Chapter 10

Forestry Technologies to **Support Tropical Agriculture**

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HIGHLIGHTS

- The medium- and long-term maintenance of tropical forest resources may depend more on sustaining lands under cultivation than on refining the use of the remaining forest.

Agroforestry

- Agroforestry, systems that use trees, crops, and/or animals on the same land, holds great promise for improving and sustaining the productivity of lands under cultivation,
- Genetic improvement of multipurpose tree species has great potential to increase the productivity of agroforestry systems,
- Rigid boundaries between disciplines have deterred agroforestry development. There is a need for a thorough rethinking of the appropriate institutional homes for agroforestry,
- Implement at ion of agroforestry systems relies on removing obstacles to adoption, improving extension services, and creating incentives to encourage farmers to adopt agroforestry practices.

Watershed Management

- Damage to tropical watersheds is most ecologically and economically significant where subsistence farmers and their livestock move onto steep uplands. Improved farming systems are needed that can ensure and enhance farmers' short-term returns and at the same time modulate water flow.
- Where flood protection for large populations in lower reaches of river valleys depends on protecting the vegetation on steep upper watersheds, costs for conservation practices in the uplands should be subsidized by the lowland communities.
- More research on the relationship between land use and hydrological systems is necessary to give watershed managers a better understanding of various management systems and their tradeoffs.

INTRODUCTION

The major cause of deforestation and forest degradation in most countries is land clearing for agriculture. In many places, the quality of land is degraded by conventional farming or grazing practices, so the farmers and herders must keep clearing more and more forest. This practice continues because people have no alternatives.

Many of the technologies discussed in this report can help to sustain forests by making forested land more productive and thus can help reduce the need for converting the land to nonsustainable uses. However, increasing the productivity of forests alone is unlikely to provide enough jobs or income for rapidly growing rural populations, For that, the productivity of agriculture has to be sustained and increased.

Agricultural productivity can be increased by enlarging the area farmed, maintaining the quality of the land already in use, and increasing the per hectare yields. Chapter 11 addresses planning technologies to direct land clearing onto sites that are appropriate for agriculture. This chapter addresses forestry-related technologies for the other two approaches. The objectives of these technologies are:

1. to enable farmers on marginal soils to continue farming in one location and to maintain or gradually increase land productivity so they can stop clearing more and more forest, and
2. to protect and allow improvement of agriculture in the more fertile river valleys by modulating waterflows and reducing erosion and siltation from upland watersheds.

AGROFORESTRY

Background

Traditional farming methods used in tropical countries were developed to reduce the risk of crop failures more than to provide maximum production. As a result, the traditional cropping and grazing systems used on relatively infertile, dry, or erosion-prone sites often involve multiple crops, intercropping, and complex crop rotation schedules. However, the traditional systems are not productive enough to provide for the rapidly expanding populations of the Tropics. They need to be modernized and further developed.

On fertile and well-watered alluvial soils where traditional farming was based on monocropping of rice or wheat, it has been possible to increase yields by adapting modern temperate-zone technologies, including applications of fertilizers and pesticides. But in the less well situated sites, many attempts to replace complex, traditional farming systems with modern monocrop agriculture have failed, apparently because of high risks from climate, pests, and difficult soils and because of the complex socioeconomic conditions that often prevail. So, in recent years, some scientists have begun developing modern technologies to improve, rather than replace, the traditional farming systems (26). This approach to tropical agricuhure development is still promoted by only a small number of agricultural scientists.

Agroforestry is a name for a collection of land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately grown on the same land with agricultural crops and/or animals in either spatial arrangements or temporal sequences. Agroforestry is a new word, not a new concept. The novelty lies in formally recognizing that many different tree-based land-use systems possess certain common features that hold great promise in the Tropics.

On fertile lands, intensive agroforestry systems, like intensive agriculture, can support dense populations. Agroforestry, however, is probably more important for improving and sustaining the productivity of the lands with soil fertility and soil moisture problems, and where lack of rural infrastructure and cash make it necessary for people to produce most of their own basic needs for food, fodder, fuel, and shelter.

Agroforestry Systems

Description

Agroforestry encompasses many well-known and long-practiced land-use systems on cultivated or grazed lands in the Tropics (table 29). Traditional shifting cultivation, bush fallow systems, and all forms of "taungya" afforestation* fall under this term, as do the home gardens of the wet tropics and the use of fodder trees and shrubs in the dry Tropics.

*Taungya: Burmese for hill cultivation. Agricultural crops are planted with trees used for wood production.

Table 29.—Some Prominent Agroforestry **Systems in Developing Countries**

Southeast Asia	Southern Asia	Mediterranean and Middle East	Eastern, Central, and Humid West Africa	Arid and semiarid West Africa	American Tropics
1. *Agro-silviculture*					
1. Commercial trees among crops 2. Fruit/shade trees among crops 3. Live fences 4. Shelterbelts 5. Taungya 6. Shifting cultivation systems 7. Intercropping in plantation crops (rubber, oil palm, coconut)	1. Taungya 2. Plantation crops + arable crops 3. Commercial trees and fruit trees with crops 4. Live fences + shelterbelts 5. Various trees on farmlands for productive functions 6. Various forms of shifting cultivation 7. Medicinal plants + agriculture species	1. Olive + cereals (on terraces, 'banquettes', 'cuvettes', etc.) 2. Poplars along irrigation canals 3. Trees for sand dune reclamation 4. 'Huertas' - small plots irrigated crops + fruit trees 5. Aromatic, medicinal arid fruit trees with crops	1. Taungya 2. Cacao/food crops/ forest complex 3. Plantation crops (oil palm/rubber) and root crop complex 4. Coffee + banana 5. Mixed perennial crops 6. Gum arabic + millet 7. Shifting cultivation/ bush fallow systems	1. Use of trees on farmlands for protective role (windbreaks, dune fixation) 2. Productive + protective role of trees on farms *(A. albida/Leucaena* + agriculture crop systems)	1. Trees in perennial cash crops (coffee, cacao, tea) 2. Trees for organic matter and mulch with annual crops 3. Tree live fences 4. Windbreaks and shelterbelts 5. Trees as support for climbing commercial crops 6. Taungya 7. Shifting cultivation systems
2. ***Silvo-pastoral***					
1. Pasture in forest plantation 2. Pasture in secondary forests 3. Commercial trees in pastures 4. Fruit/shade trees in pasture 5. Fodder trees 6. Coconuts + pasture	1. Pasture under trees 2. Plantation crops + cattle grazing 3. Fodder trees and shrubs 4. Fruit trees and commercial trees in pastures	1. Oak forest + grazing 2. Pig breeding and forestry 3. Range land improvement	1. Gum arabic + livestock 2. Plantation crops (coconut/cashew + pasture	1. Nomadic/semi-nomadic/transhuman 2. Sedentary livestock grazing systems/ browsing systems 3. Fodder tree/shrub systems	1. Trees in pasture 2. Pasture in natural regeneration forest 3. Trees lopped for fodder 4. Trees used for browsing
3. ***Agro-silvo-pastoral***					
1. Crops and grazing in plantations 2. Agriculture tree crops + grazing in forest plantation 3. Multipurpose trees with crops/animals 4. Integrated farming systems with agriculture plantation crops (rubber, coconut, oil palm)	1. Plantation crops + arable crops + livestock 2. Agriculture tree crops + grazing in forest	Range land management	1. Coconuts/other plantation crops + food crops + grazing 2. Coffee + banana + dairying 3. Horticultural complex systems 4. Plough culture complex systems	1. Forestry dominating (forest lands) 2. Agriculture dominating (crop lands) 3. Livestock dominating (crop lands)	1. Agriculture plantation crops (coconut, rubber, fruit, trees) with crops and pastures

Table 29.—Some Prominent Agroforestry Systems in Developing Countries—Continued

Southeast Asia	Southern Asia	Mediterranean and Middle East	Eastern, Central, and Humid West Africa	Arid and semiarid West Africa	American Tropics
4. ***Home gardens***					
Various forms of multispecies combination	1. Multistory plant canopies in humid regions 2. Arid/semiarid systems	Mainly in large cities	Various forms	Various forms	Various forms
5. ***Others***					
1. Silviculture in mangrove forests 2. Agri-silvi-fishery 3. Trees on bunds in fish breeding ponds 4. Swidden farming 5. Fuelwood agroforestry	1. Mixed perennial cropping 2. Irrigation systems 3. Various site-specific systems 4. Fuelwood systems	1. New system in Morocco (spice plantation for erosion control) 2. Agriculture + forestry 3. Fruit trees in deserts 4. Mushroom cultivation in forest	1. Pastoral systems with corral farming (highland/lowland)_ 2. Mixed perennial cropping	1. Oasis 2. Irrigation systems 3. Various site-specific systems	Mixed perennial cropping

SOURCE: Anonymous, "A Global Inventory of Agroforestry Systems," Biomass :241-245, 1983

Photo credit: S. Hecht

Rubber trees interplanted with a cover crop of *Pueraria phaseoloides* and grazed by cattle is one type of agroforestry system

Agroforestry systems attempt to optimize ecological and economical interactions between various components (trees and shrubs/ crops and animals) to obtain a higher, more diversified, and/or more sustainable total production than is possible with any single land use. Typical characteristics of such systems are: 1) two or more species of plants (or plants and animals), at least one of which is a woody perennial; 2) two or more outputs; and 3) a production cycle of more than 1 year.

Agroforestry can provide many goods and services. Depending on the particular situation, it may:

- increase and improve food production yields;
- produce firewood and a variety of other raw materials from shrubs and trees for farmers' subsistence, for local sale, and sometimes for export;
- protect and improve the soil's productive potential;
- improve social and economic conditions in rural areas by creating jobs and income and reducing risks; and
- develop land-use systems that draw on both modern technologies and traditional local experience and that are compatible

with the cultural and social life of the people concerned.

Classification and Assessment

Many reviews of traditional agroforestry systems and practices in the Tropics and subtropics have been published,* but most are only descriptive accounts. Rarely are any quantitative data included on the number of people or areas involved. Nor have many in-depth analyses of the environmental and economic advantages or disadvantages of the systems been conducted. The reviews do show, however, that agroforestry has been practiced for a long time with apparent success in almost all parts of the dry and wet tropical and subtropical worlds.

Agroforestry systems have been classified in different ways according to 1) physical structure, 2) temporal arrangement, 3) relative importance and role of components, 4) production aims/outputs, and 5) social and economical features (see 11,19,24,41,42). The following discussion of agroforestry is based on three socioeconomic production categories: commercial, intermediate, and subsistence (26). The divisions among categories are not discrete; rather they represent a continuum of production systems. Nevertheless, it is a suitable basis for discussing potentials and problems of further development and large-scale implementation of agroforestry.

Commercial agroforestry systems typically have as their aim the production and sale of crops, often a single commodity. These systems have been the object of systematic development efforts by horticultural, agricultural, or silvicultural institutions. Commercial tree crops (e.g., coconut rubber or oil palm) are interplanted with food crops or forage crops, or the understory is grazed by animals. The use of commercial timber species in conjunction with cacao is better developed than with almost any other cash crop system. Grazing cattle under plantation trees has attracted much attention as a promising way of increasing total yield from the land. An example is the Jari Project in Brazil, where seeding the pine plantation (Pinus ***caribea)*** with forage grass ***(Panicum maximum)*** reduced the need for weed control. The cattle then increased the total income from the system (21).

Many commercial timber and pulpwood plantations in the Tropics have been established through the "taungya" system. Farmers or forest laborers are allowed to grow crops for a few years during land preparation and early plantation phases. In exchange, they weed and care for the young trees. After an agreed-upon period, the farmers move on. Taungya has been used for more than a century and has been applied throughout the Tropics. Although well-planned taungya can provide a sequence of new ground for shifting cultivators, it removes the land from agriculture for a period dictated by the biology and economics of the forest crop and not by the needs of farmers or forest laborers.

The widespread use of this system and its many local variations is a clear indication of its success (25). The practice has been successful with ***Terminalia, Triplochiton,*** and several ***Meliaceae*** in West Africa; ***Cordia*** in Surinam; ***Tectona*** in Trinidad; and ***Swietenia*** in Puerto Rico (45). In Nigeria, the system has been applied in both wet and dry zones for tree and food production. In that country, it has been credited with providing enough food for about 700,000 people, or about 1 percent of Nigeria's food needs (13).

The increased use of commercial, commodity-oriented agroforestry is attractive in theory. However, the areas under perennial agricultural tree/shrub crops occupy about 8 percent of total arable area in developing countries today (27). Of this, only a minor part is used for intercropping or grazing. Another 2 million hectares of perennial agricultural tree plantations could be established by the year 2000 without encountering serious marketing problems (38). But this approach has limited potential for substantially alleviating land problems. Since commercial agroforestry will be intro-

*For Latin America see Budowski (7); Weaver (46); Ampuero (2); de Las Salas (12); Wilken (47); Budowski (8). For Africa see FAO (14); von Maydell (43); Seif el Din (36); Okigo (30); Iyamabo (23); IITA (22); Poulsen (33,34). For Asia see Atmosoedaryo and Wijayakusumh (4); Generalao (18); Ahmad (1); FAO (15).

duced only where opportunities for profits are clearly perceived, it is unlikely to be used on infertile land or by people who are not entrepreneurs. This objection applies less to timber plantation land, where small improvements in taungya could produce significant increases in food production. Forest plantation lands could then support considerably more people than they do now.

Intermediate agroforestry systems are where farmers with small to medium sized landholdings combine production of perennial crops for cash with annual crops for subsistence. Some of these systems are oriented toward commercial production, but they are small and the land is operated by individual farmers. Others are similar to subsistence systems. An example is the combination of gum arabic trees ***(Acacia senegal),*** which can provide good cash income to farmers, with millet in the Sudan. Another intermediate level agroforestry system occurs when commercial firms enter into contracts with small- and medium-scale farmers to produce raw materials. The British-American Tobacco Co. in Kenya has contracts with farmers who grow tobacco and the fuelwood needed for curing it, together with their own food crops.

Coffee forms the economic basis for many integrated land-use systems in this category, particularly on fertile soils in tropical uplands. In the East African highlands, multistory production is common. Timber trees such as ***Albizzia*** and ***Grevillea*** shade coffee interplanted with bananas and beans (33). Similarly, in Costa Rica coffee is grown under the shade of both timber trees ***(Cordia alliodora)*** and multipurpose trees ***(Erythrina*** spp.) (7,8). Another important crop in tropical small-holder agroforestry is coconut. Planting food crops and grazing cattle under coconuts are common practices in the wetter parts of Sri Lanka, India, Southeast Asia, and the Pacific regions (28).

Most of the economically and ecologically successful examples under this category are found in areas having relatively fertile soils, good communications, and existing market infrastructure. But many obstacles can be encountered when expanding permanent cash crops into less favorable areas, where infrastructure and markets are underdeveloped, where land tenure is uncertain, or where the environment imposes serious restrictions on intensive land use. Still, there is promise for improving existing systems through the introduction of improved varieties of tree crops, fruit trees, and compatible food crops, as well as application of fertilizers.

Subsistence agroforestry systems are oriented toward satisfying the basic needs of farmers for food, fuel, and shelter, with some products sold for cash income. Such systems are practiced by a large portion of the population of the tropical world, from livestock herders in semiarid areas to shifting cultivators in rain forests. These systems usually are practiced where serious ecological and/or socioeconomical constraints exist. Infertile soils, erosion, and/or drought can be major physical limitations. Insecure land tenure and lack of infrastructure, capital, extension services, and education are common socioeconomic constraints.

Many different subsistence agroforestry systems exist. Shifting cultivation and bush fallow are practiced in many forms throughout the tropical world. One well-known form of permanent traditional agroforestry is the home gardens of Southeast Asia, characterized by a multistory mixture of many species of trees, shrubs, climbers, palms, tubers, and often animals (pigs and poultry) (16). Other agroforestry in Asia integrates rice production with trees for windbreaks, boundary demarcation, and fuelwood production (6,16).

Oases are a prototype of agroforestry in arid lands. They contain ponds to water livestock as well as an upper story of multifunctional trees and a lower story of agricultural or horticultural plants. Though only comprising a small area endowed with water and fertile soils, they can be extremely well-balanced human ecosystems with species mixture, multistory structure, and near-perfect recycling processes (44).

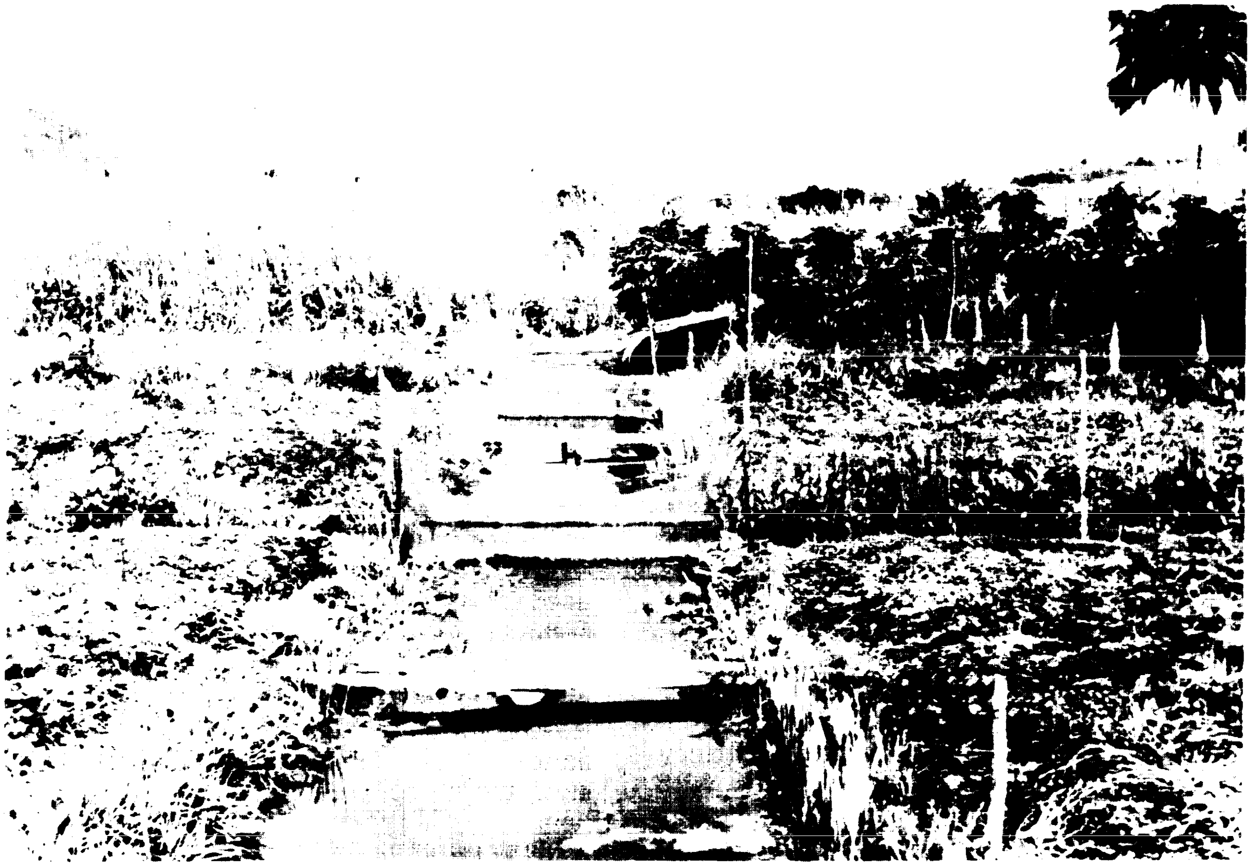


Photo credit: K. Parker

Chinarnpas in Mexico are centuries-old food production systems used where water is available year round. Narrow irrigation/drainage canals surround the plot and control water supply; mud dredged from canals serves as organic fertilizer; aquatic vegetation serves as "green manure;" fish that colonize the canals provide additional protein; trees planted along the canals hold the soil in place as well as providing other products

Millions of people practice agroforestry in areas with serious physical and socioeconomic constraints. The problem of improving the productivity and sustainability of these people's agriculture and agroforestry methods is of an entirely different magnitude than that of improving commercial and intermediate agroforestry systems. Reaching farmers can be difficult, and where subsistence farmers can be reached, they need to be convinced that the costs, risks, and benefits of new technologies are favorable. The time between planting a tree and achieving significant yields may involve risks that subsistence farmers cannot take. It also can be difficult to convince land users to make long-term investments when land tenure is uncertain. Subsistence agroforestry holds great potential for improving land use but has urgent need for technology improvement.

Technology Issues

In general, the concept of agroforestry as a sustainable approach to land use is sound. The aim is to create productive farming systems able to supply an increasing and sustainable output of basic needs, including cash. Maintaining soil fertility, preventing erosion, moderating microclimate, and other environment-enhancing roles of the tree/shrub component apparently do help sustain production.

A growing body of information exists on the various agroforestry technologies, but this is mainly descriptive and qualitative. Most scientists' interest has been in the tree/shrub component (e. g., potential tree species, their use, and management) because of the novelty of using trees and shrubs in agricultural and pastoral lands,

During the last 5 years, many agroforestry research projects have been initiated at university forestry departments and forestry research institutes. These generally study the long-term economic and ecological productivity of various trees, planted at different spacings, and combined with a food crop, which is often used as a "test" crop to quantify the competitive or soil-improving influences of the tree.

Only certain trees and crops prove to be compatible, Rubber trees, for instance, produce so much shade that underlying pasture often becomes useless within 3 years. Oil palm soils are often clayey and wet and animals tend to compact the soil and damage tree roots (17). Some crops such as sorghum, millet, and pigeon pea are highly competitive with other plants and, thus, may not be suitable for intercropping. Other crops—maize, cotton, and dry rice—are less competitive and can be intercropped. Each system has complex problems of intraspecific and interspecific competition. The aim of experimental research is to optimize combinations of agriculture, pastoralism, and forestry over space and time.

Tropical research and development organizations have become much more interested in multipurpose trees. The legume family has attracted particular attention. In general, legumes, through their bacterial relationship, can improve soil fertility and produce good-quality fuelwood as well as leaves and pods with fodder and food value. Different legume species also are adapted to a wide range of ecological conditions. Many multipurpose species are found in the legume genera ***Acacia*** and ***Prosopis.*** Several nonlegume multipurpose species are equally interesting because of their general versatility, adaptability to less favorable sites, and yield of valuable products. An example is the neem tree ***(Azadirachta indica)*** which originated in the dry zones of Asia. It is an excellent timber, fuelwood, and shade tree and produces tannins, insecticidal chemicals, and fuel/lubricant oil (35).

The greatest potential for improving agroforestry systems lies in the practically unexplored field of genetic improvement of multipurpose trees and shrubs (26). Selecting the species and varieties that are best adapted to particular purposes and site conditions for which the agroforestry systems are intended is the first step. Traditional agroforestry systems have been doing this gradually for centuries, but now with modern communications and techniques for reproducing, transporting, and testing varieties, it is possible to greatly accelerate the process.

Because the scientific attention to multipurpose trees is so new, examples of the gains that can be achieved by this selection and matching process are rare. The interest in single-purpose use of trees is older, and gains with these illustrate the potential for multipurpose trees. For example, results from 32 sites in 18 countries show that productivity gains of several hundred percent could be achieved in eucalyptus trees simply by selecting the best-adapted provenances for prevailing conditions (31).

The second step, which can begin before the first is completed, is tree breeding—crossing plants to combine particular desired characteristics, such as fodder and fuel production quantity and quality, rooting characteristics, phenology favorable for interplanting with annual crops, nitrogen-fixation, pest resistance, drought resistance, or the ability to withstand other stresses.

The potential for agroforestry systems improvements to be adopted on a large scale by farmers and pastoralists is difficult to assess. If the relevant land-use problems have been identified and an ecologically, economically, and socially well-adapted agroforestry solution is demonstrated to be feasible, then agroforestry improvements may be adopted, However, finding locally acceptable solutions to problems that are perceived by farmers is crucial. Sophisticated trials on the best spacing of trees over crops are, for example, not particularly relevant if farmers are not interested in that particular tree species.

The constraints and problems encountered in developing and disseminating agroforestry systems are many. Millions of farmers and landless people are spread over vast expanses of tropical lands. Rapid population growth, insecure land tenure, erosion, droughts, floods, declining soil fertility, lack of infrastructure, political instability, illiteracy, and other development problems often characterize those broad regions where agroforestry approaches have a potential role to play. Therefore, agroforestry development cannot occur in isolation from general social and physical constraints on rural development.

Constraints and Opportunities

Agroforestry techniques can be used to address particular land productivity problems. However, most information on the technique is qualitative and advocative. Present research and field implementation efforts are more ad hoc than systematic.

Critical analyses of agroforestry's constraints and opportunities must be made if it is to benefit from application of the scientific method. Systematic quantitative information can provide a basis from which researchers can formulate hypotheses and design efficient research strategies to develop new agroforestry systems, refine old ones, and adapt proven ones to other areas. This is necessary to ensure that only technologies with high probability of success are brought to large-scale field implementation.

The effort to organize and assess existing national and international experience in traditional agroforestry technologies and to identify promising technologies for further development is under way at the International Council for Research in Agroforestry (ICRAF). Technologies that need refinement and farm validation include alley cropping, improved fallows, live fences, contour hedges, mulch production with tree species, and fodder production. Some such programs already exist, but efforts should be made to strengthen these (table ***30).***

Table 30.—Organizations That Work on Agroforestry Systems

1. International Council for Research in Agroforestry
2. Centro Agronomical Tropical de Investigation y Ensenanza (CATIE)
3. International Tree Crop Institutes (U. K., U. S. A., and Australia)
4. Nitrogen-Fixing Tree Association
5. National Academy of Sciences (fuelwood and legume tree species)
6. Commonwealth Forestry Institute (information, research, and training)
7. East-West Center (dissemination and exchange of agroforestry information)
8. United Nations University (workshops and research programs at cooperating institutions)
9. Some components of UN ESCO/MAB research program
10. Some developed country universities
11. Some CGIAR institutions (e.g., IITA in Nigeria on alley cropping and CIAT in Colombia on *Leucaena* and *Erytherina)*
12. FAO'S Panel of Experts on Forest Gene Resources (data collection and assessment)

SOURCE: B. Lundgren, "The Use of Agroforestry to Improve the Productivity to Converted Tropical Land," OTA commissioned paper, 1982,

Since agroforestry cuts across several disciplines, it requires an integrated and multidisciplinary approach. Agronomists, foresters, ecologists, sociologists, anthropologists, and experts in other related disciplines have accumulated much data on various tropical mixed-cropping systems. Such information can become the foundation for research programs to explore ways to integrate sustainable production of food, forage, and fiber needs on appropriate lands. However, too little communication or coordination occur among these disciplines to formulate a strategy for development of agroforestry technologies. This constraint would be alleviated if interdisciplinary teams were established to conduct research on integrated land-use systems (26).

Agroforestry needs an institutional home to ensure its implementation. It is considered a subdivision of forestry, but forestry institutions deal with forest land. They seldom address the problems facing individual users of small and medium size holdings of cultivated lands. Forestry institutions, in general, do not have the range of expertise needed to develop agroforestry's full potential. The major potential for agroforestry lies in the integration of trees into agricultural and pastoral lands. The development of these lands is the mandate of agricultural institutions, which are not explicitly mandated to deal with agroforestry.

Rigid boundaries between disciplines affect funding of agroforestry research, development, and implementation. Forestry and agriculture often compete for both funds and land. In international agencies, agricultural divisions are better institutionalized, more prestigious, and, thus, better funded than forestry divisions. The forestry funds that do exist usually are channeled to conventional forestry activities.

The ratios of international financial support for research in tropical agriculture, forestry, and agroforestry, respectively, are about 200:1O:I (26), This may underestimate the relative magnitude of agricultural research support. Although the importance of research is clearly recognized in agriculture, the attitude of development assistance donors toward research in forestry is cool. Thus, as long as agroforestry funding is channeled through forestry departments, little hope exists that sufficient research funds will be available. A thorough rethinking and revision of the appropriate institutional home for agroforestry is needed.

The large-scale promotion of agroforestry would require incentives to encourage farmers to adopt practices that involve initial risks and delayed returns. Integrating trees into agricultural or pastoral systems is unlikely to succeed where short-term, insecure leases for use of land are prevalent, where trees automatically become the property of the government, or where nonrestricted communal grazing or tree cutting rights exist. Neither are farmers likely to achieve large-scale cash crop production of wood (i.e., fuelwood, poles, pulpwood, etc.] where prices are set so low that growing trees is not profitable.

To alleviate these constraints, tropical governments will need to identify and remove constraints in land tenure and provide incentives and extension services. Incentives may take the form of credits and loans that reduce initial capital outlay and minimize risk of failure. Extension services can facilitate supply of materials, train farmers, and make followup visits to monitor progress of agroforestry development. Unfortunately, forestry and agroforestry extension efforts often suffer from: 1) lack of staff with adequate training, 2) lack of networks of on-farm demonstration plots, 3) inconsistent efforts, 4) difficulty obtaining good seeds of multipurpose tree species for mass distribution to farmers, and 5) lack of infrastructure.

As institutional interest and support for agroforestry increase, it is necessary to take steps to ensure that the enthusiasm does not lead to disappointment and a sharp reduction of support. Development assistance agencies and research institutions have not begun, collectively or individually, to formulate a strategy to assure that the necessary and sufficient steps are taken to develop the potential of agroforestry,

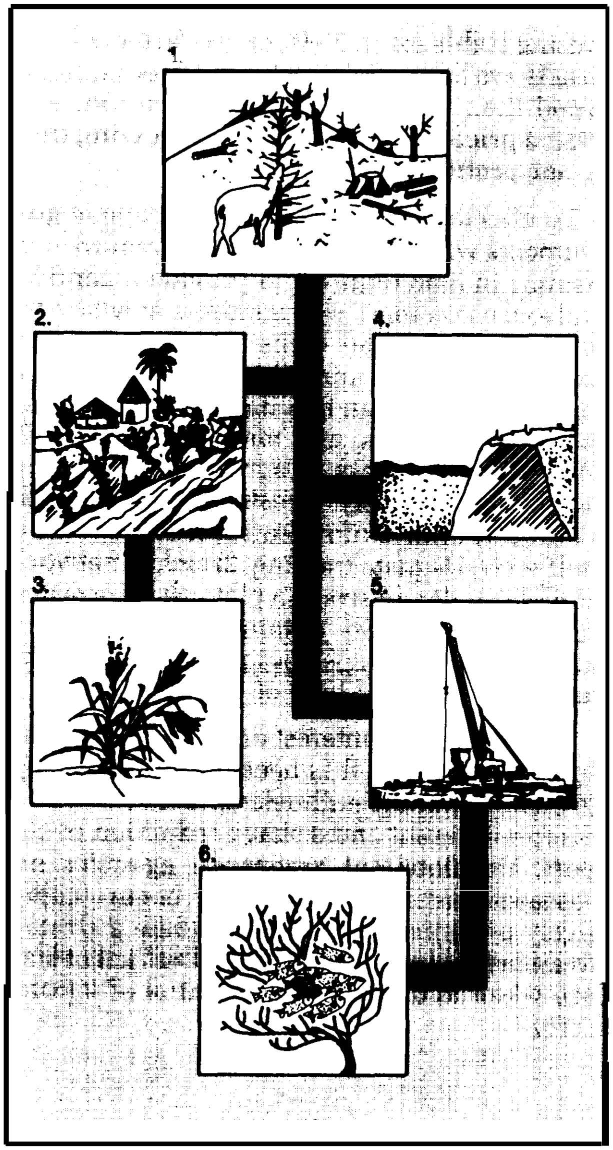
WATERSHED MANAGEMENT

Background

In an undisturbed watershed, the disposition of rain and snow melt is determined by a complex interaction of terrain, soil, climate, geology, and vegetation. Unfortunately, some common land uses seriously disturb the vregetative cover so that both the amount of water that upper catchments can hold temporarily during prolonged or heavy rains and the proportion of rain that percolates into the soil are seriously reduced. This results in much greater variations in the seasonal river flows, greater sediment loads during peak flows, and often a greater proportion of the total rainfall running off before it can be used by trees or crops (fig. 28),

For example, denudation of water catchment areas in the Indus River system has led to

Figure 28.-Effects of Poor Watershed Management



Overgrazing, deforestation, misplaced cultivation, or carelessly bulit roads In

floods far higher in the last 25 years than during the previous 60 years and has increased serious silting in the reservoirs and canals of Pakistan's irrigation system (32). In recent years in India, the cost of repairing flood damage below the Himalayan catchments has been, on average, US $250 million a year, in addition to losses of production and livelihood suffered by millions (39).

Technologies can probably be developed and implemented to help reduce these economic and human costs. The solution to these problems of land misuse depends foremost on developing improved methods of land use that are both more profitable to local communities and also give appreciably better control of the water flow. Soil conservation structures (e.g., terracing), revegetation, and appropriate farming systems are technically adequate to contain the current land degradation trend, but many of these techniques are too expensive for the farmers living in the upland areas.

Watershed Management

Description

Watershed management is concerned with controlling water flow above and below the Earth's surface from the upper to lower regions of drainage basins. Management of the upper watersheds aims to maintain or to improve the timing, quantity, and quality of water that is used in more intensively developed lowlands.

The natural vegetation on tropical mountain slopes that receive high rainfall is closed canopy evergreen forests, sometimes interrupted by shallow-soiled grass or swamp areas. Evergreen forests provide temporary storage for heavy rainfall, thus delaying water's movement into streams and reducing peak storm flow. The temporary storage occurs partly on the wetted canopy, partly in the deep forest ground-litter, and partly in the topsoil made porous by vegetation and soil fauna. Some water drains through these porous surface layers to streams. Some water infiltrates to recharge ground water and thus maintain dry-season spring flows. Some water is evaporated from the wet canopy and some is transpired back into the atmosphere through the foliage.

Watershed management includes soil conservation, road planning, contour cultivation, grassed waterways, cutoff drains, grass planting on steep banks, and other techniques to control water's impact. Soil stability, agricultural productivity, and the quality of water supplied to the lower reaches of the watershed can thus be maintained. Watershed management is an economic necessity where there is investment downstream in reservoirs for hydropower and irrigation or densely settled areas in zones of flood hazard.

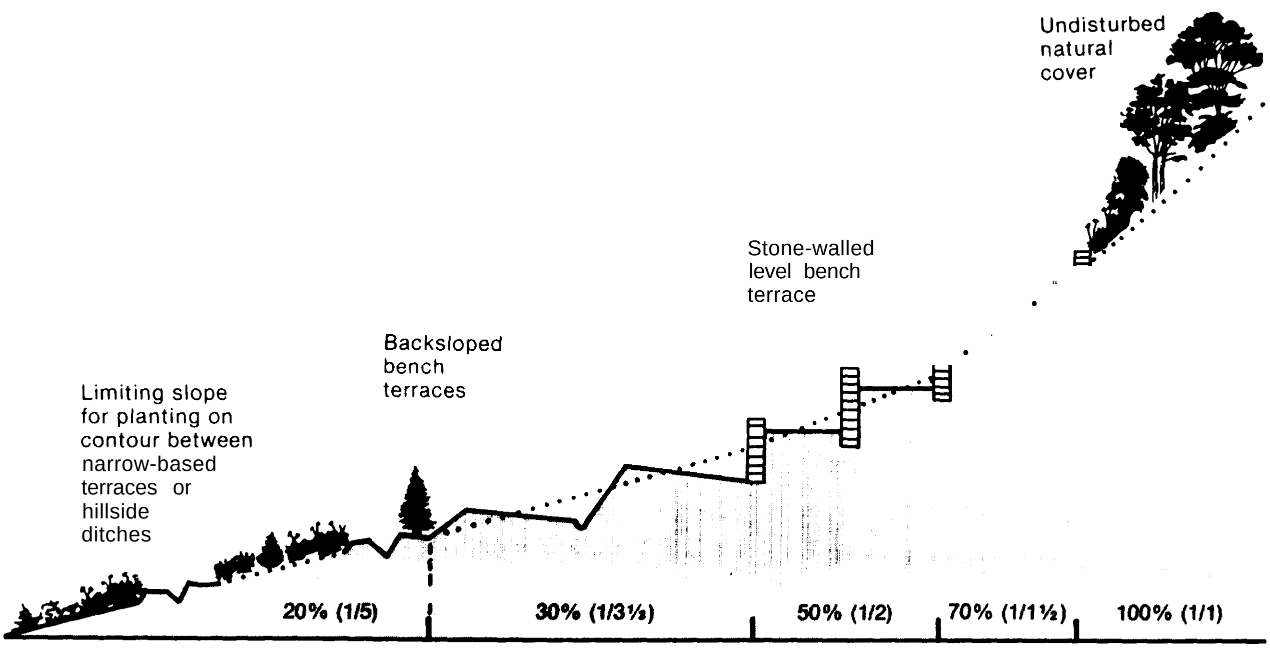
General Technical Principles

The choice of technologies for watershed management and rehabilitation varies with topography, accessibility, and population density. One of the best ways to protect downstream populations from excessive siltation and flooding is to maintain forests on all slopes steeper than 100 percent grade (45 O). Where steep slopes have been cleared, they should be closed to livestock, protected from fire, and then stabilized by planting trees for fuel and fodder, In some cases, simple protection will suffice to permit natural regrowth. For slopes between 100 percent and 20 percent, land should not be cultivated except where the soil is stable and deep. Here, cultivation can be done safely only where level or preferably backsloping terraces are maintained. For slopes less than a 20 percent grade, a variety of agricultural technologies for minimizing soil loss can be used (fig. 29),

In sparsely populated watersheds, where there are few or no people living in the upper regions of river basins, tropical watershed management is a matter of maintaining or restoring the vegetative cover that controls water flows. If forests are intact and populations are low, intensive management is not necessary, The best and least expensive method of protecting these forests is to designate them parks or protected areas. However, effective park management can be difficult to obtain. It should be based on a comprehensive plan that takes into account the previous, current, and future resource needs of people who live around and below the protected forest.

The greatest watershed problems in the Tropics, however, are not in the upper sparsely populated reaches of river basins. They are in populated watersheds, where the upper regions

Figure 29.—Siopes and Appropriate Conservation Measures

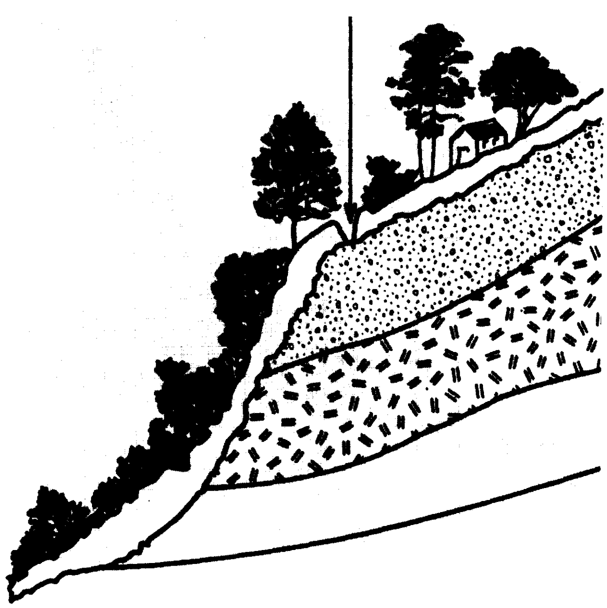


SOURCE: H. C. Pereira, "Soil and Water Management Technologies for Tropical Forests," OTA commissioned paper, 1982, are farmed and grazed, and where maintenance of natural closed forest cannot be accomplished without displacing substantial numbers of people.

In some cases watershed management technologies can be used without displacing people from upland areas. For example, where forests cover steep escarpments below settlements, runoff from the upper slopes can overload the forest soils and cause large-scale landslips, especially on geological dip-slopes (fig, 30). Such landslips are common in Nepal, parts of Zaire, and in other places where sedimentary rock formations are tilted. It maybe possible to stabilize these areas through reforestation and cutoff drains, which intercept and convey runoff to stable drainage lines and, thus, protect the soils from saturation. These drains need to be protected as well, possibly with tree cover.

The most critical need for watershed management occurs in the forests immediately above the limits of cultivation (32). Often, these are under great pressure from population growth. Such forest areas are usually too steep, shallow-soiled, and rock-encumbered for continuous cropping. Yet, agricultural communities have in many countries established traditional rights for grazing or for collection of fuel and fodder from these lands. Massive overgrazing inflicts most damage, often preventing the emergence of any effective ground cover. These activities promote erosion, which consequently forms major gulleys (29). Some areas are so steep and unstable that the only option is to prohibit all active use. In moist forest areas, if soil nutrients have not been eroded or leached away, the ability of the land to recuperate can be high. However, sustainable alternatives must be found for the displaced people, or they will, sooner or later, begin to overuse the slopes again.

Figure 30.-Cut"Off Drain to Protect Steep Forested Scarps From Landslip Hazard



SOURCE: H C. Pereira, "Soil and Water Management Technologies for Tropical Forests, " OTA commissioned paper, 1982.

Tropical forests on land with easy access and gentle topography are likely to be cleared for agriculture or other land uses. When such areas are logged and cleared, soil and water management problems do occur. Governments should restrict the use of more damaging heavy equipment to well prepared roadways. Cable ways, winching, and use of lighter logging and land preparation machinery, though likely to be more costly, can be less damaging to the soil. Operational trials with equipment designed to reduce soil damage should be conducted to test and demonstrate its utility (32).

Specific Technologies

The primary technologies available to deal with watershed problems are those associated with alteration of the surface geometry, revegetation, and improved farming.

Soil Conservation STRUCTURES

A common method to reduce soil erosion from hills in the humid tropics is to change the slope steepness and length. For example, a steep slope can be changed to many continuous flat strips running along the contour across a hillside (terraces), or a long slope can be changed to a series of shorter slopes by using discontinuous types of structure. The objective of both measures is to divert runoff along the contour toward protected drainage channels or waterways at a velocity that reduces erosion,

These and other technologies not only have physical requirements but financial, labor, and land-use rights requirements. The cost of various conservation structures per unit area depends on slope, soil, type of terraces, width of bench, presence of rocks or tree stumps, and the tools needed to build them, Since the structures can be expensive, a cost-sharing or subsidy scheme may need to be introduced by the government. Farmers often are reluctant to invest the time and effort to build such structures because of insecure land tenure. Further, labor often is not available,

Few critical, full-scale studies of terracing have been reported from the Tropics. Many small runoff plot measurements are made, but these do not reproduce the conditions of cultivation by oxen or tractor that determine infiltration, runoff, and erosion on a practical scale.

REVEGETATION

Steep mountain areas that have been cleared should be reforested to protect water and soil resources. If the objective is to stabilize soil and streamflow, the least expensive method is to protect the area from grazing livestock and fire so it can regenerate naturally. In some cases where erosion has been severe, natural regeneration needs to be augmented by seeding with grasses, legumes, and shrubs. More expensive reforestation investments are appropriate where the objectives include production of fuel, fodder, and timber of desirable species; where grasses and shrubs will not provide

Terracing

Terraces not only control erosion but also can be used to facilitate irrigation and drainage, as well as cultivation. Reversed-slope benches, continuous or discontinuous, differ in width to suit different crops and slopes. Benches improve drainage by concentrating runoff at the outside of the bench and then drain it along a controlled lateral gradient to a protected waterway. They are suited to annual, semipermanent, and mixed crops and can be applied on slopes up to 300. Variations of conservation structures include (fig. 31):

- Bench terraces: a series of level strips running across the slope supported by steep risers. These can be used on slopes up to 25° and are mainly used for upland crops.
- Hillside ditches: a discontinuous type of narrow, reverse-slope bench built across the hill slope in order to break long slopes into many shorter ones. The width of the cultivable strips between two ditches is determined by the slope of the land. They are inexpensive, flexible, and can be built over a period of years. This treatment can be applied to slopes up to 250.
- Individual basins: small, round benches for planting individual plants. They are particularly useful for establishing semipermanent or permanent tree plots to control erosion. They should normally be supplemented by hillside ditching, orchard terracing, and crop covering.
- Orchard terraces: a discontinuous type of narrow terrace applicable on steep slopes up to 300. Spacing is determined by distance between trees. Spaces between terraces should be kept under permanent grass or legume cover.
- Intermittent terraces: bench terraces built over a period of several years.
- Convertible terraces: bench terraces with the spaces between terraces planted with tree crops.
- Natural terraces: constructed initially with contour embankments (bunds) 50 cm high on slopes not over 70 and on soils having high infiltration rates.
- Hexagons: special arrangement of a farm road that surrounds or envelops a piece of sloping land treated with discontinuous terraces which are accessible to four-wheeled tractors. This treatment is primarily for mechanization of orchards on larger blocks of land and on slopes of up to 20°.

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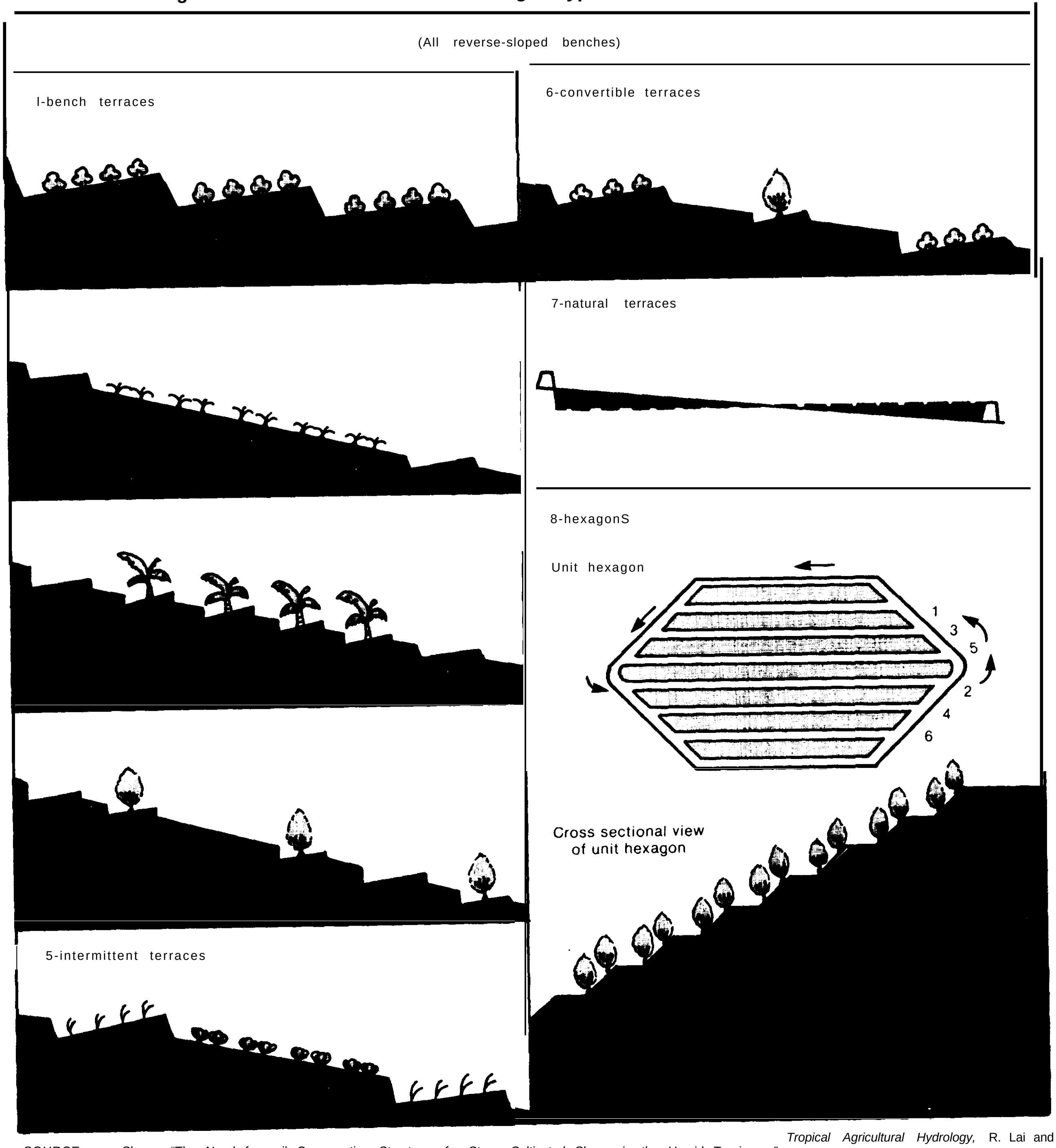
Figure 31.-Cross-Sectional View of Eight Types of Conservation Structures



SOURCE: T c, Sheng, "The Need for soil Conservation Structures for Steep Cultivated Slopes in the Humid Tropices," *Tropical Agricultural Hydrology,* R. Lai and E. W. Russell (eds.) (New York: John Wiley & Sons, 1981), pp. 357-372.

enough runoff control; or where protection from fires cannot be sustained indefinitely.

Efforts to establish tree cover on long steep slopes must overcome the erosion and landsliding that may be common to those sites. For instance, primitive dams made of rock, soil, and, if available, tree stems and branches can be built in gullies to slow water and trap soil until trees can be established. Channels and walls can be built to divert water flow from vulnerable areas. Water-spreading techniques can be used to distribute runoff water over relatively flat areas, reducing its erosive potential, Terracing, contour hedges and furrows, and low retaining walls can control sheet erosion. To establish trees it may be necessary to use contour planting, with graded hillside bunds or narrow-based terraces at suitable intervals to lead runoff into prepared drainage lines.

Perennial tree crops such as tea, oil palm, rubber, or coconut can be almost as effective as natural forest to regulate water flow, provided that soil conservation measures such as terraces and sound engineering of roads are included. Stormflow control, however, may not be fully restored, In Kericho, Kenya, where measurements of runoff from a tea plantation were taken, stormflow peak, although small, remained twice that from a comparable undisturbed forest. Thus, if large areas of forest are to be converted to tea or other estate crops, additional reservoir storage will be needed to modulate peak flows (32),

The same is true for fast growing forest plantations with short harvesting schedules. Care is needed during harvesting to minimize negative impacts. Selection of tree species also is important. ***Eucalyptus,*** for instance, planted close together will eliminate all vegetative ground cover and this can accelerate soil erosion (40). Pure stands of trees that may have their leaves closed during rainstorms, such as ***Leucaena,*** provide only partial soil protection (5), Therefore, it maybe necessary to include a second story of shrubs to minimize the impact of rain drops falling through or from the canopy.

In areas with a dry or seasonally dry climate, flood control and ground water recharge may not be considered so important as maximizing the amount of water delivered to reservoirs or to farms and cities in the lower regions of the watershed. In this case, watershed managers may decide that the closed forest consumes too much water and may prefer to maintain a grass cover, since evapotranspiration loss is greater from tall trees than from low shrubs or grass. On the other hand, in some dry, mountainous areas, trees that collect moisture on their leaves from wet air are the best mechanism to recharge ground water (9). Overall, the negative and positive impacts of grass and tree cover under tropical conditions are poorly known. Grass cover may increase the amount of runoff and flow rates may not be modulated, thus making dams necessary. Improvements in the science of hydrology are needed to provide better data to calculate the tradeoffs of management options,

Complete grass cover is an acceptable vegetation for tropical watersheds only where dry season grazing and burning can be rigorously controlled. Thus, watershed management becomes livestock and fire management as well. A strategy to reduce livestock damage in watersheds should include improving draft power and milk production per head so as to encourage farmers to keep fewer and better quality animals. This can be accomplished by introducing superior animals, by providing effective marketing systems, and by establishing livestock exchange programs. The danger exists that farmers will be encouraged to keep more livestock in addition to or in place of farming.

Fire is used to eliminate old grass growth and improve the quality of grasses for grazing. However, repeated burnings can damage soil by destroying soil organic matter and consequently reducing soil microbiological populations. Human-induced fire is common in grasslands and is difficult to control. If grass is going to be the primary vegetative cover or even the cover while trees are small, methods must be devised to control fire as well as regulate its use.

Encouraging stall or pen feeding also reduces livestock damage. On steep slopes in Pakistan, farmers participating in a reforestation program cut naturally regenerated grass under young trees and carry it to their stall-fed livestock. More fodder is produced this way than when the animals graze the hillsides. Another way to encourage stall-feeding is to provide incentives—e.g., employment of residents to plant fuel and fodder trees and tall fodder grasses on denuded common land and in eroding gullies. Stall feeding also facilitates the collection of manure for use as fertilizer.

However, stall feeding can be difficult to implement. Local constraints can develop such as increased need for labor to carry water, to harvest and transport fodder, and to clean up and spread fertilizer. Therefore, information on who does these jobs (often women) and whether they have time to take on these new tasks should be gathered before implementing such a program.

Fodder supplies can be increased by planting fodder trees or by introducing annual fodder species as a second rotation crop in permanent cropping areas. Fodder trees, pasture grasses, and legumes can be planted on embankments of terraces, on risers of terraced farmlands, near houses, and on other marginal land spots. Once vegetation is reestablished on the denuded site, controlled grazing may be allowable. However, soil compaction by livestock sometimes inhibits later natural regeneration and increases surface runoff, thus causing erosion again.

Livestock management problems in watersheds become more difficult in drier climates. Semiarid lands present the most urgent challenge. They characteristically have higher rainfall variability and greater stresses from temperature and dessication, so the land and vegetation are more prone to rapid deterioration under misuse. Creative measures must be formulated to make it profitable for livestock raisers to limit the number of livestock and to control the timing of grazing.

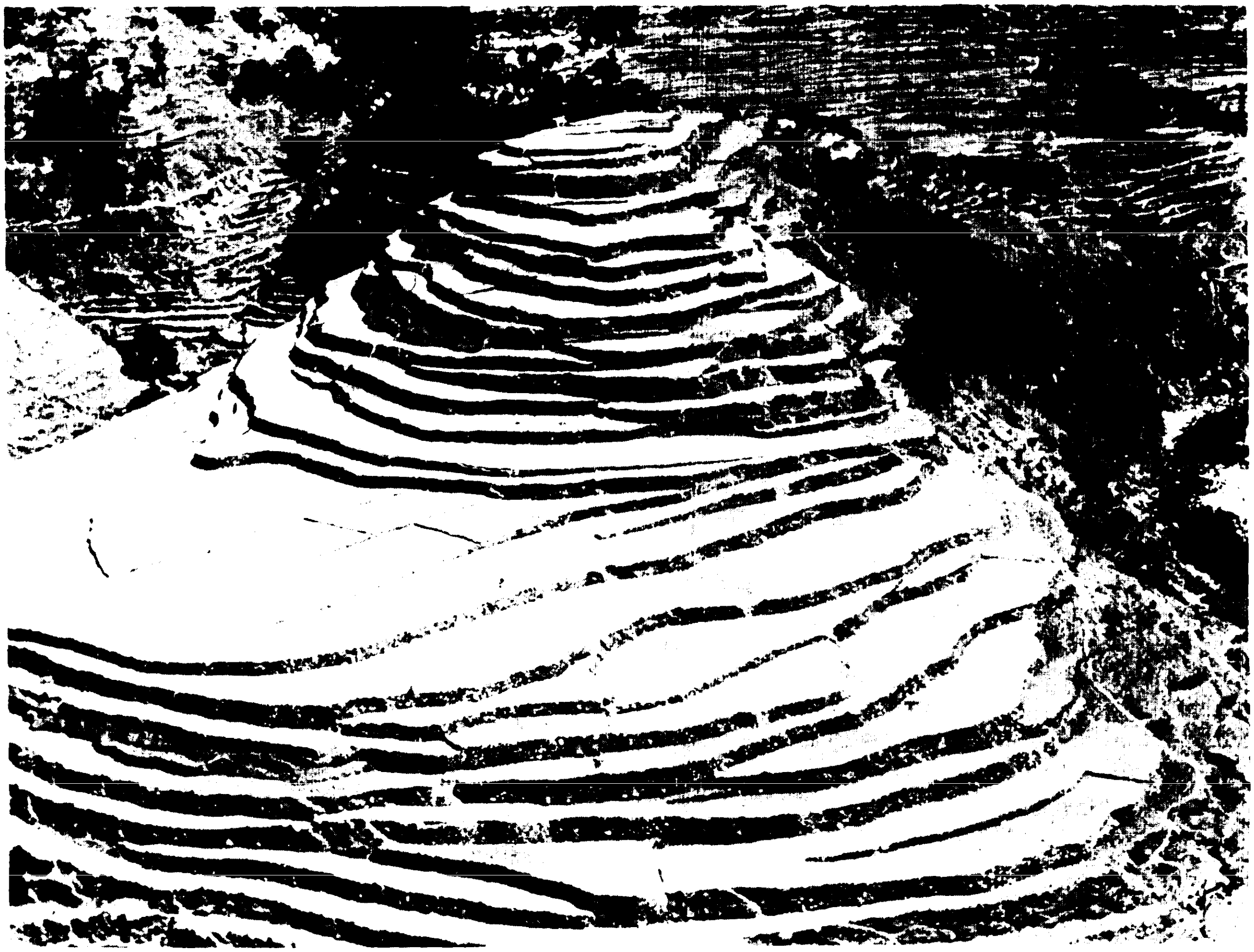
FARMING SYSTEMS

Damage to watersheds is most ecologically and economically significant where subsistence farmers and their livestock move onto steep uplands because they lack other alternatives. Mechanical structures and replanting programs will not be implemented adequately unless farmers and herders have incentives to invest their labor in conservation practices.

Where much of the population in a catchment area is dependent on agriculture, the most effective component of a watershed management strategy may be to increase production per unit area of land on the best sites. Other components include: agroforestry and other cropping systems that eliminate tillage or reduce it, contour plowing, timely sowing of seeds on contours, increasing crop plant density, and using improved seeds, fertilizers, and pesticides (48). On steep slopes farmers can be encouraged to plant hedges of nitrogen fixing trees or bushes on the contour, adopt mulching techniques, and interplant with legumes and pulses to reduce sheet erosion. In some places, fodder tree farming or bamboo plantations may be appropriate (39).

Some constraints to adoption of these practices are the farmers' skepticism toward new technologies, lack of capital, lack of infrastructure for effective input distribution, and lack of agricultural and forestry extension services to accelerate the diffusion of new technologies. Before new technologies are introduced, anthropological studies are needed to define the current practices, including what rewards people are getting, what shortfalls they are experiencing, and what benefits they expect from technology improvements. Both technical agents and local residents need to understand the incentives for change. Residents must be convinced that the benefits will be what they want if their cooperation is to be gained.

Inducements that can improve the quality of life for farmers living in upland watershed areas and encourage shifting cultivators to adopt more stable agriculture practices in-



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elude: compensatory payments to farmers excluded from upland grazing areas; timely provision of inputs such as improved seeds, fertilizer, and credit; construction of improved access roads and feeder tracks; and the provision of social services, such as improved water supplies, schools, and health clinics. Such social measures, on the other hand, can have adverse effects unless combined with rigorous exclusion of people and livestock from the steepest slopes. Improved amenities may attract larger populations into areas of critical hydrological sensitivity.

Constraints and Opportunities

Upper watersheds tend to be misused because destructive land-use systems usualIy give the greatest profit in the short term to the local population. The solution to this problem necessitates: 1) developing methods of land use that are more profitable to the local community and at the same time give appreciably better control of water flows, and 2) testing the new technologies and getting them adopted by the local community. New systems that minimize ecological damage will be accepted willingly only if people can see that it will maintain or increase their standard of living without an increase in the risk of crop failure.

The key issue in watershed management is not the construction of physical structures but the need to provide people with improved land-use alternatives. Therefore, a high proportion of total watershed project investment should be devoted to farming systems and institutional components rather than to soil conservation structures or infrastructure.

The additional labor and capital costs often incurred by new resource conserving systems are a major constraint to watershed management. Furthermore, farmers in the upper reaches of river systems generally do not accept responsibility for damages their land use may cause to farmers in the lower reaches. Conversely, lowland farmers rarely consider that they have a duty to help finance upland farmers to adopt better systems of land use. Watershed management projects usually have been designed to benefit people in the more fertile lowlands and have neglected those in the uplands whose lives are being affected more directly. This implies that some of the benefits gained downstream should be transferred upstream through taxes or perhaps user fees on irrigation water or hydropower.

Finally, there are several important unknowns regarding the hydrology of tropical watersheds. There is a dearth of first-hand research evidence in the Tropics documenting the quantitative relationships between various land uses and their effects on watershed hydrology (20).

The techniques for measuring and predicting tradeoffs of different management actions—e.g., grass cover versus tree cover—are not well developed. For moist climates, trees may be the best cover; for dry climates, grasses may be the best cover if fire and grazing control are practical. But for much of the Tropics, the choice is not clear. If more water rushes off grass-covered surfaces, less will be absorbed into the ground. Therefore, improved field methods for diagnosis and interpretation of watershed hydrology problems are needed to improve management decisions. The interactions of the many variables are too complex to expect neatly classified prescriptions for watershed management. Some basic measurement could be included in all major projects that lead to changes in land use in order to build a more adequate data base for predicting outcomes.

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