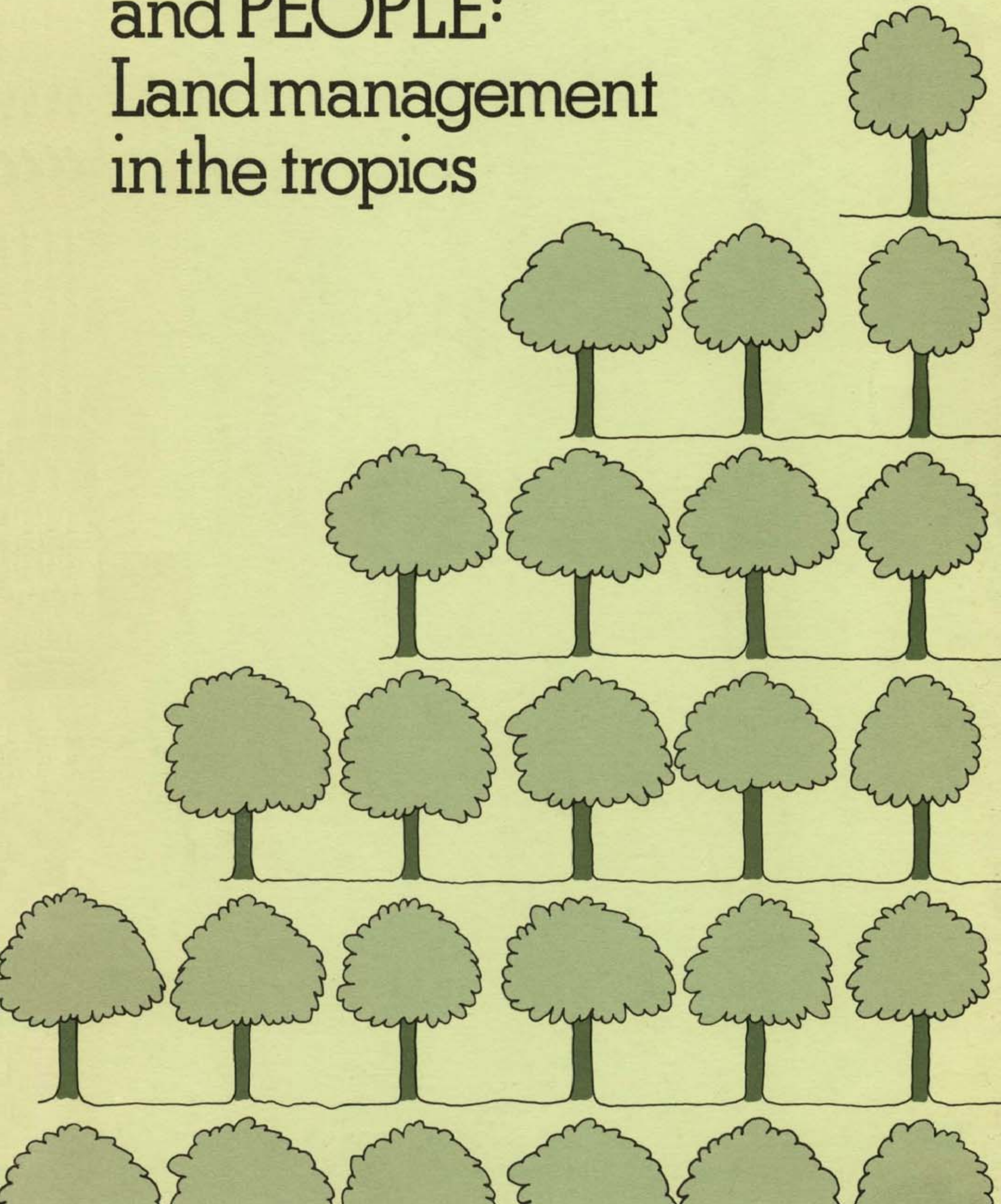
J.G. Bene, H.W. Beall and A. Côté

IDRC-084e

TREES, FOOD and PEOPLE: Land management in the tropics



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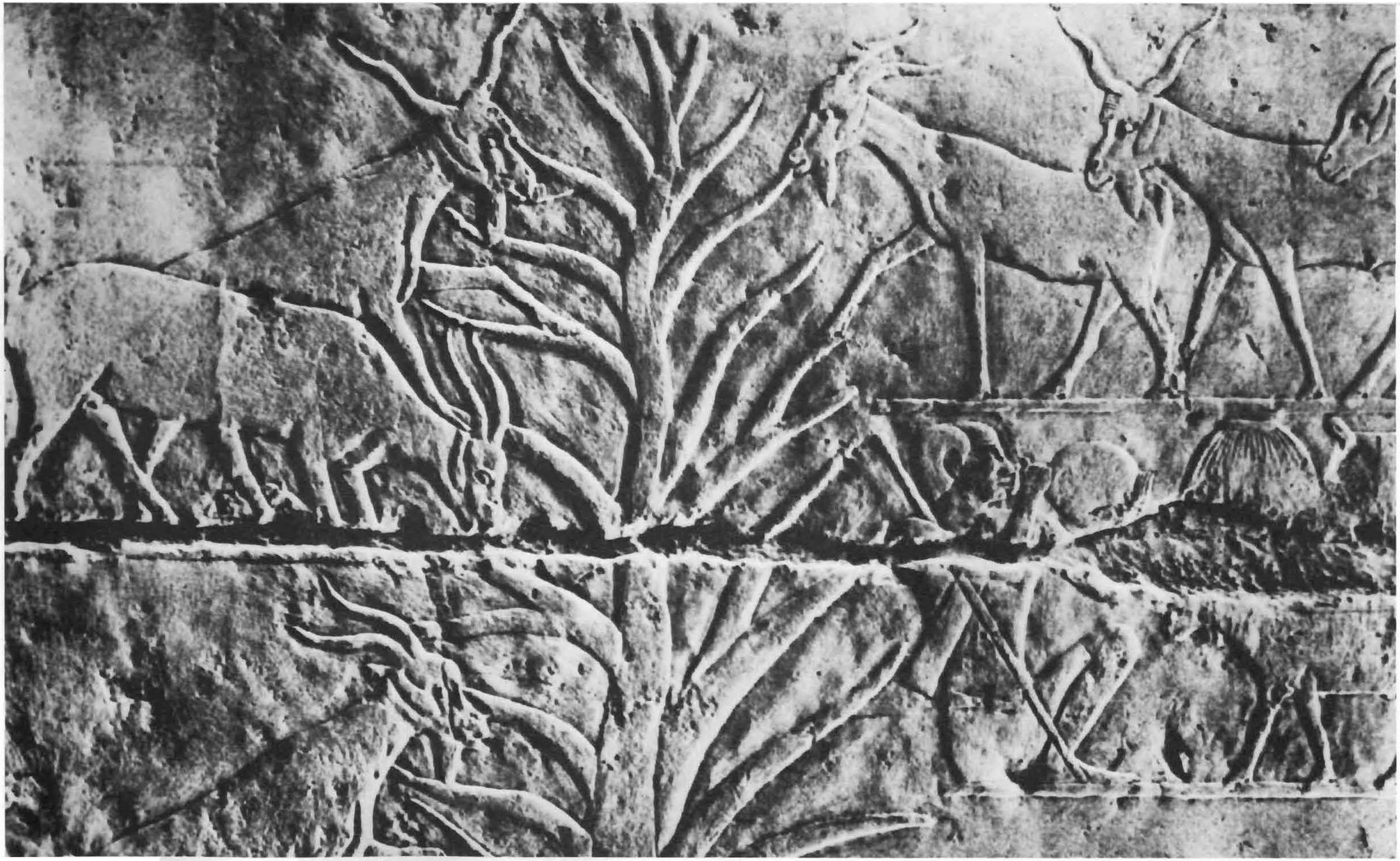
*"The forest is a peculiar organism of unlimited
Kindness and benevolence that makes no demands
For its sustenance and extends generously
The products of its life activity; it affords
Protection to all beings, offering shade even
To the axeman who destroys it."*

Gautama Buddha



Bas-relief from ancient Egypt shows that uncontrolled pasturing of livestock is an age-old problem (FAO photo).

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Trees, Food, and People:

Land management in the tropics

J. G. Bene, H. W. Beall, and A. Côté

Contents

Foreword

The immense and varied potential of the trees in the tropics is in striking contrast to the modest contribution that they now make to human welfare. Opportunities are challenging to make better use of the services and products of the forest, and to prevent the forests misuse and destruction. The potential exists to improve life for all mankind and especially that of rural peoples.

Research into tropical forestry has been stepped up recently, but no consensus has yet emerged on priority objectives. The worldwide effort remains uncoordinated, with many important gaps and serious duplications. In an effort to remedy this situation the International Development Research Centre, in July 1975, set up a project for the identification of tropical forestry research priorities to:

(1) identify significant gaps in world forestry research and training;
(2) assess interdependence between forestry and agriculture in the low-income tropical countries and propose research leading to the optimization of land use;
(3) formulate forestry research programs that promise to yield results of considerable economic and social impact on developing countries;
(4) recommend institutional arrangements to carry out such research effectively and expeditiously;
(5) prepare a plan of action for international donor support.

Using the collected background information and our assessment of research needs and priorities, courses of action have been recommended that we feel are most likely to achieve the desired results. Although the initial assignment stressed the identification of research priorities in tropical forestry, the study led to the conclusion that first priority should be given to combined production systems integrating forestry, agriculture, and/or animal husbandry to optimize tropical land use. Therefore, there is a shift in emphasis from forestry to broader land-use concepts within the text.

Acknowledgments

An advisory committee was formed early in the life of the project. Those who kindly agreed to serve on it were Drs A. Lafond, L. G. Lessard, J. C. Nautiyal, D. R. Redmond, Messrs R. W. Roberts, J. Spears, and Dr H. A. Steppler. The committee held two formal meetings, and the advice it provided at all stages of the project's development was invaluable.

Of great assistance, too, were the regional consultants who undertook to canvass informed opinion and make recommendations regarding forestry research needs in different areas of the tropics. The consultants were Prof J. D. Ovington in Australia, Dr F. S. Pollisco in the Philippines, Prof L. Roche in Wales dealing primarily with Africa, and Dr A. Samper in Colombia who was assisted by Drs R. Peck, A. Delgado, and J. Ortiz-Silva.

A workshop arranged by Prof Roche at the University of Reading, under the able chairmanship of Prof H. Bunting, included some 20 experts in tropical forestry and related disciplines. It made a very real contribution in moulding the content of this report, as did a subsequent meeting of potentially interested donors in Paris, chaired by Mr J. H. Hulse.

It would be invidious to single out the names of other individuals from the large number who were consulted by the project team at different times and on a wide variety of subjects. Some were contacted personally, others by correspondence, and all gave generously of their time and advice. Among the organizations they represented were the International Development Research Centre; the Canadian International Development Agency; Environment Canada, and other Canadian federal and provincial government departments; the United States Department of Agriculture; the Food and Agriculture Organization of the United Nations; the United Nations Development Programme; the United Nations Environment Programme; the United Nations Educational, Scientific and Cultural Organization; the Organization for Economic Cooperation and Development; the International Bank for Reconstruction and Development; the International Union of Forestry Research Organizations; the Centre Technique Forestier Tropical, the Pulp and Paper Research Institute of Canada, the Royal Tropical Institute, the Tropical Products Institute, and other research institutions; several bilateral aid agencies; universities in both developed and developing countries; and members of the consulting profession. The guidance of agriculturists and other nonforestry specialists was extremely helpful at all times, and especially in the second phase of the study.

To all the foregoing, and any who may have been inadvertently missed in the above list, the authors express their sincere thanks and appreciation.

As might be expected in dealing with so complex a subject and one on which so much basic information is lacking, expert opinion was by no means always unanimous. The views of all were taken into account, but there are many points on which the report does not reflect the opinions of all who contributed to it.

The Tropical Forest — Overexploited and Underused

Of every 10 people living on planet Earth, about four live in the tropics. For thousands of years and until the beginning of the 19th century, not much has changed in this region. Under the hot equatorial sun, and mostly well watered by torrential rains and helped by a year-round growing season, a rich and varied vegetation dominated by trees and an equally heterogeneous fauna developed and maintained itself within a complex ecosystem in which ". . . a remarkably stable balance between plants, animals and the physical environment" has been achieved (48). Although the diversity of the tropical rain forests of the world and the rich genetic pool they contain provide a resource of vast potential, the varied nature of this resource poses special problems of development.

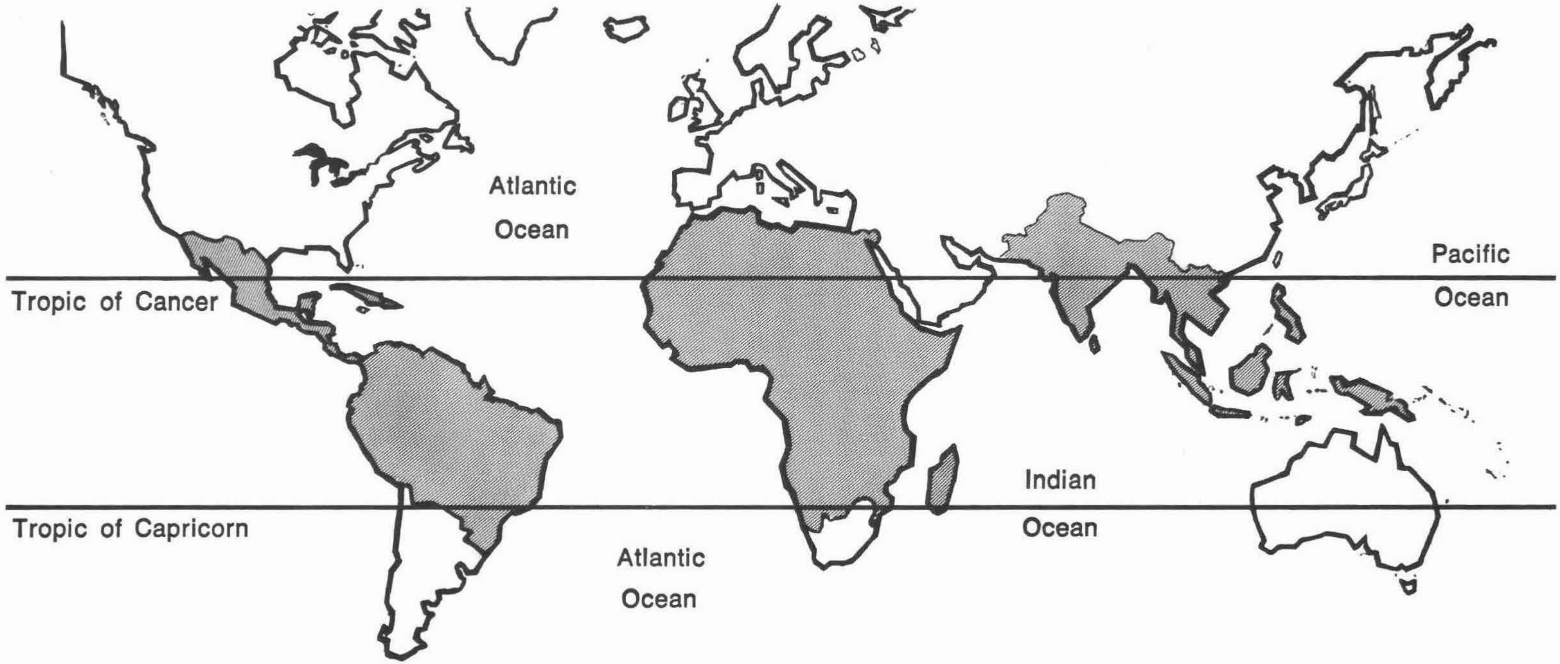
Since the beginning of the 19th century the voracious appetite of the industrial countries, and more recently the inroads of a quickly increasing population, have been transforming the tropical landscape, and this change threatens to destroy the resource base on which the livelihood of the population depends. It has been predicted that within the next 25 to 30 years most of the humid tropical forest as we now know it will be transformed into unproductive land, and the deterioration of the savanna into desert will continue at ever-increasing speed. This should not, and must not, happen.

Research to sustain larger food yields on tropical lands has been exceptionally rewarding, but there has not been a matching research effort in the tropical forest. Although this multi-storey forest is potentially the most productive system under the tropical sun, it remains one of the least understood ecosystems on earth.

By applying already available knowledge, by filling in crucial gaps in our understanding with well-focused research, and by respecting the seeming fragility of the tropical soils, natural resource destruction can be arrested and a greatly increased production of natural raw materials can be sustained.

Extent and diversity of the tropical forest

About one-third of the land surface of our planet is forested (42) and more than half of these forests are in the tropics (1). Not long ago at least 3.5 billion of the 4.9 billion hectares of land in the tropical belt was covered with trees, but most of the vegetation on about 1 billion hectares has been destroyed and the area turned into unproductive wasteland (48). Estimates of the tropical tree cover differ widely, ranging from less than 1.5 billion hectares (16) to more than 3 billion hectares (48); however, 2.5 billion hectares is probably a reasonable compromise (3).



Not all developing countries are in the tropics, and not all countries in the tropics are underdeveloped; however, it does not distort the facts too much if we assume that the tropics are the "home ground" of the developing world. The shaded area on the map identifies the tropics for the purpose of this book

Depending on soil, topography, available moisture, human intervention, and many other factors, tropical forests vary greatly in their composition, stand density, and growth rate. In fact, differences between ecological regions within the tropics may be as great as those between tropical and temperate ecosystems (38).

> ***... it has been predicted that within the next 25 to 30 years most of the humid tropical forest as we now know it will be transformed into unproductive wasteland, and the deterioration of savanna into desert will continue at ever-increasing speed ...***

The complexity of tropical forests is reflected by the numerous systems that have been developed for classifying them. One way to group them is according to the quality, amount, and periodicity of water available for the trees:

(1) *mangrove forests* grow throughout the tropics on sheltered seacoasts and along river estuaries where brackish water inundates the forest floor twice daily. The area they cover is relatively small, probably less than 5%, although no global estimate has been made.

(2) *tropical rain forests* grow in regions where precipitation exceeds evaporation for more than half of the year (15). Their total size is variously estimated as 550–850 million hectares, about 27% in West and Central Africa, 27% in Southeast Asia, and 46% in Latin America (15). They contain the most luxuriant tree growth and the greatest diversity of plant species, mostly trees.

(3) *tropical forests in areas of seasonal rainfall, mainly with closed canopy,* are estimated to cover an area of about 1.45 billion hectares (48) and are found where seasonal rainfall ranges from 200 to 1250 mm during one or two rainy periods, which are separated by severe dry periods lasting 4–10 months and having less than 25 mm of rain per month (41).

(4) *open woodland (forêts claire), savanna, shrub, or protection forests* (27), with an open canopy and usually in a transition stage to domination by grasses or brush. This condition may be due to low rainfall, but in most instances is caused by fire and other misuse of the land. There are about 400 million hectares of this kind of forest.

When one attempts to differentiate forest from agricultural and other lands, the problem of classification is further compounded in the tropics by extensive multiple uses, such as the joint growing of food crops and forest trees, and seasonal grazing of livestock in semi-arid savannas. Thus the land area classes shown diagramatically on page 21, adapted from Sommer (43) and other sources must be regarded as very approximate. The need to

Towering trees dominate the undisturbed natural forest (photo J. Redden).

develop better estimates of the areas of forest and other forms of land use in the tropics is clearly evident, and will increase as land-use planning develops.

Environmental Significance of the Tropical Forest

Far-reaching claims have been made about the tropical forests' impact on precipitation, oxygen production, and the carbon dioxide (CO_2) balance in the atmosphere. None of these claims has been substantiated (48), but undoubtedly trees take up large quantities of water that are later released into the air as vapour. The tree crowns intercept rain and nutrients, and the lateral roots, which may extend for 100 m, absorb components of the decomposing forest litter and limit leaching of the soil by heavy rains. In addition, tap roots penetrate to a depth of 30 m or more (18) and retrieve water and dissolved minerals.

Trees also reduce and even out the temperature near the forest floor, and provide shade for the relief of man and beast from the tropical sun. Tropical forests harbour and nourish a wide variety of fauna and flora, and constitute one of the largest and most diversified reservoirs of gene resources. As windbreaks, trees inhibit wind erosion, reduce desiccation, and even out runoff. Indeed the role of the forest as a soil stabilizer, affording protection both against water and wind erosion, is of major importance in maintaining environmental quality.

Climate, landform, soils, and other environmental factors influence the productivity of the tropical forest, at times in very unexpected ways. There is a limit to the rate of tree growth as air temperature increases. When the temperature exceeds 30 °C, growth processes become essentially as inactive as when temperatures are below freezing (46). Cloud cover over humid lowlands lowers photosynthetic activity and high night-time temperatures increase respiration losses.

The reduction in tree growth that occurs where the moist tropical forest merges into the savanna woodlands is well known. Less clearly recognized is the fact that where the dry season is brief or nonexistent, waterlogged soils are continuously leached of soluble nutrients and undergo oxygen (and nitrogen) stress and restricted root development, which also reduce the rate of growth.

Only recently has it been recognized that variations in local climate resulting from minor differences in elevation and exposure may have a marked effect on tropical vegetation (46). Within the tropical belt, intermediate moisture regimes in the higher latitudes and middle elevations, with longer periods of daylight, fewer clouds, and cool nights, create optimum growth conditions.

Photosynthesis is the process by which green plants use solar radiation as energy to convert carbon (from carbon dioxide in the air) and water into wood fibre, leaves, flowers, fruits, and seed. More than 90% of the dry weight of trees is derived from photosynthetically fixed CO_2 (54). The use of photosynthetic plants is by far the simplest way for man to collect and store solar energy. Most trees convert less than 1% of the incident sunlight into biomass, i.e. the total quantity of matter in the plant. However, indications are that trees with high photosynthetic efficiency and low photorespiration rates can be found or bred that will convert a substantially larger percentage of the sun's energy into biomass (43).

Tree Production Systems

Natural forest

Tropical forests are highly diverse communities, at times with more than 100 species found on a single hectare. The properties of tropical woods cover an enormous range of weight, strength, durability, colour, pattern, and other characteristics. With modern technological practices the wood of more than 1200 tree species is commercially valuable (12).

In the absence of rings, growth rates are difficult to ascertain in the natural forest of the tropics, but there is convincing evidence that, with proper management and sound silvicultural practices, yields of tropical forests may be doubled or even further increased relative to present conditions (11). Thus yields in managed indigenous tropical forests under favourable conditions could be made to approximate those in fast-growing plantations without incurring the risks inherent in extensive monocultures.

Some natural forests have been found to contain a biomass of over 1700 tonnes per hectare. The natural forest produces a total biomass of up to 50 tonnes (dry matter equivalent) per hectare per year of a very diverse and unpredictable mix of plant matter. The overall average increment of tree stems in tropical forests has been estimated as about 4 cubic metres per hectare per year (4 m^3/ha/yr), though in some forests it is probably more than double that figure (7). However, in an undisturbed mature forest there is, in fact, no net growth.

Much research remains to be done in tropical silviculture, including regeneration methods, tree breeding and tree improvement, effects of intensive culture on soils and moisture regimes, measurement of growth and yield and their response to various silvicultural treatments, and the protection and care of the forest crop. Except for a few special types of tropical forest, economical methods of management have not yet been developed that assure the regeneration of preferred species. The tropical forest is highly susceptible to change by man: forest clearance, intensive grazing, fire, or introduced pests may permanently alter the vegetation.

Plantation forest

Probably less than 1% of all tropical forests are plantations (33), but indications are that this percentage will increase in the future because of the advantages to be derived from the increased mechanization that is possible in both the growing and utilization operations with a more uniform and productive crop.

Man-made forest in the Ecudorian highlands (FAO photo).

It has been demonstrated in many tropical countries that planting of tree species carefully chosen for their capacity for quick growth with respect to local soils and climatic conditions will yield a large volume of wood in a short time. Also it is usually easier in a man-made forest to improve forest management, since management prescriptions are simpler and better use can be made of unskilled labour. Plantations can be sited most advantageously to overcome the lack of transport and community services characteristic of the developing countries of the tropics.

However, despite the many successful examples, monocultures are generally more vulnerable to specific diseases and insects than are mixtures. They depend on the selection of good planting stock and careful planning to assure that the trees will serve societies' needs when they are harvested. Clearing the land, raising the seedlings, planting, and tending are expensive operations and require the investment of large sums of money. Sometimes it is many years before returns are realized from the sale of the crop.

Combined production systems

Without the protection of trees it is often difficult to sustain annual food crops in the high rainfall tropical areas. Nutrients are rapidly leached from the tropical soils, and the cost of replacing them with fertilizer is high and requires much energy in a world in which energy is becoming increasingly more expensive.

Combining the growing of certain trees and agricultural crops on the same land or growing them sequentially is the best means of preserving the fertility and structure of many tropical soils. Probably it will also produce the greatest return to the farmer in the long term. Trees protect the fragile soil from extremes of sunlight, searing winds, and torrential rain. They also protect watersheds and water courses and so are important to freshwater and coastal fisheries.

A sequential system of growing trees and food crops called "shifting agriculture" (also variously known as swidden cultivation, slash-burn agriculture, Kaingin, ladang, chena cultivation, etc.) has been practiced by small farmers since time immemorial. The land is left to revert to brush after the food crops have exhausted the nutrients in the expectation that it can be soon cropped again. If under the relentless pressure of increasing population the interval between cropping becomes too short, soil fertility is not fully restored, the brush and young trees grown during the fallow have little wood value, and rapid degradation of the site commences (19).

A variation of this system has been introduced by foresters to reduce the cost of reforestation. Under the Taungya system, the land is farmed for 2 or 3 years and young trees are planted, often with the last agricultural crop, so that when the crop is harvested the trees are well established and able to outgrow the subsequent weed invasion. But, where trees are left to grow for 40 years or more (e.g. teak and mahogany), agricultural crops are grown for only a very small porportion of the time.

In an effort to improve either tree crops or annual crops, or both, the latter are sometimes grown under widely spaced trees, which provide light shade, leaf litter, and in some instances biologically fixed nitrogen for the soil. Other variations of this system include the intercropping of leguminous trees, grown for their soil-enriching capability and for their wood, with agricultural crops, trees, or bushes that produce food or industrial raw materials.

In regions of seasonal rainfall (250 mm or more per annum) judicious interplanting of *Acacia albida* trees increases millet yields by 500–600% (4). Pasturing livestock between trees is another way to secure a greater return from the land. As well, fish farms are successfully operated within the mangrove forests.

Opportunities such as these to increase production and improve efficiency by growing trees in combination with other crops or livestock are great indeed, are rarely recorded, and have been only partly explored. Successful groupings of plants and management methods in one area remain unknown in other parts of the world where they could bring great benefit to farmers.

Interplanting corn with *Leucaena* or some other leguminous trees could boost grain production significantly. "Miracle" trees may combine rapid growth with high nitrogen-fixing capacity, while themselves producing edible fruit, buds, pods, and leaves or other valuable material. Identifying such trees and ascertaining their effective ecological zones is a worthwhile objective.

Rehabilitation of degraded forest land

About 1000 million hectares of once-forested tropical land have been turned into semidesert during recorded history (48). In most of these regions annual rainfall is less than 700 mm and the dry seasons are very long. Vegetation on millions of hectares is destroyed each year, mostly by overcutting the forest and brushland for fuel, burning the grassland to create better pastures, and overgrazing. Once the vegetation is stripped, wind and water erosion quickly remove the thin layer of fertile soil making rehabilitation difficult and sometimes impossible.

Generally, the process of rehabilitation is slow, gradual, and labour-intensive. If the land is protected from abuse, some vegetation will slowly reestablish itself without any help. Where trees are planted, careful nursing is necessary until the roots have penetrated deep enough to reach moisture. They may require occasional irrigation during the first few years after planting, and protection from grazing and grass fires.

Nevertheless, with appropriate planting and careful management, much of this wasteland can be rehabilitated and made to produce good crops. Unless irrigated, wood production may be as low as 0.1 m^3/ha/yr (41), but every twig is of value to people starved for fuel and desperate for building material. A wide variety of drought-resistant plants producing fuel and protein-rich food and feed are known. Cashew trees grow nourishing nuts and fruit. Some acacias provide valuable exudates such as gum arabic. Other plants afford shade, produce edible pods and leaves, and improve soil fertility. On the coastal plain of Peru, trees condense water from the atmosphere and make agriculture possible in a nearly rainless region.

Shifting hillside agriculture — prelude to erosion (FAO photo).

Often a good way to revegetate is to combine drought-resistant browse plants (such as *Chenopodiaceae* and spineless cacti) with trees. The browse plants are the main source of fodder for livestock, as are the pods from the trees; and the tree leaves serve as drought reserves when other feed is not available (20). It may be necessary to import fuel for a few years into districts where reforestation takes place to prevent the premature cutting of the young trees.

Wisely managed semi-arid areas will grow two to three times more biomass than unmanaged land produces (21); on the other hand, overusing the land leads to rapid and complete destruction of all vegetation.

Where rainfall is seasonal and uneven the forest is especially vulnerable to overcutting, careless logging, and fire. Huge expanses of *Imperata* grass and other useless secondary vegetation in well-watered regions demonstrate the dangers of massive forest clearance and the need to retain some forest cover. If in the humid tropics the tree canopy is removed too quickly, weeds will take over and prevent natural regeneration of trees. Methods of rehabilitating these lands are only partly explored and seldom applied. Further research is urgently needed to find economical ways to reforest potentially productive lands.

... wisely managed semi-arid areas will grow two to three times more biomass than unmanaged land produces ...

Strong leadership and political will are required to direct scarce resources of money and labour into revegetation because returns are slow. Education of the people toward the wise use of the land to achieve optimum production and to stop short of overuse is of the highest priority. Success will require that the foresters join with other land managers, social scientists, and politicians in cooperative land-use schemes.

Utilization of the Forest Resource

The indigenous population who lived in the tropical forest was usually small and survived by collecting fruit, nuts, and edible leaves and flowers and by hunting for bush meat. To augment the diet, annual food crops were grown by shifting agriculture. Such situations are now threatened either because of population increase, exploitative logging, the opening up of forest land to new settlers for agriculture, or as a result of road building into formerly remote areas.

Today, as population increases, the period of fallow becomes shorter and the soil fertility is not fully restored. New clearings are created and abandoned with ever-increasing speed. This shifting agriculture results in the annual destruction of an estimated 10 million hectares of high forest and a steady decline in the fertility of the land (26).

Population growth is often high in areas of seasonal rainfall where agriculture can be sustained on the better soils if enough water is available. Most of these areas have been cleared of forests, except where the soils were too poor or too dry for agriculture. Under the onslaught of an ever-increasing demand for firewood these trees too are quickly disappearing, and villagers have to walk ever farther to collect firewood. Reforestation is jeopardized by the hungry hordes of goats and cattle, and the few saplings that escape the animals are destroyed by the annual grass fires.

Another kind of attack on the forest is mounted by loggers in search of a few highly valued trees in the humid tropics. "Dye woods" were sent from Brazil and Central America to Europe as early as the 16th century. Mahogany logs to be sawn into lumber were shipped from Cuba to Western Europe early in the 19th century and the furniture produced became a status symbol of the rich. The ability of Central American countries to supply mahogany was soon overtaxed and the search for "bois rouge" was extended to all of the tropical world. Similarly coloured logs, misnamed African or Philippine mahogany, were exported in ever-increasing quantities to Western Europe and North America. Other tropical woods also became fashionable because they had interesting grain or were resistant to insects, or simply because they had a good odour.

Unfortunately, only a small fraction of the tree species occurring in tropical forest mixtures is known to possess these desired properties and the loggers tend to be highly selective, taking only the best stems. As little

Fuel for cooking is becoming increasingly scarce and expensive (photo N. McKee).

as 3%, and probably on the average about 15%, of the wood volume is used for industrial purposes. Too often the best is cut and the worst reproduces so that there is a progressive decrease in quality. In the harvesting process many of the remaining trees are damaged or destroyed and the forest is severely degraded. This is especially common where the entrepreneur is under no obligation to protect the growing stock, or is inadequately supervised because of a shortage of trained foresters.

> ***... in the Ivory Coast, logging and shifting agriculture are estimated to destroy 400 000 hectares of forest each year ...***

This "creaming," frequently repeated,as well as shifting agriculture, leads to a gradual impoverishment of the forest and brings about the destruction of the forest cover. For example, in 1974 the Ivory Coast exported about 4 million m^3 of logs. This rate of logging, combined with shifting agriculture is estimated to destroy 400 000 ha of forest each year, and could lead to the destruction of the forest in about 15 years' time (44). The tragedy is that the export of choice timber from the humid zone benefits only a few people in developing countries, and not enough revenue is generated to pay for reforestation or to replace the trees with another productive crop.

Exports of tropical wood to industrialized countries are increasing rapidly. They more than trebled during the decade starting in 1962, but even so had reached only 16% of the world's total trade in forest products in 1974 (14). In Sabah, East Malaysia, 60% of all government revenues are derived from log exports, and in the Ivory Coast, forest products are the second largest export item (after cocoa). In Indonesia, log exports sky-rocketed from 1.5 million m^3 to 18 million m^3 between 1968 and 1974 (14). What these figures do not disclose is that increased exports arise from the liquidation of forest capital , and that the present rate and method of exploitation could lead within the next few decades to the disappearance of the tall, closed-canopy tropical forest as we know it.

It is urgent to reorient forest management and utilization to serve the short-term needs of the developing world while ensuring, where it is not yet too late, that the capital resource is not so depleted as to restrict future options and jeopardize the welfare of future generations. Using the less valuable trees for fuel, encouraging local manufacture of lumber and plywood for structural as well as for decorative uses, harvesting smaller, younger trees just after the annual increment has passed the maximum, and reducing wasteful utilization are some of the steps that will achieve these ends.

The broadening role of the forester

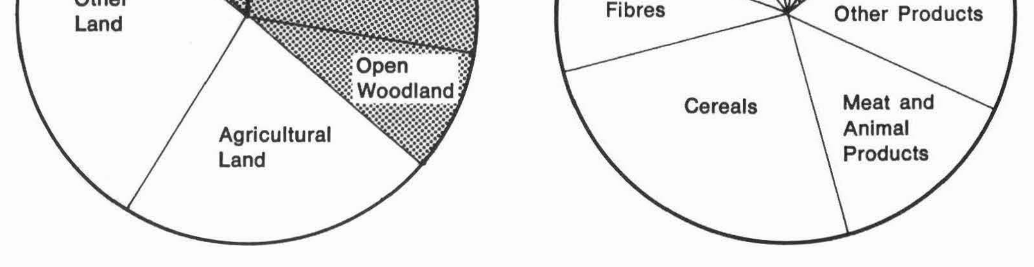
Lands on which trees predominate are usually managed by foresters. Hitherto largely trained in industrialized countries or with the bias of industrialized countries, they have too often been concerned with producing choice quality logs for export. This tendency has been aggravated by staff shortages, so that foresters have not been able to pay as much attention as they would have liked to other uses of the forest.

Although recognizing the need to apply forest management systems to assure a sustained, increasing timber yield, foresters must fulfill a multiplicity of roles and integrate forestry with other forms of land use as society requires. They must work with farmers and agriculturists to obtain more wood, food, and feed from the forest, and to grow food crops and trees in sequence or in combination on the same land while maintaining productivity. They must teach the loggers how to remove trees without jeopardizing regeneration; they must join interdisciplinary teams to solve forest management problems arising from various forms of land tenure; and they must show that the well-being of the people depends on good forest management.

The interests and responsibilities of forest land managers must be expanded to include the management of trees in any production system, not only where the product is wood, fruits, or industrial commodities such as rubber or kapok, but also where the prime function of the trees is to provide shelter for agricultural crops or to protect water catchments.

Present and potential utilization

The net primary production per hectare of the tropical forest is larger, but not much larger, than that of the temperate zone forest. The explanation for this is that not only is the proportion of usable stem wood lower but the loss through respiration and biological deterioration is very



Tropical forest areas and commodity values — a comparison: A. approximate distribution of the land area of the tropics (13, 14); B. contribution of commodity groups to the total value of the renewable natural resources sector of the developing countries, 1970 (47).

much higher in the tropics (7). Despite such losses, well-managed plantations have demonstrated that on good sites up to 40 tonnes of dry wood substance production per hectare per annum can be sustained. In the humid tropics the natural forests add 6–12 tonnes/ha/yr, but the annual yield drops to 2 tonnes/ha/yr or less in drier sites in the savanna.

FAO estimates the growing stock in developing countries as 166 billion cubic metres (b m^3) (29). The total annual stem and branchwood increment has been estimated to be as high as 9 b m^3, or about 4 m^3/ha/yr (7), which is roughly equivalent to 3 tonnes/ha/yr of dry wood substance. Ten-year-old plantations of *Eucalyptus deglupta* in Papua New Guinea have been recorded as having current annual volume increments of 51 m^3 of stemwood/ha/yr.

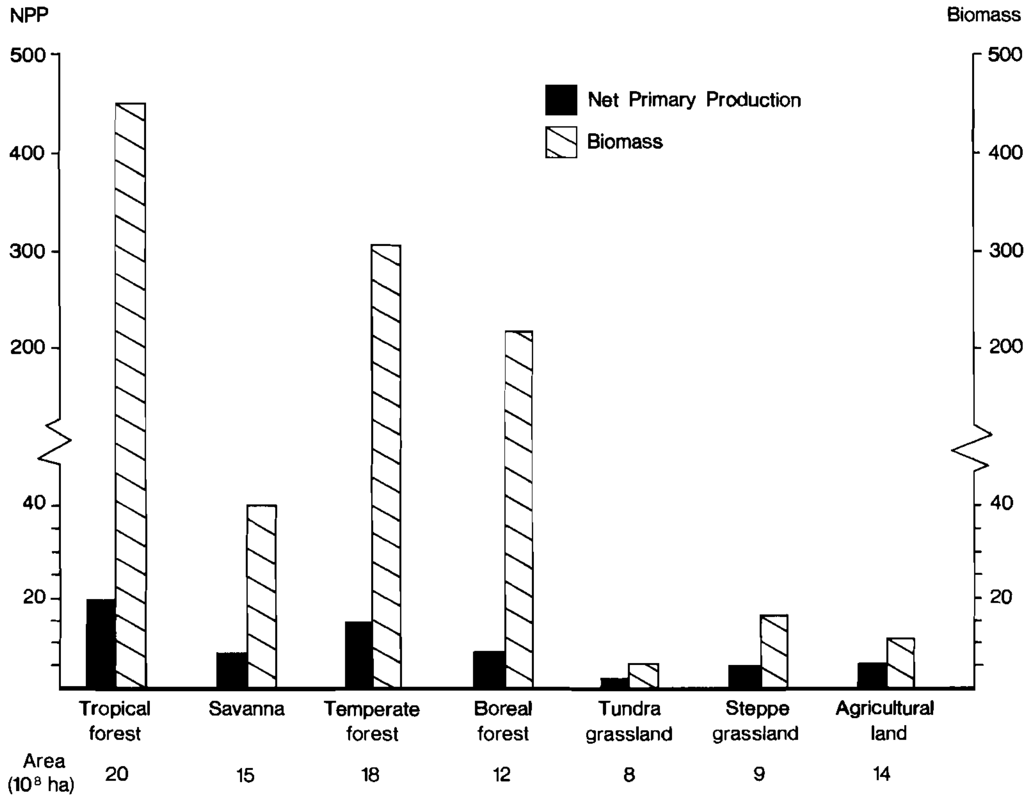
> ***...foresters must fulfill a multiplicity of roles and integrate forestry and other forms of land use...***

The tropical forest contains the planet's largest biomass, and its total primary production is greater than that of any other ecological region (27) (see figure, page 23). In addition to wood fibre, the forest yields a large variety of fruit, nuts, leaves, flowers, resins, gums, fungi, bee products, drugs, etc., that may be used as food or feed, or for medicinal, religious, decorative, and other purposes.

It is estimated that in developing countries some 860 million m^3 (0.5 m^3 per capita) of firewood are harvested annually for fuel and that 190 million m^3 of wood are used for industrial purposes (14). Indications thus are that only a small portion of the potential annual production of the natural forest is utilized. There are, however, many areas where the drain on the forest seriously exceeds the growth.

Out of the total world harvest of wood, which amounted to some 2500 million m^3 in 1974, about 17% found its way into international trade. In the developing countries, whose share of the world volume of wood harvested was about 40%, the proportion exported was a mere 6%. However, if we ignore fuel, which makes up over 80% of the volume cut in developing countries, and consider only industrial wood, about one-third of the volume cut in the developing world entered international trade (10, 14).

Most of the industrial wood is harvested in the humid tropics and from the mangrove forest. Firewood and building poles comprise the main timber crop in the forest of seasonal rainfall. The extent to which the tropical forest provides fuel and food is rarely recorded and not fully recognized, and estimates of forest production usually fail to take them into account since they are collected and used by the local population. Available statistics indicate that forest products contribute only about 5% of the value of all renewable resources produced in developing countries. (No attempt has been made to quantify nonconsumptive forest values such as watershed protection, and restoration of soil fertility following shifting



Net primary production (dry tonnes/ha/yr) and biomass (dry tonnes/ha) estimated for different types of vegetation on a world basis (27). Note that the total organic matter or biomass of the tropical forest (some 9000 × 10^8 tonnes) represents about one-half of all living plant matter. However, in temperate forests stemwood constitutes more than 30% of the total dry-matter production; whereas, in the tropical high forest it comprises only 15–20% (7).

agriculture.) Even allowing for the limitations of the basic data, this would seem to be a meagre contribution from more than one-half of the land area in the tropics. It is the more deplorable because it could certainly be greatly increased under sound resource management (see figure, page 21).

Wood harvesting

Logging operations and the transport of primary products in tropical forests are, in the main, destructive and highly labour-intensive, primitive, and inefficient by the standards of industrialized countries. With proper training for local staff, provision of support facilities, and an initial capital input, there are few technological barriers to the adaptation of appropriately mechanized wood harvesting and transport systems to much of the tropical forest region; the problems are likely to be more economic and social than technical (26).

Research is needed in such areas as: the extent to which woods operations can be "modernized" using low energy input techniques while holding capital costs to a minimum and retaining a high labour content; cost/benefit ratios; sociological implications; and the environmental consequences of road networks and other disturbances of vegetative cover and soil. The existing primitive methods of logging are becoming prohibitively expensive, and working as a woods labourer is considered a retrogressive step and such jobs are thus socially unacceptable. Improved harvesting methods are urgently needed.

Wood products

Mounting worldwide concern regarding the supply of energy from finite sources is prompting serious consideration of the further development of renewable energy sources. Among the latter, wood and its derivatives are at present the most important on a global basis; in 1970 they supplied more than three times the energy generated by hydroelectric power and contributed about 7% of the world's total energy consumption (7). Wood is the major renewable form in which the sun's energy is "packaged" so that it can be stored.

... in 1970, wood and its derivatives supplied more than three times the energy generated by hydroelectric power ...

Nearly one-half of all the timber cut in the world is used for fuel. In the tropics 80% of the annual cut is firewood (7), and 90% of the population rely on it for their domestic needs (8). But in much of the semi-arid tropics population growth is outstripping forest growth. Also, rising oil costs tend to divert more fuel wood to urban areas. As a result wood and transport costs are rising, animal dung is being diverted from fertilizer to fuel, and treeless landscapes are spreading disastrously (8).

Wood may be burned directly (which gives the maximum efficiency of conversion) for domestic use or to generate power. Or it may be converted into more versatile fuels — charcoal, methanol, and gas (7). Some charcoal research has been done in the tropics, but much more is needed on the production and use of all these fuels as well as on fuel wood sources — suitable species, establishment and management of fuel wood plantations, and utilization of otherwise waste material.

Self-sufficiency and independence, both for the individual and for society, are promoted by the development of renewable energy resources since they are likely to be of low intensity, decentralized, and dispersed.

From estimates made by Earl (7) and others it may be argued that the total energy available in the *unused* annual increment of the world's tropical forests is equal to nearly half of the world's energy consumption from all sources in 1970. This gives some idea of the vast, untapped, and renewable energy reserves latent in the tropical forests of the globe, which could be increased still further by improved forest management practices.

Traditionally, wood exported from the developing countries has been in the form of logs for further processing in the developed, importing nations, which get the benefit of values added. FAO reports that roundwood still comprises 70% of the volume equivalent of wood exported from tropical countries (13). The developing countries are thus deprived of the employment and of the badly needed foreign exchange that additional secondary manufacturing industries would provide. Moreover, the propulsive effect that this level of operations would have on the general economy is lost (13). Also, a diversified local secondary industry goes far to promote the better utilization of species in the tropical forest mixture, as in Nigeria (37).

Although lack of power or other essentials for industrial development may make it more difficult in some circumstances to attempt the conversion of primary products in the country of origin, there remains an urgent need for the development of appropriate technologies for forest industries in the developing countries of the tropics. Research is required on the economics of local industries using wood, on the sciences involved, and on the training of workers at all levels (39). New technologies are needed for the use of tropical forests and development of new products, rather than the mere adaptation of tropical woods to temperate technologies (26). An example in the food processing industry was the development of techniques for making bread from any kind of wheat. Formerly attention had been directed to developing cultivars to suit the old bread-making technology. It took someone with imagination to adapt manufacturing techniques to plants. In the same way development of techniques for making paper and composite wood from a mixture of widely varying woody and nonwoody plants in the tropics is needed.

The systematic creaming from the forest of the few species preferred for export (only 30-odd species in Africa for example) results in massive waste and damage to the forest estate. To avoid these losses, to reduce logging costs by more complete removal of available timber, and to increase forest revenue, manufacturing processes must be developed that tolerate the use of mixes of different woods in widely differing proportions, and the properties of underused and unused species must be identified and directed to specialized uses or to substitution for higher-value species.

Marketing of forest products is one of the neglected fields in the forestry sector of developing countries in the tropics (39). This situation must be corrected, while avoiding the biased assumption that the tropical forest's primary role should be a "cellulose reservoir" for the industrialized world. The field of market development is very large and has been in the hands of other than the developing countries in the past. However, some developing countries have timber export boards whose functions include regulation of trade in wood products and promotion of the utilization of previously unwanted species (13).

Development of local and regional markets is a precondition for effective harvesting of the forest and for efficiently supplying export markets. Ocean transport costs are high, and rate-setting is beyond the control of most developing countries. Industrialized countries dictate both levels of output and price in developing countries, to the latters' detriment. Lack of marketing knowledge for tropical mixes contributes to poor utilization (26).

Research is badly needed in many facets of forest products marketing, including mechanisms for product supply and demand; consumers' requirements; price stabilization; marketing strategies; freight rate structures; and improved transportation systems.

Yet another major constraint on developing large forest industry complexes is the huge investment required in associated infrastructure. How this can be utilized to generate related developments with an equitable division of costs among them, and the appraisal techniques involved, requires study.

Pulp and paper

Per capita paper consumption in developing countries averages less than 1% of that of the U.S., Sweden, or Canada. Even so foreign currency spent on the purchase of paper results in a heavy drain on meagre reserves and most countries have given high priority in their planning to the manufacture of paper. Most have a problem with the disposal of mixed tropical hardwoods, yet these hardwoods can be pulped for many grades of paper.

Many feasibility studies have been made but few paper mills have been built so far. In fact, only 6% of the world's paper capacity is in the developing world (23). None of the existing paper mills use all the hardwood logs from the tropical forest. The few successful ones receive the wood mostly from pine and *Eucalyptus* plantations; those who use wood from the natural forest operate in areas where relatively few species are prevalent, and even then many unsuitable logs are left behind in the forest.

Rubber production in the natural forest (FAO photo).

Economy of scale favours chemical pulp mills of 250 000 tonnes or larger annual capacity and these cost many hundreds of millions of dollars to build. Domestic requirements are often only for a fraction of the pulp produced and the balance must be sold on the world market at a low price.

Most developing countries have requirements of less than 100 000 tonnes of paper per year. A promising approach to solve their problem is to manufacture thermal-mechanical pulp from long-fibred plantation-grown trees and import whatever chemical pulp is required. By using the maximum of mechanical pulp and the minimum amount of chemical pulp in the mix, all the newsprint, writing, and printing paper requirements can be manufactured at a foreign currency savings of 75% or more. Another alternative is to build one chemical pulp mill to supply the requirements of a region. Initially at least, this may mean protecting the entire region by an external tariff wall.

There are some instances when agricultural by-products such as bagasse, straw, or rice husks may be converted by forest-industry technology into pulp and other products normally derived from wood. This should be carefully considered when planning optimum resource utilization.

Chemicals, sugars, and proteins

Wood is an abundant, environmentally acceptable, renewable raw material from which it is technically possible to produce most of our synthetic plastics, fibres, and rubbers. "With refinements in technology, a large, integrated plant utilizing all components of the wood for production of ethanol, phenols and furfural would be approaching economic feasibility as well, at current petrochemical prices" (17).

During two world wars large industrial plants converted wood by hydrolysis into edible sugars and grew yeast on such sugars to produce protein-rich food and feed. These processes are not quite competitive with present costs of cane sugar and soybean meal, but slight improvements in the manufacturing process or a sudden rise in the price of agricultural produce would justify the use of wood for human and animal consumption. Biodigestion by microorganisms of wood into protein is another promising approach and a breakthrough to make this process economical appears imminent.

Egon Glesinger, a former Assistant Director-General of FAO, wrote a bestseller in 1949 entitled "The Coming Age of Wood." His predictions have been largely fulfilled in industrialized countries but remain to be realized in the tropics. The scope of improvements that can be achieved is perhaps best illustrated by FAO's recent comparison of timber exports from Finland and the Republic of the Congo. Both countries have similar land areas and forest estates but the Congo has a more productive climate. In 1973 the value of forest products exported from Finland was 60 times greater than that of the Congo.

Nonwood products of trees

Normally the principal products of forest trees are derived from their fibre content in the form of roundwood, sawnwood, hewn or split wood, or wood converted to particles of pulp. However, hundreds of products are obtained from other parts of the tree. In some tropical forests the foreign exchange earning potential of these, together with products of other forest plants and animals, may be comparable with that of wood fibre products as such (36). In the high forests of Nigeria, 103 species have been identified that yield a rich harvest of minor products of this kind (37).

Among the main tropical forest-tree products in this category are: arboreal exudates such as gums and latex; drugs; dyes; edible and oil-bearing nuts; edible fruit; local drinks such as palm-wine and coconut milk; essential oils; tannins; medicines; bark products; and forage from trees such as the acacias. A comparatively new development in the temperate zone is the production of animal feed (muka) by dry-heating tree foliage. This is proving very successful in Russia (25), and its possible application in the tropics should be investigated.

Latex production for rubber, largely in plantations, is of course a major industry but this is treated as an agricultural rather than a forest product. Among the developing countries there is no consistent pattern as to the responsibility of forestry or agricultural authorities for dealing with most of the other nonfibre products mentioned. This may explain, at least in part, the apparent dearth of research on them in the forestry sector. Forestry and agricultural research institutions should cooperate to ensure that opportunities are not overlooked because a plant falls into a no-man's-land between narrowly defined disciplines although its potential for increased contributions to the well-being of developing countries is substantial.

Other forest flora and fauna

In addition to the great diversity of tree species they contain, the world's tropical forests are richly endowed with other plants as well as animals. Indeed, no other major ecological community has so many different kinds of living organisms, although most species are widely scattered and have a very low population density (35).

Although our knowledge of the characteristics and uses of tropical tree species is woefully inadequate, information regarding most other forms of life in the tropical forests is far more meagre, despite their ecological importance and potential use. As examples of what *is* known, an 80 000-ha area of rain forest in Costa Rica and Panama was found to contain 500–600 species of birds, more than four times the number in all the broad-leaved temperate forests of eastern North America (35). In low-rainfall regions of Kenya it is claimed that game-animal husbandry can produce six times the economic return obtainable from cattle on a given area, with much less environmental damage (22). In Papua New Guinea large numbers of eggs and wild pigs are obtained from the forest.

Many products of the minor flora and the fauna of the tropical forests are now being used to a greater or lesser degree. Among the flora are edible fruits, roots, and other parts of plants; mushrooms; feed and forage for animals; and perfumes, dyes, and other extractives, such as citronella oil, from grasses in forest clearings.

Most forest dwellers rely heavily on the larger fauna, both land and aquatic, for protein-rich food and for hides. Insect products include lac resin from Southeast Asia, the main ingredient of shellac; and honey, produced from the abundant flowers in the tropical forests of Asia and Africa, which with beeswax is probably the most important nonfibre crop in many African forests.

There is no question but that the usefulness of many products in this category could be greatly enhanced by research, and new products discovered. The cultivation of native species and the possible introduction of exotics should be studied, e.g. plant species suitable for silkworm cultivation. The potential dangers of transplanted species must also be anticipated, as witness the accidental development of "man-killing" species of African bees when crossbred in South America.

... beeswax is probably the most important nonfibre crop in many African forests ...

Collectively, the highly diverse minor products of plants and animals often comprise the staple cash crop of tropical forest communities. They thus tend to retard population shift into urban areas, which in itself is a good reason for fostering them (36).

Nonconsumptive forest uses

Reference has already been made to many of the "passive" ecological aspects of the tropical forest — its tremendous influence on soil and water regimes, its more debatable effects on the atmosphere and climate, its rich diversity as a reservoir of genetic resources, and its vital role as a habitat for game and other myriad forms of wildlife. The forest, too, has profoundly influenced man's social and cultural development since he first became a forest dweller. But, mainly through the promotion of tourism, the tropical forest is now beginning to assume a new environmental dimension in satisfying man's increasing ability to devote his leisure time to outdoor recreation and education.

This rapidly growing aspect of tropical forest use has great potential for the benefit of developing countries. But as the number of forest uses increases, so do the problems of resource management and conservation. Multiple-use management is indeed one of the major issues debated today at forestry gatherings in the developed countries, and the question of reconciling consumptive with nonconsumptive uses (mainly logging with recreation) is one that must be squarely faced in the developing tropical world.

This is a subject on which there is as yet very little evidence of present or planned research in the tropics, despite the potentially grave consequences of upsetting the delicate balancing mechanisms of the tropical forest ecosystem by uncoordinated multiple resource development. There is a need to classify lands for optimum use capability, and to set aside suitable areas as gene pools and for other scientific and cultural purposes (34). Fact-finding and research are necessary preliminaries to such undertakings.

Constraints on Resource Development

It is evident that there are many aspects of tropical forest resource utilization on which more information is urgently needed, if the peoples of the developing world are to realize anything approaching the maximum potential benefits that may be derived from their forests. However, the extent to which the production, processing, and sale of forest products can be increased, the methods used, and the speed of accomplishing these ends, are all subject to certain limitations. Such constraints are, for the most part, inherent in our present state of knowledge (or lack of knowledge) regarding the characteristics of the resources concerned, in the status of sociological and institutional development, and in knowing how best to influence the decision-makers to ensure that wise land use management practices are implemented. These, too, are fields in which much additional research is required. Some of the more important problem areas in this category are briefly discussed below.

Socioeconomic considerations

Since the dawn of civilization man has looked upon the forest as possessing mystical attributes. It remains to this day for many people the abode of ghosts, and for others, the place where the souls of unborn children dwell. Some tribes bury their dead in trees, and sacred forests give succour to the simple farmer and inspire philosophers and poets.

Other cultures have tended more and more to strip the forest cover. This process seems to have conditioned man to the attitude that destruction of trees is not only a matter of no consequence but even an end in itself — a sign of progress, of conquering the wilderness.

Through the centuries much human effort has been devoted to modifying natural forest ecosystems to produce food, clothing, and shelter, and to provide a variety of amenities and services. Because of the rapid rate of population increase in tropical regions, and because of the need to raise the living standards of the many underprivileged people living in the tropics, more intensive use of tropical forests is inevitable. Further pressures for greater utilization of tropical forests arise from the economic potential of the vast reserves of timber they still contain and from the apparent (often mistaken) agricultural potential of the land they occupy.

Inevitably the tempo of change will increase markedly within the next quarter of a century. Even when the local population living in the forest wishes to retain its traditional way of life it will be very difficult to restrain further change against mounting economic pressures and shortages of resources.

International concern has arisen lest this greater exploitation of the tropical forest causes a depreciation in its value to man, and this concern is reflected in recommendations made at the United Nations Conference on the Human Environment in Stockholm in 1972, in the priority given to tropical forest ecosystems in the UNESCO Man and the Biosphere Program, and by a recent series of IUCN Conferences organized to clarify guidelines for the use and development of tropical forests. There is a danger that short-term economic benefits may override longer-term disadvantages, especially with respect to the indigenous population in the forests. The interests, attitudes, and wishes of local people, of regional or national politicians, of international scientific experts, of private companies, and of foreign entrepreneurs are not necessarily identical. It is all too easy to ignore the needs of indigenous people for the sake of progress.

> ***... where people must devote most of their energies today to assure food for tomorrow, it is difficult to conserve and direct resources for the benefit of the next generation ...***

Consequently in formulating and implementing new land-use systems, or extending the area of existing systems, it is important with regard to tropical forest areas to consider the social and economic consequences to the local people who may not wish to change their lifestyle and who reject Western standards and attitudes. We may have much to learn from the way of life of people who have adapted themselves to the tropical forest system and place few demands on their environment. They need to be involved in the decision-making process that will affect the area that they and their ancestors have occupied for generations.

One aspect of concern is the health of the local population. There is evidence that many forest dwellers would suffer cultural shock if the transformation to a new style of living occurs too rapidly. Furthermore the fragmentation of the forest as clearings are made may cause the spread of diseases such as malaria, with the local population having little resistance because it has not been subjected to the disease.

Many other examples of socioeconomic factors to be considered can be given. For example, what is the impact of greater prosperity and the switch to a more intensive agricultural system on the interrelationships within family and tribal groups, on the social structure of the local community, and on religious ceremonies dependent on the forest and its products? How easily can new settlers be assimilated? Will there be greater urbanization, and what is the cost of the infrastructure? How much of the cash flow stimulated by the more intensive land use goes to the local population, and how do they spend it?

For many developing countries work in the forest is considered a demeaning, retrogressive, "back-to-the-bush" step. This attitude is often aggravated by low pay for forestry personnel in comparison with the preferred, white-collar office jobs, and by restrictions placed on any initiatives shown by field staff.

Tenure of forest land, whether tribally owned and redistributed every few years or owned by a distant government, affects man's willingness to protect the forest and to make essential long-term investments in forest development. In countries where people must devote most of their energies today to assure food for tomorrow it is difficult to conserve and direct resources for the benefit of the next generation.

The introduction of sound forest management, and the development of industries resulting from it, can take place no faster than such attitudes will permit. Also, improvements in technology cannot outstrip the rate at which man is able and willing to assimilate them — for example, it may be prudent to replace machetes by well-designed axes and handsaws before power saws are introduced.

Research is needed as to the nature of, and motivation for, man's attitudes to forests; whether or not there is a need to develop a more positive orientation of mankind toward trees and forest work; and if there is, how it may best be accomplished.

Forest inventories and land classification

Adequate knowledge of the extent and nature of any resource is a basic requirement for the sound management of that resource. In this respect the tropical forests are in a singularly weak position. Little more than 10% of their total area has been inventoried and most of the existing surveys give inadequate information (13), especially since species that are not currently valuable are usually ignored. This is, however, a global estimate; tropical forest inventory coverage varies widely between different regions. In Africa, for example, the figure is much higher than 10%.

There is increasing recognition of the need for tropical forest inventories to include certain land-use and other relevant data. Examples include estimates of population density, the extent and kinds of shifting cultivation and length of fallow period, the distribution of food-producing trees, and the accessibility of the forest in relation to population centres (38).

Of even more fundamental importance for purposes of multiple resource development is the classification of land according to its capability for each potential use (e.g. agriculture, forestry, wildlife, and recreation). Only on this basis can optimum land allocation be made in connection with resource development plans (34). It is very important that in the largely political decisions that determine land use, land capability information should carry its weight together with other economic and social factors that are usually the major, if not the only, considerations. Land-use and land-capability surveys are highly complex, involving many scientific disciplines, and in the tropics even less progress has been made with them than with forest inventories.

Great improvements have recently been made, both in increasing the reliability and reducing the cost of forest inventory, land-use, and land-capability surveys, in which new remote-sensing techniques will likely play an increasingly prominent part. The technology is generally well advanced, but a good deal of research remains to be done to adapt it to

Afforestation to check erosion (FAO photo).

tropical conditions, where it is more difficult to distinguish from the air differences in forest types. To be effective any system of classification needs to be simple to apply, and to require relatively unsophisticated instruments in the field. Local research organizations are normally in the best position to carry out survey research requiring area-specific competence.

Ecological effects of forest manipulation

This theme cannot be emphasized too strongly, particularly the need for:

(1) much more information regarding forest influences on, and interactions with, all other elements of tropical ecosystems, both in the undisturbed natural and managed states;

(2) even more research as to how to monitor what happens when tropical forests are cut or interfered with in other ways, including effects on human sociocultural and behavioral characteristics (55);

(3) studies of the forests' potential for repairing damage already done to tropical ecosystems, e.g. dune fixation (23), especially with respect to stopping the spread of arid and desert areas.

Obviously, both unplanned development and the implementation of resource development plans involving changes in forest cover, without being aware of the likely consequences, could lead to serious and potentially disastrous results.

Status of institutional development and application

The facilities and services that government, teaching, and research institutions do provide will greatly affect the rate at which a nation's forest resources can be developed for the maximum long-term benefit of its people. Successful development depends equally on the extent to which these facilities and services are able to influence decision-makers so that their results are used and applied in practice. Major elements in this institutional fabric require careful evaluation.

Forest policy

The evolution of sound forest policy is an essential but lengthy, costly, and laborious process, yielding little in terms of political popularity. Historically, forest policies have been largely aimed at protecting the forest from encroachment. In the tropics, where land is a limited, multiple-use resource, policies should be designed to ensure that the land is used to best serve the interests of the people (52).

> ***...a serious problem is lack of communication among research workers, and between them and those who should be implementing their findings...***

The formulation of basic legislation in which forest policy is given expression is a matter of prime importance. In most developing countries present laws are inadequate and lack uniformity; a coordinated approach requires expert research in many fields (39).

Forest administration

A serious problem in many countries is the inability of administrative personnel to enforce such forestry legislation as does exist. As noted earlier, the aim should be to convince people that it is in their own interest to comply with the law, rather than the rigid imposition of penalties. Moreover, good ideas for improvements in the forestry sector often fail because of ineffective administration, or because foresters are unable or unwilling to work closely with other kinds of specialists. Research is needed to ensure adequate organization, structure, staffing, financing, and support for forest services and other forest authorities (39), and to develop multidisciplinary liaison.

Forestry education and training

In developing countries, foresters' pay is often lower than that of other professionals, and too few people are attracted into this work. The lack of sufficient trained forestry personnel at all levels — professional, technical, and vocational — is impeding the introduction of known technologies and the discovery of new ones better adapted to tropical conditions. Assessment and evaluation of educational organizations, adequacy of programs, and ultimate orientation of students at all three levels are urgently needed (39). Training should be regionalized and linked more closely with operational needs and research activities (49). Many developing countries have simply adopted the educational system of developed countries, yet it may be quite inappropriate and greater attention needs to be paid to creating an education structure more relevant to their needs.

Forestry research

Thousands of scientists in hundreds of institutions around the world are hard at work to wrest increased economic and social benefits from the forest. Local priorities, the researchers' skills, and often their personal preferences determine the projects selected for research from a vast array of unsolved problems.

The organization of forestry research is beset with many difficulties, and nowhere more than in the tropics (51). There is a great need to focus on key research that will be of major significance and hold real promise of successful implementation. Factors to be considered include the estimated time to achieve results, the likely scope and impact of the results, and problems that may be anticipated in applying the results. As with education, an international program of research coordinated for ecological regions seems to be indicated (24), and merits careful study. Having regard to the prime importance of combined tree- and food-crop production in the tropics, and to the similarity of much of the basic knowledge on which they depend, there is an urgent need for integrating forestry and agricultural research and training.

A serious problem (by no means confined to developing countries) is lack of communication among research workers, and between them and those who should be implementing their findings. Of particular concern is the lack of up-to-date manuals on tropical forest management. It is essential that the wealth of scattered, uncoordinated research information (existing and future) be assembled and communicated in appropriate form to all those concerned: scientists, technicians, decision-makers, and the public. Also, research programs should be closely integrated with development projects so as to ensure that they are oriented toward national needs (24).

Implementing new knowledge in the field

It is estimated that in most developing countries not more than half of the knowledge acquired is used in the field (6); however, some countries have developed methods to apply research results quickly and effectively.

Probably the most rapid benefit to the people of the developing countries would accrue from research on how to implement existing knowledge. This is particularly true with respect to the integration of agriculture and forestry (32). Most developing countries lack effective extension services in agriculture, and in forestry they are virtually nonexistent (24). If properly developed, extension services might well play a key role in transferring existing knowledge to the field practitioner, whether at the professional, technical, or peasant farmer level.

Research Needs and Priorities

The future of the tropical forest has become of major concern. The role of trees in protecting and improving the environment is now generally recognized, and people have become aware of the great economic value of a highly productive and renewable source of a wide variety of forest products. Work in the forest is a profitable outlet for surplus labour to be invested for leaner days or for future generations. "Interdependence of forestry and agriculture is recognized as the ecologically sound base to sustain food production in the tropics" (38).

With this and the terms of reference for the study in mind, our aim has been two-fold: first to identify new initiatives in tropical forestry and land-use research that could, within a period of 5–10 years, lead to a significant improvement in the conditions of life and prosperity of rural people; and second, to outline the kind of research structure that seems most appropriate for achieving this purpose.

The potential of the tropical forest has been reviewed, and 23 problem areas have been identified that we consider of major importance. These are listed without regard to priorities on page 37. The importance of each of these problem areas has been evaluated according to criteria established in consultation with senior decision-makers who have worked for long periods with renewable resources in different parts of the developing world (see page 38 for criteria used).

Since trees grow in natural forests, in man-made forests, or as part of farming systems in the tropics, it will be convenient to discuss priorities and prospects for effective research under each of these three headings.

The natural forest

The heterogeneous natural forest is often perceived as a reservoir of trees from which to fill gaps in the timber supply of the temperate zone. Research, mostly sponsored and directed by expatriate experts, aims primarily at increasing the proportion of timber marketable for export. Several research agencies are now trying to develop techniques that will tolerate the use of a wide range of species for the manufacture of paper, wood-based panels, and wood structures, and to group different timbers so that those within each group can be interchanged for the same use. Good progress has already been made; from 1968 to 1974 the value of forest products exported from the tropics has tripled and further growth is anticipated (14). On average, 10% of the trees in the humid tropical forest are marketable now for industrial wood, and prospects are that 30% may be used by the year 2000.

Intervention in the forest, whether by humans, animals, or natural events, changes its character and the changes are not fully predictable. Except for some rare situations, we are not yet able to increase the proportion of a few favoured tree species by manipulation of the natural forest in the humid tropics. Nutrient cycling, microfauna and flora of the soil, photosynthesis in the multistorey forest, seed physiology etc. will have to be better understood before we can piece the puzzle together and

Tropical Forestry Problem Areas

1. Forest inventory methods.
2. Classification of tropical forest lands for optimum use.
3. Forest influences (water management, soil conservation, etc.).
4. Impact of various forest management and harvesting practices on the ecosystem (soils, water, wildlife, etc.) and on subsequent land use.
5. Silvicultural systems: (a) minirotation silviculture; (b) natural vs artificial regeneration.
6. Protection of forests against fire, insects, and diseases.
7. Production systems combining trees with annual crops, livestock, and/or fish: (a) in the humid tropics; (b) in the savanna belt.
8. Semi-arid area revegetation and protection from over-grazing.
9. Tree breeding and tree improvement.
10. Identification of forest trees with underused productive potential.
11. Wood harvesting and transport methods.
12. Wood as a source of energy, food, feed, and chemicals.
13. Utilization of lesser known and mixed tropical hardwoods.
14. Forest products other than wood.
15. Appropriate technology for forest industries in the developing countries.
16. Marketing of forest products and promotion of their use.
17. Environmental aspects of forests for recreation, tourism, fish, and wildlife.
18. Forest policy.
19. Forest administration.
20. Organization of forestry education and training.
21. Human attitudes to forests.
22. Organization of forestry research.
23. Implementation of research findings.

Other than identification of the main gaps in forestry research, our terms of reference did not include the *ranking* of tropical forestry problem areas in order of priority. Such an exercise would be of dubious value, since research needs vary widely according to geographical, ecological, economic, and social conditions. Moreover the process is highly subjective, and the results will inevitably be influenced by the background and experience of the group attempting it.

develop effective management systems. UNESCO, through its Man and the Biosphere program, and other institutions sponsor research that undoubtedly will lead to a better understanding of the extremely complex processes in the tropical forest. Rate of progress is not predictable at this time but indications are that it will be slow.

Even more difficult than understanding and managing the biological processes in the tropical forest is changing the prevailing attitudes of the people. Private ownership of land is a foreign concept in most of the developing world. Tenure is often temporary. Tribal land is regularly redistributed to assure equal treatment for all and to prevent anyone from becoming too powerful. Some forests are controlled by the State but this control is more theoretical than effective. Forest officers are charged with policing it, and they do this reluctantly and unsuccessfully. As soon as the forest becomes accessible, and this happens whenever a road is built into it, colonizers pour into the area to practice slash-and-burn agriculture. No power on earth will keep the landless peasant out. Land reform, Taungya afforestation, and other forms of allocating land are short-term remedies in a world where population increases by 80 million people each year.

Except perhaps in special situations, such as the protection of water reservoirs or steep hillsides, the future of the natural forest occupying large areas and operated for sustained yields is in doubt in the tropics.

The man-made forest

The temperate zone concept of the forest as the source of a large volume of uniform wood for industry and fuel is most effectively implemented in a tropical environment by establishing man-made forests of one or a few species of trees. Production of 10–30 tonnes (dry weight) of wood per hectare per annum, about 3–10 times the amount grown in the natural forest, is sustainable but we do not know for how long. Tropical vegetation is characterized by a great and ever-changing variety of plant life, especially in the humid forest. Monocultures are not a natural form of tropical vegetation. Techniques developed for the production of agricultural staples such as wheat, rice, corn, and cassava may be adaptable to tree monocultures, but one must keep in mind that however successfully the growth rate of trees is increased, it still takes 5–20 years or more until forest trees reach merchantable size. This longer time interval increases the risk enormously and the long-term effects of man-made forests on

Criteria Used for Rating Priorities

1. What is the potential importance of the proposed research in contributing to the socioeconomic and environmental welfare of people in the tropics, especially in reducing migration to cities and colonization areas?
2. How broad is the scope of the proposed research in terms of geography, and of number of people affected?
3. To what extent is the need for the proposed research felt in the region?
4. To what extent is such research being neglected or uncoordinated now?
5. Is available knowledge adequately organized and disseminated?
6. To what degree does it lend itself to formulation into a project or projects that will focus on the issue?
7. Are adequate facilities and qualified personnel available at existing international (or national) research institutions: (a) to conduct the research; (b) to apply the results?
8. If not available, how readily can facilities be provided and personnel trained?
9. Are technologies available that are easily transferrable to the cultural environment of the people?
10. Is the timing of "pay-off" from the research likely to be realistic in terms of the desired objective — say a 5- to 10-year target for achieving substantial benefits from the application of research results?
11. How important is research (vs application of existing knowledge) in solving the problem?
12. Will the applications of the research affect other resources adversely?

productivity and site ecology are still largely unknown. Nevertheless in several regions of the tropics two or three rotations of tree monocultures have been harvested successfully.

> ***... even more difficult than understanding and managing the biological processes in the tropical forest is changing the prevailing attitudes of the people ...***

National and international agencies and private industry are investing large sums in the establishment of plantations, and in research to identify and select promising tree species and provenances, and to develop improved planting techniques, management, protection, harvesting, and utilization of the crop. Even so, it is estimated that less than 1% of all tropical forests are man-made at this time, and considering the high capital cost to establish them and the ecological risk involved, it is unlikely that by the year 2000 man-made forests will account for more than 2% of the tropical forest.

Agroforestry

Agroforestry is defined here as a sustainable management system for land that increases overall production, combines agricultural crops, tree crops, and forest plants and/or animals simultaneously or sequentially, and applies management practices that are compatible with the cultural patterns of the local population.

Trees are the dominant natural vegetation in most of the tropics, and with few exceptions must remain so if the land is to be used for the greatest benefit of man. Only 11% of the land is flat enough to be worked with the plow (1). One-quarter of the land surface is too infertile to produce a crop. But the remainder, comprising more than half of all land in the tropics, although too dry, too steep, or too rocky to be classified as arable land is suitable for the practice of agroforestry.

In most of the tropical zones, trees and agricultural crops usually do best in combination. All through history, people have depended on trees for food and feed, and to maintain the productivity of the land. In the perhumid tropics trees are the most productive crop, and they remove few nutrients from the soil. In very dry areas deep-rooted trees such as *Prosopis* (algaroba), *Ceratonia* (carobs), and *Anacardia* (cashews) will grow large volumes of nourishing food where nothing else will thrive. Between these extremes of climate, trees, agricultural crops, and the raising of animals can be judiciously combined to take advantage of the favorable growing conditions and to be least affected by the constraints of the tropics, whether they are biological, social, or economic.

Land is a scarce resource and is becoming increasingly so under the relentless increase of population. Two or three square kilometres of unmanaged rainforest are needed to feed one human being. The

Agroforestry improves land use in the tropics (FAO photo).

time-tested methods of shifting agriculture will sustain the growing of enough food for 30–50 people on one square kilometre. An equal area of flooded rice fields will feed as many as 700 people.

One of the objectives of agroforestry is to "domesticate" and upgrade shifting agriculture to maximize sustained production on less well-endowed land, whether the produce is food, feed, fuel, building material, or products that can be sold. Another is to grow crops in hitherto unproductive areas.

The trend in food production over the last few hundred years has been toward increasing specialization. Forestry and food production have been so effectively separated that studies of trees whose principal uses are not timber or firewood, or trees that have multiple uses such as the rubber tree, are considered to be the concern of other disciplines. Until fairly recently the bins of industrial countries bulged with grain surpluses, there was too much fertilizer, and unlimited energy and research were mainly directed to improve tropical export crops such as coffee and cocoa. The tropical forester was concerned with conservation and timber production and the "slash-and-burn" farmer became his number one enemy.

All this has changed now; self-sufficiency in food has become all-important and the role of trees to extend food production from 25 to 75% of the tropical land areas has become a matter of great importance. But the capacity of trees to produce large food or feed crops and other goods too on marginal land or under extreme weather conditions, and to do this without jeopardy to the environment, is not yet fully appreciated.

Close cooperation between agriculturists and foresters is needed to use trees effectively in combination with other crops and animals. Forestry teaching in tropical tree science must be expanded to include all benefits from trees. A broader look at the potential of trees will also lead to the reexamination of how to group them for different objectives. The range may extend from the legendary impenetrable jungle to widely spaced trees to allow for intercropping or for pasturing.

Much knowledge about trees and their interaction with crops and animals can be found in different corners of the globe. Some of it is well documented and carefully recorded. Other information has to be collected at the grassroot level and verified.

Ample evidence indicates that trees were used in combination with farming and animal husbandry thousands of years ago, and some of this knowledge has been forgotten. Study of history will produce valuable leads.

Information collected will have to be tested on different soils in different ecological zones and disseminated to decision-makers, technical experts, and technicians and demonstrated to the farmers. Farmers will have to be trained to adapt the new knowledge to their own specific conditions.

Reconstruction and verification of present practices will reveal important gaps in knowledge and opportunities for improving the systems. Research to secure this new knowledge will have to be contracted to appropriate national and international agencies. Some of the Agricultural Research Institutes may find that they can achieve their objectives more effectively by including woody vegetation among their tools. The International Centre of Tropical Agriculture (CIAT) in Colombia, for example, could likely enhance beef production on the Llaños in Latin America by planting trees that will thrive on acid soil. These would contribute organic fertilizer to the pastures in the form of leaf litter and produce leaves and pods for emergency feed. They would shade the cattle, protect the land from air and water erosion, ameliorate stream flow, and in addition produce fuel, fenceposts, and fruit.

... more than half of all the land in the tropics, although too dry, too steep, or too rocky to be classified as arable land, is suitable for the practice of agroforestry ...

The International Institute of Tropical Agriculture (IITA) in Nigeria, after experimenting for years to protect the bare soil between agricultural crops with trash, has concluded that trees may do this better. Prof Bede H. Okigbo, the Assistant Director, Farming Systems Programme, is not only interested in reintroducing trees for soil protection into the farming system but is searching for trees that can augment soil fertility and supplement the food and feed produced by agricultural crops.

The Tropical Agricultural Research and Training Centre (CATIE) in Costa Rica proposes to combine the efforts of its agriculture, animal husbandry, and forestry departments to learn how to optimize production on small farms in mountainous country where rainfall is heavy.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India may investigate what trees should be planted for feed and firewood in semi-arid areas. An estimated 75% of the cow dung is burned for fuel today instead of being used for improving the fertility of the land.

Other international and national institutions are capable of, and interested in, filling gaps in our knowledge of combined production systems in different ecological zones. No one institute can find all the answers in one location, nor are the advantages of combined production systems confined to the tropics. For example, the growing of poplars with agricultural crops such as potatoes, turnips, squash, and honey clover is currently under investigation in Canada (31).

The natural forest of the tropics is a vast reservoir of valuable genetic resources. Trees that seem to have underused potential must be identified, tested in different ecological zones, improved where necessary, and introduced "where they are economically viable, socially and culturally acceptable, adapted to and within the means of the small farmer" (30).

There is an urgent need to carry out this research because in some regions the natural ecosystems in which the gene resources occur are fast disappearing.

The worldwide effort to improve the utilization of wood fibre has seldom been matched for nonwood forest products. There have been a few exceptions, such as latex from rubber trees, but gums , bark, spices, fruit, and other so-called "minor" forest products have seldom received the attention these potentially valuable products deserve. It is recommended that, as a first step, products that have significant economic and social potential be identified, and then systematic research carried out on how to manage the trees and how to harvest, process, and distribute their products. The research results must then be widely disseminated and demonstrated.

Economic and social benefits from the research

The possibility of improving total production by combining trees with agricultural crops and livestock has been widely demonstrated in many parts of the tropics, and there is little doubt that agroforestry could also be introduced to vast stretches of unproductive land where agriculture alone cannot be practiced at present. Systematic research is needed to find appropriate combinations of vegetation for different climatic zones and soil conditions, and to devise practices that are acceptable to the local population.

It is a misconception to believe that it takes a long time until a tree grows to marketable size or until it starts bearing fruit. *Leucaena* species will produce pods 8 months after planting and will make good pulpwood after 3 years. *Eucalyptus* trees grown for 5 years are the mainstay of Brazil's forest industry. *Prosopis* species will grow beans after 2 years, and most other tropical trees will start producing fruit, nuts, or pods at an age of 3–4 years and will continue to do so for a very long time thereafter. Many of the trees have leaves that make valuable green manure and nutritious feed, and some are used as vegetables by the local population. All trees can be used for fuel and often make excellent building material once they have become too old to produce fruit.

Some data have been published on the interaction of trees, other crop plants, and livestock, but most are too vague and unreliable for any conclusion except that trees will thrive in a wide range of environments and produce valuable crops. The following few examples have been verified, however, and illustrate what can be expected:

(1) *Leucaena* species will grow in the tropics between sea level and 1500 m altitude where annual rainfall ranges from 500 to 5000 mm, and will do well on a wide variety of soils except acid soils. If the leaves are cut every 6–8 weeks down to 100 mm above ground level, 90 tonnes/ha/yr of palatable green feed, equivalent to 23 tonnes of hay containing 26% protein, can be harvested. If used as green manure the leaves from one hectare will provide 600 kg nitrogen, 500 kg potash, and 200 kg of phosphorus fertilizer to the soil per year. If managed for fuel or pulpwood, one hectare of *Leucaena* forest will produce 33 m^3/yr of wood of 0.73 specific gravity (2).

(2) Beans of the *Prosopis chilensis* (algaroba) tree were used for food and feed by Indians long before Columbus reached America and they are still widely grown on light sandy or rocky soils in low rainfall areas (250–1250 mm/yr). Beans are produced at the annual rate of 4 tonnes or more per hectare. They contain 9% protein, 47% nitrogen-free extract, 0.6% fat, and 25% crude fibre (53). Their feed value compares favourably with barley. Ground into flour they are made into nourishing food that can be stored for a long time and can be eaten raw. Where people may have to spend one quarter of their income on fuel to cook one hot meal a day it is important to note that nuts and edible tree pods do not require cooking.

(3) *Prosopis tamarugo* (tamarugo) will grow on salt-crusted desert land where it rains less than 100 mm per year and many years go by without any rainfall. The trees receive some moisture from a foggy drizzle and roots will seek out water several metres below the surface of the soil. Once the plants are well established, leaves and pods support sheep and goats at rates comparable to those of high quality pasture elsewhere in the world (10–20 animals per hectare) (28).

(4) *Ceratonia siliqua,* a leguminous tree, produces the carob bean. It thrives best in dry, poor, stoney soil that is rich in Ca and K and it is highly drought resistant. Trees will start fruiting 3 years after planting and have a productive life of 100 years or more. A single tree will grow 500 kg of beans per year. Dry pods contain 5% protein, 86% nitrogen-free extract, 0.5% fat, and 6% crude fibre. They can be eaten raw or ground into a flour and mixed with other food, or fed to animals (50).

> ***... self-sufficiency in food has become all-important and the role of trees to extend food production has become a matter of great importance ...***

(5) *Parkia* species grow best in moist areas of Asia and Africa. Parkia beans, also called African locust beans, contain 26% protein, 50% carbohydrate, and 10% fat. They are used as food and feed. Leaves provide useful forage (5).

(6) Wide spaced *Alnus jorullensis* (alder) on high elevation (2000–3000 m) pastures in the tropics has increased forage production eightfold in Latin America, and in addition 10 m^3/ha/yr of wood for fuel and industrial use was produced on a 20-year rotation (40).

(7) In the Philippines more than 2 million hectares are used exclusively for the growing of coconut. Interplanting or pasturing animals between coconut palms has been successfully de-

monstrated on several islands in the South Pacific and in India. By adapting practices developed elsewhere to local conditions it should not be difficult to introduce combined production systems for most coconut-growing regions.

There is also an immense potential for extending combined systems of food production into areas that are less hospitable to grain agriculture. It should also be kept in mind that fruits, nuts, and pods have always been part of the diet of native people, and have only more recently been replaced by nonnative cereals.

It is estimated that more than 200 million people, scattered over 3.5 billion hectares of the tropics, obtain the bulk of their food by practicing shifting agriculture (29). Under the pressure of increasing population the food crop harvested between shortening bush-fallow periods is becoming poorer, and bush-fallow is wasteful of land. There is no reason to believe that a commercial tree crop could not be grown for wood in less than 10 years, to replace bush-fallow while replenishing soil fertility. By using presently available technology in the sequential growing of trees and agricultural crops in the humid tropics, grain and root-crop production could be increased fourfold and wood production 10-fold over the present output. By means of a hypothetical model based on upland soil conditions in Nigeria, Grinnell (19) also showed that substantial economic benefits could result from growing forest plantations on otherwise idle land during the interval between certain agricultural crops (see Table).

The cost of increasing the productivity of combined systems and of extending agroforestry into hitherto unproductive regions appears small when compared with the potential benefit of greatly increased and more consistent production. What is needed is fact finding and dissemination of verified information, demonstration, and making good quality trees available from nurseries.

Training of farmers and extension workers in the management, utilization, and marketing of tree crops should follow the successful patterns developed in the improvement of agricultural practices. The objective is to make the system more productive, more labour effective, and more resistant to weeds and pests.

Production from a 10-year-cycle of sequential cropping of grain, root crops, and trees in Nigeria. Three crops of maize, one of cassava, and one of yams per year, plus the harvest of *Gmelina arborea* trees 9 years after planting (9, 45).

Crop	Peasant farmer production	Potential average production
maize	2 t/ha	8 t/ha
cassava	10 t/ha	50 t/ha
yams	15 t/ha	40 t/ha
wood	25 m^3/ha	250 m^3/ha

Note: The figures given for peasant farmer production relate to soils degraded by excessive use; whereas, potential average production data postulate good soil conditions maintained by appropriate species combinations under suitable agroforestry practices.

Current agroforestry initiatives

Rural development is one of the most pressing issues of our time and agroforestry can help it by making the land more productive. Developing countries and donors alike are agreed that a major broad-based input into this hitherto neglected field of activity is urgently required, but so far action has been diffuse and uncoordinated. SIDA (Sweden) and FAO are now joining forces in a 5-year program of "Forestry for Community Development" — a program to promote the growing of timber in forests managed by and for small communities. ODM (Great Britain) has long advocated that tropical land management should be the joint responsibility of agriculturists and foresters.

In Canada, CIDA joined with IDRC to arrange a fact-finding meeting on agrisilviculture in Ibadan, Nigeria in 1973, and IDRC has followed up with a research project in West Africa to discover how to make the forest fallow phase of the agroforestry system more productive. CIDA is considering support for demonstration and training projects in several countries. IDRC sponsors research on intercropping in the Philippines. This includes tests of *Leucaena* in association with agricultural crops. Another phase of the same project studies the shade tolerance of sorghum, millet, tomatoes, and sugarcane in anticipation that some of these crops may be grown between coconut palms.

Indonesia, India, the Philippines, several countries in Latin America, and New Zealand are conducting research on agriculture, forestry, and animal husbandry interaction. In Holland, Belgium, and France research institutes have much knowledge about combined farming systems that have been developed in tropical countries in the past. China has achieved remarkable results during the last 25 years and indications are that in many other parts of the world valuable information remains as yet unrecorded.

The Director-General of UNEP, the Associate Director-General of FAO Forestry, and several senior representatives of donor nations and research organizations have already indicated interest and support for a comprehensive effort into the development of combined production systems.

Proposal for an International Council

It is clear that the tremendous possibilities of production systems involving some combination of trees with agricultural crops and/or animals are widely recognized, and that research aimed at developing the potential of such systems is planned or exists in a number of scattered areas. Equally evident is the inadequacy of the present effort to improve the lot of the tropical forest dweller by such means.

A new front can and should be opened on the war against hunger, inadequate shelter, and environmental degradation. This war can be fought with weapons that have been in the arsenal of rural people since time immemorial, and no radical change in their lifestyle will be required.

In the authors' view, this can best be accomplished by the creation of an internationally financed council for research in agroforestry, to administer a comprehensive program leading to better land use in the tropics.

The objects of such a council should be to encourage and support research; to acquire and disseminate information concerning agroforestry systems in developing countries of the tropics, thereby promoting better land use; and to create additional work opportunities in harmony with the wishes of the rural people. Specific objectives might be:

(1) to assemble and assess existing information concerning agroforestry systems in the tropics and to identify important gaps in present knowledge relating both to the system as a whole and to important tree components in particular;

(2) to encourage, support, and coordinate research and extension projects in agroforestry in different ecological zones, aimed primarily at filling such gaps;

(3) to support research that seeks to identify and/or improve tree species presently underused with respect to wood and/or nonwood products, to enhance the economic value and productivity of agroforestry systems;

(4) to support research on agroforestry systems that will bring greater economic and social benefit to rural peoples without detriment to the environment;

(5) to encourage training in agroforestry and in the science of tree species that form part of agroforestry systems.

> ***... a new front can and should be opened on the war against hunger, inadequate shelter, and environmental degredation ...***

The activities that the council should undertake to achieve these objectives might include:

(1) the collection, evaluation, cataloguing, and dissemination of information relevant to agroforestry, giving particular emphasis to facts, figures, and methodology, and directed primarily to field personnel;

(2) the employment of consultants to evaluate existing agroforestry systems;

(3) the maintenance of liaison with international and national agencies and researchers to assure coordination of research on agroforestry systems;

(4) the entering into contracts with scientific institutions and/or individual scientists to carry out research on agroforestry systems,

on important tree species in relation to such systems, and on the harvesting, processing, and marketing of their products;

(5) the organization and convening of seminars and working groups to collect, discuss, evaluate, and disseminate information concerning agroforestry;

(6) the promotion of the teaching of the principles of agroforestry at all levels in the education system, including teaching of the science of trees whether grown primarily for consumptive products or for nonconsumptive services;

(7) the encouragement of the orientation of forestry and agricultural teaching so that they make a stronger contribution to better land use;

(8) the demonstration, publication, and dissemination of research results and other relevant information.

In carrying out its information activities, the council should ensure that duplication of effort with other information services in minimal, and that the benefits of cooperation are fully realized. Teaching and training are essential elements of the proposed agroforestry program. Training should stress the practical aspects. The introduction of agroforestry will require initial interdisciplinary teaching of national research workers, administrators, and those concerned with implementing the system. Close contact with national institutions will thus be essential to ensure the success of the program.

The council should establish clearly defined guidelines or standards for planning and conducting research, and for evaluating and disseminating the results.

Implementation of research results is a matter of major concern. It is of critical importance that findings be quickly transferred to sizeable trial and demonstration projects at the village level, under various social, economic, and climatic conditions and in a form that can be readily evaluated and applied in rural development programs. All facets of agroforestry systems should be appraised — technical, social, and economic. Stress should be laid on quantifying the costs of, and returns from, alternative agroforestry practices, so that objective comparisons can be made. In the process of translating research results into practice, the point at which financing and coordination by the council should be replaced by support from other agencies would have to be determined.

Consideration should be given to the desirability of extending support to developing countries outside the tropics (e.g. in the subtropics or Mediterranean-type climates) where serious problems exist to which agroforestry could help in providing a solution.

It is suggested that the council be established by charter as an autonomous, international body, and that it be governed by a board of trustees whose number, qualifications, and method of election or appointment would be determined by prior agreement among those subscribing to the charter. The establishment of policies for the operation of the council would be one of the main functions of the board.

The internationally recruited senior staff might consist of one director and a small number of experts in the natural and social sciences and in the technology of forest product utilization and marketing. Consultants should be employed when and where required to broaden the field of competence of the headquarters staff.

A very tentative estimate of the annual cost for such a council is:

for operating expenses:	$ 500000
for expenses of board of trustees:	100000
for financing research to fill gaps in essential information:	1000000
for seminars:	100000
for training in tree science:	100000
for identification, testing, and improvement of trees with underused potential:	200000
for research to increase the contribution from nonwood forest products:	100000
Total:	$2100000

It would be highly speculative to estimate the return from this effort, but it appears safe to say that results would be swift in coming. Many of the practices have already been developed and are practiced in one region or another and would require only the scientific and methodical support that has benefited plow agriculture so much during the last 30 years.

The council would sponsor, assist, and coordinate research in agroforestry but would not conduct it; thus the selection of a headquarters site would not necessarily be limited to the tropics. A small, politically neutral country, with adequate facilities for the purpose, would be a desirable location whether in the developing or developed world.

Conclusions

Life in the tropics is far from easy. The struggle for survival of all things is continuous and intense. To ensure a good life for the ever-increasing population there, the skills and experiences inherited from the past must be melded with the findings of modern science.

To this end, research in the management and utilization of both natural and man-made forests, as well as studies leading to the rehabilitation of degraded tropical lands, can make contributions of major significance. Although intensified research in these problem areas is urgently needed they are, in our judgement, better served by on-going research than are the problems of increasing production from lands where the combination of trees, agricultural crops, and/or animals will optimize results. Moreover the results, in terms of benefits to the local population, are likely to be slower in coming.

Beyond question, agroforestry can greatly improve life for people in the developing world, and do so within a reasonably short time. But there are other research horizons, scarcely touched on here, that hold promise of extending still further the contributions of trees to mankind, although the timing is less predictable and the chances of ultimate success are less certain. Among the more speculative but potentially most rewarding of these are research efforts to increase photosynthetic efficiency of trees, nitrogen and phosphorus fixation, selective microbiological digestion of cellulose and lignin into proteins, and tissue culture for the propagation of planting stock.

Clearly agroforestry alone cannot solve all the problems associated with land management in the developing world, nor will the application of agroforestry techniques of itself bring about the optimization of land use, but the authors are convinced that foresters and agriculturalists together can make a major contribution toward these objectives. An international council for research in agroforestry might well provide the key to channeling resources effectively and purposefully to this end.

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