THE INVESTIGATION OF AGRO-FORESTRY SYSTEMS: METHODOLOGY UTILIZED BY CATIE

P R E F A C E

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The purpose of this paper is to document the "state of the art" of CATIE's agro-forestry studies and to serve as a basis for the discussion of methodology.

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1. INTRODUCTION

The investigation of tropical farming systems could be designed to achieve any of the following three general objectives, all of which can contribute to the development of a country but which differ with respect to the primary beneficiaries.

A) The "local" approach in which the main objective is to optimize the farmer's long term economic return per unit of land.

B) The "national' approach in which the main objective is to anticipate the long term internal requirements of a country and develop systems which will supply these needs.

C) The "international" approach in which the main objective is to maximize a country's production of exportable cash crops.

If planning, of the sort outlined in this paper, is inadequate, serious restrictions may arise during the ultimate stages of the project. For example, if the research institute and the government do not choose the same objective promotion of any new technology will be at best half-hearted.

CATIE's general objective is:

"To increase agricultural, livestock and forestry production and productivity, especially that of the small farmer of the Central American Isthmus, with the purpose of contributing to the improvement of their living standard by making proper use of the natural renewable resources within the framework of national policies" (CATIE, 1979) and hence is closest to approach A.

Agro-forestry can be defined as "A group of land management techniques implying the combination of forest trees with crops, or with domestic animals or both. The combination may be either simultaneous or sequential in time or in space. The goal is to optimize the farmer's profit whilst at the same time respecting the principle of sustained yield " (Adapted from Combe and Budowski, 1979). Clearly, this "group of land management techniques" can be classified under approach A and is strictly in accordance with CATIE' s general objective. Hence, the study of agro-forestry is being increasingly emphasized by this multi-disciplinary centre (Fonseca, 1979). Moreover, agro-forestry partially fulfills the objective of approach B, since the long term wood supplies of many developing countries are threatened (FAO, 1976) and agro-forestry methods offer one means of reducing future shortages of this vital commodity.

The objectives [1] of CATIE's agro-forestry investigations are the following:

To study and develop farming systems that integrate forestry, agricultural and animal components and which serve as a basis for the sustained yield management of tropical humid zones for the benefit of the "small" farmer.

To evaluate the traditional agro-forestry techniques that have been developed in some tropical humid zones with respect to ecological, economic and social aspects, such as water and soil characteristics, production and productivity, and potential for transferance to other regions.

To identify the potentially critical areas, with respect to the supply

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1 Adapted from CATIE. Programa-Presupuesto: 1980. Turrialba, Costa Rica. CATIE. 1979. 84p.

of firewood and charcoal, in the countries of the Central American Isthmus, and to generate technology for augmenting energy supplies based on trees grown in small wood lots or in agro-forestry associations.

To utilize the research experience for the training of personnel of the institutions located principally in the Central American Isthmus.

2. AREA OF APPLICABILITY

Agro-forestry systems have been suggested for a wide spectrum of tropical conditions and the appropriate associations or techniques will be correspondingly diverse (Figure 1) (FAO 1978; King and Chandler, 1978). CATIE's approach is to evaluate the potential of agro-forestry methods for increasing and diversifying productivity from relatively high quality farming land (Budowski, 1979a) as well as from low productivity agricultural areas since increased output from the former may reduce the need to cultivate the latter which are frequently better suited for growing trees alone. Sustained yield agro-forestry systems are being sought for low productivity agricultural lands because the small farmer (CATIE's target group) is often restricted to such areas. Modifications of associations, and even completely different associations, will be needed to promote optimal land use for these different site classes.

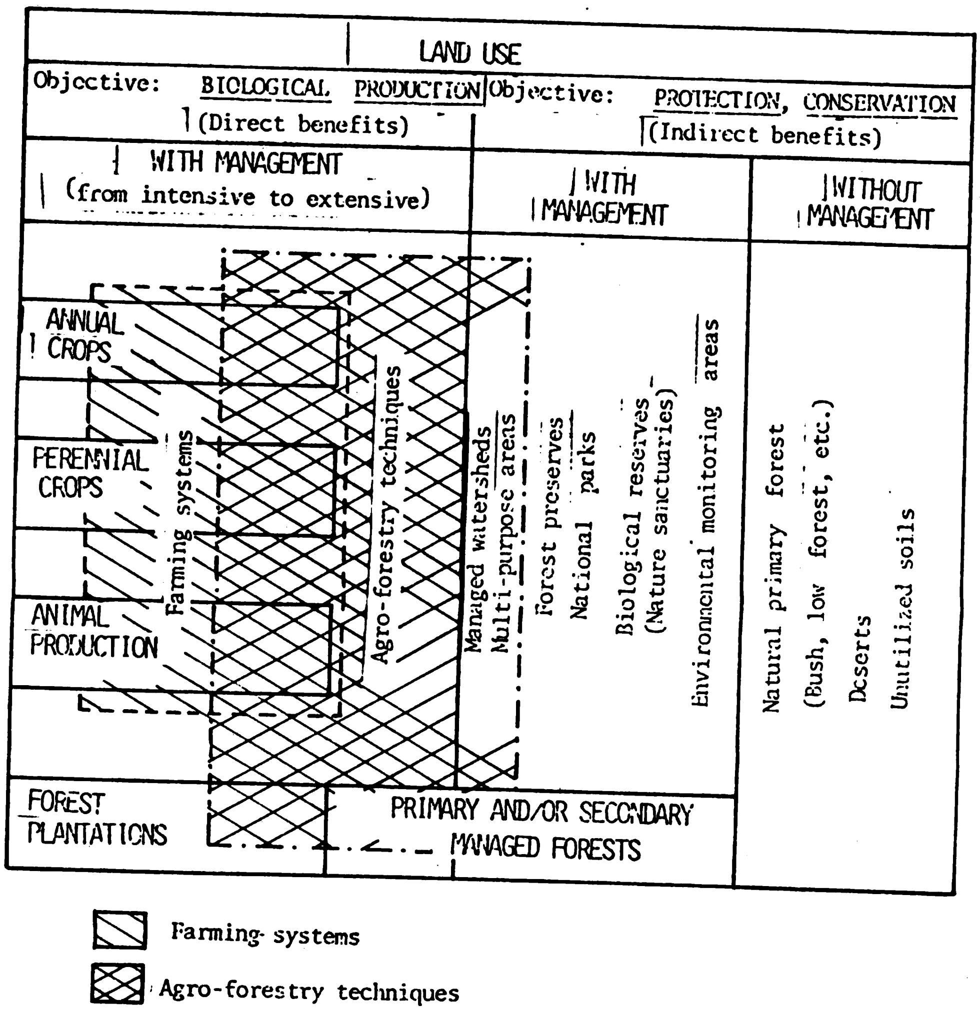

Fig. 1 Outline of a land use classification.
(Adapted from Combe, 1979).

3. GENERAL RESEARCH CRITERIA

3.1. Location of Experimental Areas.

A central criterion of research at CATIE is that existing or new technology be evaluated with respect to the ecological and socio-economic conditions pertaining to the small farmer (CATIE, 1979). This criterion can be partially fulfilled by organizing a proportion of the experimental work as cooperative trials on typical farms that belong to people who are representative of the group who should benefit from the research. The farmer's involvement is most critical during the initiation of a project, when the limiting factors of a farming system or technique must be identified for subsequent study, and in the final stages, when the improved or new technology must be intensively tested in the areas for which it is intended. The establishment of dual purpose research/demonstration zones outside an experimental station is particularly useful in this respect since feedback can be obtained from visiting scholars and students, as well as the rural people, at all stages of the investigation. This constant process of assessment may retard progress but it greatly reduces the risk of developing an inappropriate technique. However, there is also a case for complementing these trials, with similar experiments at the research station where conditions can be much more rigidly controlled, and hence statistical comparisons of potential combinations can be more satisfactorily carried out.

3.2. Relative Importance of Component Species.

The most important species components (animal, crop or tree), with respect to the well-being of the farmer, of an existing or proposed agro-forestry combination must be identified at the beginning of an investigation. Although it is feasible to develop an association which has many components of equal importance, the management decisions required to optimize the value of their products are likely to be extremely complex and hence very difficult to formulate in an acceptable fashion for "extension" services. In Costa Rica traditional associations usually contain one component whose productive capacity is of far greater interest to the farmer than that of the sum of the other components. Market or environment conditions may change the priorities but the farmer will want to bias his management to favour what he perceives to be the primary component. For example, to be acceptable to the "small" farmer, the culture of timber producing trees over coffee (Coffea spp) or cacao (Theobroma cacao) must be organized in such a way that the yield of these perennial crops is at worst only slightly reduced in the association.

However, since agro-forestry research needs to take into account a broader long term perspective, as well as the narrow short-term view characteristic of the small farmer, assessment of the total productivity per unit area, such as the "Land Equivalent Ratio", should also be considered in the development of all agro-forestry systems.(Nair, 1979). Sustained productivity is a basic goal of agro-forestry (long-term perspective) but unfortunately the farmers' acceptance of these techniques is going to hinge on the more obvious value discussed above (short-term view). The truly successful methods will fulfill both criteria.

3.3. Research Priorities

A third criterion used in agro-forestry research is to assess which components of the associations have been neglected by the farmers or earlier investigators. One way of doing this is to use the agro-ecosystems approach (Hart, 1979). Owing to the absence of a multi-disciplinary approach in many of the projects concerning the Taungya method (the temporary cultivation in a forest plantation of food crops, usually annuals, during the tree establishment phase) the available information contains accounts of studies aimed at the optimization of tree survival and growth but offers little direction on how to maximize crop yields. In Costa Rica some of the traditional methods for managing cash crops beneath shade trees have been refined whilst techniques to improve wood production and quality from the arboreal overstory are virtually unknown. CATIE, therefore, stresses the importance of data on agricultural crop yields and their profitability when studying Taungya systems and the use of silviculture to improve the productivity (agricultural crops and timber) of traditional associations.

4. AGRO-FORESTRY RESEARCH AT CATIE

The systems which interest CATIE can be classified into three groups of which the first is receiving the most attention:

a) Traditional agro-forestry systems

b) Taungya systems

c) Other agro-forestry systems

4.1. Traditional Agro-forestry Systems

All the tree-crop and tree-pasture associations that are part of traditional farming systems could be improved but research has had to be concentrated upon the few which appear to have the greater potential.

An outline of a methodology which could be used to choose, investigate and subsequently improve the most promising associations is given in Table 1.

TABLE 1

Steps in the investigation and development of traditional agro-forestry systems.

1. Identification of the techniques and components.
2. Delimitation of the area where an association is or could be used.
3. Description of an association.
4. Selection and establishment of observation/demonstration plots.
5. Quantification of an association.
6. Data processing and summarization.
7. Design of improvements or alternatives.
8. Field testing of improvements or alternatives.
9. Evaluation, validation and adoption of the proposed improvements or alternatives.

4.1.1. Identification of the techniques and components.

A number of traditional associations found in Central and South America have already been identified and provisionally classified with respect to spacing, management techniques and species. (Combe and Budowski, 1979; FAO, 1978). These associations have usually been labelled by means of their component species such as the "laurel-poró-coffee" (Cordia alliodora Erythrina poeppigiana-Coffea spp) association but this method can fail to be precise since it can fail to differentiate between cultivars, and in the above example species. One of the problems in the coordination, or comparison, of different agro-forestry projects is that a critical parameter, such as crop yields, will often be highly dependent upon the nature of the crop cultivar (and species in the given example). Thus, the influence of other factors, such as site and management practices, can not be contrasted for different zones without close cooperation between projects and great attention to experimental design.

4.1.2. Delimitation of the area where an association is or could be used.

The sources of information used to identify the existing and the potential areas for an association include photo-interpretation, available data on the location of a particular agricultural practice (e.g. coffee production, milk production), life zone classification systems and preliminary ground surveys. Socio-economic and legal constraints also have to be considered. Some promising agro-forestry combinations for a number of different regions in Central and South America have already been identified (Budowski,1979b). For example, in Costa Rica:

- *Alnus acuminata* (tree) with *Pennisetum clandestinum* or *Axonopus scoparius* (pasture) in high altitude dairy zones;
- *Cordia alliodora* (tree)-*Erythrina poeppigiana* (tree)-*Coffea arabica* (shrub) for the middle elevations of the Atlantic watershed;
- *Cordia alliodora* (tree)-*Inga* spp.(tree)-*Theobroma cacao* (shrub) for the Atlantic coastal plain.

At this early stage in the investigation the potential of a particular association must be assessed and the different associations which could be developed for a zone or country must be given an order of priority for study. This priority order could be related to the number of people (rural and/or urban) who could benefit from the use of each association, the present comparative standard of living of the possible benefitting groups, or from a different point of view the logistical considerations for research on the different possibilities.

4.1.3. Description of an association

The four major tools for carrying out this step in the investigation are: 1) one visit (i.e."static") surveys (see for an example Bermudez, 1979a; Ugalde,1979). 2) multi-visit (i.e.dynamic) surveys (see for an example Avila, Ruiz, Pezo and Ruiz, 1979, and Rockenbach, 1979). 3) informal contacts with farmers, 4) some preliminary field assessments. The type of information sought concerns socio-economic data; intra- and inter-component spacing; canopy heights; management techniques; locally perceived benefits and limitations; local knowledge regarding the association including folklore and superstition.

Appraisal of the component characteristics which are advantageous or disadvantageous should also be carried out.

The more influencial factors limiting the utility of an association, and hence those aspects which will need detailed investigation, are determined using the above information.

4.1.4. Selection and establishment of permanent demonstration plots.

Case studies to test a set of hypotheses concerned with the potentially limiting factors, should now be formally set up on land managed by the farmers. This type of field trial is essential but the merits of working on land belonging to the experimental station should not be ignored (see 3.1.). For example, CATIE's studies on Cordia alliodora with crops or pasture presently includes ten permanent plots established with cooperating farmers (Beer, Clarkin, De las Salas and Glover, 1979; Rosero and Gewald,1979). However, three student thesis projects on associations including this species (biomass production, Molleapaza, in draft-1979; coffee yields, Gonzales, in draft-1980; run-off/erosion, Bermudez,1979b) and an investigation of the temporal changes in the soil and environmental conditions beneath a variety of combinations, some of which contain Cordia alliodora (Enriquez,1979), have been or are being studied on the CATIE estate. The information that has been collected during the establishment phase of the latter trial can not be obtained from existing examples of the combinations.

The success of an "in situ" study on traditional agro-forestry systems will depend upon the selection of suitable farms for the establishment of the permanent observation/demonstration plots. The first requirement is a farmer who is very willing to cooperate since without uniform management of the plot (which remains the prerogative of the farmer) many results will be invalidated. The second requirement is a homogeneous association, preferrably with comparable adjacent areas lacking one component, so that the land use with and without this component can be contrasted. A third requirement is that the plots should be readily accessible to the investigator (or an assistant permanently stationed within the case study zone) if reliable records on the traditional management practices are going to be produced.

In order to encourage maximum cooperation it is worthwhile developing informal arrangements whereby the research team provide some free labour and/or materials for the farmer by way of compensation for the inevitable interference in his working schedule. Full explanations of the objectives and results of the project are a valuable means for securing good relations and prompting feedback from the rural people.

4.1.5. Quantification of an association

The quantitative analysis of agro-forestry associations can be divided into two areas:

a) Environmental and biological;

b) Socio-economic.

CATIE's approach to the improvement of traditional associations is generally from the silvicultural point of view, and this forms a third area in which working hypotheses have been formulated (Combe, 1979).

The mensurational techniques are those developed for the biological sciences.

Table 2 outlines the initial measurements that are being taken (nos.1-6) or are proposed (nos.7-8) for some of the associations found in Costa Rica. Their classification into these 'areas' is not always straight forward since some can be allocated to more than one 'area'. Task 1, 3, 4, 6 and 7 only concern "environmental and biological" details whilst 5 is a "socio-economic" measure. Task 2 involves two'areas'and 8 illustrates that this type of division can not be clear-cut since the investigation of nutrient cycling must include determination of the magnitude of artificial as well as natural fertilizer inputs; factors which have obvious "socio-economic" implications although we would normally classify this task under "environmental and biological" measurements.

Most of the above measurements will have to be repeated during the different stages of growth recognizable for a particular combination. This information is not only needed for a thorough evaluation of the combination but also for the development of discrete management recommendations appropriate for the different stages of growth .

In certain cases silviculture in traditional associations may be noted (for example: pruning, precommercial thinning of natural regeneration,harvesting). However, generally these techniques will only become significant at a latter stage of the project when alternatives or improvements are being designed and tested. The more obvious silvicultural possibilities are given below:

a) Regeneration-source (natural, transplanted, wildings, transplanted locally raised seedlings, commercial stock, coppice, vegetative propagation), season, spacing, restocking, cultural practices (protection, fertilization, weeding), costs.

TABLE 2

Tasks proposed for the quantification of traditional agro-forestry associations in Costa Rica.

	Task	'Area'
1.	Describe the architecture of the association.	Environmental and Biological
2.	Record details of the management practices.	Environmental and Biological Socio-economic (Silviculture)
3.	Determine the rate of volume growth of the tree species.	Environmental and Biological
4.	Measure the crop yields with and without a tree overstory.	Environmental and Biological
5.	Estimate the economic consequences of including the tree species using 3 and 4.	Socio-economic
6.	Assess other factors influenced by the inclusion of a forestry component. (e.g. rates of infiltration and erosion, weed proliferation, microclimate).	Environmental and Biological
7.	Classify the soil.	Environmental and Biological.
8.	Study root interactions and nutrient cycling.	Environmental and Biological (Socio-economic)

b) Pruning and pollarding-timing, criteria (size, form, socio-economic reasons), technique, severity, use of pruning and pollarding residues (e.g. chopped for mulch), effect on crop yield, effect on wood production and value, other effects (e.g. weed proliferation, shade regulation, nutrient incorporation), costs.

c) Thinning-timing, criteria (size, spacing, form) use of products (e.g. fence posts), effect on unit area wood volume increment, effect on crop yield, other effects (e.g. weed proliferation, shade regulation), cost-benefit analysis.

d) Harvest-timing (e.g. with respect to crop harvest), criteria (size, form and socio-economic reasons), logging techniques, product utilization, crop damage and effect on crop yields, other effects (e.g. soil stability and fertility), markets, costs.

Tree management in agro-forestry systems should be based upon the principles of conventional silviculture with these specific techniques being adapted to produce optimal conditions for the development of the associated crops and pastures whilst respecting the principle of sustained yield (Combe, 1979).

4.1.6. Data processing.

Productivity comparisons (economic, total biomass, yield of a particular component) between different combinations, or of a monoculture versus a combination, are a basic means for appraising existing and improved agro-forestry associations. Statistical tests will obviously play an essential role but their value is always limited by the available examples and the sampling techniques used. For example, the absence of a homogeneous population in the existing examples of an association, severely restricts the use of statistics, and this type of evaluation has to be carried out in specially designed and maintained plots that preferably would be situated on land belonging to the research station. Notwithstanding this reservation preliminary conclusions, from which improvements and alternatives can be developed, can be derived from quantitative data recorded on the appropriate farms and from published information on the corresponding monocultures. Provided this latter information is weighted with respect to environmental and soil characteristics a great deal of data is available, against which the potential of an agro-forestry association, and the importance of its limiting factors, can be judged.

Indirect benefits, such as environmental protection, must enter into the evaluation but these are so dependent upon the circumstances of each particular case that no generalized guidance on their significance can be given. Final assessment of the potential benefits from an association should include a careful evaluation of both the short term benefits and the maximum sustainable yield.

4.1.7. Design of improvements or alternatives.

It could reasonably be argued that this and the previous two phases should not be discussed separately, since in practice ideas for new or improved associations will be continuously modified as information is received and will in turn indicate where new measurements are required.

The greatest omissions in the improvement of traditional associations generally lie in the field of silviculture. There is invariably a clear potential for increasing the volume and value of wood production, crop yields, and indirect benefits of an association, through the application of silvicultural techniques.

Socio-economic data collected in steps 3 and 5 (Table 1) is put to most use during this, rather than the preceeding, phase. In order to facilitate their adoption all proposed techniques have to be cheap, relatively simple, labour demanding only during the slack periods of the agricultural calendar, mainly based upon local resources, and should imitate existing environmentally sound practices. Political and land tenure restraints must be allowed for to ensure that the target group are amongst the beneficiaries and hence are encouraged to adopt the recommended techniques.

4.1.8. Field testing of improvements or alternatives.

Complementary trials should be designed for both the experimental station and the cooperating farms to produce data for statistical analysis.

Data from the regional surveys (4.1.2.) together with soil and environmental data ought to be used when deciding the location and number of repetitions needed to adequately test a technique or association in the survey area. Since observations have to be taken at various intervals in the development of an association, long-term trials are always involved and great care is needed to choose farms with secure tenure and experienced management. Existing stands of trees or an established association may be manipulated to provide repetitions for one of the more advanced growth stages but they can not provide all the necessary information.

The initiation of tree improvement trials, for arboreal components of agro-forestry systems, may be justified at an earlier stage of the project (e.g. step 4 of Table 1). This is true for Cordia alliodora which is obviously going to continue to be important for small farmers and has such variability in form that genetic improvement programmes should lead to large benefits (Dyson, 1979).

4.1.9. Evaluation, validation, and adoption of the proposed improvements or alternatives.

If the proposed techniques are demonstratively worthwhile to the extension services of the government departments for agriculture,forestry and animal husbandry, then personnel of these departments should gradually take over the continuing evaluation and promotion of the new techniques.

In cooperation with the research institute they will have to train the farmers and prepare publications and education aids that are orientated towards the level of education of the rural people who could use the improved farming systems. Field days to the stategically placed observation/demonstration plots, which were established during the preceeding phases, have to be organized. Checks and revisions of the guidelines and of the extension service need to be periodically carried out.

4.2. Taungya Systems

The study of this technique at CATIE (then IICA) was initiated in 1962 (Aguirre Corral, 1963) and has been continued as a series of student thesis projects (Munoz Aldean, 1975; Aguirre, 1977; Fernãndez, 1978;Magne, 1979). There was little relevant data for Central and South America which could be developed when this series of investigations began. Therefore, the research commenced with a design step (7 in Figure 2) and all subsequent studies of Taungya systems have been carried out on CATIE land. However, "small" farmers have been involved through cooperative arrangements (Aguirre Corral, 1963).

The adoption of Taungya systems, as they are usually practiced elsewhere, depends upon the existence of a strong forestry organization (normally a government department) dedicated to the establishment of forestry plantations. The absence, for many years, of such organizations in Central American countries probably lies behind the apparent lack of interest in the potential of Taungya systems. In the case of Costa Rica, the only country for which there is presently sufficient information to attempt promotion of the methods, two factors indicate that a typical Taungya reforestation scheme would be unsuccessful (see King, 1968 for a discussion of the limiting factors). These are insufficient land hunger and comparatively high levels of income for the agricultural population.

Taungya could, however, play a valuable role in Costa Rica as a method of establishing multi-strata agro-forestry combinations. The most recent Taungya experiment concerned the cultivation of Zea mays, Vigna unguiculata and Phaseolus vulgaris in a new plantation of Terminalia ivorensis (Magne, 1979), a tree species which has many of the advantageous characteristics that make Cordia alliodora so suitable for agro-forestry combinations. Part of the continuing trial on this site is going to be a study of the development of associations formed by underplanting Coffea arabica, Theobroma cacao and Citrus sinesis. This type of land use sequence could be promoted as a means to encourage farmers to plant improved tree stock, rather than relying upon natural regeneration for the timber producing component of their traditional associations. Moreover, farmers commonly raise food crops, such as Zea mays in immature coffee plantations and hence modifications of the Taungya techniques should be readily and easily adopted by "small" farmers.

Many of the early steps suggested for the investigation of traditional agro-forestry associations (Table 1) would not be required for the study of Taungya systems. However, step 2 (delimitation of the area of applicability) must be kept in mind throughout any study of farming systems and the details already given for steps 6, 7, 8 and 9 apply to any research on agro-forestry systems.

4.3. Other Potential Tree-crop Associations.

Tree-crop associations, could be classed as hypothetical or they could be proven combinations that had never been utilized in the study area. In most cases the probabilities of finding successful agro-forestry systems are greater when research is based on the latter class since qualitative data on the environmental constraints will be available while this can not be known of the former class. Thus, at CATIE this transference has usually been used as a basis for the proposal of tree-crop associations. Examples are the testing of various living fence post species, such as *Gliricidia sepium* and *Erythrina* spp., as sources of animal fodder (Martin and Ruberté, 1979) and the proposed introduction of cattle into existing pine plantations (Adams, 1975).

Examples of some hypothetical associations are:

1) *Simarouba glauca* and/or *Leucaena leucocephala* planted in blocks or lines with the food crops *Zea mays* and *Sorghum bicolor* in order to reduce erosion in the Tejutla area, El Salvador. (Gewald, De las Salas and Rosero, 1979).

2) Various agro-forestry associations, specifically planted for fuelwood production, which have been proposed as part of a project designed to promote the development of energy supplies based on trees (CATIE-ICAITI-ROCAP, 1979). The suggested systems include native traditional, foreign traditional, and new associations.

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