity of human capital to adjust the farm-household system to changing conditions (Müller, 1997).

The average farm-household income in the village compared with the average national farm-household income denotes the relative position of the population of the village regarding the economic satisfaction of their needs. A considerably higher or lower level of well-being in the research area in comparison with other regions could be considered as a driving force for migration to or from the village/watershed.

Additional indicators are the housing facilities and the level of formal education of the children, because construction and schooling are two do-
mains into which the income from cocoa is often invested (Ruf, 1995b). The land tenure system is vital with respect to sustainability, in particular for cacao plantations, which are often established by migrants (e.g., De Rouw, 1987). The latter are only interested in sustainable production if their legal situation is stable.

Qualitative investigations of the farmers’ perception of their situation (life histories, satisfaction with the actual situation, perception of the future possibilities) could complete the socio-economic investigation and contribute to the understanding of the farmers’ decision making.

The indicators at the national level are needed to evaluate the risk of production. They are qualitative rather than quantitative.

**Data Analysis**

It is very ambitious to aspire to detect differences in the degree of sustainability in a statistically significant way. A major uncertainty is caused by the fact that the data do not stem from a controlled experiment, where all factors—except the one to be examined—are kept at constant values. Unfortunately, such a procedure is not possible when the overall sustainability of a system is to be assessed, compromising as it does ecological as well as socio-economic factors.

However, for a number of individual indicators such as soil characteristics, cocoa yield or income from individual commodities, statistically valuable results can still be expected. In our case, variables measured in the plots are aggregated for each plantation (mean value or median). The results for shade classes at the field and farm level can be compared using linear regression and/or multivariate statistics (Flury and Riedwyl, 1988; Green, 1993). The definition of more than two classes of shade permits the application of regression methods. Cross comparisons between plots of the same shade class within plantations of different classes (e.g., plots type “a” within plantations type “A” and “B”) can indicate differences which are not due to the degree of shading (e.g., different soil characteristics in strongly shaded plots in plantations managed differently may be caused by fertilizers and not by the degree of shade). This is made possible by selecting the same number of plots in all plantations. The disadvantage of fixed numbers is that more precise information will be collected for small plantations as compared to large ones.

The number of indicators can be reduced by means of factor analysis. Furthermore, discriminant analysis can contribute to identify the most important indicators for distinguishing between different production systems (Müller, 1997).

If the data collection lasts long enough to detect changes within one
single plot, plantation or household, time series analysis can be used in addition. However, even data based on only a few years (three to four to level annual variations) should allow the detection of differences between different classes.

It is tempting to aggregate individual indicators to one overall measure of sustainability. Such an index could be easily communicated and used for public and political discussions. Barnett et al. (1994, as quoted by Barnett and Riley, 1995) suggest that "a database is required of all accountable outputs and inputs [of agricultural systems] with appropriate weighting factors. Only then can a single index of resource use be produced and costs and benefits determined." The problem is with the "appropriate weighting factors," which are likely to be subjective. Cansier and Richter (1994) reject such a single index and see no other possibility than to work with a set of physical indicators for sustainability—like the ones proposed in Table 1. Their interpretation will be a matter of scientific know how and experience. The conclusions will not be free of subjective interpretations, but the subjectivity is not hidden behind anonymous "factors" which suggest unbiased expert knowledge.

As an example, Müller (1997) assesses the sustainability at the farm-household level with the help of ordinal and cardinal sustainability indices, seven indicators representing environmental issues and seven socioeconomic indicators, respectively.

Institutional Setting

Such a research program would probably have to be initiated by an international research institution such as the ones belonging to the Consultative Group on International Agricultural Research (CGIAR). A small, interdisciplinary team could test the approach proposed here in a region of one of the cocoa producing countries of West Africa. If the methodology turns out to be feasible, it could be extended to other regions and countries in collaboration with the National Agricultural Research Systems (NARS). Such a program could lead to a constructive collaboration between CGIAR centers and the NARS as well as within the NARS, as recommended at the International Consultation on the NARS Vision of International Agricultural Research, 12-14 December 1994 in Rome, Italy.

DISCUSSION

It will not be possible to prove or disprove the research hypothesis as such with statistical methods alone. Statistically, existing differences can
be detected for particular indicators, namely the ecological and economic ones. With the latter, the problem of the monetary evaluation of subsistence goods must be resolved by approximation. Amongst the social indicators, information on the nutritional and health status can be quantified (anthropometric measurements). The other indicators are needed to explain eventual differences and contribute qualitative information.

The economic indicators can be monetarized and then aggregated. However, in order to reflect the economic reality of the household, the financial and the subsistence parts of the household budget must also be considered separately. Otherwise, a possible profusion of subsistence goods may mask a cash shortage which can be vital. For the ecological indicators, a set of physical ecological measures will be obtained. For each of them, the “direction” which is favorable for achieving sustainability can be indicated (e.g., the higher soil organic matter is or the lower pest incidences are, the more sustainable the system becomes). It is likely that individual indicators will show opposite trends within one treatment (e.g., shade class A (B) being “more (less) sustainable” with respect to indicator 1 and “less (more) sustainable” for indicator 2). To calculate an overall index of sustainability would require a quantification of their relative importance: is it more important and (how much more) to increase soil organic matter or to decrease pest attacks? There is no methodology yet available to conduct such an exercise.

A possible solution might lie in the setting of “acceptable” limits which a system must not exceed in order to be considered ecologically sustainable (Callicott, 1991, cited by Barnett et al., 1994; Müller 1997). Amongst several systems meeting these requirements, the one with the best economic performance would be preferred. If none of the systems meets the requirements, a ranking should still be possible.

CONCLUSIONS

This research approach is expected to yield concluding information on the relative degree of sustainability of peasant cacao plantings, depending on the degree of shading (or intensity), within three to four years. The rationale that the effects of different management strategies build up over time and can be assessed and compared after a decade or tow, holds for other tree crops as well. Rubber, for example, is often produced under similar conditions as cacao (Gouyon, 1995). The method proposed can be adapted, with the necessary modifications, to other tree crops and other geographical regions. The investigation of the sustainability, instead of the productivity or the profitability of tree crops, can contribute to the for-
mulation of government strategies for smallholder tree crop production, based not only on agronomic evidence obtained in the controlled environment of experimental stations but taking also into account the socio-economic reality of the peasant planters.

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