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A Handbook on the

MANAGEMENT OF AGROFORESTRY RESEARCH

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Preface

Good agroforestry research, like all good applied science, creates new and useful information. The techniques for forming and testing hypotheses about agroforestry are quite similar to those used in other fields of applied research. So why is this book necessary? It is for two reasons, both particularly important for developing nations.

First, agroforestry is a relatively new field of applied science, based on concepts from both agriculture and forestry. While investigators new to agroforestry research tend to rely on the field with which they are most familiar, a synthesis of these concepts and methods is required. A similar synthesis is needed between the concepts of the social and biological sciences in the context of agroforestry. Integration across professional and disciplinary lines, as a consequence, presents a major challenge in managing agroforestry research.

Second, few books are available in agriculture, forestry, or natural resources that are guides for beginning researchers. Yet many scientists are initiating agroforestry research, and large, complex national and multinational programs are developing in and among Asian and other developing countries. Examples of these include the International Council for Research on Agroforestry (ICRAF) based in Nairobi; the All India Coordinated Research Program in Agroforestry established by the Indian Council for Agricultural Research (ICAR); the Multipurpose Tree Species Research Network, sponsored by the Forestry and Fuelwood Research and Development Project (F/FRED) for Asia based in Bangkok; and several other international centers and national institutes. A practical overview of the research process will help research managers and scientists in this new applied field make better use of the major investments now being made in agroforestry research.

Consequently, if you are managing an agroforestry research program, project or career, this book is intended to assist you. We describe the major components of the research process and place them in the agroforestry context. We explore the similarities and differences between agriculture and forestry research. We do not repeat material from the literature that is readily available, but summarize or direct you to that literature. Because agroforestry research tends to be long-term, complex, and interdisciplinary, this book emphasizes defining problems, establishing research programs, formulating research questions and hypotheses, and preparing written research plans that will serve as protocols regardless of personnel or administrative changes. Our goal in writing this book is to improve communication among investigators and between investigators and their clients.

The first section of the book begins our discussion with an overview of agroforestry research directions in chapter 1. In chapter 2, we define and examine agroforestry problems, then proceed to developing programs of research based on our understanding of problems in chapter 3. We emphasize written

study plans, and devote chapter 4 to this subject. Chapter 5 concerns research implementation, which is followed by evaluation in chapter 6.

The second section of this book, prepared by Drs. Salleh Mohd. Nor and Hashim Md. Noor, highlights the challenges of agroforestry in Asia and suggests the applications for our approach to managing agroforestry research. This section may be read by itself or in conjunction with the main body of this book.

No book can be written without strong support from many quarters. We appreciate the useful conversations we have had with colleagues in Asia and suggestions from reviewers of earlier versions of the materials presented. We are especially thankful for the financial support of the Agency for International Development and the institutional support of Winrock and the F/FRED team, most particularly Thomas C. Niblock, the project manager. Our deepest thanks to Karen Seckler and Denise Felton Bryant for editing this manuscript and to Melinda Murtha for handling the logistics and word processing.

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SECTION 1

Managing Agroforestry Research

CHAPTER 1

Agroforestry Research Directions

Agroforestry is the deliberate growing of woody plants, nonwoody plants, and often animals for human purposes, simultaneously or in deliberate rotations on the same unit of land. More broadly, it is the combination of silvicultural, agricultural, and other land-use technologies so that their joint application will increase productivity, sustainability, or equity, or achieve other social goals. Because agroforestry adds new plants, crop patterns, and management needs to previous land uses, it is by definition complex.

Major research themes common to all agroforestry are presented in our discussion as general notions or hypotheses. They are best used as guidelines; they are not a substitute for careful problem analysis at the beginning of or during the research process.

AGROFORESTRY RESEARCH: BASIC OR APPLIED

Agroforestry concepts are derived from observed practice rather than academic contemplation. Consequently, agroforestry spans the content of many academic specialities as well as the two major forms of human knowledge about landscape use: forestry and agriculture. Each speciality has its own jargon, methods, paradigms, and culture. Thus, the academic basis as well as the practice of agroforestry is complex.

Agroforestry research is performed to benefit specific groups of people called clients; consequently it is an applied field of scientific inquiry. King (1987), in tracing the history of agroforestry, for example, points out that the *taungya* system was developed from the practical need to incorporate annual cropping with the establishment of teak plantations. Similarly, *Prosopis lineraria* has been incorporated for centuries into dryland farming in what is now Rajasthan. In fact, people in most places and in most times have mixed trees and farming.

Agroforestry knowledge will advance most rapidly through better understanding of selected basic social, biological, and physical processes and interactions, and through the construction of theories based on that understanding. The study of existing operational systems in use by farmers is the first key to understanding the interactions basic to agroforestry. Gordon and Ghildyal (1986) argue that putting basic scientists in direct contact with farmers who use these systems is one of the more productive ways to generate and test useful hypotheses.

The scientific process begins with an empathic appreciation of farmers, their problems, and their land-use technologies and systems. We suggest some structured approaches for understanding farmers' objectives and constraints and formulating testable hypotheses by asking objective questions. This combination of pure science and on-farm experience confounds any neat distinctions between what is basic and what is applied. The lack of clear demarcation between basic and applied work in the conduct of agroforestry research is fundamental. A theoretical or conceptual base is particularly important in understanding current systems and in defining their similarities and differences.

THE ECOSYSTEM PARADIGM

Agroforestry is inherently variable over space and time. Its successful practice depends on predicting and controlling the interactions of plants, animals, people, and the environment. The ecosystem paradigm is a logical and useful theoretical base.

This paradigm, most simply described, assumes that a given system can be defined by a boundary, and all mass and energy transactions within the system and across the boundary can be identified. An ecosystem is formed by the definition of an explicit boundary. The boundary is often, but not always, recognizable by natural demarcations such as watersheds, soil or vegetation types, or ranges of animals (Likens and Bormann 1985). For agroforestry purposes, it is especially important to define the ecosystem's boundary to include the major influences on crop components and behavior. For example, the portion of the agroforestry system below the surface of the soil, and therefore the location of the lower boundary of the system, will vary with soil and crops. Ecosystems are usually defined within macroclimatic zones, but the components of an agroforestry system may profoundly influence the microclimate through, for example, influences on solar radiation interception, air movement, and water drainage.

All mass and energy transactions within and across the ecosystem boundary can be expressed as equations. At least conceptually, all mass and energy gains and losses by the system can be estimated and explicitly stated at a level of accuracy and precision sufficient to the level of prediction sought. No major system components can be disregarded, no mass or energy can remain unaccounted for, and all transactions—gains and losses of mass and energy by compartments within the system—must be stated quantitatively to an equal accuracy and precision. This seemingly cumbersome restriction is critical because interactions underlying crop successes or failures often have been missed when investigators have examined only part of a system.

Historically, the ecosystem paradigm has been more widely examined and used in forestry than in agriculture, although it usually was not called by that name. The ecosystem view has become more useful in agriculture as concepts and values such as sustainability, integrated pest management, and low-input management increase in importance, and it is now often explicitly used.

Agroforestry practices involve the complex insertion and removal of plant, animal, and microbial materials, other modifications of the environment (for example, soil treatments and water control), and the infinite variety of interactions that then become possible. The complexity of agroforestry demands

that the most current technology be used to expose these mechanisms and thus to efficiently test quantitative hypotheses. Agroforestry will benefit from a more complete and verifiable accounting and comprehension of biophysical mechanisms underlying the increments or decrements from yields of desired products.

New methods of analysis and measurement make the energy and mass accounting required by the ecosystem approach easier. Measurement of solar radiation, gas exchange in photosynthesis, respiration and transpiration, biological nitrogen fixation, and many other ecosystem variables are now possible in the field. Modeling and statistical analysis techniques can be coupled efficiently with data acquisition in the field through the use of microcomputers and appropriate software. Thus agroforestry research based in the ecosystem view is amenable to the use of the most sophisticated research methods available. Sophistication in itself is not a virtue, however, and simple methods are appropriate for many objectives. For example, much can be learned about production and allocation in agroforestry systems by applying the techniques of plant-growth analysis (Watson 1952).

Applying the ecosystem paradigm and methods to existing agroforestry systems will enhance both ecosystem theory and agroforestry practice. In particular, application forces more conscious examination of the variable and poorly predictable social systems and socioeconomic requirements that regulate inputs and outputs. People and social factors are integral parts of all agroforestry systems, and these factors are best combined with biological concepts by viewing them as part of the ecosystem (Burch 1989).

The social dimensions of agroforestry, combined with the disciplinary orientation of researchers, the variety of sites and organisms involved, and the necessary use of the ecosystem paradigm make agroforestry research and application complex from the outset. There is a logical starting point, however, from which to approach the system and that is the ultimate user of agroforestry information—the farmer implementing agroforestry systems or the professional making agroforestry prescriptions.

AGRICULTURE AND FORESTRY COMPARED

A brief examination of the often divergent characteristics of agriculture and forestry and their implications for scientific research (table 1) will help in understanding the major agroforestry research themes. An examination of the two fields indicates major differences.

Table 1.1. Comparison of characteristics of forestry and agriculture

Forestry Characteristics	*Agriculture Characteristics*
perennial woody plants	annual or biennial plants
focus on vegetative growth	focus on reproductive growth
thousands of species	tens or hundreds of species
mixed culture frequent	monoculture frequent
multiple products and values	single or few production goals
extensive, low-cost cultivation	intensive, high-cost cultivation
positive wildlife values	negative wildlife values
negative domestic animals values	positive domestic animals values

Agricultural Research

Agricultural research has been conducted since the first domestication of plants and animals. On-farm research has been largely deductive and confined by its focus on intensive selection and cultivation of plant and animal products in relative monoculture. Most formal research has been conducted in the last 50 to 100 years on relatively few products of high nutritional and economic importance.

The rapid rotation and regeneration schedules of most crop plants and the relatively short lifetimes of most domesticated animals have aided agricultural research.

For agricultural crop plants, emphasis has been on reproductive growth. Crop-plant and animal residues are treated as byproducts. While residue value is acknowledged, selection and treatment directed toward producing residues has been limited to date. The concentration on reproductive structure and success coupled with short rotation and gestation periods has facilitated rapid genetic change and, thus, a relatively high genetic capacity to adapt to stress. Agricultural research has capitalized on these traits, achieving remarkable yield increases. The green revolution, for example, was based on short-strawed/big-headed ideotypes that represent the reallocation of net photosynthate from stem to seed. Perennial horticultural crops are intermediate between agriculture and forestry. While similar to agriculture in the emphasis on reproductive growth, they share with many trees slow regeneration times that make selection research so time consuming.

Improved agricultural yields have matched food production with population growth since about 1960, although food-distribution systems have rarely been synchronized with the social changes that result from population growth. The need to shift research attention toward distribution and equity issues facing food producers and consumers is one of several factors that will encourage the synthesis of forestry and agricultural research in the future.

Forestry Research

Forestry research, unlike agricultural research, is relatively recent. The supply of forest products has, until the population increases of the last few decades, generally exceeded demand, and production pressures have remained relatively constant. Although in theory thousands of species are potential research subjects, forestry, like agriculture, has concentrated on a few species of economic importance. Progress is inhibited by slow rotation and long regeneration/reproduction times. The growth and utilization characteristics of most tropical tree species are little known.

Forestry's focus on vegetative growth results in quite different views of carbon allocation—really the manipulation of allocation of net photosynthate among plant parts—from those prevalent in agricultural research. A single species of interest generally has one primary use. However, most perennial species have many more possible uses: fuel, timber, manufactured goods, pulp, and food products. The variety of end products affects research on carbon allocation, morphology, and physiology. Lengthening life span results in the production of many secondary products. This further compounds the complexity of research on plant/plant, plant/animal, and plant/animal/human interactions.

Forestry production, unlike agricultural production, has not increased with population growth. Given the greater weight, size, and variety of end use, forest products have even greater distribution problems than food crops.

Most efforts have focused on timber species. Total usable stem volume, straightness, roundness, and other characteristics that affect utilization for solid wood-fiber products have been the criteria for selection and breeding programs. Commercial timber criteria have some validity for multipurpose trees, but other criteria concerned with fodder protein, limbs for fuelwood, nitrogen-fixing capacity, and many other values are equally important. If total biomass production per hectare is fixed, the choices focus on allocation of net photosynthate toward potential end uses.

Recently, research on multipurpose trees has increased, but the tendency worldwide is to mimic agricultural research by concentrating research and development on only a few species intended for widespread planting. Planting multipurpose stands of trees on Asian and African farms is like intercropping food crops to reduce risk and meet the diversity of yields needs. Design of multipurpose stands may represent a sounder strategy for both research and practice. Although between-plant competition will remain a critical issue, selection among tree genotypes can focus on the characteristics desired in single products.

Forestry and Agriculture Complementarity

The ecosystem view was formulated by scientists contemplating forests and ponds, not farming systems. On the other hand, scientific work on the genetic and cultural improvement of crop plants is far more advanced in agriculture than in forestry, where such research is just beginning to have an effect on yields. Woody plants have often been viewed as inherently less productive than annual crop plants. This is not necessarily so from a biomass-yield view (Gordon 1975), and it may not be so from a net value or productivity viewpoint on many sites that are marginal for food-crop production. Agricultural crops are ecosystem components, and trees can be crop plants. The ecosystem approach and the crop-improvement approach are complementary. Combining them can and should lead to more productive agroforestry systems desired by farmers and other beneficiaries.

The mixing of trees and annual crops emphasizes several conceptual rules applicable to all research on agroforestry systems:

1) All organisms within the system boundary are treated as system components, not just those of direct economic interest. Thus, for example, mycorrhizal fungi, wild animals, and pollinating insects may determine experimental outcomes.

2) The entire area within the system is viewed as the production base, not just the area occupied by crop plants. When yields per unit area are calculated end rows, edges, access roads, and irrigation channels must be considered as area allocated to production.

3) Transactions across system boundaries over time become particularly important determinants of the level at which production can be sustained. Loss of nitrogen and mineral nutrients in particular must be measured and replaced if stable or increased production is sought (Bormann and Gordon 1989).

4) Interaction patterns between organisms and human activities become overt determinants of current and future yields. If, for example, domestic livestock are not managed to protect young trees, systems that include tree planting will not perform well.

5) Below-ground interactions between species and between higher plants and microorganisms and animals become more important than in monocultures. A variety of root systems within the same area leads to a complex set of possible symbioses, diseases, and competitive relationships, all difficult to observe.

6) Functional descriptors are needed, similar to leaf area indices (the total area of leaf surface divided by the land area that supports it), that can at least theoretically be used to compare performance across and among species.

MAJOR AGROFORESTRY QUESTIONS

Agroforestry research questions are concerned with individual plant components, the interactions between these individual components, the interactions of the plant components with their biophysical environment, and the consequent results in terms of useful yields of food, fiber, and animal products. Current productivity and long-term sustainability estimates are the integrating element of these major agroforestry questions that focus research on information needed by farmers and other clients.

Species Selection, Propagation, and Improvement

The general agroforestry hypothesis with respect to the manipulation of genotypes is that species can be chosen, propagated, and improved so that they fit together in beneficial ways. The model often cited is the layered forest of the humid tropics in which a great variety of species grow and reproduce in a variety of spatial and time-sequence patterns. Most agroforestry systems, however, must accommodate many species that differ in their basic physiology from those found in the humid tropical forests. Most notably these include the C_4 grasses like maize, sorghum, and sugarcane. C_4 crops are adapted to hot, bright, high moisture-stress environments. Also included are the table vegetables that are primarily roots or reproductive structures.

Advanced techniques for monocultural crop improvement are available by which within-species variation, selection, and breeding leads to higher yields. These are often applicable in agroforestry research. On the other hand, improving existing annual crops for use where they are shaded by trees or subjected to new kinds of competition in the root zone is a task relatively new to the agricultural crop breeder. For example, the presence of trees may foster soil microorganisms or add allelopathic compounds that are detrimental to annuals. New shapes and leaf orientation may be required for annuals subjected to vertical or lateral shade. Thus, the creation of additional within-species variation, historically the limiting factor in annual crop improvement, may be particularly important in agroforestry. Fortunately, new biotechnological approaches bear the promise of purposefully expanded within-species variation for complex systems such as agroforestry, although probably not in the very near future.

Better species selection techniques and the application of joint performance standards are needed for both annual and perennial plants that are candidates

for use in agroforestry. Annual crop improvement has not concentrated on species selection, although much work on varietal selection is potentially applicable to species selection. Because of their longer regeneration times, woody perennials usually require a combination of selection and vegetative propagation for rapid improvement. Rapid methods of replicating genotypes are key to the genetic improvement of agroforestry systems. Also required are methods for quickly compiling and analyzing reproductive characteristics and propagule performance under stresses of light, moisture, and temperature for the vast array of woody species potentially available for use. Again, cell culture and recombinant DNA techniques will be useful in rapid improvement of perennials, and probably should be applied first to those promising species that are difficult to propagate vegetatively.

Joint performance standards are relatively new to both agriculture and forestry. Their development, and methods for applying them, are primary agroforestry tasks. Obviously, classical yield trials of the kind now used in single-species tree and crop breeding will be too costly to apply to mixtures. Less expensive approaches, such as single plant and stand models, must be adapted to agroforestry research.

The standards themselves must derive from the utility and sustainability of the whole system, rather than solely from the harvested portions of the individual components. Two concepts likely to be useful are microcosms and agro-units. Microcosms are controlled environments that simulate field conditions under which joint performance is to be measured. Agro-units are the smallest recognizable field area in which the tree-crop interaction occurs, and thus are suitable for evaluating joint performance (Huxley 1986).

Competition and Complementarity

Research on how single crop species respond to competition for light, moisture, and nutrients is plentiful in agriculture and not uncommon in forestry. However, research on competition and complementarity between multiple-species crops is rare. Adding the effects of soil microorganisms and fauna and above-ground pests and diseases again illustrates the complexity of agroforestry research. Yet these complex factors determine the long-term viability of agroforestry systems.

When two or more species are grown together purposefully, more information is needed to understand and predict the performance of the system than when one species is grown. The almost universal presence of weeds makes the problem at least familiar to agronomists and foresters. Under some circumstances and for some objectives, a combination of species can be complementary. Replacing undesired plants with desired ones complementary to the main crop can reduce costs, improve yields, or both. This is the basis for the *taungya* and similar silvicultural systems where agricultural crops are grown with commercial timber species during the first few years of a crop cycle or rotation.

As woody species are domesticated and moved widely over the landscape, they have the potential to become weeds. A systematic framework for testing woody species for weed potential needs to be developed and universally applied. More positively, pest and disease control characteristics of many woody and herbaceous plants need to be cataloged and analyzed for intercropping potential. In a given place, will birds increase in numbers as trees are introduced? Will

they eat harmful insects or the crops themselves? These are only a few examples of competition and complementarity issues requiring agroforestry research.

Soil, Water, and Microclimate

From antiquity trees have been known as modifiers of soil, local and distant water supplies, and local climate. Indeed, much of the justification for agroforestry is based on the use of trees for precisely these purposes, especially in rehabilitation of degraded lands. The general hypothesis is that these effects, through proper management, can be made more positive than negative. Yet in most locations, we know little of the long-term effects of planted trees on soil-formation processes. While there are indications that tree planting can make localities more humid and increase groundwater supplies, few comparative experiments have been installed, and very few have been installed in areas where agroforestry is being advocated. Eucalypts, for example, are often a controversial genera in farm forestry and social forestry schemes. Their commercial value often is high for pole timber and pulpwood, but serious allegations are made about the allelopathic characteristics of leaf litter and their adverse effect on local groundwater supplies. These controversies, however, have stimulated few serious experiments to test hypotheses.

Good soil, water, and microclimate data, derived from modern measuring techniques and meteorological stations, are essential for comparative experiments. Few agroforestry research sites are instrumented to the level of simultaneous collection, for example, for solar radiation, precipitation, and wind-speed data. Each research site should be, and some researchers (for example, Dr. Chin Ong at ICRISAT) are developing inexpensive techniques for environmental monitoring on agroforestry research sites. Ultimately, systems of comparative experiments spanning a range of social as well as biophysical conditions will be needed to help sufficiently understand agroforestry effects on climate and soil to make useful predictions about the consequences of its wide adoption.

Yield Prediction

Predicting agroforestry yields within useful limits of accuracy and precision differs from predicting either forest or annual crop yields. New approaches to yield prediction are required because of the interactions between annual and perennial components, the long time periods to tree maturity, and the potential variety of harvested products and environmental services.

Applied research produces information for use by defined clients. Information, in this sense, is structured data that are useful for solving a client's problem (Bentley 1985). It is another management input, and it is not free, at least from a social if not client viewpoint. Too much information, like too much water, fertilizer, or pest protection, does not increase net value yields. In some cases, too much information may reduce yields by overwhelming or confusing clients. Consequently, agroforestry researchers must be conscious of the volume and cost of the information they produce.

Yield predictions for monocultures of trees and crops traditionally were modeled and estimated on a per-unit-area basis with assumptions of conventional management and inputs. Choices among inputs, especially spacing,

fertilizer, water, and genotypes, have become more complex. Consequently, estimates of single plant yields under competition have been integrated into stand-level estimates of total and net biomass yield per hectare (Clutter et al. 1983). Single-plant models often prove much more cost-effective than traditional approaches.

Yield models need to account for allocation of net photosynthate among species (especially among annual crops, woody perennials, and fodder grasses) and allocation within species among plant parts (for example, seed, leaves, stems, and roots). To obtain such yield estimators as functions of managed inputs using conventional agronomic experiments is expensive. Cost efficient experimental designs and field-sampling designs must be integrated. Thus, methodological research on combining individual plant data and area data and on combining cross-sectional data and time series data to obtain accurate (unbiased) and precise (low variance) estimators of yield as a function of natural and farmer-controlled factors is a high priority for agroforestry.

Because agroforestry systems have by definition more components than either agriculture or forestry systems singly, agroforestry experimental designs are more complicated and experiments occupy larger field areas. Agroforestry systems usually include tree rotations of many years, so experiments can occupy space over a decade or more. These simple constraints have profound implications for the design and location of agroforestry experiments. The concepts of statistical and economic efficiency, as a consequence, are of great importance. New information costs money and other source resources, especially scientist time. The first goal is to minimize the cost of providing given information by research. The second goal is to ensure that the cost of new information is balanced by its value.

The many interacting components and the large areas required, particularly if conventional replicated-block field designs are used, makes agroforestry less suited to the classical experimental farm than annual crop research. The testing of mechanistic hypotheses on components of "real" systems in farmers' fields and their synthesis using ecosystem methods and logic not only saves time and money but has the added advantage of putting scientists and farmers in direct communication and cooperation (Gordon and Ghildyal 1986). When farmers' income and security are put at risk by experimental manipulations, however, farmers must be compensated for potential and actual losses. Nevertheless, this approach may be considerably cheaper than expanding experimental farms to accommodate all agroforestry research.

Regression models to test hypotheses about gradients and interfaces between crop components, with data obtained from samples of production agroforestry sites, may often be the experimental approach of greatest effectiveness. In many situations, however, conventional comparative "from bare ground" designs will be needed, for example, where no existing production systems present the comparisons sought. In these instances, an exceptional amount of thought should be given to how to extract maximum utility and data from what will surely be a large, relatively long-lived experiment. The integration of hypothesis testing is something to which foresters and agronomists have not yet given detailed thought, but to which they will as the cost of agroforestry experimentation of this kind becomes more obvious.

If sustainability is to be tested as a criterion for specific systems, then yields must be estimated far into the future. To do this will require the establishment

of measurement criteria for total mass and nutrient content over a vast range of plants and soils. It will also require the establishment of verification experiments that encompass many crop cycles. A network of these experiments, permanently in place across a sample of the landscapes upon which agroforestry is likely to be practiced, is necessary to accurately answer questions about sustainability (Bormann and Gordon 1989) and will be useful in improving equations for yield prediction.

CHAPTER 2

Agroforestry Problems

The purpose of agroforestry research is to help clients achieve their goals. The most obvious clients are farmers, especially resource-poor farm families in the tropical uplands and humid lowlands. Other clients include forestry and natural resource agencies, rural development authorities, village associations, and other groups that want to use agroforestry technologies to further organizational goals. Clients also include extension agencies and nongovernmental organizations that help farmers and organizations obtain new information and apply it.

GOALS OF AGROFORESTRY RESEARCH USERS

Those who prescribe agroforestry interventions and those who perform agroforestry activities are motivated by both social and economic goals, but prescribers are more often motivated by social motives, while farmers are more concerned with direct economic or financial goals.

Social Goals

Social goals include rural development, site productivity, watershed protection, and preservation.

Rural development

Increased incomes and employment are the economic objectives of rural development, but the social goals are usually broader and include considerations of equity. Provision of adequate nutrition, health, housing, and education for rural people, especially resource-poor families, requires a broader view. Increased income and employment are important means for achieving these social goals, but other means are necessary to improve livelihoods in contexts where many farm families practice subsistence agriculture and do not participate fully in the market economy.

Rural development has taken on a new importance as the migration to urban areas has increased. Social sustainability—the stability of social systems at a national level—requires sustainable rural development that encourages people to stay in rural areas and villages. Agroforestry is one of many means for improving the productivity of rural resources, especially those that can benefit rural poor people and improve their well-being relative to urban opportunities if they migrate.

Site productivity

In many developing nations, productivity per hectare is declining on land resources that are marginal for food production. High-productivity lands are affected by increased flooding or siltation of irrigation systems, and mismanagement of irrigation leads to soil salinization or alkalinization with consequent productivity losses. India, for example, has 266 million ha of rural lands:

	million ha
Cultivated (irrigated, rainfed)	143
Uncultivated (forest, range, other)	123

At least 100 million ha of uncultivated lands and over 50 million ha of cultivated lands are degraded, often seriously, by erosion or other soil-productivity losses. Such symptoms do not bode well for sustainable rural development.

Watershed improvement and other environment protection

The symptoms of reduced soil fertility are expressed by declines in water quality, especially increased turbidity and reduced soil and groundwater storage. Other environmental qualities such as increases in air temperature movement, reductions in wild animal populations, and losses of natural ecosystem and habitats frequently worsen as well.

From a social standpoint, these problems are interrelated. Miller et al. (1989) argue that the development and management of rural resources should pursue the general goals of sustainability, productivity, and equity. Agroforestry technologies and the related social and managerial systems for use of trees in agricultural contexts can contribute to each of these goals. Trees are not the only critical component of agroforestry systems, however, and agroforestry systems are not the only means of increasing sustainability, productivity, or equity. Application of agroforestry research can make the biggest possible contribution to rural development by concentrating on components and system designs that contribute to achieving these three social objectives.

Economic Goals

Farmers are particularly motivated by economic incentives, and the economic condition of farmers has well-known social effects on those around them and those dependent upon them. Economic goals include:

Increasing net income

Livelihoods can be improved by production of wood, fruit, and fodder either for sale or for increased subsistence use within the family. Also, incomes are increased by greater yields through more efficient use of site resources.

Reducing risks

Included is market flexibility through a greater variety and a more continuous flow of products, as well as income stability over market and weather cycles.

Improving environmental services

Crop protection and an improved farmstead work environment (for example, windbreaks and shade trees) are valuable; rehabilitation of degraded lands and protection of lands have both direct and indirect economic value.

Accumulation of wealth and savings

This may involve capital formation through accumulated tree growth or access to credit packages and other economic and social benefits established in rural developments programs.

Each of these goals can be measured in subsistence contexts. Crude but useful transformations are possible using opportunity costs. For example, the time allocated to a subsistence crop like fuelwood could be allocated to a cash crop like chickens. Labor value can be estimated by alternative uses of time that produce cash wages.

CLIENTS AND RESEARCH

Applied research problems are best defined according to the clients' needs for information. This requires the researcher to understand the clients' problems.

Problem Definition

Economic, social, and other goals are adopted by public and private agencies seeking rural changes, as well as by individual farmers. The goals become site-specific objectives when they are modified for a specific place, time, and pool of resources by a specific person or group. These specific objectives, and the individuals or groups that have them, are the beginning point for preparing agroforestry prescriptions and the research that supports them. Ackoff (1962) and Stoltenberg et al. (1970) define a problem as having five elements. All five must be explicitly and specifically described if the problem so defined is to be the basis for an agroforestry prescription or research project.

The client

The client is one or more people who must make one or more decisions involving agroforestry. They are the direct users of agroforestry information and materials and, thus, are direct recipients of the outcome of agroforestry research. Unless at least one such real individual can be identified, the research or prescription that follows is not based on a client's needs.

The client's objective

The client must wish to achieve an explicit objective as a result of decisions made. An objective must be clearly and, if possible, quantitatively stated to enable all concerned to measure the degree of achievement. Clients may, of course, have several objectives. If several are presented, they should be ranked by priority. Often several objectives can be synthesized, fusing cost and revenue estimates into a net-revenue or

profit-maximizing goal. Some objectives can be stated as constraints; for example, a family-level requirement for kilocalories of subsistence food constrains the resources available for agroforestry practices. Such constraints also can be expressed as risk aversion. Farmers often perceive that new technologies entail risks of not meeting basic food or cash requirements.

Alternatives to reach the objective

Usually there are several ways to approach a single objective. If only one choice exists, there is no decision problem. Often, the choices farmers must make are both critical to their survival and can be irreversible from a social viewpoint. Helping clients by giving them better information as they choose among alternatives is a primary role of agroforestry research.

Doubt

If there is no uncertainty on the client's part — or if there is truly only one way to approach the objective — then research and practice can do little to help in the short term. The development of new and better alternatives, especially where there are currently none, is a major research role. Another role of research is to reduce the uncertainty and risks associated with predicted responses to inputs. For example, better estimates of tree growth on farmers' fields enables more rational choices about using agroforestry systems.

Context

The client, the client's objectives, and the pursuit of these objectives occur in a specific location and social context. These must be described in a completely defined problem statement. This description must locate ecosystem boundaries and specify the system components most closely related to the objective. Similarly it must describe the human dimensions of the problem.

Scientific research may be needed to define any or all of the five elements; to enlarge the number of options; or to compare the biological, economic, or social consequences of alternative pathways. Human medicine increasingly focuses on maintenance and improvement of health rather than solely on treatment of disease. Agroforestry prescriptions and research, in the same sense, should focus on the creation and pursuit of opportunity rather than solely on the solution of existing problems. Raintree (1986) characterizes the general attributes of healthy land as productivity, sustainability, and adoptability; and Miller et al. (1989) argue for productivity, sustainability, and equity as the central values or objectives of rural development. Unused systems — those not adopted by clients — cannot maintain or improve the health of the land. Healthy land-use systems are those that meet the objectives of those who live on and from the land.

Diagnosis and Prescription

To continue the metaphor, Raintree (1986) has compared the process of problem definition in agroforestry diagnosis to the practice of medicine:

> The ultimate practical aim is to develop agroforestry land management systems and technologies with specific capabilities to solve land management problems in areas where agroforestry is deemed to have a role. When confronted with an ailing land use system, the task facing agroforestry planners and practitioners is to identify and prescribe relevant treatments. The nature of the task is analogous in many respects to that of the medical practitioner confronted with an ailing human organism.

Prescription follows diagnosis. Based on scientific knowledge, both diagnostics and prescriptions are improved by the use of verifiable information derived from scientific research. Scientific research on agroforestry may originate solely from the curiosity and speculation of a scientist far removed from agroforestry considerations, or it may be directly based on site-specific objectives of the clients and the problems they define. Regardless of its source, research produces information that is applied as a prescription made by a practitioner. If the client likes the results — if the stated objectives are achieved — the research is worthwhile.

Distribution of Research Results

How client information finds its way to researchers and how research information finds its way to clients can be described as a system that serves the client, who has the problem or opportunity; the practitioner, who diagnoses and prescribes for the client; and the researcher, who provides new information to support diagnosis and prescription.

A farmer or landowner can assume all three roles, or a vast chain of institutions, organizations, and individuals can share the roles. The isolated farmer revising or changing cropping patterns and products is an example of an individual performing all three roles. The agroforestry network under the auspices of the Indian Council on Agricultural Research, a U.S. land-grant university, and the state cooperative extension service are examples of large systems that serve groups of farmers and other landowners.

Integration

The successful pursuit of agroforestry research begins with clients and careful problem definition. It is critical for the researcher to be initially and continually sensitive to the client, regardless of the organizational layers between them. Innovative hypotheses frequently derive from observation of practical systems and their practitioners, especially farmers.

The history of science presents many instances in which major advances were precipitated from the observation of production processes. This is true of biology, agriculture, and engineering and has often occurred in physics and chemistry. Thus, Freunhofer described emission spectra of elements based on observations of furnaces used in glassmaking; and Sadi Carnot, an engineer, developed the best quantitative statement in his time of the second law of thermodynamics based on his experience with steam

engines. An approach for structuring such interactions and integration through systematic inquiry — asking the right questions in the right order — is outlined in the next chapter.

CHAPTER 3

Developing Programs of Research

The development and implementation of agroforestry research programs requires leadership and organization. These are the essential characteristics of good management. Agroforestry research management is leading and organizing program development, implementing studies, and synthesizing results into information that is useful to clients. Effective programs of applied research are based on the use of careful scientific method and directed to clients' information needs.

PROGRAM DEVELOPMENT

Effective programs of applied research use the knowledge base to formulate hypotheses, test them, and reassemble the results of the tests into information needed by clients. Program development requires research managers to lead in the development and organization of ideas; program implementation requires research managers to lead in organizing resources—people, funds, and facilities. The resources devoted to agroforestry research should respond to the questions posed. All too often, applied research programs are driven by the available research capacity rather than client needs. From an overall management viewpoint, the research system should set priorities for solving problems and allocate its resources toward the highest-priority problems.

A system driven by clients' needs is easiest to visualize when no research establishment exists and no people, funds, or facilities are devoted to answering research questions. Development of a research program defines the information needed, the ideas available, and the hypotheses and studies required to answer critical questions. The program of research then defines the resources needed for the research. Even if a set of resources exists, however, the resources should change over time in response to changes in the needs of clients (figure 3.1). Figure 3.2 is a simple schematic of a program development model.

The relationships among these elements, as well as the specifics of each element, are described in more detail in table 3.1. Information needs of clients define what is relevant in the body or knowledge of science. Scientific method defines what can be researched, what hypotheses can be tested, and what agroforestry phenomena can be estimated or predicted. The clients determine the value of information; the researchers determine the cost of information.

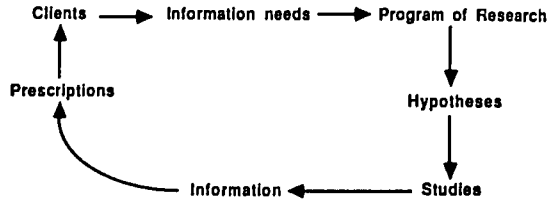

Figure 3.1: A client-oriented research system

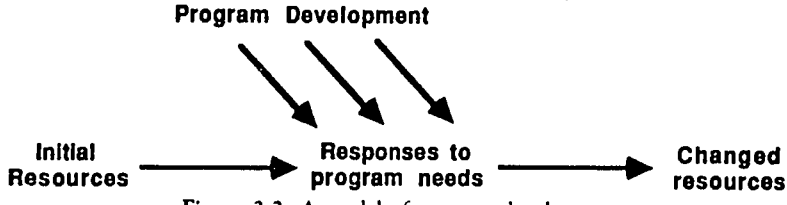

Figure 3.2: A model of program development

Table 3.1. Key elements of an agroforestry research program

Clients and their systems
- description and understanding problems of clients
- field observations structured to lead to hypotheses and tested information to solve problems
- valuation of new or improved information

Theory and previous empirical work
- body of concepts or principles
- results that are transferable or sufficiently generalized to be continually tested and refined
- assumptions or working hypotheses

Data, information, and understanding
- variables defined in measurable terms
- hypotheses and models as structures for understanding
- keys—thinking and testing
- logic as a test
- observations as a test

Research programs as information needed by clients
- client problems
- information needed to solve client problems

Generation of hypotheses restated
- compare and contrast method
- theory and literature method
- initial test—how well it explains what is observed

Studies
- objectives/hypotheses testing
- methodology choices
- information value as a criterion
- cost of research as a criterion
- simplicity as a criterion
- interpretation/understanding as a criterion
- expected results
- value to clients (versus cost of studies)

Interpretation
- new hypotheses/new studies
- useful information

Prescriptions and clients
- client-specific prescriptions
- based on initial and continuing diagnostics
- actions by the client
- results monitored as part of the agroforestry research program

CLIENT PARTICIPATION

The first crucial step in the research process is the flow of information and ideas from clients and their world to those who provide agroforestry prescriptions and research. Clients' use of research results actually begins with problem definition or diagnosis—in other words, simultaneous to the research process itself. Since agroforestry is both a complex and a new field of scientific research, the problem definition and information transfer tasks necessary to all good applied research become particularly critical.

Agroforestry problem analysis itself requires research. In every situation, the ultimate usefulness and rate of adoption of research results will be determined as much by the care and thought that precedes the design and conduct of experiments as the care and thought devoted to performing and describing experiments.

In agroforestry and other rural development fields, the problems and opportunities are often those of resource-poor people. For good reason, they may avoid risk and be particularly reluctant to change their traditional practices (Chambers 1983, Chambers et al. 1989). Also, clients with the most pressing problems may not have the most easily researchable problems; in fact, those with accessible problems or opportunities may overshadow the needs of the more obscure. In addition, those identified as clients may in fact be decision makers, and not the most appropriate ones. For example, most extension audiences traditionally have been male, but women may be the primary participants in agroforestry programs. If this is true, most of the costs and benefits of an agroforestry system affect women, not men. Such misidentification of the client group leads to poor problem formulation and poor transfer of research results.

Several attempts have been made to formalize the information-gathering process. Gordon and Avery (1985) described a set of essential concepts for the use of forestry in rural development that are equally applicable to agroforestry. The process known as diagnosis and design was devised to "serve as a reliable tool for arriving at effective and adoptable agroforestry solutions to local land use problems the world over" (Raintree 1986). Farming systems research methods generally begin with gathering information about clients (for example, see DeWalt 1988).

Written agroforestry prescriptions are not yet common, but they will rapidly become so. The design, rationale, and content of prescriptions is the central theme of this and the following chapter.

ESSENTIAL CONCEPTS

Nine essential concepts underlie the use of trees in rural development (Gordon and Avery 1985). Researchers can use them to define the context in which their clients live and to apply the ecosystem paradigm in their research. The nine concepts are divided into two groups: management and technology. They are adapted here for use in planning agroforestry research and transmitting the results.

The Management Concepts

Locality

The needs and desires of local people and their interactions with local resources determine the applicability of particular agroforestry practices and their usefulness in development. Reaching an operational definition of locality requires the following steps:

1) Define a geographic boundary and the human population size and diversity for the locality in which the agroforestry practices are to be applied (for example, the ecosystem).

2) Determine the development priorities and agroforestry and other relevant objectives of the people within the boundary.

3) Describe political, economic, and social facts and trends that may support or block pursuit of these objectives.

Inventory

Vegetation, soil, and climate information supports ecosystem estimates of potential and actual agroforestry production on sites within the locality. An information-gathering inventory should:

1) Relate kind and quality of inventory information needed to objectives.

2) Define ecosystem components.

3) Choose data sources and measurement methods.

4) Perform the inventory.

5) Interpret and present results to clients, practitioners, and researchers.

Socioeconomics

Economic and social profitability determines which agroforestry practices people will adopt. Therefore, quantitative economic methods allow agroforestry practices to be compared and related to larger development objectives using the following steps:

1) Define alternative ways to reach development objectives.

2) Specify constraints.

3) Choose quantitative methods and gather data.

4) Compare alternatives subject to constraints.

5) Describe and analyze strengths and weaknesses for each alternative.

Policy

The legal and political context in which agroforestry is practiced shapes and limits its usefulness as a developmental tool. By changing rules, societies change what is possible, equitable, and profitable to achieve. A systematic understanding of the policy context requires that the researcher takes four steps:

1) Identify all administrative, legislative, and customary laws and policies directly bearing on agroforestry in the locality.

2) Identify laws and policies that bear on other land uses, particularly subsidies, taxes, and tenure.

3) Identify major political initiatives and trends and determine how they might affect agroforestry in the locality.

4) Describe rights of access to resources and products as they are allocated by law, policy, and custom within the locality.

Control

The quantitative monitoring of production systems and the human and animal populations related to them is necessary to evaluate progress toward goals and to anticipate and solve problems. To establish these controls, the researcher should:

1) Choose quantitative measures for each development objective.

2) Select monitoring techniques consistent with original inventory and the necessary level of precision.

3) Choose a measurement interval that will reveal anticipated rates of change.

4) Monitor and use the data to direct action toward development goals or to modify goals that are shown to be unrealistic or unobtainable.

The Technology Concepts

Ecosystems

Understanding mass and energy flows through localities provides the basis for sustainable development by demonstrating that all components can interact. Explicitly connecting inputs and outputs allows calculation of efficiency and its improvement. The steps for defining ecosystems are as follows:

1) Define the ecosystem boundary, which is often the same as the locality boundary.

2) Describe the mass and energy flows that are most important in view of the development objectives.

3) Connect inputs with outputs by explicitly defined processes (looking particularly for unexpected or boundary interactions).

4) Calculate maximum and actual productivity.

Tree and crop culture

Biological and physical manipulation of plants, animals, microorganisms, soils, and microclimate underlies sustained production and provides investment opportunities that are environmentally sound. To determine the best system for each locality, the following steps should be taken:

1) Choose agroforestry systems that meet development objectives.

2) Display and discuss alternative practices and systems.

3) Select criteria for choice among systems derived from the development objectives and boundary conditions imposed by the locality, inventory, ecosystem, and socioeconomic constraints.

4) Choose, install, and monitor systems.

Sustainability

Sustained productive capacity at a given quantity and quality level is the result of the integrated use of site and biological resources. This requires quantitative estimates of nutrient, soil, and genetic losses from the system and their systematic replacement or enhancement as follows:

1) Choose measurement standards for a selected or existing productive capacity.

2) Monitor productive capacity and gains and losses in system components.

3) Replace what is lost or add more for enhanced productivity with careful attention to interactions arising from additions.

These essential concepts are difficult to apply completely in any given development or agroforestry project. They should be considered as a template to determine where agroforestry development and research fit into any particular scheme for rural improvement and as a broad guideline for allocation of money and effort. Of greatest importance is the emphasis on considering and monitoring whole localities rather than single processes or products or efforts of single disciplines to understand them.

DIAGNOSIS AND DESIGN

Diagnosis and design concepts have been extensively analyzed and reviewed in numerous publications by ICRAF (Raintree 1986) and others (for example, Miller et al. 1989). These concepts treat the constraints and potentials of existing land-use systems and candidate agroforestry technologies in a six-step analytical sequence:

1) Characterize the essential features of structure and function in existing land-use systems and identify output subsystems.

2) Evaluate the performance of the subsystems, identifying problems defined by gaps between potential and actual performance.

3) Determine what constraints limit the performance of the subsystems—for example, land resources, investment capital, time, technologies, tenure, and information.

4) Identify general areas for potential interventions that will remove constraints and improve performance; are some of these of an agroforestry nature (candidate technologies)?

5) Determine constraints that modify the appropriateness of candidate agroforestry technologies (components and practices).

6) Identify remaining potentials for specific agroforestry technologies that exist or could be developed.

The diagnosis and design process leads to alternative solutions, provides for their testing on-farm, and develops new systems at experiment stations. Although the need for research addressing the basic mechanisms underlying agroforestry is not explicitly treated, the examination of existing and potential systems will help identify those components in greatest need of better understanding.

DEVELOPING HYPOTHESES

The scientific method is in essence the development and objective testing of hypotheses. Volumes 2 and 3 in this series deal explicitly with the bodies of biophysical and social science theory and hypotheses commonly useful in agroforestry research (Avery et al. 1990, Burch 1990). Journal articles (for example, *Agroforestry Systems*) research station publications, and many other books are useful sources of new methods.

Although central to applied science, the development of hypotheses often is not treated explicitly in academic courses or literature. Agroforestry requires a combination of field observation and theoretical review to generate useful hypotheses. This combination is required for several reasons. Client problems define information needs, and without field observations, we do not know what information is needed. Also, existing farming systems provide a wealth of information that can lead to useful hypotheses.

On the other hand, the observed complexity requires some framework to interpret and transform conclusions into hypotheses. Theory or working hypotheses are the results of past research that is relevant and useful. By theory, we mean general principles that have been tested and are reasonably portable, that is, they are applicable over a range of ecotypes or agroclimatic zones, social settings, or time periods.

Because the techniques are different in method if not in principle, we discuss in sequence field analysis, theory, and their integration. We start with the clients, their perspectives, and the social purposes of trees in rural development.

In the generic sense, problems are a deviation from our expectations. This is easiest to understand when we have a well-defined standard. For example, seedlings from a farm forestry nursery are dying. This is a symptom. What is causing the seedlings to die? Crops near trees in an agroforestry system are producing less usable yields. What is causing this symptom? The grasslands near a village are sparse, and sheet erosion and gulleying are observed. Why?

Action-oriented people and organizations usually respond to a symptom with corrective actions. This is appropriate only if the cause is obvious and the situation calls for routine action. A perscriptive approach to problem solving following limited diagnostics characterizes much of what action organizations like agricultural extension or forestry departments do. For example, seedlings are clipped at the top. Goats clip seedlings. We should protect the seedlings from goats. The assumption is that the diagnosis is correct. Recognition of stock combinations of symptoms, leading to perscriptive actions is the basis of much of professional training and service. Going directly from symptoms to perscribed actions works when the relationship between cause and effect is known and understood. It is not appropriate if we do not understand the causes of the symptoms we observe.

Diagnosis is the process of considering alternative causes of the symptoms. Identification of cause is critical. Protecting seedlings against goat browsing will not solve the problem if young children are cutting the tops for fuelwood. Reducing the edge effect between trees and crop plants will not solve the problem if the problem is due to a disease unrelated to the proximity of crops and trees. The diagnostic process is called causal analysis by Miller et al. (1989). The causal analysis framework asks questions about the reality of the symptoms. The framework of questions enables applied scientists to gather data from reality and structure that data into information. By critically comparing the data about a symptom and its context, alternative ways of understanding reality and possible linkages between causes and symptoms can be generated. Causal analysis is nothing more or less than the scientific

method, but the focus is on application in situations of importance to specific clients who are concerned with specific actions and results.

The process of

HYPOTHESIS → TEST → HYPOTHESIS → TEST → ETC.

is familiar to all professionals as a simple statement of the scientific method. Most detailed discussions focus on methods of testing hypotheses, however, not the process of generating useful hypotheses. This discussion is concerned with generating hypotheses. The method

SYMPTOMS → DIAGNOSIS → HYPOTHESIS → TEST → ACTION

is as old as science and often used in natural and social sciences. With a client-problem orientation, a method is needed to explore cause-and-effect relationships based on systematic inquiry into the empirical evidence at hand rather than paradigms, theory, or conventional wisdom. The emphasis on empirical reality links the intellectual frameworks used and keeps attention focused on problems of direct concern to agroforestry researchers. The process is based on structuring quantitative and qualitative data into information. By giving form to data, it becomes information about a problem. Data by itself has little meaning. When given form in terms of a problem and theory, information and knowledge are created. Knowledge is understanding the causes of observed symptoms in the context of actual problems.

Asking Questions

The basic question is, "What is causing this symptom?" The causal analysis structure asks a sequence of systematic question to identify possible causes:

1) What is (are) the symptom(s)?
2) What is (are) not the symptom(s)?
3) Where is the symptom?
4) Where is not the symptom?
5) When is the symptom observed?
6) When is the symptom not observed?
7) How frequent, how much, how often is the symptom observed?
8) How frequent, how much, how often is it not observed?

Each pair of questions—"what is" and "what is not"—leads to two additional questions:

9) What is the difference?
10) When was the difference first observed?

This series of ten questions can also be arranged in a tabular format as seen in figure 3.3.

The first eight questions are objective in nature. They can be answered by facts, which can be tested by repeated observation. This method of "compare and contrast" is the basic set of questions that underpin any major advancement in our scientific understanding of the biophysical and social worlds; it is the essence of objective inquiry about reality. This is the logic of experimental control, sampling, and comparative analysis. It is the root of "similarities and differences." What the framework does is organize and record the responses so that more of the information we have can be brought to bear on the comparisons being made.

	Are Symptoms?	Are Not Symptoms?	Difference? When?
What?			
Where			
When?			
How often?			
How much?			
Frequency?			

Figure 3.3: A schematic format for causal analysis

Answering Questions

We suggest the following steps for using the question format:

1) List—but do not discuss responses to the eight questions.
2) Discuss and revise observations to assure that the best information available is being used.
3) Avoid leaping to conclusions about the cause—stay away from hypothesizing until you are ready for it.
4) Make comparisons of similarities and differences.
5) List hypotheses—but do not discuss.
6) Discuss and refine hypotheses.
7) Conduct internal tests—are the first eight questions answered?
8) Conduct external tests.

The steps through making comparisons of similarities and differences require critical, comparative thinking. The first pairs of *what*, *where*, *when* and *how much* questions require objective responses, although they may be either quantitative or qualitative. That is, other observers must agree with the response given the same observation. As in any measure, quantitative or qualitative, the meaning of the measure is at issue. What does "seedlings are dead" mean? For the purpose of causal analysis, a symptom does not need to be defined absolutely, but it must have the same meaning each time it is used. You and other observers must agree on the meaning of the responses.

Sometimes it seems no information is appropriate or available for an objective response. One of the framework questions may not discriminate between symptom and nonsymptom. This in itself is vital information. For example, what if the cause of the symptom does not vary in time? If the response to the framework question is unknown, consideration should be given to obtaining the information. For example, if you are not sure if the symptoms changed over time, you can decide to gather more data. The

objective observations and the comparisons for differences lead to a subjective step—what hypothesis (or hypotheses) might explain the differences observed? The response to this question is subjective and creative. It can be asked and answered without an objective foundation. Indeed, hypotheses in scientific inquiry all too often are generated by using inadequate or outdated theory, opinion, bias, or the flashes of genius found in the romantic myth of science. In practical situations, ignoring reality and relying solely on subjective opinion about causal mechanisms generates false information and misunderstanding that leads to inappropriate decisions and operational plans. Attending to the empirical context of a problem increases the likelihood that the hypotheses generated will be plausible, at the very least that the known features of the problem will be explained.

Testing Hypotheses

The final step is testing the hypotheses. This is critical and objective. First, does it explain the initial eight observations? If not, a hypothesis probably can be rejected. Second, does it answer similar questions from a different population. This is the "experimental" test that characterizes most of science, perhaps to the point of dominating many disciplinary fields. As in any hypothesis testing, there is no proof, only rejection of the hypothesis. However, not being able to reject a hypothesis when tested in a context different from where it was generated increases the chance that the explanation does explain the symptom. It is better understanding we want—understanding upon which to base actions—not absolute truths.

The value of the information is in its use. It is important to work through the analysis before gathering additional information: the hypotheses created through a causal analysis process may be testable without additional information.

Separating the objective and subjective steps and separating the critical and creative elements leads to better answers. No formula exists for good thinking, but the framework and process steps do provide a basis for organizing information and bringing the information available to bear on the problem at hand. In causal analysis, there is a tendency to "jump to cause"—assuming that you know the underlying causal relationship. There are many reasons for this response, but we think the key is that perscriptive responses are very efficient.

The causal analysis framework forces us to use what we know to identify the most likely causes. The framework helps us to distinguish applicable from unimportant data. The rejection of easy explanations and conventional wisdom is part of the framework's merit. An explanation resulting from causal analysis has the attribute that it explains all that we know of the problem situation. In hypothesis testing, there is no proof, only disproof. Explanations from causal analysis, however, must explain the internal observations and explain external observations as well, so the explanation is as complete as possible given what we know.

When we use what we do know in explaining a symptom, we are less likely to blame, jump to conclusions, or assume that the answer is in hand.

Also, new and at times novel solutions often begin with understanding the problem context and causes more completely.

Just as the framework is no substitute for good thinking, a causal analysis based on scant data is less likely to yield hypotheses that will solve the problem than hypotheses based on adequate data. The degree of uncertainty in decision making effects the quality of the decision. Here too the quality of data effects the degree of understanding.

Data and information are not free, as we stated earlier. It costs money and time to gather data, put it into a framework that generates information, and finally convert it into knowledge for solving problems. Complete information is not possible. The test for justifying additional data are the questions, "how would it change the actions resulting from your analysis?" and "what are the potential values of these actions to your clients?"

The framework provides a means to assess the impact of additional data. It allows you to determine whether more or better data would lead to additional comparisons and hypotheses on the one hand, or to rejection of hypotheses on the other. You cannot reject a possible explanation without objective information.

CHAPTER 4

Written Study Plans

Some investigators contend that written plans for research are inconsistent with the creativity and flexibility that are necessary ingredients of high-quality science. For a few individuals this may be so. For most, however, the opposite is true.

The pain of preparing written plans can be eased by viewing them for what they really are—creative documents intended to aid rigorous thinking. Written study plans, if prepared not just to meet bureaucratic standards, actually expand opportunities for creativity. They allow the researcher to accumulate ideas so they can be easily recalled and reconsidered, and they allow formal review by colleagues that often adds new insights and syntheses. It is easier to be flexible—to change methods or directions—if you know in detail your previous methods and directions. Thus, one of the most important functions of written plans is to remind researchers of what they formerly thought. The final plan, when combined with results of analysis, is the first draft of the research report and eventual publication.

Written plans also have other practical benefits. They may be required where money or permission is needed from someone other than the individual or group doing the research. They usually save money; it is cheaper to make and correct mistakes on paper than in the laboratory or the field. Particularly in agroforestry research, carefully written plans are the principal means available to ensure continuity over the long time spans needed to answer important questions.

CONTENT

Written study plans vary greatly in their format and their intended audience; nevertheless, good plans share a common set of components. The following list describes the minimum set each study plan should contain. These components provide continuity if the investigator is unable to carry out the planned research personally; they permit review before actual implementation and evaluation during the research process and after completion; and they are a protocol for all concerned with the study.

Title

The title summarizes the objective(s) and alerts the reader to the question posed and answered on completion of research and to what potential changes might result.

Author and date

All plans are written by people and usually several drafts are required. Because their purpose is communication, readers need to know with whom to communicate. The date differentiates among drafts and provides a historical record in the study files.

Abstract

A brief exposition should concentrate on why the research is to be done; what hypothesis is to be tested and how; and what expertise, time, and money are to be allocated. It rarely should be more than a typewritten page; in a typical plan of 25 to 40 pages, this is two to three percent of the length of the full plan.

Problem/opportunity statement

A study plan must have a section that clearly tells why the research is being done and describes the context of the research, the genesis of the ideas on which it is based, and the intended direction. The most critical elements are (1) the clients for whose use research results are intended, (2) their problems from their own perspectives, (3) the information gaps and consequent value of new or improved information, and (4) the researchable questions. It presents the most relevant findings from the literature, and it describes the five client-oriented attributes that define the problem at hand, including how these were ascertained (for example, field-farm visits or structured interviews with farmers and extension agents.)

Objective(s)

The objective is the intended outcome of the research—the kinds of answers expected for the researchable questions. Usually, the objective is presented as a hypothesis to be tested, along with alternative hypotheses and alternative effects of either supporting or rejecting the hypothesis. A good objective describes tests of achievement and indicates the scope (time and money) of the effort needed to achieve it.

Mechanistic hypothesis

Mechanistic hypotheses are structured guesses about what will happen if certain carefully defined conditions are met. They explain why the described outcome will occur—the causal mechanisms. The causal mechanism is important for two reasons: it establishes a basis for the expectation, and it facilitates interpretation and further experimentation after the test has been conducted.

Variables and sources of variation

The attributes or factors of experimental and sampling systems must be classified into independent and dependent variables. In a simple equation, the independent variables are causal factors and the dependent variable is the symptom or effect. A discussion of how variables are recognized and chosen and how they will be measured or controlled provides understanding of the logic of the hypothesis and its test. This is

especially critical in agroforestry research, where often the theoretical factors cannot be measured directly and proxy variables are used. For example, stem diameter and height are measured to estimate stem volume.

Study design and analysis

A study plan should describe the statistical or other models to be used in synthesizing and interpreting data from the study. Detailed analytical procedures, including statistical tests, are presented and possible results outlined.

Methods and operations

The methods must be described or referenced in sufficient detail so that someone other than the author of the plan can carry out the study. If a field study is planned, the layout must be completely described and mapped, including detailed location information.

Reports

To whom the results are directed and how they are transmitted should be outlined so that results can be reported in the absence of the author of the plan. This section should list formal reports to the research institution, peer-reviewed and other research publications expected, and means for transferring results back to clients.

Activity and responsibility schedule

Expected achievements and expected dates of accomplishment should be listed, including the timing of all research operations and who is responsible for completing and reporting each operation.

Budget

The budget should include all resources (money and materials) needed to achieve the objective(s) of the study, their sources, and a schedule of expenditures. The items must include people, supplies, travel, equipment, services, other direct costs, indirect costs, and other appropriate costs (for example, subcontracts).

Literature cited

All citations of published material necessary to understand the problem, objective, and method are included in the literature review, but it ordinarily stops well short of an exhaustive review or a seminal discussion of the conceptual issues at hand. The literature review is the previous written work directly relevant to the study objective, hypothesis, and methodology.

THE WRITING

Writing a study plan may take a few days or weeks. The thought that precedes the writing and the actions that follow may take years or even decades. Indeed, writing down the plan is a small portion of a continuum that includes (1) prior research, thought, and discussion with clients, extension agents, and research peers; (2) field and laboratory research

activities; (3) publication and extension of the results and conclusions; and (4) evaluation of the results and conclusions by others. The study plan is an early draft of the final publication, to which must be added data, analytical results, and conclusions.

The Title

To begin writing the plan, write the title. Titles, as the component list indicates, are concise indications of outcome. Study plan titles are often stated as questions, but this is not required. Titles do have to be clear, specific, and to the point if they are to fulfill their functions of (1) selecting the audience; (2) containing the key words that will lead to proper indexing; and (3) making ideas understandable and attractive to readers. Titles should be specific, not general; active, not passive; and only long enough to include all necessary information.

Problem Statement

After writing the title, prepare the problem or opportunity statement. The problem or opportunity is the reason you propose to do the research. The reason may be a gap in existing scientific information, or it may be satisfying a need for information that farmers or others may have. In either case, one of two methods may be used to describe the problem. If you have difficulty in writing the title, write the problem statement first to clarify your thinking.

One mechanism for systemizing your understanding of client problems is to use a simple matrix such as figure 4.1 (Miller et al. 1989). Objectives and constraints can be listed as criteria on one side of the matrix. This listing is most useful if the criteria are ranked from most important to least important from a client's perspective. On the other side of the matrix are alternative land-use technologies for a particular situation.

	Land-use Technology Alternatives				
Criteria	A	B	C	D	E
1	X_{1A}	X_{1B}	X_{1C}	X_{1D}	X_{1E}
2	X_{2A}	X_{2B}	X_{2C}	X_{2D}	X_{2E}
3	X_{3A}	X_{3B}	X_{3C}	X_{3D}	X_{3E}
4	X_{4A}	X_{4B}	X_{4C}	X_{4D}	X_{4E}
5	X_{5A}	X_{5B}	X_{5C}	X_{5D}	X_{5E}

The Xs are response estimates of the alternatives in terms of the criteria.

Figure 4.1: A decision matrix

Our matrix brings together what we know about the problem and what we do not know. If only one criterion is listed, it is a symptom that we do not know much about our clients and ought to spend more time with them. If we have only one alternative, this also may reflect a lack of field observation, or it may reflect the relative newness of agroforestry technologies. Missing Xs represent gaps in information. Imprecise Xs represent opportunities to improve information quality.

If we start with only alternatives A, B, and C, then D and E represent new designs. We develop new designs to better achieve our client's objectives or meet their constraints. For example, alternative D might produce higher agroforestry yields and alternative E might produce more food crops while the agroforestry system is developing. Our new designs might lead us to an as-yet undefined alternative F that does both.

This approach to structuring our client's problem can be diagrammed using a conventional agronomic or forestry yield relationship (figure 4.2).

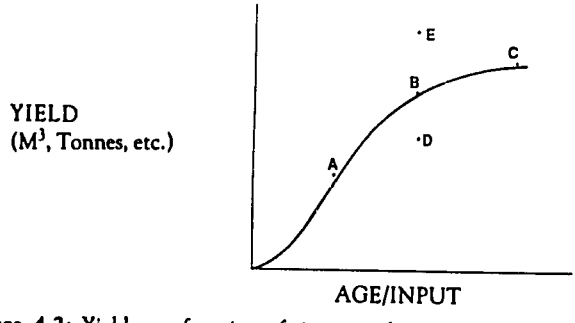

Figure 4.2: Yield as a function of time or other inputs (for example, fertilizer, water, labor for spacing)

The yield curve represents efficient alternatives; for the given level of inputs, the maximum useful agroforestry output levels are achieved. This represents a set of choices (points A, B, C) that can be presented to a farmer as alternatives in terms of output objectives and input constraints. Calibration of such choices, in the sense of estimating responses to known alternatives, is a useful baseline activity in agroforestry research.

Choice D is not an efficient alternative, and it is not a useful prescription. However, as we will discuss later, field observations often identify behavior like alternative D. Why are farmers doing this? This is the critical diagnostic question. Until the causal forces are understood for what appears to be irrational behavior, research cannot help. A good initial hypothesis is that farmers are not being irrational; we simply do not understand their behavior.

Choice E is not currently a technical possibility. It is, however, a design goal. Effective applied research, which represents the creative integration of theory and practice, is designing new and more efficient alternatives.

Some specific decision matrices illustrate this approach to structuring client's problems. Table 4.1 is for upland farms in the lower hills of India. Four alternatives are going to be considered. The first alternative is the best of current practices in terms of soil and water conservation. The other three alternatives are modifications that are perennial plants rather than mechanical barriers (*bunds*, or small dikes) to stabilize soil and slow surface water runoff.

The criteria are deliberately "open" in nature. Food, for example, can be a complete listing of crop yields on a per hectare basis. Income can include barter; it might also include subsistence produce like fodder and fuelwood. Risk can be a simple measure, such as the chance of not

Table 4.1. Indian agroforestry on private upland marginal farms

	Alternatives			
Criteria	A	B	C	D
Food				
Income				
Risk		Matrix of response estimates		
Input cost				
Sustainability				

Alternatives:
A: Cereal grains and pulses with *bund* terraces to control water and soil erosion
B: Same as above with Leucaena hedge row on *bunds* for fuelwood, fodder, and soil stability
C: Same as A but with perennial grass (for example, vetifer) on bunds for fodder and soil stability
D: Mixed contour alleys for cereals, grasses, mixed tree species, and legumes with rotation of cereals, legumes, and grasses

producing the minimum amount of food required by the family unit. Cost is straightforward in terms of cash requirements, but labor requirements during the busiest crop season may be the critical cost. Sustainability includes measures of expected change in productivity from year to year. These may be direct—for example, total net biomass/ha/year—or indirect—depth of organic soil horizons or surface water runoff/ha.

The Java case (table 4.2) is a similar illustration, using a *taungya* system on public forest lands. The current situation is like point D in figure 4.2—the results are inefficient. Farmers are not producing enough food, and the public forests are not being reforested. In some cases this situation has lasted for years and even decades.

Table 4.2. Example of Java social forestry on public lands

	Alternatives		
Criteria	A	B	C
Food			
Reforestation			
Tenure		Matrix of response estimates	
Other risk factors			
Input costs			

Alternatives:
A: Close spacing of timber species (mainly teak)
B: Wide spacing of same timber species
C: Mixed spacing including fruit and fodder trees

The criteria again are open. The top two criteria represent the primary objectives of the two critical client groups, associations of farmers and the public forestry corporation. Tenure and other risk factors indicate the social sustainability of a particular technology. In later research, criteria may be defined separately for each client group because they face different, albeit connected, problems.

The alternatives vary from the current standards (A) to a very flexible approach that favors farmer needs. On paper, alternative A best satisfies the forestry agency objectives. This logical conclusion, however, assumes that it adequately serves farmer needs. This assumption will be tested as a working hypothesis by posing another alternative hypothesis—effective reforestation only occurs (or occurs more frequently) when the agroforestry system produces more food and other products desired by farmers and produces them for a longer period of time before the forest canopy closes and cuts off light to farmers' crops.

In both cases, two points are worth noting. First, the initial set of alternatives considered are probably limited to what has been observed in practice or can be easily designed, but these alternatives provide a basis for understanding the biophysical and social context. Second, the initial set of alternatives are a springboard to designing or refining yet better alternatives.

The first research step in these problems is to gather what is known about the response of each alternative in terms of each criterion. The information may be qualitative or it may be quite precise and quantitative. Missing information and poor quality information provides one set of research agenda items.

The client-oriented method contains the five elements of a researchable problem:

- The client or decision maker
- The client's/decision maker's objective(s)
- Options or alternative ways of achieving the objective(s)
- Doubt about which pathway to choose
- The context or environment of the decision

Then the research proposed is described as an attempt, through better information, to modify or improve one or more of the five. Frequently, agroforestry research is done to remove or reduce doubt about which alternative produces the best economic or social return.

The second method, gap-in-knowledge, asserts that a useful piece of information is missing, based on what is available in the literature or upon observation of practice. This is less useful for agroforestry research because the field is at an early stage of information development. The two methods usually converge as proof of the gap becomes more rigorous, since the gaps often limit choices in client-driven problems.

Objectives

The objectives of the research should be clearly stated in a distinct section of the study plan. As indicated, an objective can be stated as an hypothesis to be tested, with a clear explanation of what should follow if it is

supported or rejected. Ideally a study plan should have one objective, but if multiple objectives are presented they should be listed in order of priority. We make a distinction between programs of research and research studies in chapter 5 that helps research planners specify one study objective.

In the client driven model, the objective statement should relate the decision maker's objective to that of the research proposal. The two objectives are almost always different. The client's objective is usually an action step, for example, to plant more trees on arid lands to provide fuel and fodder. The researcher's objective is usually to provide information, for example, to identify fuel and fodder species that grow best on arid lands. Clarification and separation of client and research goals in the objective statement is crucial because the plan's objective is to tell the reader what the desired research outcome is.

The Mechanistic Hypothesis

The construction of a mechanistic hypothesis that can be proved or disproved by observation or experimentation is the primary creative act of science (Popper 1962). It is approached systematically, just as novel writing or oil painting are. Good hypotheses originate in, and capture in testable ways, insights gained from observation and thinking, reading, discussion with clients and peers, or other forms of communication. Systematically tracking responses to observations and ideas in a journal or a computer file is an aid to hypothesis formation.

The hypothesis itself comprises a prediction and a mechanistic explanation of why the prediction should be accurate. Once tested, the hypothesis provides a causal explanation of why the result predicted happens (the dependent variable) in reference to the causal forces (the independent variables). Usually the mechanistic explanation provides grounds for the test of the hypothesis and an initial explanation or interpretation of the eventual results of the hypothesis test.

Hypotheses that are novel and subject to direct test are preferable to those that are old or subject only to indirect testing. New hypotheses that are directly testable yield clearer results, usually at lower cost. Old hypotheses usually have already been tested and reported. Although confirmation through repetition is important, new hypotheses that are modifications or extensions of older ones yield new information, as well as confirmation, when tested. Indirect tests of hypotheses often are more costly because they require more measurements and because they are less likely to yield an unequivocal result.

An example is testing the hypothesis that biological nitrogen fixation is occurring in a system and therefore may be sustaining productivity. Several approaches may be taken—and more than one usually should be—but direct verification of nodulation and nitrogenase activity will be cheaper and more certain than measuring soil nitrogen accretion.

Many researchers form two or more hypotheses in relation to a single problem. If these alternative hypotheses can be tested by a single experiment that clearly shows one or more to be incorrect, knowledge is advanced more rapidly and economically. This general method has been termed *strong inference* (Platt 1964).

A good objective statement, in addition to the presentation of mechanistic hypotheses, will

state an intended outcome;
contain internal criteria for assessing accomplishment;
contain minimal statement of method;
indicate the time and money needed to achieve it;
be concise;
be realistic;
be as unitary and specific as possible.

The construction of the remainder of the plan flows from the title, problem statement, objective statement, and mechanistic hypothesis. All decisions regarding the choice of variables, design of experiments, analysis of results, scheduling of activities and components of the budget, and reporting of results are conditioned by the problem and objectives. Until the problem and objectives are specified it is impossible to make rational decisions about the other plan components.

REVIEWS AND REVIEWING

Perhaps the most important step in the preparation of a written research plan is to obtain constructive review. Reviewing study plans is a difficult and often unrewarded task, so investigators must work diligently to select and encourage good reviewers.

Two kinds of reviewers are essential to maximize improvement of the plan: (1) scientific peers who understand the kinds of hypotheses and methods that the author describes, and (2) users of the kinds of research proposed. Only in the most basic studies will both kinds of reviewers be drawn from the same group. Peer reviewers should be chosen from those pursuing similar studies but who are independent enough to be honestly critical. If the study pursues a particularly controversial hypothesis or uses controversial methods, the reviewers should include those most likely to object. This is a difficult requirement for most researchers to face, but is a "must" for new departures.

Often the user reviewer is a manager, practitioner, or farmer. Although the reviewer may not be intimately familiar with the methods described, a user can comment on direction, access to specific members of the audience, and the usefulness of the research results. In agroforestry research, users can often usefully comment on location, logistics, and operations. Effective communication is critical. The researcher who "bullies" or otherwise intimidates users on intellectual grounds will not get useful reviews from clients or users.

All reviewers' comments should be taken seriously and should be either accepted or rejected only after careful thought. One of the major benefits of written plans is to avoid costly errors while there is still time. Thoughtful responses to a critical review is the chief method to avoid such errors. Ultimately, the plan and its outcome are the responsibility of the author, and it is clearly unethical to proceed with research for which the author cannot accept responsibility.

One of the best ways to encourage good review is to become a good reviewer of others' proposals. Reviewing is an art for which the basic principles are simple:

1) *Review quickly or not at all.* A good practice is to return the manuscript unreviewed if it cannot be accomplished in two weeks.

2) *Be constructive.* A reviewer's job is to help the author improve the plan. If suggestions for improvement are sarcastic or contemptuous, they are more likely to be ignored and the effort wasted.

3) *Be specific.* Precise instructions for needed changes should be given wherever possible, using examples and rewriting.

4) *Structure comments for ready use.* Usually a three-part presentation will suffice: general comments on direction, methods, and presentation; specific suggestions for improvement; and editorial or very specific comments about the manuscript.

5) *Use the list of components of written plans.* Check each plan reviewed.

As a recipient of reviews, recognize that the reviewer is always partially right. The problem may be misdiagnosed. Rather than your design being flawed, for example, your logic or explanation may not be complete or readily understandable. If a reviewer poses another way of looking at the problem, consider it, and at minimum state why you chose a different path.

CHAPTER 5

Implementing Agroforestry Research

A simple definition of management is to set goals and measure progress toward those goals. The primary management goal in agroforestry research is to derive useful prescriptions for farmers and related clients who use trees in an agricultural context. The research process may be simple and direct. A field diagnosis is made, an hypothesis is developed and tested by field observation, and prescriptions are developed and given to farmers. Or the research process may require several experiments and other methods for gathering data, analyzing it, and testing hypotheses. Several iterations may be necessary as possible paths are rejected. Regardless of the complexity of the process, the research manager is moving toward the goal of prescriptions.

Progress toward this goal can be measured by five benchmarks (figure 5.1):

1) An overall program concept is needed.

2) A written plan is required for each study. Study plans are more concrete than the overall research program, and the program concept will evolve as each study is designed and completed. The program concept is the research strategy in broad and general terms. The study plans are tactical and preferably narrow and specific. Keeping this distinction clearly in mind will accelerate the production of useful results from agroforestry research. At the same time, research strategies will evolve that give vision over long periods of time to direct specific studies toward specific and useful results.

3) The third benchmark is completed studies with scientifically interpreted results, the best indicator of which is publications such as internal reports, experiment station bulletins, and peer-refereed journal articles and monographs.

4) Outreach or extension materials. These include popular articles and manuals for extension personnel or farmers, but more important and useful are highly visual materials that may be used in the field. The IRRI rice production manuals are a good example, and examples are beginning to appear in agroforestry. The drawing or picture explains itself, and a few words of text can be in the local language.

5) Prescriptions for specific clients. If the extension materials are specific, the fourth and fifth benchmark may be the same. The desirable result is improved client practices, which means improved client well-being. This is the meaning of rural development.

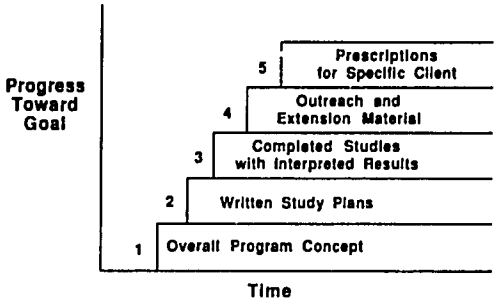

Figure 5.1: Benchmarks of progress toward the goal of agroforestry prescriptions

The key to effective prescriptions is scheduling and controlling research resources. Research programs and studies should determine the allocation of research resources—people, funds, and facilities, not the other way around.

MANAGEMENT OF PEOPLE AND MONEY

Research is an expensive activity. It is labour intensive; often over 80 percent of total direct budgets are salaries, wages, and associated benefits. Sophisticated equipment increasingly is critical to certain research tasks, and transportation and other field-crew logistics can require careful planning and management. Effective use of people and money requires good management.

Research study plans are critical tools for management. Once the hypotheses are selected and research designs developed, much of the research process is like managing any other operation. Unfortunately many researchers are not good managers. Unnecessary and often costly delays occur in field and laboratory implementation; data goes unanalyzed; manuscripts are not completed, edited, and submitted on time; budgets are exceeded or budget constraints prohibit proper completion of certain research phases. The starting point for avoiding poor performances is complete plans with detailed budgets.

Scheduling

Often called *action planning* (Miller et al. 1989), scheduling is familiar to all researchers. It is what Americans call a "to-do" list in simplest terms. What do I have to do today? Plans are a way of organizing research activities and action so results occur within a reasonable period of time. Research is not a process, however, where results can be as controlled as industrial processes that lead to accurate time specifications. Consequently, plans must be flexible and frequently updated.

At this level plans are most precise. The essential elements of a schedule of activities are:

what actions need to be taken
who is responsible for each action
when each action should be completed

To be useful as a research or management tool, a study plan must include a schedule of activities or tasks to be completed, those responsible, and dates for completion. Table 5.1 illustrates a simple study plan for establishing a multipurpose tree species (MPTS) trial, measuring the growth, and analyzing the results.

This kind of plan is used worldwide by industrial firms and many public agencies. Management according to such plans is often called *management by objective* or *goals and controls*. The plan is important because research managers control against it. If an activity or task is not completed on schedule, corrective action is taken. Either the results are brought into conformity with the plan or the plan is changed.

Table 5.1. A study plan for a multipurpose tree species trial

Step/activity	*When*	*Who/unit*
1. Select species to be tested	1/6/89*	Alim, Silviculture
2. Select site	1/7/89	Alim, Silviculture, Huk, agronomy, Khan, soils
3. Design trials	1/9/89	Rhaman, biometrics
4. Prepare site	1/12/89	
5. Obtain seed	1/12/89	Alim, silviculture
6. Raise seedlings	1/4/90	Ali, nursery
7. Transport seedlings to site	1/3/90	Alim, silviculture
8. Plant seedlings	1/5/90	Rao, farm management
9. Weed trials	quarterly	Rao, farm management
10. First year measurements	1/11/90	Alim, silviculture
11. Analysis of first-year results	1/2/91	Rhaman, biometrics
12. Interpretation of results and preparation of report	1/3/91	Alim, silviculture
13. Review of results and revision of study plans	1/4/91	Alim, silviculture, Huk, agronomy, Khan, soils

*As per the American style of writing, i.e. 1/6/89 to be read as January 6, 1989, and so on.

The planning process influences the likelihood of successful and timely completion of research. The principle investigator can do all the planning, make assignments of responsibilities to junior scientists or technicians, and then control results in terms of planned dates for completion of tasks. Research institutes and universities often are hierarchical, and this style of management generally is understood by all concerned.

However, more involvement by those who are responsible for specific activities and results usually leads to better plans, fewer failures to stay on schedule, and more effective corrections when needed. Everyone, regardless of role, has something to contribute to the research process. When they are asked to contribute, they do, and they become more committed to the quality of results and deadlines of schedule. In the jargon of management, they feel some ownership of the problem.

Participation in planning shifts the basis of leadership and authority from power—"I'm in charge and you will do what I tell you to do!"—to knowledge and expertise. The principal investigator has authority because of understanding the overall research problem, the specific hypotheses to be tested, and the research design and analytical steps to be used in testing. In a specific step, such as certain site preparation or laboratory analyses, someone else may know more or have higher skills. The quality

of the overall research results will be improved by including these people in the planning process. The tradeoff is sharing authority and shifting from power to knowledge as a basis for authority. An effective planning process is open, and all concerned can contribute. This process is used by many public and private research organizations.

An open planning process, however, is an ideal that can be approached by stages over several years. In highly structured organizations and societies, an open planning process cannot be established instantaneously. A starting point may be simply discussing and looking for ways to improve a plan developed by the senior investigator. After this becomes an established step, participants can be invited in earlier to help identify steps and sequences of research activities, better scheduling, and so forth. The target style of participatory planning may take several years to achieve.

Fuelwood Study Example

The components of a useful study plan were outlined in the previous chapter; here we focus on the connections between research programs, hypotheses, and studies. Suppose a hypothesis has been formulated that fuelwood prices are rising in response to scarcity in the area surrounding a small city. If the rise is rapid enough, planting fuelwood plantations may be an attractive investment for women's cooperatives in nearby villages. However, the attractiveness will be reduced if alternative supplies of inexpensive wood could be transported from more distant forested areas. This hypothesis, which is a bit complex, can be stated as a schematic model (see figure 5.2).

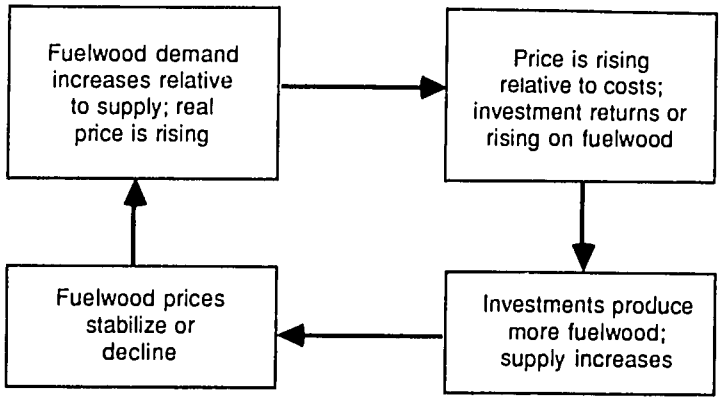

Figure 5.2: The simple dynamics of demand, price, investment and future supply of fuelwood

This model describes the objective of the clients, which is to make returns on their investments, and the factors that affect the returns. These refine into five general steps:

1) Estimate the growth and yield of fuelwood plantations on sites available to the women's cooperatives.

2) Gather and analyze data on fuelwood in the city market to test the hypothesis that it is rising and estimate the rate of change.

3) Investigate the supply alternatives and the likelihood each will be tapped in the future.

4) Investigate the structure of fuelwood markets and ascertain the accessibility of these markets by the women's cooperatives.

5) Investigate small timber markets, using the same methodology as step 1 for fuelwood.

Is this a single study or a group of five interrelated studies that makes up an agroforestry research subprogram or project? The answer depends on the context. If steps 2 through 5 can be done quickly as part of the diagnostics, then the focus is on the single hypothesis that women could make adequate returns on investments in fuelwood plantations. If steps 2 through 5 are complex and require time and detailed methodological steps, each is best treated as a separate study. The schedule is useful only if it is implemented. Implementation requires follow-through on each activity. Does the individual responsible understand the assignment? Does the researcher have the skills and resources needed? Once the research activity is started, are the activities and results on schedule? If not, why? Target dates can be changed. Activities can be redefined. But these changes are symptoms. If the symptoms are poor planning in the first place, then the research manager needs to learn how to plan better.

The critical elements of follow-through are (1) taking corrective action when planned activities are not completed on schedule, and (2) learning from experience. For example, problems that might occur in carrying out the study plan for estimating the growth and yield of village fuelwood plantations include first determining whether or not the desired range of ages and stand densities occur. Overcoming this difficulty may require integrating village fuelwood-production data with data from young commercial timber plantations or natural stands. A second problem might be that animal damage to fuelwood, a women's crop, is high because it is not considered valuable by men who manage the animals. This may require working with groups of men and women to create some effective demonstrations of the response of trees to protection from animal damage. Each of these problems, if considered beforehand, can be resolved.

Budgets

Budgets are plans converted into the required resources and funding by activity or line items. Budgets also constrain study plans and require changes to keep within fund allocations.

Budgeting is easiest to do by activity or task. For example, measuring village fuelwood stands may require six months of technician time and one month of professional supervision. In an Indian context, for example, this might require Rs 9,000 for salaries and wages and Rs 7,000 for additional benefits. In addition, Rs 10,000 is required for petrol and oil for a vehicle and Rs 5,000 for seedlings. These line items then can be summed by activity to get a line item budget for the year or total research project.

Budgeting can be helpful even in contexts where most of the research

costs are allocated by the appropriation and distribution processes of a central research authority. For example, an agroforestry research project may receive funding for:

1 senior scientist
2 junior scientists
3 technicians
1 secretary
3 general laborers
30 sq m office and lab space

Only other direct costs, like fuel or plant materials, require budget requests.

Nonetheless, the budgeting process can help set priorities and keep the focus on achieving more useful results from the available resources. Professional and technical people and the facilities themselves have opportunity costs because they can be used for other studies. Resources can be used (1) to produce few, if any, research results, (2) to produce many results of mediocre quality, (3) to produce a few high-quality results of value to the agroforestry research peer group, or (4) to produce a few high-quality results of value to clients. The only socially acceptable choice is between the last two possibilities. Indeed, the best applied research programs contribute to both the client's need for information and the body of useful scientific knowledge.

PRESCRIPTIONS

Written prescriptions contain sets of directions for carrying out agroforestry interventions. Prescriptions are important to researchers in two major ways: first, they are the specific means by which research findings are translated into action; second, they are closely akin to written research plans.

The notion of a written prescription carries with it the suggestion of bureaucracy. Formal prescriptions are obviously absurd in some situations, as where the clients who will follow the prescription cannot read. However, there are strong reasons for the use of written prescriptions wherever possible. These four reasons are similar to our arguments for written study plans:

1) Continuity is essential because those who start the process may not finish it.

2) Concise explanation of the intervention can be laid out for quick reference by critics or the merely curious.

3) A written document encourages clarity of thought and the possibility of thorough review.

4) Later evaluation is possible because the data upon which the prescription is based are available; indeed, comparison between prescription and result is a key to effective evaluation.

Structure of Prescriptions

A good prescription is written in plain language, is concise, and has a minimum of tables and graphs. It presents evidence of ecosystem sensitivity, data quality evaluation, and rational problem analysis. It

should clearly indicate the components of the problem and cell choices considered, not only the alternative prescribed. Without fail, it should include (1) an explicit action plan with dates and specific objectives and (2) a budget commensurate with those objectives.

A checklist for preparing or reviewing written agroforestry prescriptions includes:

1) *Contents*
   - context (opportunity/problem, environment)
   - objectives
   - alternatives for achieving objectives
   - criteria for choice among alternatives
   - operational prescription with schedules
   - forecast of effects
   - impact on context and environment
   - data and underlying concepts
2) *Rationale*
   - provides continuity
   - provides explanation and defense of activities
   - demonstrates clear thinking
   - demonstrates adequate data and use of concepts
3) *Organization*
   - begins with title, author, data, and abstract
   - as above under Contents
   - logistical framework shows operations, dates, and responsibilities
4) *Style*
   - brief and to the point
   - plain language, not jargon, to reach a wide audience
   - clear illustrations (tables, graphs, maps)
   - inclusion of only necessary data
5) *Characteristics*
   - ecosystem sensitivity
   - evidence of data quality and quality control
   - rational, objective problem analysis
   - explicit plan of action with dates and names

Relationships of Studies to Prescriptions

Studies generally are most effective if they test a single hypothesis or set of closely related but alternative hypotheses. This is the premise of chapter 4, on written study plans. The overall research program is required to identify the relevant hypotheses and rank them in importance for testing. Also, the program concept provides a more general framework for integrating or synthesizing study results.

In an hypothesis test, we obtain data that are given structure by the hypothesis itself. A sophisticated hypothesis often will be elegantly simple but produce considerable useful information. For example, the hypothesis that, in a given gently rolling landscape, alley width and

percentage of land allocated to trees affects total useful yields can be tested in various ways. A simple test simply asks if food yields are different with wider alleys of cereal crops and narrower alleys of tree crops. If an analysis of variance reveals significant differences among three different alley widths—and the differences are in the expected direction—we have not disproved our hypothesis, but we have not learned much either. In particular, we have not learned anything about useful yields of non-food crops—such as fodder, fuelwood, small timbers—and we canot predict the response of cereal or other yields to alley widths and overall land-use allocations.

A slightly more sophisticated test would look for significant differences in each of the useful products as caused by variations in alley width of cereals and of trees. A yet more useful set of results would be equations, for example:

Cereal yield/ha = $A_0 + A_1$ (Cereal alley width) + A_2 (Tree alley width)
Fodder yield/ha = $B_0 + B_1$ (Cereal alley width) + B_2 (Tree alley width)

and so forth for each desired product yield.

If the A and B coefficients are significantly greater than zero and the sign is what our theory and past observations lead us to expect, we reject the null hypothesis. Our test also produces a quantitative model instrument we can use to predict yield responses for managerial decisions. This predictive or response estimating information leads us directly to a basis for developing prescriptions.

Yet more sophisticated but simple equations can add generality to predictions. For example, rainfall and soil type may be significant over an agroclimatic zone. With this information, we might be able to develop prescriptions for farmers on a site-by-site basis.

OUTREACH AND EXTENSION

One last subject must be mentioned before closing this chapter on implementing agroforestry research and that is the extension program. While extension and outreach programs are not the subject of this book, they are sufficiently similar in objective and clientele to warrant a brief discussion.

The term extension, coined in late 19th century England, described education as external to the school system. Since then, however, this method of education has been directed specifically toward rural populations, primarily as a way to transmit agricultural production and management techniques to farmers. The U.S. cooperative extension system and variations on it have provided models for agricultural extension worldwide.

The objectives of extension are clear:

> The central objective of an agricultural extension service is to provide farm families with new knowledge and skills along those lines of their *current interest* and *need* which are closely related to *increasing farm production* and *improving the physical level of living* of farm families. (Mosher 1978).

Mosher also identified the principal components of extension programs.

These include clients, techniques, financial soundness, demonstration, teaching methods, timing, impact, and intensity of activities. Extension, therefore, ideally is a way of giving

> assistance to farmers to help them to identify and analyze their production problems and to become aware of the opportunities for improvement (Adams 1982).

The similarities between extension programs and the application of agroforestry research are clear. Both must depend on and be propelled by the needs of the primary client, the farmer.

However, classical extension, as used in the developed countries was based on "trickle-down" logic, conceptualized in an already modernized agricultural system. Improvements in production were discovered by research and passed down to farmer clients (Seepersad 1985). It is therefore not difficult to view the farmer as the recipient of research rather than as an initiator. This may explain why extension programs based on this system have unfortunately failed in developing countries. If these programs can be made to succeed, they will first have to reorient themselves to the needs of the farmers in the same ways we have enumerated for effective application of research in agroforestry in this chapter.

CHAPTER 6

Evaluation

Evaluation of agroforestry research ultimately rests on an assessment of the degree to which clients' objectives are met by the results of the research. The major tools in evaluation are identical to those used in the first information-gathering step. The cycle of diagnosis, prescription, research, prescription, and back to diagnosis leads to evaluation. The cycle is a continuous one in healthy systems on healthy landscapes.

However, other criteria for research evaluation must also be used because long periods of time usually elapse before results are effectively transmitted and it becomes clear whether clients' objectives will be met. One way to improve transmission techniques is to begin with effective listening and observation in the problem-definition stage at the outset of research.

The interim research-evaluation criteria (those applied before transmission of final results to clients) can be placed in two groups: (1) those internal to the research process that indicate whether the methods of science are being effectively applied and (2) those external to science that indicate whether the results of the research are likely to effectively reach clients.

INTERNAL CRITERIA

Internal criteria are chosen to expose the rigor of thought and action applied to a specific study or set of studies, regardless of their discipline or intended use. Thus, they are equally applicable to all kinds of agroforestry research and are founded on the same principles used in constructing written study plans (see chapters 4 and 5).

The following is a suggested set of questions to see whether internal criteria are met:

- Is a mechanistic hypothesis explicitly presented?
- Is the hypothesis test proposed logically sound? Is it clear that at least one possible outcome of the experiment(s) will force rejection of the hypothesis?
- Are alternative hypotheses presented?
- Are controlled and uncontrolled sources of variation in experimental materials presented? How will they be measured and treated in the analysis?

- If the hypothesis test depends on statistical inference, is a model of the components of variation presented, along with the structure of the statistical tests to be conducted after data is collected?
- Is the objective of the experiment clear and commensurate with the experitise, time, and money allocated for its completion?
- Are the methods to be used clearly described and available to the researcher? Is it clear exactly where the research will be done?
- Is it clear to whom and how the results of the research will be reported?
- Has the literature been searched for supporting and precedent studies? Are five to ten citations included? (More may be indicative of "padding" rather than good scholarship.)

EXTERNAL CRITERIA

These criteria are chosen to estimate the likelihood that the results of the research will reach potential users and whether the potential users will become actual users. The following questions are suggested to determine whether or not external criteria have been met:

- Did the researcher and the clients both participate in the definition of the research problem?
- Is it clear why the research is being done?
- Is the pathway by which the results will reach users explicitly stated?
- Is the location of research commensurate with the characteristics and operations of the potential users?
- Can the researcher name at least one real client for the research? Do clients know of the research and where it is being done?
- Is the researcher free of administrative or public pressure to accept or reject specific hypotheses because of political or cultural reasons?
- Is the researcher free and encouraged to publish results openly in peer-reviewed journals?
- Is the researcher free and encouraged to participate in the transmission of results to clients in a variety of forms?
- Is the researcher rewarded, at least in part, based upon the degree to which his results are used by clients?

Both internal and external criteria can most easily be applied if written research plans exists, which is a strong reason for their use. The criteria can be applied to any research effort, however, through discussions with those responsible. They can also be used to evaluate completed and published research.

Although research can best be evaluated with the help of documents, documents should not serve as the entire basis for evaluation. Visits by evaluators to research sites and with clients are essential to a balanced evaluation. Conversations between evaluators and researchers, in circumstances that allow researchers to be candid about problems, are essential if improvement in future research is a desired consequence of the evaluation process.

Scientific research is creative thought followed by rigorous honesty. Any influence that constrains either creativity or honesty is counterproductive, but a good evaluation process is an excellent tool for identifying and correcting such problems.

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LITERATURE CITED

Ackoff, R. L. 1962. *Scientific Method*. John Wiley and Sons, New York.

Adams, M.E. 1982. *Agricultural Extension in Developing Countries*. Longman Group, Ltd., Harlow, UK. 108 p.

Avery, M.E., M.G.R. Cannell and C. Ong (eds.). 1990. *Biophysical Research for Asian Agroforestry*. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi. (In press).

Bentley, W.R. 1984. The uncultivated half of India: problems and possible solutions. Ford Foundation Discussion Paper 12. New Delhi. 30 p.

Bentley, W.R. 1985. Agroforestry: a strategy for research and action in India. Ford Foundation Discussion Paper 17. New Delhi. 8 p.

Bormann, B.T. and J.C. Gordon. 1989. Can intensively-managed forest ecosystems be self-sufficient in nitrogen? *Forest Ecology and Management* 28:1-10.

Burch, W.R. 1988. The uses of social science in the training of professional social foresters. *Journal on World Forestry and Research Management* 3:73-109.

Burch, W.R. (ed.). 1990. *Applications of Social Science Theory and Methods to Agroforestry Research*. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. (In press)

Clutter, J.L., J.C. Fortson, L.V. Pienaar, G.H. Brister and R.L. Bailey. 1983. *Timber Management: A Quantitative Approach*. John Wiley and Sons, New York. 335 p.

Chamberlain, T.C. 1980. The method of multiple working hypotheses. (reprinted in) *Science* 148: 754-759.

Chambers, R. 1983. *Rural Development, Putting the Last First*. Longman Scientific & Technical, Harlow, UK. 246 p.

Chambers, R., A. Pacey and L.A. Thrapp. 1989. *Farmer First: Farmer Innovation in Agricultural Research*.The Bootstrap Press, New York. 238 pages.

DeWalt, B.R. 1988. Halfway there: social science in agricultural development and the social science of agricultural development. *Human Organization* 47(4):343-353.

Gordon, J.C. and M.E. Avery. 1985 A prospectus for the video-assisted teaching of forestry as a tool for rural development, with special reference of India. Report to the Ford Foundation, New Delhi.

Gordon, J.C. and B.P. Ghildyal. 1986. Forestry research to help farmers: from mechanisms to markets. *Proceedings of the 18th IUFRO Congress*, Ljubljana, Yugoslavia. Sept. 7-16, 1986.

Gordon, J.C. 1975. The production potential of woody plants. *Iowa State Journal of Research*. 49: 267-274.

Huxley, P.A. (ed). 1986. A manual of methodology for the exploration of multipurpose trees (MPTSs). International Council for Research in Agroforestry, Nairobi.

King, K.F.S. 1987. The history of agroforestry. In: *Agroforestry: A Decade of Development*. H.A. Stepplen and P.K.R. Nair, eds. Nairobi: International Council for Research in Agroforestry. p. 3-11.

Likens, G.E. and F.H. Bormann. 1985. An ecosystem approach. In: *An Ecosystem Approach to Aquatic Ecology: Mirror Lake and Its Environment*. G.E. Likens, ed. Springer-Verlag, New York.

Miller, S., C. Shinn and W.R. Bentley. 1989. *The Long Run: Tools for Rural Action*. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. (In press).

Mosher, A.T. 1978. *An introduction to agricultural extension*. Agricultural Development Council, Inc., New York. 114 p.

Platt, J.R. 1964. Strong inference. *Science* 146:347-353.

Popper, K. 1962. *Conjections and Refutations*. Basic Books pp. 53-59.

Raintree, J.B. 1986. D & D user's manual: an introduction to agroforestry diagnosis and design. International Center for Research on Agroforestry. Nairobi. 110 p.

Seepersad, Joseph. 1985. Extension programming in developing countries—new direction. *Agricultural Admin*. 20:101-118.

Stoltenberg, C.H., K.D. Ware, R.J. Marty, R.D. Wray and J.D. Wellons. 1970. *Planning Research for Resource Decisions*.Iowa State University Press, Ames Iowa. 183 p.
Watson, D.J. 1952. The physiological basis of variation in yield. *Advanced Agronomy*. 4:101-45.

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SECTION 2

The Agroforestry Challenge in Asia

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Agriculture and forestry are two essential sectors in the economies of many developing countries. However, they face large social and economic problems due to the unabated and increasing need for food, fodder, energy, and lumber. These are the direct results of rapid population growth.

The consequence is that most of the accessible forest lands in Asia have already given way to agriculture and other forms of land use, creating a conflict between agricultural production and forest management and conservation. Adopting the alternative land-use technologies of agroforestry should be part of the solution.

The main objective of agroforestry is to optimize production and economic return per unit area, especially in rural communities, while respecting the principles of sustained-yield forestry and soil conservation. Although the term *agroforestry* conveys different meanings to people in different regions, the concepts are generally similar. Agroforestry combines modern science and ancient practice. It includes any sustainable land-use system that combines trees and agricultural production, including livestock, on the same unit of land, simultaneously or sequentially, taking into consideration the social and cultural practices of the local communities, the economic requirements of forests and agricultural crops, and the ecological status of the sites.

This system of land use can provide diversified raw materials (fodder, honey, fuelwood, food, meat, and wood products) and contribute stable employment in rural areas.

NEED FOR AGROFORESTRY TECHNOLOGIES

Many developing countries face several agricultural and ecological problems: exploitation of forest resources, soil degradation and loss, increasing population pressure, and insecurity of land tenure. Some of the most significant aspects of these problems are described below. Agroforestry systems and practices hold promise for meeting these challenges.

Exploitation of Forest Resources

For decades, forests of the world have been harvested, destroyed, and converted to other land uses. These practices are affecting food production, agricultural productivity, fuelwood and fodder supplies, soil fertility, quantity and quality of water resources, and germplasm and genetic-resource reserves.

Deforestation and excessive harvesting have been attributed to many factors, including:

- population growth resulting in continued demand for arable land, including land for shifting cultivation
- demand for fuelwood and fodder, involving illegal cutting and processing

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- unsustainable exploitation of forests for industrial timber production and export
- government policies regarding land tenure, economic incentives, forest settlement, infrastructural development, and other developmental issues

The Food and Agricultural Organization (FAO) of the UN (1983) reported a number of facts about and implications of currents trends in the status of the earth's forests:

- More than half of the world's tropical forests have disappeared since the turn of the century.
- The current rate of deforestation exceeds 11 million ha a year.
- More than one billion people are suffering from shortages of food and fodder.
- Developing countries' imports of forest products exceed US $ 10 billion.
- The destruction of tropical forests is resulting in widespread loss of unique ecosystems, directly contributing to the diminution of plant and animal genetic resources.
- More than half of the developing world's population lives in the 56 most critically affected countries.

East and South Asia have 232 million ha of closed forest that include a wide range of climatic conditions and forest types, especially in China and India (see table 1). Because human population in this region is denser than in many others, it has a low forest area per capita. Furthermore, most forests are not well located in relation to existing population centers.

Table 1. Forest areas in the major subregions of Asia, 1980 (millions of hectares)

Subregion	Land area	Natural Vegetation			
		Closed forest	Open forest	Forest fallow	Shrub
Continental SE Asia	190.3	65.9	18.0	34.9	4.5
East Asia	13.5	6.6	0.0	0.0	0.0
Insular SE Asia	244.0	144.4	3.0	25.7	23.9
China (PRC)	929.1	92.0	15.6	1.0	29.6
South Asia	478.2	61.1	6.6	11.0	6.9
Tropical Oceania	51.8	37.9	4.5	1.4	0.1
Total	1906.9	407.9	47.7	74.0	65.0

Source: ADB 1987.

In developing countries, 1.5 billion people depend on wood for cooking and heating. According to FAO (1984), in 1982 fuelwood contributed 53 percent of energy used in Africa, 16 percent in Asia and the Far East, and 16 percent in Latin America. The annual total consumption of fuelwood in developing countries is 1.38 billion cubic

meters. This constitutes more than 81 percent of the total roundwood production for 1983. In one country alone, the Philippines, 79 percent of households use fuelwood for cooking, and each family consumes an average of 4 cubic meters a year (Cabrido 1984). Based on this figure, Philippine fuelwood consumption was estimated to have reached 30.5 million cubic meters in 1984.

Fuelwood use increased 33 percent between 1970 and 1982 (UN, 1984) and FAO (1983) predicted that almost 3 billion people will experience fuelwood scarcity by the year 2000. In order to keep up with demand, the fuelwood committee of the government of India estimated in 1982 that at least 3 million ha will have to be planted each year in quick-yielding tree species up to the year 2000.

However, increasing food requirements, compounded by other agricultural needs, compete with forestry requirements by increasing demand for more agricultural land. FAO (1987a) estimates that even if crop yields on lands already cultivated were to increase by 72 percent, another 200 million ha will have to be cleared over the world in the next 15 years to meet food needs. Deforestation will be the probable result.

Soil Degradation and Loss

Much of the area in the tropics that is farmed by traditional methods, including land under shifting cultivation, has fragile soils or soils with special management needs: predominantly Ultisols, Oxisols, Alfisols and associated soil types. Many of these soils are classified as Low Activity Clay soils because of their limitations, special management requirements, and other distinctive features that affect their potential for crop production (Juo 1981).

Oxisols have problems of aluminum toxicity, low nutrient reserves, nutrient imbalance, and multiple nutrient deficiencies. Ultisols, in addition to having these problems, are prone to erosion, especially on bare sloping ground. The major physical limitations of Alfisols and related soils make them highly susceptible to crusting, compaction, and erosion. They have low moisture-holding capacity and acidify rapidly under continuous farming.

The high erosive potential of tropical rains aggravate these soils' problems, causing progressive deterioration in soil structure resulting in crusting and low infiltration rates; such changes lead to accelerated soil erosion, even on gentle slopes.

The productivity of tropical soils depends on maintaining their physical, chemical, and biological characteristics. Fertilizer alone cannot sustain the productive potential of the soil for an economic level of crop production. Besides, much of the fertilizer is lost in runoff water, through leaching and volatilization.

INCREASING POPULATION PRESSURE

Population growth is the source of increasing demands on wood and land resulting in forest exploitation and conversion. Table 2 shows the

demographic indicators of the Asian region. The population of Asia excluding Japan will increase from 2,697 million in 1985 to 3,419 million in 2000.

Table 2. Demographic indicators of the Asian region

Area	Total fertility[a] 1980-1985	Infant[b] mortality 1980-1985	Annual[c] population growth rate	Urban[d] population as % of total population
East	2.34	36	1.22	28.6
Southeast	4.11	73	2.05	26.3
South	4.72	115	2.14	25.2
West	5.22	81	2.79	55.0

Source: United Nations 1986.

a) The number of children an average woman will have if current age-specific fertility patterns remain constant.

b) The number of babies who die before their first birthday in a given year divided by the number of births in that year, multiplied by 1000.

c) Includes the effect of international migration.

d) The definition of *urban* varies between countries.

To understand the impact of population growth on agricultural production, the figures in table 2 must be compared with total per capita, land and arable per capita land as shown in table 3.

Table 3. Per capita land resources of Asian countries, 1985

Country	Total land per capita (hectares)	Arable land[a] per capita (hectares)
Afghanistan	3.92	0.48
Bangladesh	0.14	0.09
Bhutan	3.32	0.07
Brunei	2.49	0.01
Burma	1.82	0.26
China	0.91	0.09
India	0.43	0.22
Indonesia	1.14	0.09
Japan	0.31	0.03
Kampuchea	2.48	0.40
Korea DPR	0.59	0.11
Korea REP	2.24	0.05
Laos	5.75	0.21
Malaysia	2.12	0.07
Mangolia	82.02	0.71
Nepal	0.85	0.14
Pakistan	0.79	0.20
Philippines	0.55	0.08
Sri Lanka	0.40	0.07
Thailand	1.00	0.34
Turkey	1.58	0.50
Vietnam	0.55	0.10

Source: FAO, 1987b.

a) Arable land—land under temporary crops, temporary meadow or pasture, market gardens, and land temporarily fallow.

Thus, increasing populations, decreasing forest areas, and minimal per capita arable land make it mandatory to consider other systems of land use.

Insecurity of Land Tenure

In most countries of the developing world, land is the most valuable possession: wealth and status are measured by land ownership. When farmers are given temporary leases to develop government land, it is difficult for them to be committed to long-term cultivation practices that produce no immediate or obvious economic benefit. Shifting cultivators also are not interested in planting trees with crops because they are illegal occupants—they have no security of land ownership. Hence, many Asian farmers have little attachment to the land they cultivate, do not plant trees, and are not interested in improving the soil for future use.

On the other hand, traditional land allocation to family members often diminishes the size of holdings to the extent that they are uneconomical to farm. As a consequence, some members of families that do not own land may opt to encroach on forest reserves as illegal cultivators.

AGROFORESTRY SYSTEMS

During the last few years, many traditional and modern agroforestry techniques used by farmers in different parts of the world have been observed and described. The main systems are:

- *taungya* system
- farm-and-grove system
- tree planting among agricultural crops
- combined tree, shrub, and animal production
- home garden systems
- alley cropping

A more detailed summary of these and other practices by location is found in table 4. The main agroforestry systems listed are explained more fully as follows:

Taungya System

Taungya means hill cultivation. The *taungya* system was practiced as early as 1856 in Burma in establishing teak plantations (Tran 1978). The practice has since spread throughout Asia, Africa, and Latin America, being modified to suit local needs and conditions. Many of the forest plantations in the tropics, particularly in Asia and Africa, have been established by the *taungya* system, which indicates that agricultural crops and trees can be grown together, at least during the initial stage of establishment of a forest plantation. Farmers are temporarily allotted government lands and contracted to plant specific tree species. While the trees are young and before the canopy closes, the farmers are allowed to plant food crops and cash crops for their own benefit, while maintaining the trees. Although the main objective of this system is to rehabilitate degraded forest area, food production being a secondary benefit, it can be considered a step towards

Table 4. Agroforestry systems and practices

Major system	Practices	Regions where used
Agrosilvicultural	Improved fallow (in shifting-cultivation areas)	Southeast Asia, East and Central Africa, American tropics
	Taungya	South Pacific, Southeast Asia, South Asia, East and Central Africa, West Africa, American tropics
	Tree gardens (primarily fruit and nut trees used also for firewood)	South Pacific, Southeast Asia, Middle East and Mediterranean, American tropics
	Hedgerow intercropping (alley cropping)	Southeast Asia, East and Central Africa, West Africa
	Multipurpose trees and shrubs on farmlands	Throughout developing world
	Crop combination with plantation crops	Throughout developing world
	Multipurpose fuelwood trees	South Pacific, Southeast Asia, East and Central Africa, American Tropics
	Shelterbelts, wind-breaks, soil conservation hedges	Throughout developing world
Silvopastoral	Protein bank (cut-and-carry fodder production)	Southeast Asia, South Asia, East and Central Africa, West Africa, America tropics
	Living fence of fodder trees and hedges	Southeast Asia, South Asia, East and Central Africa, American tropics
	Trees and shrubs on pastures	Throughout developing world
Agrosilvopastoral	Woody hedges for browse, mulch, green manure, soil conservation, etc.	South Pacific, Southeast Asia, South Asia, East and Central Africa, West Africa, American tropics
	Home gardens (with herbaceous and woody plants)	Throughout developing world
Other	Aquaforestry (silviculture in mangrove swamps; trees in bunds of fish-breeding ponds)	Southeast Asia
	Shifting cultivation	South Pacific South Asia, East and Central Africa, West Africa, American tropics
	Beekeeping with trees	South Pacific, Southeast Asia South Asia, Middle East and Mediterranean, East and Central Africa, West Africa

Source: Nair 1986

the transformation of shifting cultivation to agroforestry. It provides an inexpensive means of afforestation and a satisfactory return to the farmer who cultivates the area. However, the system has been criticized as an exploitive practice for afforestation because farmers are forced to leave once the trees begin to shade out the crops—a period of two to three years in most cases. The Tanzanian government, therefore, has abolished the system (Aron 1985). Nevertheless, it is still being practiced in heavily populated countries such as Indonesia, India, and Japan.

Farm-and-Grove System

In the farm-and-grove system, farms are interspersed with groves of trees that may vary from being a predominantly wild forest that is consciously preserved, to groves composed largely of domesticated tree species planted by man (Olofson 1981). These two forms may alternate in a highly productive mosiac across the landscape.

One of the most striking examples of a farm-and-grove system is that of the Ifugao of the Cordillera Central mountain range in northern Luzon, Philippines, described by Olofson (1981). The Ifugao are best known for their wet-rice fields and irrigation technology on steep terrain. They also plant trees for firewood, building materials, utensils, furniture, tools, and religious figurines; fruit trees and grove crops; bamboo and rattan; and medicinal plants. The woodlot is weeded, pruned, and thinned as the trees grow. This system also helps conserve water needed for irrigation and prevents soil erosion and land slippage.

A simple version of this is the practice of border planting trees on farms. Border planting is often used when the food crop needs little or no shade and is placed in the wide, central, open space. The trees serve as boundary markers, live fences, or windbreaks in addition to producing wood, fodder, fruit, and green manure. Among the most commonly used trees are *Leucaena*, *Calliandra* and *Sesbania*.

Planting Trees among Agricultural Crops

Intercropping takes advantage of the mutual benefits obtained from combining trees and agricultural crops. Various systems of intercropping under commercial trees such as coconut, oil palm, and rubber have been developed to maximize land use and economic return to communities. Cropping systems involving coconuts and a variety of agricultural and fodder species are common in India and the Southeast Asian countries (Nair 1979). Agricultural tree crops such as coffee, tea, and cocoa are traditionally grown under the shade of one or two strata of tree canopies (Budowski 1980).

In southern Thailand, Sukwong (1982) reported practices involving planting rubber trees in alternate strips of five rows or in alternate rows with forest trees, mainly of *Parkia javanica*, *Alstonia macrophylla*, and *Eucalyptus camaldulensis*. In Indonesia, intercropping of fast-growing species (*Calliandra callothyrsus*) or elephant grass (*Pennisetum purpureum*) under tree plantations (such as *Pinus* spp. and teak) has been reported by Satjapradja (1982). Similarly, 25,000 ha of land in the central highlands of Papua New Guinea have been planted with a combination of

coffee, food crops (such as banana), and *Casuarina oligadon*, which provides shade, timber and fuelwood (Bourke 1984). In Malaysia, rattan has been underplanted in rubber; when the rubber trees reach the end of their economic life and require replanting, rattan is harvested prior to felling the trees.

In China, about 1.3 million ha of farmland have been intercropped with *Paulownia*, a fast-growing valuable timber tree. *Paulownia* was reported to protect wheat from hot, dry winds that decrease the yield as much as 40 percent (Yoon and Toomey, 1986).

Combined Tree, Shrub and Animal Production

An agroforestry system that includes animal husbandry can be arranged to accomodate ecological, economic, and social constraints. Falvey and Andrews (1978), for example, reported a trial to graze cattle in young plantations of *Eucalyptus camaldulensis*, *E. grandis*, and *Pinus kesiya* in the highland region of northern Thailand. In Malaysia, sheep and poultry have been integrated into rubber and oil palm plantations. Beekeeping is also practiced. By integrating animals into agroforestry systems, smallholders' income is increased by producing meat and other protein, by contributing organic manure, and by reducing weeding costs.

Another interesting practice, not yet widely used, is aquaforestry, which combines silviculture and fishery. Sukwong (1982) reported examples in the central rice-producing plains around Bangkok, where private *Casuarina* plantations of more than 1,600 ha are established. At some of these plantations, ditches are dug between rows of *Casuarina* for fish culture; at others, agricultural crops are interplanted. Aquaculture also is practiced in mangrove forests in Southeast Asian countries. In sericulture, the combination is shrubs and insect larvae: silkworms are raised by feeding them mulberry foliage.

Home Garden Systems

Home gardens are multistoried agroforestry systems where the canopies of the component species are arranged to occupy different vertical strata. The tallest species have foliage requiring or tolerating strong light and high evapotranspiration; the shorter species have foliage requiring or tolerating shade and high humidity. Usually, most of the upper canopy is occupied by coconut, followed by fruit trees. The lower strata is filled by banana, cassava, and other crops. At ground level, vegetables and other herbaceous crops are grown.

Home gardens are a common feature in Malaysia, Indonesia, the Philippines, Thailand, Sri Lanka, and India. They are very significant on the world's most densely populated island, Java. Species diversity and plant density vary from place to place and are determined by ecological and socioeconomic factors. The plants and animals of the home garden supply many of the owner's needs. The plants are important for their aesthetic and ornamental value; for religious purposes; for the production of daily staples such as food, fuelwood, and vegetables; and for cash income, for example from fruit and building materials like wood and bamboo.

Poor people plant more staple crops, vegetables, and fruit trees, whereas the well-off tend to grow more ornamental plants or high-value cash crops. Commercialization seems to degrade home gardens because it causes declines in species diversity. On the other hand, trying to improve home gardens by only considering economic and nutritional factors can also jeopardize the system. High-yielding but high-input and high-risk species and varieties increase the productivity of the home garden at the expense of the stability, equitability, and sustainability of the system (Soemarwoto, 1987).

Alley Cropping

Alley cropping is a sophisticated agroforestry system in which fast-growing, nitrogen-fixing shrubs are planted as hedgerows, and food crops are interplanted between those hedgerows. This system was developed at the International Institute of Tropical Agriculture in Ibadan by B.T. Kang and his colleagues in 1984. The system provides wood (stakes and firewood) and green foliage for fodder or green manure for food crops. Kang et al. (1984) reported that in alley cropping using *Leucaena* as the hedge crop 6 metric tons of stakes and 15 to 20 metric tons of leaves and twigs containing over 160 kg nitrogen, 150 kg potassium, and 15 kg phosphorus were produced. When the green manure was applied to the food crop plots, yield increased considerably and sustainably. Considering the limited inputs available to the peasants and traditional farmers, alley cropping practice should be adopted on a wider scale.

ISSUES AND CHALLENGES

Several land-use issues pose challenges for agroforestry researchers: shifting cultivation, woody perennial and multiple cropping, and traditional systems.

Shifting Cultivation

Shifting cultivation (swidden agriculture) is being practiced by 240 to 300 million people on nearly one-half of the total land area in the tropics. In the Asia Pacific region alone, 30 million people are dependent for their subsistence on shifting cultivation over an area of 75 million ha (Srivastava 1986). The farming system has been used for thousands of years and is excellently adapted to the ecological conditions. A maximum of 5 to 10 percent of the total area is cultivated at a time. The traditional sustained forest/fallow management system works in only a few extremely thinly populated areas, such as among the Dayaks in Borneo, the Aborigines in Peninsular Malaysia and in parts of Papua New Guinea (Abdul and Faizah 1988).

In central India, 17.52 percent of the total land surface of the state of Orissa, involving about one million people, is directly affected by shifting cultivation. It is the only means of survival for those sections of the population that do not possess any lowland or terraced plots of land

because of the pressure of population or because they are later immigrants who have no suitable lands for permanent cultivation (UNESCO, 1979).

In Indonesia, an estimated one million people practice shifting cultivation in the thinly populated areas outside Java and Bali. *Imperata* grasslands resulting from shifting cultivation occupy about 16 million ha with an annual increase of 150 thousand ha. The Indonesian government's policy is to improve this degraded grassland area into more productive agricultural lands through transmigration programs and intensive agriculture.

In the east Malaysian state of Sarawak, shifting cultivation is common and is used predominantly on the tropical mountain terrains. In 1976, about 30,000 households in the state were actively involved in shifting cultivation. In Sarawak today, it is estimated that about 2.8 million ha of forest are currently or have at one time been in a shifting cultivation cycle.

It is also estimated in Sarawak that 30,000 ha of virgin jungle is slashed and burned each year by shifting cultivators. This threatens the tropical forest (causing an annual loss of timber valued at 300 million Malaysian dollars) and erodes the soil. The government has tried to encourage farmers to cultivate perennial cash crops such as rubber, coffee, pepper, and fruits and thus become a stable and sedentary rural population.

In the Philippines, as of 1972, 172,000 ha of forest were destroyed annually, 80,000 ha of which were attributed to shifting cultivation. By 1972, about 26 percent of 5.1 million ha of forests were denuded by shifting cultivation. The approximately 120,000 families involved in this activity are not limited to tribal groups, but includes also lowlanders, displaced landless peasants, and unemployed urban poor.

Shifting cultivation has been widely practiced by tribal peoples living in some provinces in the northern and central regions of Thailand. It is also practiced in rural lowland areas all over the country. There are three groups of shifting cultivators. First are the pioneers or mobile farmers who clear climax forest every year for planting opium and hill rice. Second are the established shifting cultivators who live at lower elevations and farm for extended periods within their fixed territory. And the third are the incipients who have recently joined the activity because of population expansion and limited paddy land.

Shifting cultivation is not peculiar to the primitive tribes, for it can be found in countries like Sri Lanka and Korea. In the northern-most mountainous part of Korea, it is practiced by people who escape to the mountains for political, economic, and religious reasons. A similar example can be found among the Shinhala-speaking people of Sri Lanka. Table 5 shows the extent of shifting cultivation in the Asia Pacific region.

Even though shifting cultivation has provided a livelihood for substantial numbers of Asians, it is a wasteful and inefficient system. Crop productivity is low and soil productivity is at risk especially when fallow periods are shortened due to population pressure. It is only viable in sparsely populated areas with a maximum of 50 people per square kilometer.

Table 5. Extent of shifting cultivation in the Asia Pacific region

Country	Population dependent on shifting cultivation ('000)	Total area affected by shifting cultivation ('000 ha)
Bangladesh	108	1,000
Brunei	20	120
Burma	2,600	1,420
Fiji	—	200
India	2,700	10,000
Indonesia	12,000	35,000
Laos	1,000	3,000
Malaysia	1,640	4,700
Papua New Guinea	1,000	4,000
Philippines	830	2,000
Sri Lanka	60	1,000
Thailand	1,000	4,000
Vietnam	5,000	8,000
Total	27,958	74,440
Rounded to	30,000	75,000

Source: FAO publication cited by Srivastava (1986)

Woody Perennial and Multiple Cropping

Woody plantation crops such as rubber, oil palm, coconut, areca nuts, and cashew nuts are usually planted as sole crops, often on small holdings. Because of the long time required before the crop can be harvested, it is a common practice among smallholders to intercrop the trees with short-term cash crops such as banana, pineapple, tobacco, cacao, groundnut, and vegetables. Small animals such as sheep and goats also are raised on plantations. Woody perennial and multiple cropping systems are promising land-use technologies for solving the food and fuel crisis. Existing systems of intercropping and integrating animals in tree-crop plantations, however, need to be modified and improved to enable new technologies to be employed. In addition, physiological, biological, and ecological constraints require immediate solutions if agroforestry is to be accepted and practiced in the future. The entire process of selection and breeding, crop raising and tending, and production management have to be revised and restructured. Regional and global germplasm banks for agroforestry should be established since lack of suitable germplasms can hinder the development of agroforestry.

Climate conditions in the tropics are suitable for field crop production during much of the year and many cropping-pattern alternatives are available. As the number of possible sequential crops per year increases, the number of alternatives expands.

There are, however, a number of physical factors that influence multiple cropping, including amount of rainfall, ability to irrigate, and soil characteristics. The gradual or rapid onset or decline of heavy rains determines the type of rice suitable for culture, that is, which crops should be used as second or third crops, and the planting pattern. Rainfed agriculture is particularly important in Southeast Asia because it has the

lowest percentage of irrigated land in Asia—19 percent compared to 21 percent in South Asia and 47 percent in East Asia. (If Indonesia, with 54 percent of the irrigated land in Southeast Asia is not considered, the difference becomes more striking.)

Soil conditions influence cropping patterns primarily through water movement, drainage, and tillage capability under high rainfall. Without adequate rainfall or irrigation, multiple cropping is difficult, especially in upland areas. On the other hand, for upland crops on heavy soil, tillage for land preparation and weed control is difficult during periods of high rainfall.

The main characteristics of the farm economies of Southeast Asia are small farm size, dispersed production, low real wage rates in certain areas but rising wages in others, an increasingly large research and extension capacity, generally high interest rates but availability of low-interest loans for high-priority projects, and a strong demand for agricultural produce but increasingly unstable prices. These factors all relate to cropping systems.

Smallholder agriculture is affected by high marketing costs for agricultural produce. Much of the profits go to the many middlemen who are required to collect produce from the small producers and distribute it to consumers. The real agricultural labor wage is already high in Malaysia, is edging up in Thailand, and is likely to move higher in the Philippines. However, it is still low in Indonesia—less than half the rate paid in the Philippines and Thailand. The investment of financial capital in agriculture is also increasing, assisted by aggressive government programs that provide low-interest loans for either operating funds or investment capital. In the Philippines, all banks operating in the country must allocate 25 percent of their loan value to agriculture.

Traditional Systems

The well-developed homestead area, the mixture of upland crops, the intercropping of trees (such as coconuts) with annuals, and the integration of animal enterprises into the system are principal aspects of the traditional system. It is, however, a system not fully understood scientifically. Improvements must be made in how resources are used; in the use of high-yielding, short duration, fast-growing varieties; in spatial and temporal arrangement of the plant components; in long-term effects on the stability of the production base; in protective benefits; and in input-output relations.

RESEARCH NEEDS

In Southeast Asia, research scientists and extension workers doubled between 1965 and 1974. Furthermore, in 1974 South and Southeast Asia combined had 36 percent of the world's extension workers but only about 4 percent of the agricultural researchers (Harwood and Price 1976).

Agroforestry is changing as a result of the need to answer questions that arise when existing production systems are modified or new ones are

designed. The crucial question is whether the land-use system currently practiced on better sites should be modified to accommodate agroforestry or vice versa, since incorporation of woody perennials or animals in a conventional farming system usually leads to management and marketing problems.

A general framework for research programs must be based on a multidisciplinary land-use diagnosis so that they are logically derived from regional opportunities and constraints. Socioeconomic issues also play a part in identifying research needs in agroforestry and designing appropriate methods, including linkages with national programs, local agencies and nongovernmental organizations (NGOs).

More specifically, research needs to identify production and management objectives at both the macro and micro levels to increase and stabilize the income of the farmer. At the macro level, market demand and supply of agroforestry products should be studied to enable policymakers to judge the short-run returns and to evolve measures that can increase product supply. The long-run effects of soil and water conservation also must be considered when assessing the amount and allocation of investments in agroforestry.

At the micro level, studies should be made before and after new techniques or technologies are introduced in order to understand the effects on farmers' income of applying agroforestry research. Political and economic constraints and evaluation options for institutional change should be identified. In addition, the study of interaction between agroforestry and existing production system needs to be considered.

National agencies and NGOs should collaborate in testing technology. The access of NGOs to farmers could help in evolving a social-laboratory approach to technology design. The package of technology should be tailored to the needs of the farmers. For subsistence farmers, the technology should provide not only food, fodder, fertilizer, and fuelwood but also some cash income. For market oriented farmers, a package of information should be built to suggest combinations of trees and agricultural crops, the best combination management practices, costs and benefits, markets, and sources of financial and technical assistance.

THE ROLE OF NONGOVERNMENTAL ORGANIZATIONS

Nongovernmental organizations can play an important role in developing the agroforestry system within a country (Hedge 1986). Although agroforestry has many economic and ecological benefits, poor and marginal farmers are not interested in a new technology unless it ensures additional direct benefits, preferably cash. Additional needs such as training and establishing an input supply program are relevant. NGOs can contribute to the success of new land-use patterns by testing the feasibility and social acceptance of new models in the field. Because they have the advantage of close interaction with farm families, they can more easily listen to farmers' suggestion and modify the models. Lastly, NGOs are in a position to help establish marketing networks.

CONCLUSION

Agroforestry is not a perfect system; there have been both successes and failures with the various systems adopted. Nevertheless, as a whole, agroforestry has provided viable alternatives of land use, especially in fragile environments in Asia where the existing systems have failed. With a suitable environment and compatible social conditions, agroforestry systems should provide substantial rewards. A good agroforestry system should be able to solve social and economic problems and overcome physiological, ecological, and envrionmental-protection constraints that hinder its development and adoption in the region.

LITERATURE CITED

Abdul, Manaf Ahmad and Faizah Abood Haris. 1988. Community forestry in Southeast Asia: a review. In: *Community Forestry and the Community: Workshop Proceedings*. Kuching, Saarawak, Malaysia. May 23-26.

ADB (Asian Development Bank). 1987. A review of forestry and forest industries in the Asia-Pacific region. Manila.

Aron, M. 1985. The complexities of community forestry. *CERES* 18(2):20 Rome.

Bourke, R.M. 1984. Food, coffee and casuarina: an agroforestry system from Papua New Guinea. *Agroforestry Systems* 3:272-279.

Budowski, G. 1980. The place of agroforestry in managing tropical forests. Paper presented at International Symposium on Tropical Forests: Utilization and Conservation. Yale University, New Haven, Connecticut.

Cabrido, C.A., Jr. 1984. Fuelwood management by rural households. Canopy International 10(4):3-5.

Falvey, L. and A.C. Andrews. 1978. Agrisilviculture: joint production of wood and food. Paper presented at Eighth World Forestry Congress. Jakarta. October 16-28, 1974. 7p.

FAO (Food and Agricultural Organization of the UN). 1983. *Fuelwood Supplies in Developing Countries*. FAO. Rome.

FAO (Food and Agricultural Organization of the UN). 1984. *The State of Food and Agriculture*. FAO. Rome. 185 p.

FAO (Food and Agricultural Organization of the UN). 1987a. *Agriculture Toward 2000*. FAO Rome.

FAO (Food and Agricultural Organization of the UN). 1987b. FAO *Production Book*. Vol. 40. Rome.

Harwood, R.R. and E.C. Price. 1976. Multiple cropping in tropical Asia. In: *Proceedings of Symposium of Am Society of Agronomy*, Crop Science Society of Am and Soil Science Society of Am. Knoxville, Tennessee p 11–40.

Hedge, N. 1986. Role of non-government organizations (NGOs). In: *Agroforestry Research in the Semi-Arid Tropics*. Report on working group meeting at ICRISAT. Patancheru, India. August 5-6, 1986.

Juo, A.S.R. 1981. Mineralogical grouping of soils with variable change in relation to management and classification. Paper presented at International Conference of Soil with Variable Change. Palmerston North, New Zealand. December 11-18, 1981.

Kang, B.T., G.F. Wilson and T.L. Lawson. 1984. *Alley Cropping: A Stable Alternative to Shifting Cultivation*. International Institute for Tropical Agriculture. Ibadan, Nigeria.

Nair, P.K.R. 1979. Intensive multiple cropping with coconuts in India: principles, programmes and prospects. Advances in Agronomy and Crop Sciences 6. P. Parey, West Berlin.

Nair, P.K.R. 1986. Some examples of prominent agroforestry systems and practices in the developing countries. *ICRAF Newsletter* 17 (May): 4-5.

Olofson, H. 1981. Indigenous agroforestry systems. Paper presented at Workshop on Environmentally Sustainable Agroforestry and Fuelwood Production with Fast-Growing, Nitrogen-Fixing, Multi-purpose Legumes. East-West Center, Hawaii. Novermber 12-20, 1981. 36p.

Satjapradja, O. 1982. A concept to develop agroforestry on Java Island, Indonesia. Paper presented at Regional Working Party Meeting on Agroforestry Research and Development for Southeast Asia at SEAMEO Regional Center for Graduate Study and Research in Agriculture (SEARCA). Philippines. May 24-25. 13 p.

Soemarwoto, O. 1987, Homegardens: a traditional AF system with a promising. . . *In: Agroforestry, A decade of Development*, H.A. Steppler and P.K.R. Nair, eds, p. 157-172. ICRAF, Nairobi.

Srivastava, P.B.L. 1986. Shifting cultivation problems and alternatives. FAO Regional Office for Asia and the Pacific, Bangkok. Field Document 10. 77 p.

Sukwong, S. 1982. Agroforestry in Thailand. Paper presented at Regional Working Party Meeting on Agroforestry Research and Development for Southeast Asia at SEAMEO Regional Center for Graduate Study and Research in Agriculture (SEARCA). Philippines. May 24-25, 1982. 9p.

Tran, V.N. 1978. Agrisilviculture: joint production food and wood. Paper presented at Eighth World Forestry Congress. Jakarta. October 16-28. 16 p.

United Nations. 1984. *United Nations Energy Statistic Yearbook*. UN, New York. 254 p.

United Nations Department of International Economic and Social Affairs. 1986. World population, prospects, estimates and projections as assessed in 1984. ST/ESA/SER A/98. UN, New York.

UNESCO (United Nations Educational Scientific and Cultural Organization). 1979. Research design: a comparative study of swidden cultivation in Asia. Report of regional meeting. Bangkok. April 19-23.

Yoon, C.S. and G. Toomey. 1986. Paulownia-China's wonder tree. *Report* 15(?):11-13.