Agroforestry in the West African Sahel (1983)

Pages
95

Size
5 x 9

ISBN
0309326443

Advisory Committee on the Sahel; Board on Science and Technology for International Development; Office of International Affairs; National Research Council

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United States of America

NATIONAL ACADEMY PRESS
Washington, D.C. 1983

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This report has been prepared by the Advisory Committee on the Sahel, Board on Science and Technology for International Development, Office of International Affairs, National Research Council, for the Office of Sahel and West Africa Affairs, Bureau for Africa, Agency for International Development, Washington, D.C., Grant No. AFR-0929-G-SS-1104-00.

Copies available from:

Board on Science and Technology
for International Development
National Research Council
2101 Constitution Avenue, N.W.
Washington, DC 20418 USA

Exploitation of natural riches necessary to humanity's material welfare must not damage our ecosystem as its equilibrium is vital to mankind. The African man knows this well for he has signed a pact with Earth and Nature for many a millennium.

His Excellency Mr. Abdou Diouf
President of the Republic of Senegal
Statement on conservation
IUCN *Bulletin* 1982

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PREFACE

The Advisory Committee on the Sahel was created in 1978 by the Board on Science and Technology for International Development, at the request of the U. S. Agency for International Development. The committee's work has focused on environmental rehabilitation and development in the Sahel.

In an effort to formulate a long-term environmental strategy for the Sahel, the committee conducted two studies under its current 18-month grant: one on environmental rehabilitation in the West African Sahel (see National Research Council 1983) and one on agroforestry in the West African Sahel. This report provides an overview of agroforestry in the Sahel today, the basic problems that are encountered in the current practice of agroforestry, and the opportunities that are available to donors such as the Agency for International Development, to promote agroforestry in the region.

"Agroforestry" or, more properly, agro-silvo-pastoralism, is a new term for the old practice of growing woody plants with agricultural crops and/or livestock on the same land. Unlike people in many areas of Africa, rural Sahelians have long practiced agroforestry. Agricultural crops such as millet, sorghum, maize, cowpeas, and groundnuts are often grown by Sahelian farmers under a park of *Acacia albida* (apple-ring acacia, or gao), precisely because the farmers realize that they will reap better harvests when they plant their crops in close proximity to *A. albida* stands. Indeed, the answer to the Hausa riddle, "Where does the growing season go during the dry season, and the dry season go during the growing season?"--"Into the *Acacia albida*"--reflects the intimate relationship between this tree and the agricultural systems of the region. Other species, such as *Acacia senegal*, are similarly valued.

There is ample evidence that traditional agroforestry is a very efficient system. However, although studies on the symbiotic relationship existing among trees and crops and animals have been undertaken over the last several decades (for example, research at the Agricultural Research Center at Bambey, Senegal, on the benefits of *Acacia albida* was carried out as early as the late 1930s), why this system of intercropping is so beneficial and works so well is not fully understood.

Although more research on agroforestry is needed, certain generalizations can be made. Vegetative cover and biological diversity are not only essential to the maintenance of a stable environment, they are also important to the maintenance of stable agricultural systems. While monocultural cropping can be extremely productive, it requires complex management, heavy input of fertilizer to replace the continual drain of nutrients, and careful attention to outbreaks of disease or predation which can destroy an entire crop. Mixtures of species, however, can produce a variety of products, can better assure food sufficiency, and are much more resistant to disease and moisture stress than are simpler systems. Moreover, the complex root structure of the diverse species that constitute agroforestry systems assists in retrieving nutrients from deep in the soil, holds moisture, and reduces erosion.

While agroforestry is a way of life to the Sahelian agriculturalist, from the Groundnut Basin in Senegal to the Waday region of Chad, development experts are still divided on what works best, what direction future efforts should take, and what basic problems and potential solutions exist. The differences in opinion appear to be due to the diversity that exists across the Sahel, not only in the physical environment but also in traditional use patterns and--a point often overlooked--government policies, efforts, laws, and regulations, and their enforcement. It is therefore not surprising that various specialists have arrived at different and sometimes conflicting conclusions, depending on their particular field of expertise and where they have gained their experience. The report reflects these differences and attempts to give a balanced overview of an emerging field of study.

In order to gain a broad understanding of what agroforestry is and how it can be used in the Sahel, we felt it was important to look at the theory and principles on which it is based and its practical application. The following people contributed to this effort.

Hans-Jürgen von Maydell of the Institute for World Forestry was asked to describe the potential for agroforestry in the West African Sahel and to recommend tree and shrub species appropriate for agroforestry systems in the region. James Thomson, a natural resources management consultant, contributed background information on social and institutional factors to be considered in designing and implementing agroforestry projects. John Raintree of the International Council for Research in Agroforestry provided a systematic approach to project identification, which appears as Appendix B. In preparing this report, the committee has drawn heavily on the material provided by these experts.

A draft of this report served as a resource document for a regional agroforestry workshop held in Niger in May-June 1983. The comments and observations of several participants in the workshop are reflected here. The contributions of J. D. Keita of the Food and Agriculture Organization of the United Nations, and Marilyn Hoskins of Virginia Polytechnic Institute, were particularly helpful.

This study has also benefited from the knowledge and experience of others familiar with the Sahel. Committee members Fred Weber and

Francis LeBeau enriched the content of our meetings and the final report with the practical insights of some 40 years of experience with environmental and agricultural issues in the Sahel. Robert Fishwick of the World Bank, consulting geographer Peter Freeman, George Taylor II of the Agency for International Development, Jeff Romm of the University of California at Berkeley, and Peter Ffolliott of the University of Arizona provided valuable comments on earlier drafts of the report. Finally, we would like to acknowledge the contributions of the many Sahelians and representatives of regional organizations and international assistance agencies whom we consulted in the course of this study.

In evaluating and synthesizing these diverse opinions and experiences, we relied greatly on the knowledge and analytical skills of our staff members, Jeffrey Gritzner and Carol Corillon, who contributed to both the substance and quality of this report. We were also assisted in many ways by others. Michael G. C. McDonald Dow attended our meetings and made important intellectual contributions based on his years of experience in the Sahel. Alverda Naylor willingly and capably performed the many clerical tasks necessary for the completion of the study. We are indebted to Sherry Snyder for her perseverance and diligent efforts in editing the report. Cheryl Hailey typed various drafts, and Irene Martinez prepared the final version for publication.

Leonard Berry
Chairman
Advisory Committee on the Sahel

OVERVIEW

Traditional systems of agroforestry in the Sahel represent highly sophisticated approaches to food production in regions characterized by extremely variable precipitation, high temperature, often nutrient-poor soils, a variety of crop diseases, and crop predators such as granivorous birds, rodents, and locusts, which can dramatically reduce harvests.

Traditional Sahelian agroforestry systems are structurally arrayed in such a manner that leaf area indices are relatively high, resulting in correspondingly high photosynthetic efficiency and biomass production. Many of the traditionally important grain crops in the region, such as sorghum and millet, are C_4-pathway crops, which are capable of converting very high light intensities into growth more efficiently than is possible in exotic C_3 crops such as wheat and rice.

These systems of agroforestry are also efficient in locally modifying temperatures and in intercepting rainfall, facilitating infiltration, and maintaining satisfactory soil moisture levels. This, among other benefits, reduces moisture stress in plants and regulates soil temperature fluctuations and soil-water relationships, thereby assuring the survival of critical soil organisms such as nitrogen-fixing rhizobial bacteria. Perennials contribute to the enrichment of the agricultural systems through nutrient cycling and help control wind and water erosion. The use of *Acacia albida* in traditional Sahelian systems is illustrative of the important contributions made by woody perennials to agricultural production in the region.

In the past, Sahelian agricultural systems had greater crop diversity. This diversity resulted in higher levels of assured food availability, because the differing requirements of the various crops and the selectivity of most crop diseases and predators prevented the magnitude of losses that can occur in the less complex monocropped systems. The range of products, in addition to food, included fodder, fuel, gum, resin, tannin, and medicinal products. Because the annual and perennial crops included in agroforestry systems characteristically are harvested at different times, labor inputs are distributed over longer periods.

In many areas of the Sahel, shifts to monocropping and open-field cultivation have resulted in lower potential productivity, reduced groundwater recharge, disruptions of soil ecology and nutrient cycling, and increased soil erosion. Because these shifts in cultivation practices have been accompanied by widespread environmental degradation in the region and the loss of native plants and animals that have traditionally served as alternative sources of food in the event of crop failure, rural Sahelian populations have become progressively less self-reliant and more vulnerable to natural hazards, such as drought, and to economic adversity.

This report provides an overview of traditional Sahelian production systems and explores approaches by which modern science and technology can complement the knowledge and experience of rural Sahelian populations in developing more dependable, resilient, and socially acceptable agricultural systems.

CHAPTER 1

Desertification in the Sahel

"Sahel" has become a synonym for enviromental degradation and the desperate struggle for survival in a region losing its carrying capacity through a series of severe drought years and the destructive impact of human activity on natural resources, a process commonly termed desertification. In this case, desertification, or desert encroachment, does not refer to the southward extension of the Sahara Desert but to the formation and expansion of desertlike patches around cities, villages, wells, and other centers of concentrated activity.* In this report, the term "Sahel" is broadly applied to the semiarid Sudano-Sahelian zone. Areas receiving between 400 and 750 mm of precipitation are emphasized.

CLIMATE

While water deficiency can be addressed by instituting a variety of more environmentally sound water use and conservation practices, it remains, nevertheless, the key limiting factor for life in the Sahel.

Rainfall distribution patterns are highly irregular in time and space. The rainy season generally lasts from July to October, with an average of 24 rainfalls, 10-12 of which occur in August. Rainfall intensities range from 5 mm to over 50 mm per event. While 5 mm of rainfall are considered effective for wild and cultivated plants, 20 mm or more are required to produce the surface runoff essential for filling temporary and permanent water holes and replenishing groundwater reserves. Figures 1 and 2 show mean annual precipitation and associated vegetation types in the Sahel.

The climate is further characterized by high diurnal temperature fluctuations and low relative humidity. During the "cool" dry season, from November to February, daytime temperatures often peak above 38°C and fall to 12°C during the nighttime, with relative humidity averaging

*See the National Research Council's companion report, Environmental Change in the West African Sahel (1983), National Academy Press, Washington, D.C., USA.

15-25 percent during the day and 40-50 percent at night. During the "hot" dry season, from March to mid-July, temperatures commonly exceed 43°C during the day and drop as low as 17°C at night. During the rainy season, from July to October, temperatures range from 35°C during the day to 22°C at night, with relative humidity from 95 to 60 percent. Thus considerable moisture is lost through evaporation. In addition, the harmattan--a dry northeasterly wind--occurs frequently from November through February, causing considerable desiccation and wind erosion.

IMPACT OF HUMAN ACTIVITY

In addition to the effects of climate on the Sahel's fragile environment, man and livestock also play major roles in desertification. Even where an ecological balance exists among man, animals, and the surrounding natural vegetation--as existed throughout the Sahel a few generations ago--extensive deterioration will generally occur when population pressures exceed a critical level. As a result of a growth rate of 2.6 percent, the population has almost doubled in the last 20 years. By the end of this century, the present population will have doubled again.

With increases in human populations have come increases in herds of cattle and small ruminants and changes in the traditional land use

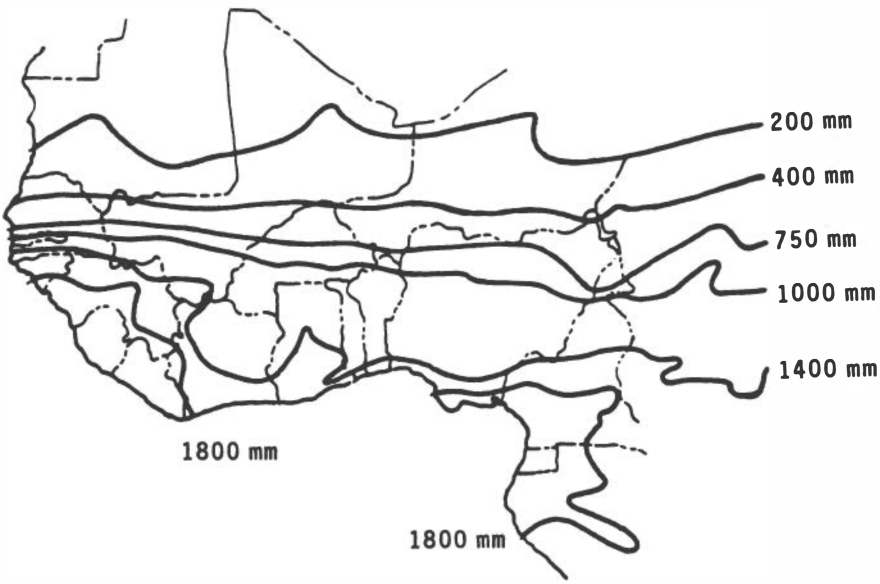

FIGURE 1 Mean annual precipitation. (Source: Weber 1977)

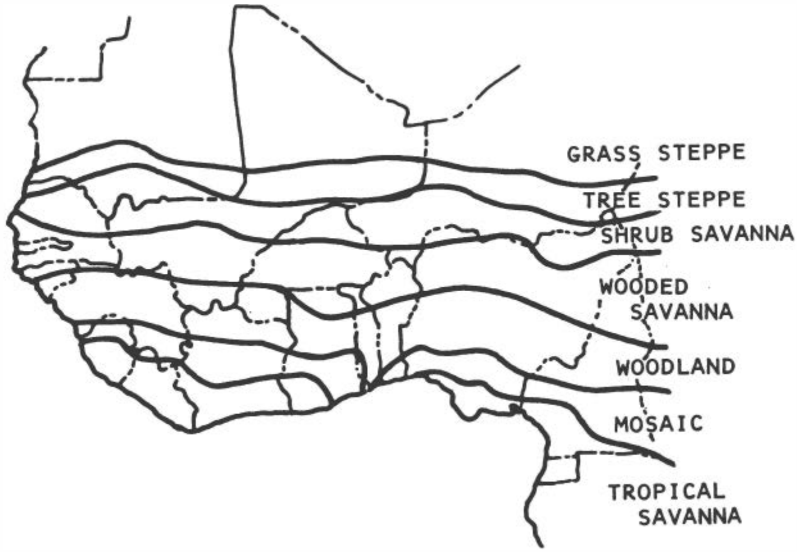

FIGURE 2 Vegetation zones, based on the Yangambi classification of African vegetation types by the Commission for Technical Cooperation in Africa South of the Sahara. (Source: Weber 1977)

patterns of various ethnic groups. Herders, who once were predominantly nomadic, tend to settle around permanent sources of water in villages and even in towns. They remain with their herds in the northern part of the Sahel throughout the year, whereas formerly they migrated southward to more favorable pastures during the dry season. A network of deep wells, powered by diesel engines, has tapped fossil groundwater resources to make water available throughout the year in many areas where it was not previously assured. The net result has been a rapid increase of herds of cattle and small ruminants (Figure 3). As many as 20,000 head of livestock are often concentrated within a few kilometers around wells. The locally available vegetation on which they depend has already been overexploited, degraded, impoverished, and, in fact, has largely disappeared, leaving desertlike "islands" around the wells.

The destruction of the herbaceous or grass layer, as a result of overgrazing and trampling by herds, marks the beginning of desertification. Plants die and their roots no longer hold the thin topsoil, which is washed or blown away. Fine clay particles spread over bare patches during the short rainy season, causing surface hardening and sealing. Seeds cannot penetrate these hardened surfaces.

FIGURE 3 Cattle herds have increased rapidly in the Sahel, and in many areas their numbers now exceed the carrying capacity of the pasturelands. (IFC/World Bank Photo by K. M. Ibrahim)

Frequently these patches are covered by stagnant water for extended periods during the rainy season. Because of the destruction of the topsoil cover and loss of organic matter, rains are no longer absorbed where they fall but drain toward lower lying areas, causing the slow but certain death of trees and shrubs due to lack of water or, where it accumulates, to waterlogging. In some areas, the process of degradation continues until the ability of the soils to retain water is almost completely lost.

Even where there is little wind, terrain is flat, and soils are too sandy to cause runoff, continuous farming of the same fields will eventually deplete the soils to such an extent that the land will have to be abandoned or revegetated unless specific steps are taken to maintain or increase soil fertility. While the revegetation of barren flats is extremely costly, fencing off endangered areas for 3-5 years during the initial phases of degradation can lead to an astonishing recovery of the vegetative cover.

Advanced farming technology can also accelerate degradation. For example, the removal of stumps, indiscriminate and more complete land clearing, and the use of machinery for deep plowing or frequent tillage expose ever larger areas of land to wind and water erosion. The introduction of cash crops such as cotton requires more thorough land clearing and places higher nutrient demands on the soil. Mechanized transport (even bicycles or donkey carts) permits local farmers to reach more land and makes possible the transport of firewood or charcoal over longer distances. Livestock improvement activities require more grazing resources, and irrigated agriculture requires more water.

A final cause of degradation is migration. People of the Sahel and Sudan are mobile by tradition. During the last few decades, however, there has been a steady movement from rural lands toward central settlements, causing rapidly increasing pressure on natural resources in the vicinity. Firewood has been drastically overexploited within a range of about 100 km around many capital cities, resulting in a severe energy crisis. Moreover, many young people are leaving the Sahel to try to make a living in urban centers along the West African coast. This exodus is severely draining the area of capable manpower and is reflected in a reduction in the numbers of agricultural workers in the Sahel.

RESOURCE CONSERVATION MEASURES

The concept of carrying capacity is useful in looking at development or conservation issues since the limits of the available natural resource base cannot be ignored. It is encouraging that a margin still exists between actual and potential production capacities and that locally appropriate resource management options can be pursued through changes in land allocation and land use. When examining resource conservation measures, the following objectives should be considered:

- Providing people with adequate supplies of basic goods and services
- Conserving those resources that still exist
- Increasing the region's long-term sustained carrying capacity.

Long and often disappointing experience has conclusively shown that any conservation activity, to be replicable, must be understood and accepted by the local population. Without the willingness of villagers to cooperate and eventually integrate whatever technique is introduced into local farm and land use practices, any idea, regardless of how valuable it might be, simply will not take hold. Because it is the rural, local people who ultimately decide the feasibility of any new idea, the following criteria must be taken into account.

First, the intervention must be technically sound and must focus on such factors as the limited amounts and irregularity of rain and the periodic occurrence of drought years. Rainfall, though infrequent and irregular, is often a direct result of violent, local convectional storms of short duration and high intensity. Under such circumstances even small watersheds or catchment areas yield sharp, high peak flows. Spillway capacity of improvement efforts has to be large, as these short, high-volume flows carry unusually large amounts of sediment, which can quickly destroy inadequately designed water control structures. Terraces intended to control water erosion must accommodate such flows, or they will rapidly wash out. Rainfall quantities and distribution patterns, compared with those of temperate zones, are extremely erratic. Mean annual precipitation is little more than a general indicator. Rainy seasons that are above or below average are frequent (Katz and Glantz 1977).

Second, investments in agricultural development activities must be appropriate to local skills, techniques, and tools. Projects relying on heavy equipment, expensive commodities, and outside technical assistance require such a large capital outlay that there is little chance the project can be replicated or continued by the local people once outside help has ceased.

Third, proposed activities will almost certainly require some changes in and adaptation to the existing local socioeconomic framework. Increased production and higher returns are not the only criteria used in calculating whether a new idea or technique is worthwhile to all concerned. In fact, local farmers may be more interested in protection against "downside risks" than in a chance to gain higher returns.

Fourth, to be successful from an institutional point of view, the interventions considered should be compatible with the existing political thought in the region of concern.

Finally, cultural values, including those dealing with traditional patterns of tenure and use of land and natural vegetation, are deep-rooted and reflect generations of experience. Modifying animal herding practices in ways that appear minor to outside project designers may well be the focal point of resistance on which an entire scheme may founder. Cultural attitudes and inflexibility may prove insurmountable in many other ways: restrictive definitions of the role of women, reluctance to abandon seasonal migration, traditional views of land tenure, or open grazing rights can pose serious obstacles to an otherwise well-designed conservation project.

Conservation measures, within these practical limits, are outlined below; agroforestry and related efforts are underlined. (For specific agroforestry techniques, see Chapter 4.)

1. Increased soil fertility

   a. Introduction of Acacia albida or other leguminous trees into farm fields
   b. Cover crops, farm management (rotation)
   c. Manure, compost, residue
   d. Tree crops, combined with agricultural crops (Taungya)

2. Revegetation

   a. Access and use control
   b. Seedbed treatment, direct seeding, planting
   c. Fire management

3. Erosion control

   a. Wind
      (1) Shelterbelts/live fencing
      (2) Sand stabilization, dune fixation
   b. Water
      (1) Contour planting/farming to control sheet erosion
      (2) Vegetation strips
      (3) Infiltration ditches, berms, terraces
      (4) Bank and slope protection to reduce channel erosion
      (5) Small check structures, gully plugs
      (6) Small dams to slow surface runoff.

4. Conservation of surface water

   a. Micro-catchments
   b. Water spreading, water harvesting
   c. Reservoirs, ponds

LAND USE PLANNING

Land use planning involving the integration of agriculture, animal husbandry, and useful trees and shrubs can take several courses. Production can be undertaken concurrently and continuously on the same tract of land; systems of alternating or rotating land use can be employed; or production activities can be geographically separated so that use pressures are distributed over a larger area. All of these variations are elements of traditional Sahelian land use strategies (see Chapter 2). Specific future strategies and emphases will naturally vary depending on local needs and preferences. Nevertheless, the key is to balance overall land use so that total economic returns and social benefits are maximized in the short and long runs.

While land use planning is a useful tool, traditional cultural values often govern the way land is used, owned, or transferred by individuals, families, tribes, ethnic groups, or entire nations. In many areas of arid and semiarid Africa, retaining current land use patterns, in the face of increasing demographic pressures and notions of progress, is leading to resource destruction. The "first come, first served" approach to the exploitation of common goods such as rangeland or indigenous trees interferes with conservation efforts, requiring the introduction of access control and use regulations. If land and soil resources are to produce, on a sustained-yield basis, more than they do now, basic readjustments of present use patterns and beliefs must be made.

Changes in land use based purely on resource management logic are unacceptable to most societies, where the first priority has been and still is the survival of the clan or tribe. Seasoned by generations of experience with recurring, devastating droughts, local farmers and herders feel they cannot afford to abandon their current strategies, particularly when they believe no other options are available. Farmers and pastoralists do not destroy their environment out of indifference or carelessness: currently, they have no other options for existing or for surviving periods of drought.

However, more productive land use patterns could be adopted if governments and regional agencies shared the risks. Considering the above constraints, the best that one can expect is that a more "rational," balanced approach to land use can be established gradually, beginning with low-risk, small-scale demonstration projects, which might serve as examples of how things could work. Such demonstrations might include:

- Small watersheds with well-planned conservation measures; controlled, multipurpose use of fuelwood and forage; surface water development

- Agroforestry projects that use land in a balanced manner to serve several local needs (stable farm soils, fuel, fodder)

- Small, well-identified grazing areas with the necessary vegetation and water reserves restored to help small, well-managed herds survive the next drought.

Unfortunately, only a few incomplete (and expensive) demonstrations have actually been carried out in the field so far.

Numerous large-scale land use schemes have been tried, with very mixed results. Group ranching, with or without herder cooperatives, in East Africa is one example. Results, judging by the slow adoption rate by the local herders, are inconclusive.

Large-scale irrigation projects are being constructed in the major river basins at current (1982) initial costs of over $10,000 per hectare. Although "poor" herders and farmers are being resettled, the rupture of family ties, abandonment of traditions, and exposure to different life-styles have increased divorce, suicides (practically unheard of before), and mental illness. Social tension, political unrest, and the incidence of diseases such as malaria and schistosomiasis have increased (Bodley 1975).

These experiences suggest that, in spite of knowing what logical and systematic land use measures could stem and possibly reverse resource degradation, there is currently no acceptable answer as to how--at the same time--to meet basic social and cultural needs, which are often closely tied to traditional land use patterns.

Carefully planned, sensitive schemes throughout Africa have attempted to bring about the necessary changes with a minimum of social tension and disruption. While insufficient progress has been made thus far to say that real changes are on the way, encouraging examples do exist.

- In Senegal and in Chad, pastoralists have cooperated in government-sponsored efforts and private initiatives to revegetate open rangeland. Traditional herders have planted trees in open spaces of the grass steppe, strictly on a voluntary basis and without compensation.

- In the Ngong hills of Kenya, local farmers now construct infiltration ditches and gully plugs and plant trees on their farmland to provide additional erosion protection. This initiative was based in part on a recently compiled "District Environmental Profile."

- In Niger, in the vicinity of a project where, with the help of the American private voluntary organization CARE, over 250 km of shelterbelts have been planted in the last 6 years, villagers are putting pressure on the local administrators to help them carry out a similar project around their own fields.

Similar projects have been undertaken in other parts of arid and semiarid Africa. Subtle change is possible; some approaches do work. These limited success stories show, however, that new land use techniques must recognize, consider, and work within the basic social, economic, and cultural frameworks of the people involved. Agroforestry would appear to be almost uniquely capable of integrating these diverse environmental, social, and economic variables into coherent, stable systems of production.

CHAPTER 2

Traditional Land Use Systems

ENERGY FLOW AND PRODUCTIVITY IN TRADITIONAL SAHELIAN AGRICULTURAL SYSTEMS

In determining the potential productivity and sustainability of an agricultural system, it is often useful to analyze the energy flows that connect the farmer with his crops and livestock. Energy flow, as used in this report, refers to the transformations and sequential dependencies of solar energy as it passes through the food chain.

Solar energy is the ultimate source of all life on earth. The basic source of energy for man is the chemical energy derived from food. The ultimate source of this food is vegetation. In energy analysis, this vegetation is termed "primary production." It is based on the capacity of plants to transform solar energy into chemical matter through photosynthesis. Man exploits solar energy by eating plants or the animals that eat plants. This relationship is often expressed in terms of the following unidirectional energy flow: primary production (vegetation) ⟶ herbivore (livestock) ⟶ carnivore (man), with subsequent recycling through decomposers such as bacteria and fungi (Bayliss-Smith 1982).

The amount of solar energy available for primary production is a function of geographical position. This energy is conventionally measured in joules (J). One joule equals 0.239 calories. A larger unit, megajoules (MJ), is often used to describe inputs of solar energy. One MJ equals 239 kilocalories. Approximately 10.5 MJ/day are required in human diets to maintain basic metabolic processes and regenerate tissue. In the Sahel, the annual input of solar radiation is on the order of 0.63 MJ/cm^2--much higher than inputs in humid tropical or temperate regions.

Only a relatively small proportion of incoming solar energy, 1 J/cm^2/hr, is converted into chemical energy as a result of photosynthesis by plants. Because photosynthesis is inefficient in its use of solar energy, it is necessary for farmers to increase vegetative cover and to arrange it in such a way that its foliage can achieve optimal productivity. The amount of foliage is often measured through the leaf area index--the total leaf area (in cm^2) per unit of soil surface (in cm^2). Experiments with many crops have shown that a considerable amount of solar radiation is wasted by falling in the gaps between leaves and between plants (Bayliss-Smith 1982). Too much plant cover can also be harmful because many leaves will be shaded and will therefore function inefficiently.

Although variation in leaf area index, availability of water and nutrients, and other factors will account for most differences in crop performance, the efficiency of photosynthesis is also influenced by the proportion of visible light that can be converted into carbohydrate by different plants. These differing capabilities relate to the so-called C_3 and C_4 pathways for carbon dioxide use; the former generally associated with temperate species, the latter often associated with plants in tropical and arid regions. The C_4 species, such as millet and sorghum, are able to convert very high light intensities into chemical energy more efficiently than C_3 species.

Temperature, moisture stress, and nutrient availability also impose constraints on plant growth. Moisture stress is of particular importance in the Sahel. Approximately 100 mm of rainfall per month is necessary to sustain crop growth. Hence, the hydrological growing season in the region between the 400- and 750-mm isohyets would generally be from 2-4 months. Nutrient deficiency is both an important constraint and the only one that is not, in practical terms, beyond the farmer's ability to control. Nitrogen, phosphorus, potassium, calcium, and magnesium are particularly important nutrients.

In a traditional Sahelian agroforestry system, trees, shrubs, and annual crops are often integrated in such a manner that leaf area indices are relatively high, permitting correspondingly high levels of productivity during the short growing season. The prominence of C_4-pathway staples, such as millet, sorghum, and maize, further contributes to the productivity of traditional agricultural systems. The deep-rooted trees and shrubs in the systems provide a wide range of products of importance to local populations, forage for livestock, and microclimates that support greater crop diversity. They also recycle critical nutrients, including the important nitrogen contributions of leguminous species such as *Acacia albida*. Research in Senegal has revealed that yields of millet and groundnuts grown under *A. albida* trees on infertile soils increase from 500 ± 200 kg/ha to 900 ± 200 kg/ha. In addition to increased crop yields, there are 50-100 percent increases in soil organic matter, improved soil structure, increased water-holding capacity, and a marked increase in soil microbiological activity beneath the trees (Felker 1978). In addition to nitrogen-fixing rhizobial bacteria, there are larger populations of other important soil organisms, such as the mycorrhizal fungi that are so important in facilitating phosphorus uptake in plants. The increased stability and productivity of these systems reduces the need for extended fallows.

The perennial components of traditional Sahelian agroforestry systems are also effective in intercepting rainfall, promoting groundwater recharge, and preventing erosion. According to some climatologists, there is also a possibility that increased perennial ground cover increases or maintains higher levels of rainfall (National Research Council 1983).

Departures from traditional systems of agroforestry in the Sahel have often included the clearance of trees and shrubs from agricultural lands. Land is cleared for a variety of reasons: the perceived need to reduce competition with crops for water, to eliminate roosts for granivorous birds such as *Quelea quelea* (black-faced diochs), and to permit the use of mechanized farm equipment. Unfortunately, the clearance of woody perennials also results in lower potential productivity: the leaf area index and groundwater recharge are often reduced, soil temperatures and soil-water relationships become less stable, soil ecology is disrupted, nutrient cycling breaks down, and erosion increases.

In many instances, complex mosaics of traditional C_4 food crops and legumes have been replaced by monocropped systems of comparatively less efficient C_3 cash crops such as rice and cotton. One result is that a much narrower range of food and other plant products is available for local use, with a corresponding reduction in the self-reliance of rural populations. In the absence of leguminous field trees, these crops require heavy applications of costly commercial fertilizer. Fertilizer requirements are further increased as the mineral nutrients contained in the crops (approximately 5-10 percent of the dry weight of the plants) are lost to the system with the export of the crops. It has been estimated that in some areas the shift to open-field cultivation has reduced the human carrying capacity of the land from 25-40 individuals/km^2 to 10-20 individuals/km^2 (Felker 1978).

TRADITIONAL STRATEGIES OF LAND USE

Two strategies of land use have been employed so far and will, to some extent, continue to be essential in the Sahel. The first is based on nomadic pastoralism and is characterized by:

- Extensive use of vast areas for grazing
- Mobility of people and livestock, as a flexible reaction to even small environmental and climatic changes
- Year-long engagement in land use; seasonality is met by rhythmic migration, adapted development of herds
- Multiple exploitation of plant cover but no cultivation of plants
- Little regular market sale of production
- Animals (cattle, camels, donkeys, goats, and sheep, as well as wildlife) are at the center of all traditional life.

The second strategy is based largely on sedentary rainfed agriculture, characterized by:

- Intensive use of small favorable sites
- Relative immobility of residents; if applicable, shifting or rotation of fields within easy reach of the family compound
- Short season of concentrated agricultural efforts, dependent on rains (July-October); seasonal "unemployment" frequently taken up by nonagricultural jobs in towns and cities

- Cultivation of a few plant species for specific products; supplementary multiple use of natural vegetation
- Only minimal livestock (e.g., small ruminants such as goats) kept for products used in the household (milk, meat, hides)
- Field crops beyond subsistence demand are regularly sold or exchanged for various goods.

Additional strategies of regional importance, but more localized application, would include the highly productive recessional (décrue) agriculture practiced along the margins of seasonally fluctuating lakes and rivers.

Sedentary agriculture is expanding northward, and there is increasing overlap and competition as well as a mixture of the original two basic types of land use. The major problems and conflicts arise in the transition zone between pastoralism and rainfed agriculture.

Natural stands of trees and shrubs have always played a supportive role for both pastoralism and agriculture. With important exceptions such as oasis agricultural systems, however, they have seldom been regenerated or newly planted by local people. In most areas of the Sahel, continuous selective exploitation and land use practices that are incompatible with tree growth have changed the original climax, eliminated many species of trees and shrubs, and resulted in degraded stands on the one hand and in local concentrations of certain species on the other. For example, such highly esteemed trees as *Prosopis africana*, *Lannea* spp., and *Ximenia americana* survived only in the southern savanna lands; apart from relic stands, they have disappeared from the Sahel proper. Other species, such as *Adansonia digitata* (baobab), *Butyrospermum paradoxum* (shea-butter), *Parkia clappertoniana* (West African locust, or néré), and *Calotropis procera*, concentrate in disturbed areas around human settlements. Bush fires have also played and still play a decisive role in species selection, resulting in a "fire-climax" in which only a few resistant species survive.

Tree culture as a preliminary stage of real "forestry" never had a place in traditional land use systems. Therefore, in discussing the following three agroforestry systems, the multiple and sometimes intensive use of naturally growing trees and shrubs largely represents the forestry contribution. These three systems are variants of the two land use strategies involving trees: first, mainly with livestock (silvo-pastoral systems); second, with agriculture (agro-silvicultural systems); third, with both in combination (agro-silvo-pastoral systems).

SILVO-PASTORAL SYSTEMS

Silvo-pastoral land use is predominant in all areas of the Sahel not used for agriculture. There are two main types of silvo-pastoral systems. The first predominates in the northern part of the Sahel where there is little rainfall and where nomadic or transhumant pastoralism is the main land use. Trees and shrubs, which form a more-or-less open canopy over the grasslands, according to site conditions, supply a substantial part of the livestock's fodder needs.

H. N. Le Houérou (1980) has suggested that, under prevailing conditions, up to one-third of all forage could be supplied by trees and shrubs. Leaves and fruits account for about 5 percent of average livestock fodder needs during the rainy season and up to 45 percent toward the end of the dry season. Their importance, however, is not only to be measured in kilograms of available dry matter but, even more importantly, in terms of fodder quality (for example, content of digestible protein, minerals, and vitamins). Research in northern Senegal has shown that an average tropical livestock unit (corresponding to one 250-kg bovine) consumes about 1,200 kg of grass and herbs and more than 500 kg of woody forage between November and July (dry season). As the net annual increase of grass and herbs in this region is between 300 and 1,300 (average 700) kg per hectare (ha), and that of accessible and digestible forage from woody plants is about 120 kg/ha, empirical research has shown that during the entire year, about 5 ha of average bushland are needed to feed one tropical livestock unit. There is considerable variation, however, subject to soil and rainfall conditions. Only 1 ha will be needed on highly productive sites--for example, in seasonally flooded depressions; over large parts of the drier northern Sahel, however, at least 10-20 ha or more will be required.

Trees and shrubs of the Sahel have thus played a significant role in livestock management. Governments in the past often responded to apparent demand by establishing vast silvo-pastoral reserves, now under the supervision of the national forest and range management services. In addition to forage, trees and shrubs furnish important supplies of edible fruits and leaves to the many people who do not grow agricultural crops. They also provide wood and many other products, including medicinals from the "ever-present pharmacy."

Natural grasslands with a relatively high proportion of trees and shrubs continue to form the basis of a more-or-less sustainable silvo-pastoral land use system over millions of hectares and for millions of people. Growing populations and steadily increasing numbers of livestock, however, have led to critical and destructive developments during the past few decades. Without improvement and controlled management, the carrying capacity of northern Senegal appears to be just below 1 person and 25 livestock units per square kilometer (100 ha). This would result in the annual removal and consumption of over 125 kg of woody forage and around 5-7 kg of wood and minor forest products per hectare, compared with the annual increment of 120 kg of accessible and digestible woody phytomass and 123 kg of wood and bark as measured at Fété-Olé, Senegal. In other words, pressure on woody forage has reached its critical level in most areas, whereas wood consumption for household use becomes destructive in concentrations of more than 25 people per square kilometer. These figures, although provisional and of rather local validity, not only indicate the definite limits to further growth but also explain the existing threat of desertification in some parts of the Sahel.

A second type of traditional silvo-pastoral system is found mainly in the southern Sahel (largely in areas with more than 500 mm annual rainfall) and in the transition zone between pastoralism and rainfed agriculture. Here, on the same plot of land, crops of millet, cowpeas, and groundnuts are grown during the rainy season. After harvest the fields are opened to livestock to feed on agricultural residues and weeds; during the rainy season the livestock are maintained on the surrounding grasslands. This form of rotation is well established and adapted to the ecosystem and to local needs, and is practiced by sedentary or semisedentary farmers, often by agreement with migrating herders (Gallais 1975). The system comprises a phase of green fallow over several years, where trees cut at stump level recover. These fallows usually offer much richer grass and herb vegetation than surrounding bushlands. Woody plants play a subsidiary role in this system; trees are lopped, and leaves and pods are collected as additional fodder. Leaves of bushes and trees sprout 6-8 weeks prior to the arrival of rain, supplying a valuable protein source at the time of greatest forage scarcity.

AGRO-SILVICULTURAL SYSTEMS

Agro-silvicultural systems combine tree and shrub utilization with rainfed or, occasionally, irrigated plant production. Most include a livestock component as well. Perhaps the best-known examples are the oases of the desert and subdesert zones. These systems are described in detail in the early literature of the northern Sahel.

Travelers' chronicles dating from the Middle Ages to the late nineteenth century describe agro-silvicultural systems in the northern Sahel that contained a far greater diversity of crops than is found in the region today. There was frequent mention of northern grains, such as wheat and barley, as well as Mediterranean vine and tree crops such as grapes, olives, and figs. Many of these crops were associated with Berber and Arab settlers from the north and were apparently supported by summer rains, the more frequent winter rains received in the past, and by supplemental irrigation (Robert 1976).

Other major grain crops included sorghum, millet, and maize. Garden crops grown in the oases included broadbeans, lubia, peas, carrots, okra, turnips, swedes and cabbage, cucumbers, various kinds of melons, pumpkins and squash, purslane, eggplant, tomatoes, radishes, beets, onions, garlic, and chili peppers. Sugarcane was also widely grown. Important exports from the oases included mallow, sesame, saffron, cumin, coriander, "Sudan" chilies, raisins, cotton, indigo, esparto grass, and henna. Noteworthy among the trees and shrubs associated with these systems were date palms, lemon trees, Seville orange trees, mulberry trees, pomegranates, and almond, peach, and apricot trees. Wild species exploited for food included colocynth, *Zizyphus* spp., *Hyphaene thebaica* (doum palm), truffles, *Nitraria tridentata*, and wild grains such as the seed of *Aristida pungens* (Nachtigal 1879, Levtzion and Hopkins 1981).

Representative of the agro-silvicultural systems of the southern Sahel would be that of the Yatenga region of Upper Volta. In the Yatenga systems, the areas nearest the settlements are under almost permanent cultivation. Fertility is maintained by nutrient cycling through trees--particularly Parkia clappertoniana, Tamarindus indica (tamarind), and Butyrospermum paradoxum; short, 2-year fallows; and by dressing the fields with ash and manure collected in the pasturelands beyond the zone of cultivation.

The crop rotations employed in the region largely reflect soil qualities. For example, the following rotation would typically be associated with hydromorphic soils:

Year 1	Maize associated with cotton
Years 2-6	Sorghum and cowpeas
Years 7-9	Groundnuts
Year 10	Grazed fallow

On better agricultural soils, the fallow period is frequently eliminated:

Years 1-6	Maize
Year 7	Sorghum and cowpeas

In this rotation, cotton is associated with cereals every 2 years. On lands that are degraded or difficult to cultivate, millet and sorghum are cultivated for a period of 5 years, followed by grazed fallow or the cultivation of groundnuts (Food and Agriculture Organization 1981).

Today, a number of agro-silvicultural systems appear to be practiced in the Sahel. Gardens are found within settlements where water is available, usually with a tree component that provides shade and shelter and, often, edible fruits or leaves. The same holds true for intensively managed, irrigated, and fertilized gardens near urban centers. Both subsistence home gardens and cash-generating market gardens are highly productive. Fruit and pod-bearing trees, shade trees, and hedges or living fences are the "forestry" components, sometimes supplemented by decorative woody plants. Mangoes, citrus trees, guavas, Zizyphus mauritiana (Indian jujube), cashews, palms, Ficus spp., and wild custard-apples are prominent kinds of fruit trees. Shade is often provided by Azadirachta indica or similar species, while fencing is provided by thorny species of Acacia and Prosopis, and by Commiphora africana, Euphorbia balsamifera, flowery shrubs such as Caesalpinia pulcherrima (paradise-flower), and other species.

Close to the settlements is a ring of suburban gardens, often irrigated, in which cassava, yams, maize, millet, sorghum, rice, groundnuts, and various vegetables are grown, for subsistence as well as sale, depending on the ecozone.

Outside the villages in areas of adequate rainfall are bush farms, often more than 1 ha in size, where the region's main agricultural crops such as millet, sorghum, maize, and groundnuts are grown. These farms may be and sometimes are so far away that people have to build shelters to stay there for many days without returning home. Woody plants are often cut from the fields to avoid competition with crops or to deny nesting to birds, and for use as fencing material. Where possible, however, *Acacia albida* or food trees (for example, *Butyrospermum paradoxum*, *Parkia clappertoniana*, *Tamarindus indica*, *Borassus aethiopum* (ronier), and *Hyphaene thebaica*) are left and often carefully maintained and protected. With some regional variations, a very old and sophisticated tradition of food-tree culture flourishes, which has resulted in an almost perfect combination of single-tree management and intensively managed farmlands and therefore merits detailed study.

AGRO-SILVO-PASTORAL SYSTEMS

These systems combine all three elements of crops, trees, and livestock in both space and time. Two systems are mentioned here. The first is a rotation system that is common in the Republic of Sudan but is also known in Chad and Niger. It is based on about 20 ha of family-owned land subdivided into 4 sections to be rotated every 5 years. For example:

Years 1-5	Plantation of *Acacia senegal* trees; in between agricultural land use (for example, where millet is cultivated).
Years 6-10	First harvest of gum arabic from the trees; cutting grass from fallow land.
Years 11-15	Period of full yields of gum arabic; controlled grazing possible between trees.
Years 16-20	Final harvests of gum arabic; clearfelling of the acacia trees (used for firewood, charcoal, posts); grazing.

The rotation continues with replanting and agricultural use in the twenty-first year. Depending on site quality and rainfall, these 20 ha can maintain a family of 5-10 people.

The second system is found in many parts of the Sahel where rainfall and groundwater level permit the growth of *Acacia albida*, the remarkable multipurpose tree of semiarid Africa. Outstanding examples are to be seen in Senegal (near Bambey) in parts of Upper Volta, and in southern Niger (Dallol-Maouri). *Acacia albida* is, in fact, often regarded as a sacred tree. Proverbs refer to it: "The tree is your better friend: it never demands but always gives." The sultans of Zinder, in former times, used to cut off the hands of people who illegally felled an *Acacia albida*.

This leguminous, nitrogen-fixing tree has a deep taproot system that enables it to tap lower sources of water and nutrients inaccessible to agricultural plants. It is leafless during the agricultural season and therefore does not compete with crops for light. It produces leaves and provides ample shade during the hot dry season--a phenomenon known as "reverse foliation." The leaf litter of the trees contributes nitrogen, other nutrients, and much-needed organic matter to the fields. In addition to soil improvement, which results in up to 100 percent higher yields than those outside the range of Acacia albida crowns, this tree produces large quantities of qualitatively valuable forage by shedding its apple-ring-like pods during the dry season. The wood is used for local construction and as fuel. The thorny branches serve as fencing material, and many parts of the tree provide medicine for people and livestock. About 20 adult trees per hectare will guarantee an almost perfectly balanced system of agroforestry with high yields in millet production in the rainy season (Figure 4) and more than 1,500 (sometimes as much as 2,500) kg of pods for feeding cattle and small ruminants; that is, sufficient for the supply of one tropical livestock unit per hectare in the fodder-deficient dry season. Therefore, Acacia albida has been given high priority in agroforestry projects in suitable parts of the Sahel.

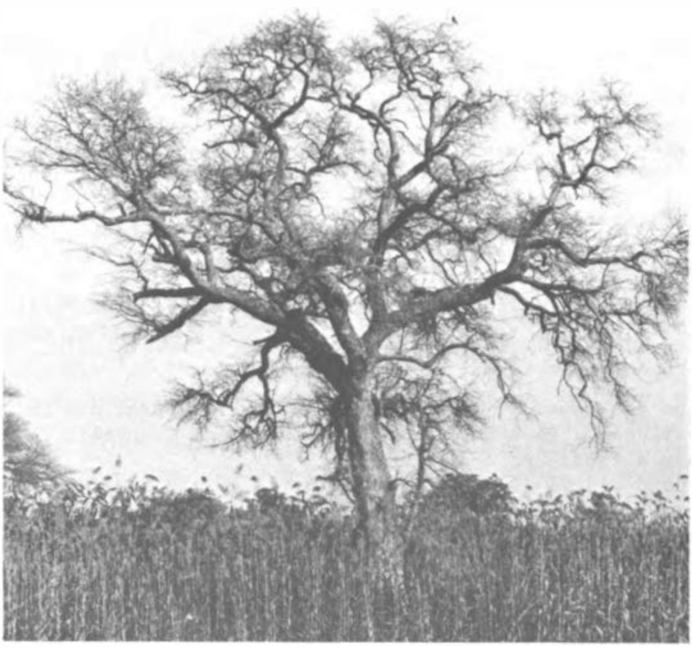

FIGURE 4 Upper Volta. Yields of millet and sorghum may increase three or four times if grown in fields with Acacia albida trees. About 20 adult trees per hectare are recommended in agroforestry systems. (Centre Technique Forestier Tropical)

CHAPTER 3

Uses and Potential of Agroforestry

As indicated earlier, the term "agroforestry" covers a variety of land use systems in which woody perennials are directly associated with agricultural crops and/or livestock in order to realize higher productivity, more dependable economic returns, and a broader range of social benefits on a sustained basis. Agroforestry can contribute to rural development in the Sahel by:

- Increasing the variety and stability of food supplies
- Providing a sustained supply of fuelwood
- Producing wood and a variety of other raw materials from shrubs and trees for construction, for farmer's subsistence, and to provide a constant supply of locally important "bush products"
- Protecting the productive potential of a given site and improving its environment and carrying capacity
- Safeguarding sustainability through appropriate intensification of land use, and improving social and economic conditions in rural areas by reducing risks and creating jobs and income
- Developing land use systems that make optimal use of modern technologies and traditional local experience and that are compatible with the cultural and social values of the people concerned.

In large but sparsely populated regions there is usually either no need or no possibility for intensive land cultivation. This has been, and in some areas still is, the case in the rural Sahel. In these areas, people have developed outstanding skills in exploiting available self-regenerating natural resources. They know the characteristics and products of most plants. In the Sahel, there are hundreds of species of trees and shrubs that are used in a variety of ways: for food, fodder, firewood, building poles, fiber for cordage, tannins, dyes, stains and inks, gums, resins and waxes, poisons and antidotes, and drugs for medicinal and veterinary purposes (see Chapter 2). In traditional subsistence strategies, woody plants were used effectively in combination with grasses and herbs and were kept in balance with the needs of wildlife and livestock, according to water availability and other local conditions.

With population growth, competition between farmers and herders has increased. Urban migration has created markets for food produced by proportionally fewer people. In areas where arable land becomes scarce, people turn to new land and more intensive practices. They try to accomplish this in two ways. One is through specialization, by crop monoculture, to achieve maximum yield of one product. Daily needs are met by exchanging or selling the surplus in order to obtain other goods and services. Alternatively, production can be diversified to satisfy most of the needs of a household or community. The bulk of production is locally consumed, and only small quantities are exchanged for goods not obtainable by other means. Although agroforestry is not necessarily confined to subsistence economies, it is clearly easier to meet the requirements of rural populations through a system of land use that integrates agriculture, pastoralism, and forestry than through monoculture. This is particularly true if natural sites and economic conditions such as infrastructure, access to markets, and purchasing power are marginal.

ECONOMIC BENEFITS

Crop yields in Sahelian countries are among the lowest in the world. Costs of agricultural infrastructure, fertilizer, and pesticides are among the highest and therefore are beyond the reach of most farmers. The attraction of agroforestry is in the greater potential stability of the system in responding to drought and heat stress, in its nutrient cycling and improved moisture balance, and in the greater variety of products it yields. In any given location, the type and extent of a suitable mixture of trees and crops will depend on environmental factors, such as soil type and rainfall, and on the purpose for which the crops are grown.

The following sections describe the potential benefits resulting from growing a combination of trees, shrubs, and agricultural crops.

Food

Agroforestry can increase the dependability of food supplies, thereby reducing risk in rural economies. As will be shown later, it also contributes to making the best use of scarce water resources. Under Sahelian conditions of extremely variable rainfall, risk is reduced by growing more vegetation per unit area compared with other systems, using mixtures of species, multistory structure, extending the growth period, and protecting and improving the soil. Trees and shrubs play an important role. Fruits and leaves of many species are edible and form part of the staple food of Sahelian people. They also are important sources of fodder for livestock, especially during the dry season, and therefore indirectly contribute to food production through animal products. Similarly, agroforestry systems often provide habitat for wildlife and thereby increase the availability of bush meat. The many foods available from agroforestry systems can provide a more varied and potentially more nutritious diet.

Energy

Some families in the Sahel, particularly in urban centers, spend one-third of their income to buy firewood or charcoal. In others, one working day per week of one or two of the family members, often women and children, is spent collecting firewood from the open bushland, often located considerable distances from their homes. Field research in many parts of the Sahel indicates that, on the average, at least 1 kg of firewood is needed for the daily supply of one person. The actual amount of firewood or charcoal required is dependent, in part, on the inherent density of the wood, as heavier woods yield more energy on a per unit volume basis than lighter woods. Continued uncontrolled firewood collection results in severe destruction of vegetation.

The most severely affected areas are those in the zone between the Sahel proper and the savanna, where increased farming and herding have led to the greatest overuse of the vegetation. In the northern Sahel, the lower population density limits the degree of severity of deforestation; in the southern savanna region, rainfall is adequate to support a relatively plentiful supply of biomass fuel. Exceptions are the result of urban demand, which may extend for hundreds of kilometers as in the case of the charcoal supply for Nouakchott provided by the disappearing *Acacia nilotica* (gonakier) forests along the northern bank of the Senegal River.

Firewood plantations appear to have economic and ecological limitations in the true Sahel. Alternative energy supplies are not available or are too expensive. More than 90 percent of all household energy requirements are met by wood. Single tree or shrub cultivation, as applied in agroforestry and adapted to the environment, can make more firewood available to rural households.

Agroforestry satisfies other energy needs as well. Modern Western agriculture requires constant supplies of energy such as liquid fuel for mechanized farming, transportation, and production of mineral fertilizers. In Sahelian agroforestry, however, the need for mechanization is reduced, and the need for fertilizer can be met instead by animal manure, by mulching and composting of organic waste, and by nutrient cycling through deep-rooted woody perennials.

Renewable Raw Materials

Trees and shrubs are important sources of raw materials in the Sahel, since few others are available. Wood, in addition to firewood, ranks first; it is used in almost every aspect of daily life. Of these many uses, traditional building, fencing, and production of agricultural and household implements and furniture are most important.

Utility wood (predominantly poles, small logs, branch-wood for roofing, or thorny brushwood for fencing) is obtained through selective, single-tree utilization; thus destruction by clearfelling rarely occurs. This highlights the possibility of producing wood on agroforestry land in single tree units that perform various productive and protective functions while they are growing.

In addition to wood, many other products from trees and shrubs are used locally and are even exported. The best-known product is gum arabic from the Acacia senegal, a small leguminous tree that grows in sub-Saharan Africa from Senegal to Somalia (Figure 5). It is currently among the most commercially important natural gums in the world. In addition to a broad range of domestic uses, gum arabic is used in the manufacture of medicine, chewing gum, confectionery, soft drinks, and a variety of foods. It is also used for printing in the textile industry. Although more than 80 percent of all gum arabic on the world market is produced in the Sudan, many Sahelian countries, including Mauritania, Senegal, Mali, Niger, and Chad, export smaller quantities and are making concerted efforts to increase their production. Gum arabic can be produced extremely well in agroforestry systems because the Acacia senegal integrates well with other crops and provides fodder for livestock. It has been traditionally used in this way for centuries in the drier areas of the Sahel.

Increasing the number, species, variety, and quality of trees and shrubs on lands formerly used only for rainfed agriculture or as pastures can improve the supply of many of these products. There is an outstanding demand for tree and shrub products both locally and for export because substitutes are not available, are too expensive, or because natural products are preferred.

Environment

When a natural ecosystem is replaced by one managed for subsistence or economic purposes, potentially competitive plants and animals are deliberately eliminated, while others disappear because of changed site conditions. As a rule in arid areas, having fewer species leads to greater risks to productivity because the simpler system is more vulnerable to drought, erosion, pests, and all the uncertainties of agriculture. Agroforestry, on the other hand, protects the environment by approximating the natural three-dimensional structure of a mixed tree/crop system and by maintaining or even increasing the number of plant species. Expensive failures of large-scale monoculture development schemes in the tropics, notably involving cotton and groundnuts in the Sahel, indicate that the kind of land use practiced successfully in temperate zones is not easily transferable. Agroforestry involves changes that benefit the farmer by substituting crops for natural vegetation, thereby reducing economic risks because the system can adapt to local conditions and generate a greater variety of products and resources.

FIGURE 5 The Acacia senegal is a small leguminous tree well suited to agroforestry systems. It produces a variety of products, including gum arabic, which is used in foods and beverages, in pharmaceutical preparations, in confectionery, and in a wide range of industrial applications. (Gum Arabic Company)

SOCIAL BENEFITS

Agroforestry can help people to be more self-reliant by meeting daily needs through a more varied and often more productive economy, and by reducing the need to import food, fuel, fertilizer, herbicides, pesticides, fodder, building materials, and other products. It also enables rural Sahelian populations to relate economic production directly to their own cultural traditions and management capabilities rather than to alien perspectives and approaches to management, which are often insensitive to local needs, capabilities, and conditions. By increasing the self-reliance of rural populations and maintaining cultural continuity, agroforestry can help stabilize rural communities and reduce the destructive social anomie so often associated with rapid socioeconomic change. By simultaneously permitting increased production while relieving pressure on environmental systems, agroforestry also enables rural populations to maintain or restore the traditions of environmental stewardship so basic to the long-term well-being of the Sahel region.

FLEXIBILITY

Soils and vegetation in the Sahel vary, even over short distances. The great variety of sites has, in the past, too often been disregarded in development projects. It is nearly impossible for people unfamiliar with the region to detect site differences during the long, dry season. As indicated in the example of agriculture in the Yatenga region of Upper Volta (Chapter 2), however, site quality has always been carefully respected by local farmers and herders.

Agroforestry combines plants and animals that are well adapted to varying site conditions. Existing vegetation may serve as an indicator in the selection of more productive species to meet local needs. Unfortunately, however, knowledge about effective plant associations in agroforestry generally is quite limited. Research in this area has been neglected compared with research on conventional cropping systems because of the emphasis placed on improving productivity of good agricultural land in order to feed larger numbers of people. The associations among plants in agroforestry systems are more complex, and the research is more difficult and time-consuming because of the relatively long life of the perennial species involved.

The Sahel is not suited for true forest. Growing large, closed forests is probably not possible with the region's limited rainfall; however, selected trees and shrubs (or small groups of them) can be grown successfully on soils suitable for their specific nutrient and moisture requirements. The same holds true for agricultural crops.

The sustained and multiple use of seasonally flooded depressions and areas with adequate groundwater availability appears widely neglected. Although these seasonally flooded depressions are used for watering cattle during the Sahelian rainy season, they could be converted into small "agroforestry oases" with an upper story of multifunctional trees and a lower story of agricultural or horticultural crop plants. Several areas with satisfactory groundwater recharge, such as the Bahr al-Ghazal depression of Chad, could support higher levels of agricultural production.

Agroforestry is extremely flexible in its adaptability to ecological niches; and, because of its diversity, it does not impose heavy pressure on specific sites. Beyond the traditional knowledge of local farmers, herders, and other experts in land use, much remains to be improved through trials and experimentation. Each system of agroforestry, with interactions between plant associations and their individual components, is faced with the problem of competition among and within species. The goal of agroforestry is to reduce this competition by optimizing combinations of agriculture, pastoralism, and forestry over space and time.

Correlations between optimal and minimal population densities and sizes of woody as well as annual plants need to be quantified. Some work has already been done on optimum tree spacing and mean annual rainfall, which will help to develop relevant land use techniques with variable numbers of individual trees. Minimum factors for plant growth show a certain intraspecific variation. This offers an opportunity to optimize plant associations.

Agroforestry also offers techniques to make optimal use of land on a small scale. There are many interdependencies among plant and animal species to be considered. All animals and man depend on plant biomass production through photosynthesis. Many woody plants depend on rhizobial bacteria or mycorrhizal fungi; others are parasites, saprophytes, or climbers. The food preferences of various forms of livestock are generally complementary--some being primarily browsers, others being preferential grazers. The productive potential of adapting plant and animal species to particular sites in the Sahel has not yet been adequately exploited.

ACCEPTABILITY

Agroforestry has been defined as a sustainable land management practice that increases the overall yield of the land, implying management strategies compatible with the cultural practices of the local population. Agroforestry can be improved by new techniques such as irrigation, fertilization, and subsoil treatment, and particularly by selecting and breeding more productive economic species. Local species should be given preference because they are adapted to the sites and their uses are well known to the people; however, exotic species may have attractive production capabilities in the new environment.

The belief that Sahelian people tend to be conservative, if not entirely against all innovation, is not true. There is, in fact, ample evidence of change. For example, when it is said that nomads continue to enlarge their herds irresponsibly, only for purposes of prestige, this is only a half truth from an external perspective. For the nomad, a large herd composed of animals of all ages will have a larger number of survivors after a period of drought, giving more security to the herd's owner. Similarly, a farmer who has many children and, during years of high rainfall, extends his fields into rangeland areas or around a water hole (thereby giving his cattle access to water), is trying to reduce the risks of harvest failures and lack of grain. It is also true, however, that these strategies often result in increased environmental degradation. Greater effort must be made to reconcile changing local needs and practices with sound environmental management.

Another especially relevant aspect of land use in the Sahel is that in the present and at least for some future decades, prevailing conditions in the Sahel set definite limits to growth. Although very substantial increases may be possible in specific locations and in selected sectors, higher agricultural yields should be only one among a number of strategies to increase human ecological carrying capacity. Others would include:

- Improving the quality of the products (for example, higher nutrient content and better digestibility of crop plants, higher yield or value of cash crops)

- Saving scarce resources (for example, by introducing fuel-efficient stoves, less wasteful charcoal-making technologies, and water-saving trickle irrigation)

- Substituting deficient items with those more readily available (for example, living fences and hedges for barbed wire or wooden fences; compost and mulch for imported fertilizers).

These measures will involve making resources available to the local farmers and herders beyond usual agricultural or forestry projects. While this may appear to be a handicap that retards progress, it is, in reality, a multiple-strategy approach based on the way people see their problems and on the way they are accustomed to addressing necessary changes.

CHAPTER 4

Agroforestry Applications

When applied to the traditional African smallholder, the term "farm management" refers to a mixture of crop diversification, crop rotation, and introduction (where adequate water and appropriate soils are available) of small vegetable gardens, fruit orchards, and forage production for locally owned livestock.

Since intense heat is a major constraint in Sahelian environmental management, shade trees are highly valued. Villagers frequently request trees that provide shade for the family compounds, for school buildings, or for the marketplace. Despite the need for good farmland to provide basic staple food crops, local farmers often are willing to set a few corners aside for trees. High on the list are fruit trees: mangoes, citrus, guavas, and papayas. Next come "food trees." Many local sauce and stew recipes call for substantial amounts of leaves from various local trees such as *Adansonia digitata*. Forage trees and shrubs are also highly desired.

Quite often, farmers do not interplant more of these useful trees only because seedlings are not available. While the introduction of plastic pots in nurseries has made it possible to produce planting stock of this kind, most forest services plant rapid-growth exotic species used in larger scale reforestation schemes and only recently have begun to promote local species.

As noted elsewhere in this report, trees can play several important roles if they are properly integrated into conservation-oriented farm practices. They produce shade, fruit, and other foods, but when integrated into soil-conservation activities such as the construction of berms and terraces, they can provide cover and protection against wind and can anchor water-control structures. They also improve the microclimate. Furthermore, leaves and other litter fall to the ground and resupply the soil with nutrients and organic matter. Well-selected trees and shrubs can contribute to soil conservation and improvement and the restoration of ecological balance and, at the same time, play an important role in providing food, fuel, fiber, pharmaceutical products, economic products such as gum and honey, and many other items that have disappeared because of advancing desertification.

Tree Crops

Many indigenous fruit and food trees play an important role in providing more balanced diets and/or additional farm income. In areas receiving more than 700 mm of rainfall, or along mares or depressions, two tree species are of particular interest: Butyrospermum paradoxum and Parkia clappertoniana. Both furnish important products that are used in even the most modest kitchen. Shea butter is produced from the former by a long and tedious process and provides fats and vegetable protein, which are inadequately supplied by standard cereal staples. The pods and seeds from P. clappertoniana are used as the base for such local sauces as soumbala which, like shea butter, provide proteins as well as vitamins and minerals otherwise missing from diets. A refreshing vitamin-rich drink is derived from the sticky pods of Tamarindus indica. The acid contained in these pods is mixed with local millet and sorghum gruel to make them more digestible. Moringa oleifera, very much appreciated for its edible leaves, is found in many local gardens. Ficus spp., Zizyphus spp., Balanites aegyptiaca (desert date), Borassus aethiopum, and other species similarly serve as important sources of food. These trees contribute so much to the basic diet and traditional well-being of Sahelian populations that they are considered valuable assets in farm fields as well as around compounds and villages, even if they compete to some extent with staple crops.

Natural regeneration of Acacia albida and other valuable species is declining in many places. Intensive farming (including weeding and land clearance by animal traction or tractors) no longer allows a farmer to weed around young seedlings. Animals in ever-increasing numbers browse on the young shoots and destroy what is left. However, all of these species have been successfully established in nurseries from seeds and transplanted into fields, and seedling supply need not be a problem.

The major issue in planting trees, then, is to find local people who are willing to take the extra steps necessary to plant and protect the seedlings during the first few years. After the harvest, animal owners allow their livestock to forage on the stalks and leaves of the previous season's crop. While it is not always possible to ask animal owners to keep their sheep, goats, cows, or donkeys away from newly planted trees, which may be scattered throughout the farm fields, it can and has been done in selected sites with considerable effort, supervision, and care.

Shelterbelts

Shelterbelts occupy a special place in agroforesty. Where wind and heat adversely affect farm yields, properly designed shelterbelts can increase production substantially. Net production increases of over 30 percent in protected fields have been reported in Niger (in the Bouza District windbreak project).

What began as an effort simply to establish a living barrier against winds, quickly developed into a multipurpose operation.

Properly managed, shelterbelts produce not only firewood, poles, and branches for fencing but also some fruit and forage. Further, as leaves fall from the trees, they are scattered across the fields, providing the soil with critical nutrients and substantial amounts of organic matter.

In certain regions, it has been found that although people are reluctant to set aside larger blocks of farmland for tree plantations, they are less opposed to taking a strip of land out of farm production to establish shelterbelts. Cooperation can be easily arranged because farmers are convinced that they increase crop yields, even after the land they occupy (around 10 percent) is taken into account. The reasons for this receptivity should be carefully documented so that cooperation in such efforts can take place elsewhere.

The current preferred approach to establishing a multipurpose shelterbelt is to have a mix of rapid-growth species for immediate protection; slower-growing trees that eventually grow quite tall, extending the wind-shielded area; and smaller trees or bushes that produce a variety of by-products (such as *Acacia nilotica* pods, which are in strong demand by local tanneries) and fill the air spaces closer to the ground.

For further information regarding the establishment of shelterbelts in the Sahel, see the National Research Council's report, *Environmental Change in the West African Sahel* (1983).

Contour Planting

The planting of valuable, multiple-use tree species in association with terraces, berms, and ditches in soil conservation projects allows socially beneficial production to be combined with much needed soil conservation measures in Sahelian farming systems.

Vegetation Strips

Horizontal vegetation strips consisting of bands of different trees and shrubs established along contour lines to prevent soil loss by erosion is another concept worth mentioning. These strips can eventually be rotated every 10 years so that an adjacent band is established while the previous belt is cleared and its restored and rejuvenated soils farmed again.

Trees and shrubs can also be used effectively to protect and stabilize slopes and banks along natural erosion channels or along runoff swales in farm areas.

RAINFED AGRICULTURAL PRODUCTION

Among the numerous factors that limit crop production under rainfed conditions in the Sahel, two are of overriding importance: (1) the efficiency with which crops and range vegetation use available moisture, and (2) soil fertility and the availability of critical plant nutrients. These two factors are intimately interrelated.

In many traditional systems, crop production, soil fertility, and soil structure (an important determinant in the capacity of the soil to hold and supply water) were maintained by extended fallow periods between shorter cropping cycles. During this fallow period, native plant species--predominantly deep-rooted, woody leguminous species--became reestablished and provided ground cover essentially equal to that provided by the natural vegetation before the land was cultivated.

Under alternating cycles of 3-4 years of cultivation and 15-20 or more years of fallow, soil fertility and structure, including organic matter content, were maintained with virtually no deterioration over time. Soil fertility was maintained through the recycling of mineral nutrients by trees and shrubs with deep root systems extending beyond the leached surface horizons, and through biological nitrogen fixation by soil microorganisms such as *Rhizobium* spp. and various free-living, nitrogen-fixing bacteria and blue-green algae. Soil structure was maintained by the combined action of the deep and extensive root systems of the trees and shrubs and by leaf fall. The enhancement of capacity to absorb water contributed to the maintenance of soil moisture at capacity levels, thus controlling runoff and thereby reducing erosion.

As the intensity of land use has increased with population growth, the long fallow period has been reduced. In some cases, the fallow period has been so reduced that few trees and shrubs survive to become reestablished and make sufficient growth to be useful. The vegetation that develops during the short fallow period is dominated by shallow-rooted grass species that contribute little to regeneration of soil fertility and structure. The recycling of nutrient elements and nitrogen fixation essentially stops. The infiltration of water into the soil is reduced, thus increasing runoff and erosion. Reduced ground cover further facilitates wind erosion. Although there are few reliable data to confirm this, it appears that the productivity of Sahelian soils has declined under more intensive cultivation.

Investigations by the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) in Senegal and Upper Volta have demonstrated that the adverse impacts of the intensive use of Sahelian soils can be counteracted by the use of a variety of management practices. The use of heavy applications of manure or crop residues, applications of chemical fertilizer, and subsequent deep plowing were found to maintain and even increase productivity under conditions of continuous cropping with grain crops for periods of up to 20 years.

Unfortunately, these results have found little application. They are usually beyond the capabilities of Sahelian farmers, who have little manure, use crop residues for animal feed and other uses rather than for soil improvement, have little physical or economic access to chemical fertilizers, and are usually unable to practice deep plowing because they lack equipment and because the labor requirements are difficult to meet as most workers are engaged in the harvest and other activities such as crop transport and storage. Moreover, maximum effectiveness is achieved only if all practices are combined. The use of chemical fertilizers alone, for example, does not provide as good a response as when used in combination with the other practices.

The IRAT work, while demonstrating a technical methodology for maintaining productivity under continuous cropping, has not produced a practical solution or method for applying the technical solutions within the constraints under which most Sahelian farmers work. The challenge to researchers now is to develop practical methods for applying these technical solutions. It is within this context that agroforestry might best contribute to agricultural production in the Sahel.

The following comments relate only to the use of agroforestry plant species in combination with crop production for maintaining or enhancing productivity.

The principal objective of the farmer in the Sahel is the production of his basic food needs—grain and legume seeds. Any practice that interferes with achieving this objective is not likely to be accepted. Moreover, the precariousness of survival in the Sahel is such that the promise of better production, that is, better living in future years, is not sufficient incentive to ensure acceptance of a practice if doing so increases the risk of failure in satisfying current basic needs, or if it diverts meager resources, especially labor, from the task of producing basic food requirements. These conditions impose very definite limits on options for incorporating productivity maintenance or improvement schemes in the Sahelian rainfed agricultural production system. Hence, perhaps one of the principal advantages of agroforestry in the Sahel is that it is functionally and conceptually related to traditional agricultural systems in the region, and its implementation can therefore be supported by existing knowledge and techniques. In this context, agroforestry can be seen as an effort to strengthen and further diversify existing Sahelian systems.

A wide range of options has been suggested for the incorporation of agroforestry elements in agricultural production, including:

1. Various forms of intercropping and mulching

   a. Intercropping with food crops
   b. Intercropping with fodder species
   c. Intercropping with browse species
   d. Intercropping with multiple-use species (food, forage, fuel, construction materials, etc.)
   e. Strip cropping with any of the above-mentioned types of crops
   f. Use of mulch carried to cultivated fields from essentially nonarable areas.

2. Use of leguminous plant species in a managed fallow system alternating with crops (strip cropping is a special example of this).

Studies to date have focused almost exclusively on the several intercropping options and variations of these. Although many species--mostly leguminous--have been mentioned in connection with intercropping, few have been studied to any degree, with the exception of the generally herbaceous food-producing species and a few woody species of genera such as Leucaena, Gliricidia, Prosopis, and Acacia. Very little has been done, or even suggested, to develop managed fallow systems that would simulate the traditional natural fallow system in terms of its capacity to restore soil fertility.

The study and development of managed fallow systems seem to offer some promise, particularly if certain prerequisite conditions can be met: (1) the system and species used must have utility other than that of soil improvement (for example, food, feed, construction, fuel); (2) the system must not compete for labor during the peak period of labor demand by the food-producing systems; (3) it must be capable of producing useful soil regenerating effects in a relatively short period (2-4 years); (4) it must not require a substantial outlay of capital; and (5) the system must be manageable (that is, the species used must be easily established). Furthermore, the species used must be capable of rapid early growth to reduce weed competition; they must not become weeds themselves or harbor insects, disease, or bird pests; and they must be easily destroyed in order to return the land to cultivation.

To date, the systematic evaluation of species, both native and exotic, for potential use either in the intercropping or the managed fallow systems has not been undertaken. A thorough understanding of the behavior of the different species under a few carefully selected conditions would greatly facilitate the conceptualization of potentially useful systems that could be tested in a wide range of environmental conditions. The time spent in such a systematic study of species would probably be more than compensated for by reducing the trial-and-error nature of the ad hoc studies carried out to date.

FORESTRY AS A COMPLEMENT TO SAHELIAN AGROFORESTRY

Much can be done in the forestry sector both to support agricultural production and to better assure environmental diversity. The Sahel, as mentioned earlier, is not forest land, and many discussions about forestry in the Sahel actually refer to the better-watered savanna zone. Forestry as a land use system in which trees dominate and in which artificial or natural regeneration, silvicultural treatment, and rational wood or multiple use are practiced will have to be studied in order to find a system appropriate for the Sahel. Given the generally harsh conditions, this will not be easy.

"Traditional" forestry can, however, serve the following roles:

1. Protective functions resulting in improved quantity or quality of production within the context of an integrated multiple land use system

    a. Improvement of the microclimate at the site
    b. Regulation of the water regime

c. Preservation, restoration, and improvement of the soil
d. Protection of land in use (cropland, pastures, settlements, water basins, roads)
e. Preservation of plant and animal species, protection of wildlife.

2. Productive functions as a supplement to animal husbandry and dryland farming; that is, production of:

a. Wood as an energy source (firewood, charcoal)
b. Wood as a building material
c. Fruits, food, and leaves as food and fodder
d. Additional forest products for commercial use and export, such as gum arabic, tannin, and fibers.

3. Protective and productive functions that lead to social benefits

a. Improved supply of goods to satisfy daily need; creation of reserves for periods of drought or other emergencies
b. Activation of resources for economic development
c. Creation of jobs, with special consideration of spatial and temporal concentrations.

Although trees and shrubs have always played an important role in the lives of Sahelian people, the potential of these woody plants has not yet been fully developed. Hence, the forester's responsibilities in the Sahel ideally would be to maintain the existing woody vegetation, to establish and maintain new local and exotic trees, and to improve their productive and protective functions which help prevent desertification, solve household energy problems, and thereby contribute to the stabilization of human societies and environmental systems.

WHAT CAN BE DONE?

There are three different levels at which action can be taken: governments, communities, and individual households.

Action by Governments

Governments, represented by their forest services and sometimes supported by international assistance, are trying to protect and preserve valuable natural forest resources, carry out inventories, and improve woodland management. Forest plantations should be established on government land in the vicinity of population centers or markets, preferably with one or several fast-growing species, yielding firewood and utility timber. Afforestation costs are high (between US $500 and $1,000 per hectare) and yields are low (rarely over 2 m^3/ha/yr)--a very expensive undertaking while funds are extremely scarce (Keita 1981). Regarding the magnitude of demand, afforestation can only solve very specific problems on a small, local scale. In addition, there is a very serious shortage of technically trained manpower. Although locally available manpower should be substituted for mechanization insofar as possible, this proves difficult in large-scale afforestation efforts in the Sahel because basic work like clearing operations and soil work (deep-digging, breaking up heavy or stony soil such as lateritic soils, and subsoiling) may require heavy equipment. Also, the bulk of establishment and maintenance work falls within the rainy season (from June to the end of September), and it is almost impossible to mobilize people for forest work when food production has priority and, in fact, requires the presence of every able-bodied member of the family in the fields. Thus, forestry is facing not only a shortage of funds but, more seriously, competition for manpower and, of course, competition for suitable land.

In addition to preventing forest destruction--for example, by uncontrolled bush fires or illegal felling--the forest services at the outset should concentrate on the establishment or improvement of local nurseries to supply tree seedlings of high quality for village tree planting at the proper time. Forest services should also function as advisors to rural communities and individual tree planters to promote private activities instead of acting mainly as forest police or collecting taxes for what were formerly free uses of forest products.

Forest services should, moreover, promote agroforestry by opening their plantations for private interplanting of agricultural crops. Even controlled grazing or cutting of grass for livestock would be of mutual benefit and would make people understand the usefulness of forestry operations. The current practice of fencing plantation perimeters, keeping people out, and penalizing those who enter creates hostility instead of willingness to cooperate. Agroforestry, however, could facilitate dialogue with rural people, may prove to be of high educational value, and may help to improve the forester's revenues and reputation at an early stage.

Action by Communities

Forestry at the community level is most easily introduced in societies that have a strong traditional structure and are accustomed to neighborhood cooperation and joint efforts in land management. The leaders of these communities, or the speakers for local development councils, will help to identify the products that people need from the forest. They can arrange for suitable land to be demarcated for tree planting, and for the proper timing of forestry and farmwork.

Village forestry has great promise in the Sahel. The most obvious application is for shade trees to be planted in the village in public squares such as the market, and in front of public buildings such as offices, mosques, and schools, and alongside roads. There quite often will be a demand for a community tree nursery (if not already available from the forest service) to supply shade and fruit or food trees. Step-by-step extension work can gain cooperation, leading ultimately to community-owned forest tree or shrub plantations that provide firewood, poles, fodder, and various other forest products and that also have protective functions by serving as windbreaks, providing erosion control, and contributing to sand-dune fixation.

Action by Households

Quite often it will prove more effective to cooperate with individual progressive farmers than with an entire community or with a farmers' cooperative. Occasionally, farmers who are willing to cooperate may be very selective, because they may have had bad experiences with government or international projects or because they know better than their advisors how to satisfy their specific needs, how to consider site differences, the utility of tree and shrub species, and the risks of planting. Farmers will plant and protect trees if they can expect the initial benefits from them within 1-4 years, if the full right to dispose of their trees rests untouched by official supervisors (and the forest law), and if growing trees is compatible in time and space with their traditional land use patterns.

FERLO MODEL: A CASE STUDY

An agroforestry land use model has been developed in the Ferlo Region in northern Senegal to meet people's demands and to combat desertification by increasing the carrying capacity of the region. The Ferlo is rangeland with annual rainfall between 150 and 350 mm in the northern zone and between 350 and 550 mm in the south. Soils are mainly loamy sands with local variations. Nomadic and transhumant herders (Fulbe, Tokolor, and Moors) in the north and sedentary farmers (Wolof) in the south make up the major part of the population.

In 1975 a German-Senegalese forestry project was initiated to:

- Develop an agro-silvo-pastoral land use system adapted to local needs where all measures preventing desertification and securing sustained yield should be combined. The local peasant population was to be involved in tree-planting projects as part of a self-help program.
- Aid in restoring the seriously endangered vegetation around six deep-well sites.
- Create guidelines for the permanent settlement of people in numbers proportional to the ecological carrying capacity of the environment.
- Increase the production of gum arabic, fodder, food, and wood.
- Improve regional protection against bush fires.
- Improve the efficiency of the Forest Service.
- Create jobs and opportunities for cash income.
- Prevent catastrophes and gain experience in effective regional development under Sahelian conditions.

The strategy for achieving these objectives was relatively simple. As the region is heavily degraded, initial emphasis was placed on the identification of critical centers of degradation, such as well sites. Remedial measures were then undertaken radially from these centers with diminishing intensity. The strategy relates well to the environmmental needs of the region, as well as to the socioeconomic requirements of the semisedentary population (see Figure 6).

A plot of suitable land was identified by local village authorities (ideal size is 100 ha, although smaller plots may be chosen). This area was allocated to individual families, about 5 ha per family. These families were given sole responsibility for management of the land and will also be the only beneficiaries. All clearing operations were carried out in the traditional manner with local tools during the dry season. Thereafter, as part of "technical" assistance, cross-subsoiling was done with a tractor or Unimog, working to a depth of 40-70 cm. (Cross-subsoiling helps keep the moisture from rainfall available to plants for a much longer time than with other techniques.) In addition, the plot was temporarily fenced with barbed wire, where necessary. All of these operations required an investment of US $50 to $250 per hectare from project funds.

Since 1975 the project has developed from a Forest Service enterprise to an integrated rural development program with active village participation. Recent development has focused on farm or community forest activities on private farmland. Though simple, the model is very flexible.

The farmers now plant *Acacia senegal* or other useful tree seedlings using 10 x 10 meter spacing and at the same time plant traditional crops between the trees. They grow millet, groundnuts, and cowpeas during the rainy season for 3 years; weeding is done simultaneously for crop plants and trees. According to available information, overall yields are impressively higher than those of traditional fields. Whether this is due to deep subsoiling, careful protection of the land against animals and bush fires, or the ameliorative effects (shade, wind control, nitrogen fixation) of the trees, or because of all three, remains to be investigated in detail. After 2 years of fallow the natural grass vegetation will recover and surpass biomass production of adjacent pastures. This process can be further improved by sowing selected fodder grasses. Grass eventually has to be cut to avoid competition with the young trees, but it can be sold at the well center, where thousands of head of livestock assemble daily during the dry season.

When the trees are about 5 years old, sheep, and to some extent, cattle and even goats can be admitted to the plantation. It appears that 1 sheep/ha/yr can be fed without doing harm to the trees. The *Acacia senegal* trees yield gum arabic over a period of 15 years. Gum arabic is a traditional and profitable product of the region; its price is guaranteed by the government. Twenty years after establishment the trees will be felled for firewood and poles, and the cycle will be started again.

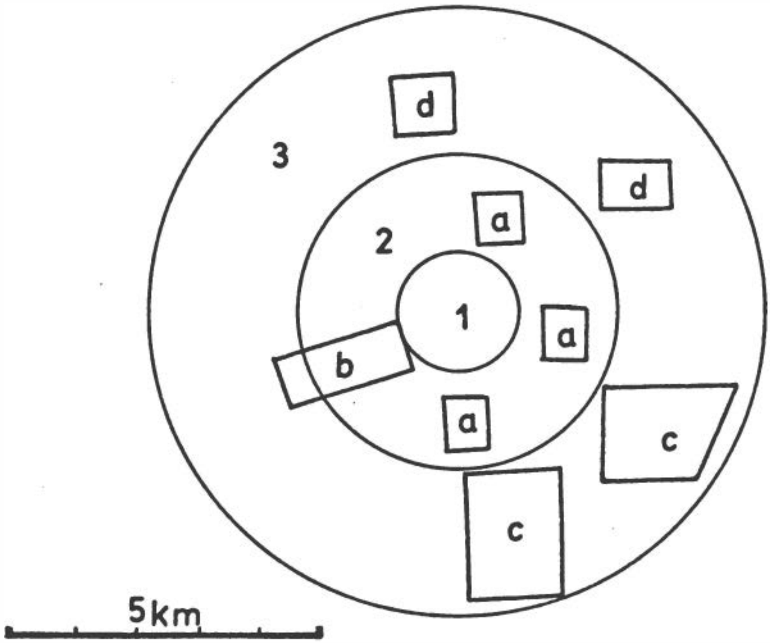

FIGURE 6 Plan of land use in the area surrounding the well sites.
(1) Center of development (deep well, village): water supply through deep well, administration buildings, residence area, marketplace, shops, workshops; small plots with trickle irrigation for home gardens and vegetable production.
(2) Inner land use zone: (a) agroforestry plots of some 100 ha each to be managed by about 20 family units; (b) intensive range management of fenced grasslands, with high percentage of tree and shrub cover.
(3) Outer land use zone: (c) forest plantations (e.g., with *Acacia senegal* and, if applicable, with intermediate rainfed agriculture or controlled grazing), production of gum arabic, firewood, poles, etc.; (d) protected areas (eventually fenced or with firebreaks) for natural regeneration of local species. All other areas are left to traditional land use. (Source: H.-J. von Maydell)

This system is flexible in that the trees and their products and the crops can be used, and because it meets a variety of basic local needs. It is, moreover, fully acceptable to the people and makes them less dependent on outside assistance. As proof of the project's popular acceptance, more than 20 villages with over 1,000 families had voluntarily joined the program within 2 years of its initiation, and all participants say they are much better off than before. The Senegalese government has used the same guidelines for a large-scale project in the adjoining region to the west, and the European Community Development Fund (FED) will sponsor a similar project to the east.

This system involves increased responsibility on the part of program planners and managers and the scientists who must ensure that the system follows the overriding principle that every product, every function and organization of land use must be compatible with the sustained productivity of the human and natural ecosystems. Meeting this responsibility in turn demands that a considerable amount of interdisciplinary applied research be undertaken. In every project, each farm or village forms a system of many components with close interactions; therefore, isolated activities may severely disturb the whole project or, at a minimum, have desirable or undesirable effects on the other components. Consequently, applied research in support of agroforestry land use development is considered an integral part of and a precondition for success. Such research might include observations made by farmers and herders as well as desk and laboratory work in expatriate institutions and should always be correlated with practical fieldwork and local needs.

EVALUATION

It is generally accepted that evaluation is needed at each step of a development process. Determining what constitutes "evaluation," however, is often more complicated than one might suppose. The simplest criterion would be to ask "Does it pay?" Of course, basic rural development goes far beyond monetary considerations. A farmer who was asked what he thought about the changes that took place after he joined the agroforestry program said: "I am satisfied in my heart." A governor, asked how he evaluated agroforestry in his region, replied: "People, under stress, used to be aggressive and destructive. They are now cooperative. This is the change we welcome." How should such statements be converted into monetary terms? How should conservation of endangered species, of natural resources, and reduction of risks in land use or achievements in making people aware of their responsibility for their country be valued?

Other sectors are more easily quantified and qualified for evaluation purposes. Monitoring of sites, crops, social changes, and so forth, plays an important role in this context; so do trend analyses and interpretations. In principle, evaluation of project impact requires that an inventory be made at the time of project initiation to define a baseline for future comparison. Evaluation of the project should then quantify and qualify changes in the natural and social environments. The human aspect is particularly likely to be difficult to assess because of subjective responses to change. There will be positive records: firewood production increased tenfold; grass production increased threefold; 1,000 ha of moving sands were stabilized and converted to silvo-pastoral cropland. Agroforestry land use systems, in the long run, will be judged against two criteria: (1) the persistence and (2) the resilience of the agroforestry scheme under Sahelian conditions. Persistence refers to the ability of the system to remain as it is, despite environmental and human influences. High persistence means small variations and high resistance to destruction. Resilience refers to the probability of quantitative and qualitative changes, that is, response by adaptation. An ecosystem with high resilience, when disturbed, accommodates high-amplitude variation, but it returns to its former structure as soon as the disturbance subsides.

Sahelian ecosystems are subject to high-amplitude change and are very flexible in terms of ecosystemic response to these changes. Both persistence and resilience are needed to survive in the Sahel. Agroforestry, properly applied, offers a wide range of techniques, species, and strategies to enable Sahelians to meet their basic needs.

CHAPTER 5

Sahelian Agroforestry: Institutional Considerations

What are the institutional problems involved in the design and implementation of agroforestry programs in the Sahel? In this chapter we focus on information and participation issues that must be addressed if agroforestry extension programs are to work effectively. To this end, a checklist is provided of potential constraints--technical, economic, financial, legal, and political--that may impede or, in some settings, totally block efforts to promote agroforestry. Program designers can begin tackling these issues early in the project design stage, thus markedly reducing difficulties later when agroforestry program personnel seek working rapport with farmers and herders, who will inevitably carry the bulk of the day-to-day burden of Sahelian environmental management. Forestry and agricultural agencies, which now are and likely will remain material- and personnel-poor (Club du Sahel 1981, 1982a), can at best only point the way toward better environmental management practices; they can never apply them on any significant scale.

This chapter is divided into three sections: (1) an initial, brief statement of the problem and general outline of a solution; (2) a review of preliminary information useful to project planners who want to incorporate into agroforestry programs institutional elements that encourage sustained popular participation; and (3) design criteria for effective agroforestry extension systems.

PROBLEM STATEMENT AND SOLUTION OUTLINES

Problem

The problem, in its simplest form, is how to establish working agroforestry programs in arid areas. A "working" agroforestry program will ensure environmental stabilization or improvement. It will also provide for an increased flow of benefits from the environment to its major users--people and livestock.

People will generally benefit if stock numbers and health levels can be increased without damage to supporting environments. They will enjoy increased access to livestock products, improved food crop production efficiencies, and enhanced environmental capacity to supply fuel, construction wood, and other forest products indispensable to their well-being. Chapter 3 offers a more elaborate definition of the potential range of outputs from an effective agroforestry system.

A working agroforestry program as defined here assumes extensive, largely spontaneous popular participation in program-promoted activities. Given current and probable future staffing levels, neither agricultural and livestock services nor their traditionally poorer colleagues in forestry departments can hope to muster enough manpower to work individually with rural dwellers to improve indigenous agroforestry techniques, let alone put those lessons into practice throughout the vast Sahelian area. Either rural people in the Sahel will teach as well as do agroforestry or it will not be done.

"Doing agroforestry" is a complex task. It requires capability and willingness to assess varied specific local conditions, field by field, and then find and implement solutions by associating trees with food crops and pastures. The goal must be to lessen or overcome problems that rural dwellers face in trying to maintain a fragile renewable resource base while, at the same time, extracting from it the wherewithal to stay alive. An approach to the detailed diagnosis and design of agroforestry systems based on East African experience is described by Raintree in Appendix B.

Participation by rural people in agroforestry projects or programs cannot be limited to simple execution of generalized strategies recommended by experts. Sahelian conditions are too complex to admit of formula solutions. Instead, pastoralists and farmers must be helped to build on what is, frequently, a substantial existing local capital of agroforestry experience and techniques. They will require assistance from local experts if they are to get the most out of their environments consonant with sustained-yield use. But experts, in turn, will require the willing and conscious participation of rural people in thinking through agroforestry problems (Thomson 1980a). Those who till the land and herd the animals must become full partners in any realistic effort to create a working agroforestry system under Sahelian conditions.

To achieve the goal set out, experts and Sahelian foresters must find ways to work with and through rural people. They can no longer permit themselves the luxury of "purely technical" operations, which by and large have been dismal failures in terms of both cost effectiveness and environmental management (Club du Sahel 1981, 1982a, 1982b). Implicit here is the need for an extension service capable of promoting agroforestry under Sahelian conditions.

Approach to a Solution

This definition of the problem sets two requirements for a solution. First, in order to interest rural people (who already lead a marginal existence) in resource management, programs must appear to them as worthwhile activities. Second, solutions must be tailored to fit the contours, institutional as well as natural, of local settings.

Solutions will involve people if the solutions promise net benefits and do not overtax local resource bases or organizational capabilities

(Thomson 1980b). Institutional and natural characteristics of local settings are clearly not immutable. But if renewable resource management is to depend on increased external support for environmental management--for example, from donor contributions--or on changes in the working rules of local life in thousands of Sahelian communities, realism demands careful assessment of chances of success. Planners will be well advised to think through proposed changes to determine whether they can be effected and then sustained. If changes are feasible, in terms of costs to the target group of resource managers—rural Sahelians--and in terms of sustainability, both of new rules and levels of external funding, then management of renewable resources in specific locations may become a reality. If not, other approaches to stemming Sahelian environmental degradation must be sought.

RELEVANT PRELIMINARY INFORMATION

Agroforestry planners will require three general kinds of information: (1) baseline data on renewable natural resource availability, in the context of control and use rules; (2) knowledge of people's attitudes toward desirability of managing particular renewable natural resources; and (3) clear and precise understanding of factors constraining management of these resources. State-of-the-art technical information on production levels associated with realistic alternative mixes of trees, agricultural crops, and livestock is necessary, in turn, to match with the on-site baseline data sets.

Baseline Data

Human activity is almost always patterned and takes place in special, channeled ways in particular settings. Planners need to build up detailed descriptions--word and number pictures--of what people are doing with resources and how they are doing it, so they can analyze trends in resource use with confidence and sophistication.

A number of general topics must be covered concerning each resource if the global picture regarding trees, pastures, or soils--or interactions between these and other renewable resources--is to be meaningful and accurate. In general, the following areas must be covered (in some situations, supplemental information on other topics will be indispensable):

1. Current availability of renewable natural resources by district within the country. Of particular importance in the context of agroforestry projects will be information on condition of the woodstock (all ligneous plants, from small bushes to trees). Pasture, soil, water, and human food supply conditions must also be investigated.

2. Probable evolution of supply and demand situation for each resource in surplus, equilibrium, and deficit areas.

3. Identity and nature of user communities exploiting each renewable resource.

4. Benefits--both nonconsumptive (for example, trees for environmental stabilization, enclosure, and soil regeneration) and consumptive (for example, wood for fuel and construction materials)--that users derive from renewable resources.

5. Existing management efforts designed to maintain or enhance resource availability, be they private, local, and indigeneous, or external, government/donor-sponsored attempts.

6. Terms and conditions of access to and exploitation of renewable resources both within and outside of management districts. These are often heavily influenced by:

   a. Formal rules--laws, administrative decrees, resource use codes, association statutes, or "customary laws," and the like, which bear on control and use of renewable natural resources.

   b. Effective rules--determined by decisions of enforcing officials and judicial authorities, concerning application of formal rules to real instances of trouble and disputes (Thomson 1977, and literature cited there by Commons, and Llewellyn and Hoebel).

   Note that the effective rules may be the same as formal rules; they may also diverge in small or large ways, depending on the extent to which enforcers and judicial officials enjoy leeway to determine, in individual incidents, what the real law will be for that dispute. In the final analysis, effective rules control and guide conduct: individuals make calculations regarding resource use based mainly on what they think will happen if a dispute arises, and less on terms of formal, paper rules.

   Note further that "no rule" is still a rule; for example, a forestry code may precisely define, on paper, terms of lawful access to certain tree species, but the code provisions may never be enforced in some areas. In such circumstances, the rule of access is generally "first come, first served," which implies that nothing will constrain resource use short of full exhaustion of supplies. (In surplus supply situations, this may well be the most appropriate--"reasonable and efficient"--resource use rule.)

Information on these points should be collected whenever and wherever efforts at resource management are to be mounted. In Sahelian agroforestry programs, as noted, five types of renewable resources appear of prime importance:

1. Woodstock
2. Pastures
3. Soils
4. Water
5. Human food supplies

The assessment schema outlined above will be briefly illustrated using an analysis of woodstock conditions; it can be similarly applied to the other renewable resources.

Woodstock Assessment: An Illustration

Basic woodstock ecological sub-areas within the country must be identified as a preliminary step. These sub-areas might include places where bush cover still predominates, regions of interspersed fields and fallows, permanent agriculture under a tree canopy of species such as *Acacia albida* or *Butyrospermum paradoxum*, and areas of substantial deforestation.

Quality and quantity of remaining wood supplies, as well as the kinds of pressures to which they are subjected (local and distant demand for firewood and building poles, cutting for fodder and fencing, and so forth), must then be precisely described. This information, combined with demand projections from current consumption levels and population growth rates, will permit assessment of probable future deficit areas. (Such projections, however, do not alone justify siting projects in probable deficit areas.)

User communities should be carefully canvassed about the benefits they derive from the woodstock. On-site uses may include soil regeneration and/or stabilization, erosion control and fencing, and consumptive uses of products such as fuel, building materials, food crops, medicines, and fencing. These data can be particularly helpful at the design stage if they reveal hitherto neglected bargaining counters to promote conservation and resource management.

Within each ecological sub-area, data should be gathered on efforts to increase the woodstock in any of the following ways:

1. Industrial plantations
2. Community woodlots
3. Individual or family woodlots, or scatter-site, in-field plantings
4. Shelterbelts, live fencing, dune stabilization, gully control
5. Managing natural regeneration (either for on-site or consumptive uses)

In each instance, accurate, detailed information about sponsorship, initiation, management, and implementation of such efforts will reveal the range of existing agroforestry activities and possible pitfalls of different approaches.

Finally, the working rules of resource use should be identified. Is there a forestry code? To what extent does it control access in a formal sense, and how is it applied in fact, by area? Where an existing code is irrelevant, because it is not enforced, what are the local rules governing tree tenure or property rights regarding trees? Through what means can they be enforced? Detailed information of this sort promotes real understanding, both of peoples' attitudes toward resource management and of the hurdles they may perceive in various management schemes.

Popular Interest in Resource Management

Popular willingness to invest time, energy, goods, and money in renewable resource management critically conditions feasibility of participatory resource management schemes. Villagers with little practical experience in working together toward common goals over long periods of time will likely have trouble managing a village woodlot held in common. Those accustomed to sustained collective action may reject a program focused on improving individual farmers' resource management capabilities. Planners and designers thus need to spend time finding out how people organize to do things in the area of resource management.

A healthy dose of skepticism is in order when assessing villagers' initial answers to the question, "How would you like to manage resource X?" Village spokesmen may know that current government policy emphasizes a particular format or way of working, for example, "collective action," "individual initiative," "youth groups," "cooperatives," or "the Party." Chances are good that villagers will "want" to manage resources in the preferred manner, if only to avoid antagonizing government officials in the short run. If the opening question runs, "Do you villagers want to organize a collective woodlot?" any collective orientation villagers may express must be viewed even more skeptically, since they will assume the government's preferred format has been stated in the question itself. Even rephrasing the question to a simple, neutral inquiry about the villagers' interest in managing resources at all may not escape biased replies if spokesmen know there is a push on to promote reforestation, for example.

To penetrate this frequently encountered protective smokescreen of politically conditioned responses and get to the realities of village organization, the investigator needs to find out how people carry out other activities. Is farming--usually the fundamental activity in Sahelian rural communities--largely an individually run activity? If there are cooperatives, how well do they function? If trees have been planted in the village, or terraces built on village fields, or if other forms of resource management have been attempted, how were those efforts undertaken? Were they done collectively or individually or by families who owned the property? What was the impetus for the action? Did individuals or some sort of collective group in the village decide, perhaps after consultation with outsiders, that they wanted to start something in the realm of resource management; or did woodlots or rock dams or windbreaks result from a government program imposed on villagers, or from inducement provided by a donor-financed or private voluntary organization project?

Once the general nature of resource management activities is clear, designers will have an easier time assessing feasibility of different organizational approaches to resource management. They should be able to discount the facade of politically structured responses and, through careful examination of real activities, arrive at a general sense of what will and what will not work in a community.

Investigators, however, should be wary of concluding, from collective or individual activities in areas other than resource management, that the same orientations will automatically carry over into the resource realm. Particularly if resource management has no prominent place in local traditional activities, it would be wise to adopt a frankly experimental orientation to the problem of organization and encourage villagers to try a variety of approaches, each individual or group doing more or less as he, she, or they see fit. It may also turn out that villagers are willing to manage resources, but only when the task is imposed upon them, and when state officials shoulder the burden of making sure each villager does his or her share. (For an enlightening discussion of this type of problem in the context of land reform efforts, see Popkin 1979:50-51, and literature cited there.) Where this is the case, resource management operations will be limited by the size of the civil service contingent that can be detached for such activities.

Constraints on Participatory Resource Management

Five general categories of constraints may impinge on resource management efforts: technical, economic, financial, legal, and political. (Thomson 1981:125-48, presents a more detailed formulation and illustrations of these constraints.) Each will be examined and briefly illustrated by examples from the area of woodstock management.

Technical constraints may inhere both in the environment and in the particular species of trees or shrubs selected for use in reforestation activities. In the Sahel, seedlings must be able to survive in the face of harsh temperatures, irregular rainfall, and frequently poor soils (unless special arrangements can be made to irrigate young plants). Some species, particularly among the exotics, simply cannot survive under Sahelian conditions. They can be planted; but as hundreds of stunted or failed *Azadirachta indica* (neem) plantations attest, they will not necessarily prosper. In other cases, seeds or seedlings of appropriate species may not be available at the right time. Inadequate seed collection or production capacities may explain this and may be remedied with relative ease, but the constraint nonetheless often exists. Finally, genetically improved local species are not yet available. If the local species' hardiness can be coupled with improved growth rates and production of subsidiary forest products, popular interest in reforestation may well pick up noticeably.

For many Sahelians, the idea of planting trees at present raises as many problems as it solves. In certain cultures and agricultural settings, farmers view trees with disfavor as unwelcome competition. Villagers may not yet grasp the full range of values that shelterbelts or live fencing can provide, although in many areas a very clear perception of the usefulness of certain trees has existed for a long time. The extent to which Acacia albida and Butyrospermum paradoxum have been promoted by rural people proves the point. Adansonia digitata, Parkia clappertoniana, and other species have also been widely cultured by Sahelians interested in their fruits and other by-products.

Finally, popular ignorance of silviculture operates in many places as a factor constraining investment in renewing woodstocks. Many Sahelians have much to learn about seed preparation methods, nursery techniques, and methods and timing of planting. Some would also benefit greatly, as would experts, from clearer appreciation of the values of certain local species, best forms of association with crops and pasturelands, low-cost methods of promoting natural regeneration, and the like. Popular education in silviculture has become indispensable, as an important key to more intensive management of Sahelian woodstocks. The extent to which many Sahelian cultures relied, until recently, largely on passive investment in woodstock management, through systems of bush fallowing or shifting cultivation, makes this educational undertaking doubly pressing. The woodstock was allowed to take care of itself, under conditions where it was rarely over-exploited; in most places, it regenerated admirably on the strength of almost entirely natural processes. Now, however, changing land/man ratios impose the necessity for intensified silviculture. Drastic reduction of bush areas, particularly when accompanied by severe, localized environmental degradation, has sapped the efficacy of many passive regeneration techniques. Rural dwellers in many places must now master new techniques if they are to survive in their present habitats.

Economic constraints revolve around the question of profitability of proposed improvement schemes. If farmers and herders can demonstrate to their own satisfaction that investment in reforestation will pay off, they can be expected to show more interest in the matter. In much of the Sahel, active reforestation is, for all practical purposes, a new idea. It has arisen only with the sharply decreased availability of firewood supply--a recent phenomenon in many rural areas (and not as yet a universal one). But examples already exist of individuals making money through investment in wood production for market, and more are developing each year. This orientation will take time, but sharply increasing prices of forest products throughout the Sahel guarantee that activities that were irrelevant 10 years ago, when wood supplies remained adequate in most places, will rapidly take on increased importance. It is critical to capitalize on this rising current of popular interest, by putting practical technical and economic solutions at people's disposal.

The development of markets for various kinds of wood, and price increases that annually outstrip inflation (Club du Sahel 1981, 1982a, 1982b; Winterbottom 1980), have convinced many Sahelians that they must provide for their own consumptive needs on a systematic basis. The impetus to learn tree-raising techniques sharpens as wood supplies dwindle and demand escalates with growing populations. To the extent that technical innovations or newly acquired silvicultural skills lower costs to rural people of investing in new increments of wood supply (family or community woodlots, natural regeneration in the fields, and so forth), multiplication of reforestation activities at the local level throughout the Sahel become possible and indeed probable.

Financial constraints depend mainly on the cost of reforestation processes. Land, labor, and materials may all be scarce items in different Sahelian settings, particularly where intensifying population pressure has confirmed labor migration as a standard response to food shortages. Reforestation techniques that demand a substantial labor component may be beyond the capacity of local communities to provide when able-bodied young people have gone elsewhere in search of work. Complicating the problem are traditional labor bottlenecks during the rainy season, when many critical reforestation actions must succeed each other in timely fashion.

Evolving popular mastery of silvicultural techniques, as well as improvement in techniques themselves, may eventually alleviate if not fully resolve these problems. Anything that shifts the burden of investment in reforestation from the rainy to the dry season seems positive in this regard. Promoting natural regeneration appears especially promising here.

Inadequate credit arrangements may also hinder popular reforestation attempts. Manufactured fencing materials such as barbed wire, chicken wire, and posts may eventually justify initial outlays in some circumstances, but most people will remain too poor to envisage such purchases. Subsidized loans and forest product price rises may sharply modify this situation in the medium term, but in the short and long runs, solutions will more likely be found through improvement in live-fencing techniques. This may involve both enhanced popular awareness of the possibilities of live fencing and a greater mastery, at the local level, of nursery techniques. Species that will meet several additional needs, such as human and animal food production, firewood, and building materials, and that will provide fencing and fencing materials in the form of a reliable local source of thorns, ought to facilitate enclosure. At that point, problems of stock control may become somewhat less pressing.

Legal constraints will be embedded in the effective rules, whether these closely reflect formal rule provisions or some quite different local arrangement. Where property relations are ambiguous, either regarding land or tree tenure, investors will be cautious. In the particularly discouraging case of the improperly enforced state forestry code--these codes in the Sahel usually provide for management and control of woodstock use by foresters--trees may be treated as an unmanaged common property resource in which each individual is, in effect, free to take what he wants without fearing that sanctions will be imposed. Under such circumstances, investment in reforestation must strike most rural dwellers as nonsense; they correctly see little probability that they will reap any benefits from their work.

The legal process concerning enforcement of tree-tenure relations is also critical. If "available" recourses, such as finding and informing the roving forester of a code infraction on one's land, are prohibitively expensive, they will not be invoked. If they are not invoked, rules will not be enforced, and common property woodstocks will not be managed.

In each case, however, it is important to identify local working rules governing woodstock use and management, and to do so before attempting to propose projects or programs envisaging investment, in any form, in woodstock management. In areas where a formal forestry code is not applied, local working rules will determine, either actively or passively, how wood is exploited and to some extent whether investment in reforestation is reasonable (in places where supply remains adequate, investment in new increments will find little favor with rural Sahelians, whom experience has convinced of the virtues of passive management, that is, regular fallowing and nothing more).

Political constraints turn on villagers' or herders' incapacity to control local or outside exploiters of renewable resources and on the inability, widespread in Sahelian states, of local communities both to formulate and modify their own renewable resource management rules in light of changing conditions, and also to enforce them regularly, as a framework for management activities. These problems relate to larger political issues, such as inter-ethnic relations and rural development, which public officials, particularly in francophone areas, have tended to handle until very recently as problems amenable to control only through extension of government networks (for detailed illustrations of these points in the Nigerian context, see Thomson, in press). In very recent years costs of this strategy, and its considerable limitations, have become increasingly apparent to most observers familiar with the reality of government- and donor-financed rural development projects. The growing sense that decentralization must occur, in close association with efforts to enable local communities to deal with such issues as resource management, is certainly promising for future renewable resource management.

In summarizing this section, it must be stressed that information about resource availability by local area, popular attitudes toward management of different resources, locally preferred strategies for managing resources, and social or institutional constraints on management activities is often hard to come by. It is, in other words, high-priced information. Some data will be so expensive as to preclude obtaining them in adequate amounts through donor-financed personnel.

The secondary position is then to create an extension system that uses local peoples' knowledge in these areas to reduce the costs of gathering information. But such participation will not be without cost. It will inevitably complicate and slow planning processes and make implementation of management activities more cumbersome, at least initially. But basing planning and execution on solid, reliable information about local circumstances should make agroforestry programs much more effective over the long run.

AGROFORESTRY EXTENSION

The three types of preliminary information just discussed--baseline data on renewable natural resource availability, ownership, and use rules; information about popular interest in managing particular resources; and constraints that may complicate management of these resources--will indicate areas where severe environmental degradation has occurred, and where popular management opportunities might be identified and developed. To realize and capitalize on these potential opportunities, a working system of communication with villagers must be established.

Extension System Design Criteria

The term "extension system" may imply to some a one-way, top-down flow of information from experts to farmers and herders. If so, the term is inadequate. In this chapter, "extension system" is defined as a reliable, two-way communication system. Information flowing in both directions will be critical to the process of pinpointing difficulties at all levels in resolving resource management problems: rural dwellers' intimate knowledge of their own microenvironments, as well as experts' knowledge of genetic engineering, plant compatibilities, soil conditions, and resource management techniques that have worked elsewhere, will prove indispensable to effective management efforts.

Messages moving through the extension system must also reflect local people's knowledge of their social, economic, legal, political, and organizational circumstances. These factors have as much to do with environmental stabilization and upgrading as do nursery skills and the latest technical advances. Local people are the ones who can most efficiently calculate what will and what will not work for them in resource management. In exactly the same way, they can best put to the acid field test experimental-station hypotheses and results about appropriate plant associations, resource conservation schemes, planting techniques, and so forth. In both the technical and social realms, villagers and pastoralists, because they must grapple with specifics of complex local environments, go beyond the generalizations that often underlie experts' management propositions to test whether an idea or process will work <u>here</u>. If extension systems function properly, they will encourage farmers and herders and help them to tailor solutions in light of what they know about limiting factors in their environments. Through such participation, modifications in general formulas necessary to make them effective in a given environment can be introduced.

Existing Extension Possibilities

Content, form, and process will interact in a developing agroforestry extension system. Some information (content) can be transmitted through almost any set of extension institutions; but how valuable that information will appear to clientele, and what use they will make of it, will depend very much on the form of the extension system (its institutional design) and the communication process associated with it.

Program designers can roughly determine fairly early what they want an agroforestry extension system to do. The task can be as simple and specific as "teach people how to plant and care for nursery-raised neem seedlings properly." It can be as complex as the following. First, find out what people are interested in doing, by region (or by district, village, or family). Depending on circumstances, they may want to plant nursery-raised seedlings of various types. They might prefer to learn how to raise seedlings of their own choice. They might want to start at the beginning, by learning how to collect, grade, prepare, and plant seeds. On the other hand, they might like to learn how to intensify production of natural regeneraton, or to acquire new soil and water conservation techniques based on agroforestry principles. Once the basic interests of particular groups or individuals have been identified through a careful dialogue, the second step will be to find out, in detail, what they already know about these activities. Third, extension workers can proceed to teach them more of what they want and need to know, while simultaneously making them aware of other possibilities which they can examine for feasibility in light of their knowledge of local conditions. Finally, the extension system should provide materiel back-up for extension activities, whether it be in the form of hand tools, fencing materials, or facilities for regional or local experimental stations, agroforestry resource centers, and so forth. (For a discussion of what such centers might attempt, see National Research Council 1981:87-92. Note that materiel back-up should also be provided to extension workers, in part as encouragement and in part to permit them to do their job better.)

These kinds of major orientations or definitions of extension system goals will then permit designers to move to the next step of evaluating existing extension possibilities. In some settings it may be possible to graft agroforestry extension efforts onto existing communications systems that have been established, for instance, by forestry, agricultural, or livestock agencies, or by individual rural development projects. This would be particularly effective if existing extension workers could receive supplemental training, enabling them to appreciate the complexities of integrated agroforestry systems. To determine whether the use of existing extension systems is advisable in a given place, three questions must be asked concerning communication:

1. What messages are being transmitted by existing systems and in what directions?
2. How well are they being passed?
3. To what extent can additional messages to farmers and pastoralists be effectively moved through these networks?

Answers to these questions, coupled with data acquired through preliminary investigations outlined above, will suggest whether new information exchange systems focused on promoting agroforestry ought to be created and, if so, where. This will be a very subtle process, particularly where some positive agroforestry programs are already under way. Planners will have to identify target areas on an experimental basis. Choices should reflect the need for resource management, popular demand for information about improved agroforestry methods, and political opportunities in light of other programs already functioning in given jurisdictions.

Agroforestry Extension Systems

Whether a policy decision is made to work through existing systems or to develop a new set of institutions specifically designed to foster popular agroforestry, it will be important to devise a series of working hypotheses to be tested in experimental and implementation phases. These hypotheses should help program designers, project personnel, and outside evaluators to monitor activities and results and to clarify the value of original formulations. Where correction becomes necessary, modifications in hypotheses should be introduced but in a conscious manner. Projections must be made about how extension tasks can be accomplished, formulated as working hypotheses. It also is necessary to determine to what extent--and by what means of evaluation of results--these hypotheses will be confirmed or rejected.

Several hypotheses are proposed here as possible models to be adopted or adapted by future forestry programs. They also provide a summation of points made in this chapter.

1. Agroforestry extension systems must, to succeed, encourage local people both to implement positive resource management techniques and to experiment with them, using indigenous systems where applicable, and outside expertise or an amalgam of both where such knowledge is appropriate.

2. Systems that provide the greatest increase in resource productivity for a given investment, or a given improvement in resource productivity for the least investment, will be most successful.

   a. Most farmers and pastoralists live fairly marginal existences in difficult environments; they can afford only limited investments.

   b. If actively promoting natural regeneraton of vegetation proves the least expensive approach, it should be explored intensively and extensively.

3. To get wide and in-depth coverage of target populations, extension networks will have to involve farmers and pastoralists as teachers of their fellows. This implies some sort of training program. A CILSS seminar, sponsored by the Agency for International

Development, has produced specific recommendations for Sahelian countries and has outlined an agroforestry curriculum. An informal but sustained education program might well be best, if it could be united with some form of regular, ongoing activity.

4. The vehicle that might carry extension messages and information flows from individual field experiments to higher levels and, inversely, might be a mini-nursery program designed to transfer knowledge about nursery techniques to (self-selected) villagers, and through their efforts, to make seedling stock easily available at the local level. If nurserymen were allowed to sell their produce as well as their advice on promoting natural regeneration and other forms of renewable resource management, they would have a constant incentive to perform well in order to attract and hold a clientele.

5. Given the public good expected from effective agroforestry extension work--environmental stabilization or improvement--it would be appropriate to subsidize network members where this proved necessary to keep them operating and moving ahead. Such individuals should not, however, become fully paid state or project employees, since this would reduce their economic incentive to be responsive to their clientele.

6. If extension networks associated with mini-nursery programs could be tied in directly with regional agroforestry "learning and experimental centers," local extension agents would have a point of contact with experts capable of answering their resource management questions either from their own knowledge, or by contacting others who could, or by devising experiments at the center or elsewhere to generate answers.

7. Such a resource management extension system should be designed to produce a continuous flow of feedback to the agroforestry learning and experimental center about local resource management problems, successes, and failures, and to identify the best opportunities by area to develop resource management techniques in light of preliminary information and the outcomes of subsequent activities.

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APPENDIX A

Selection and Use of Tree Species

CRITERIA FOR SPECIES SELECTION

Many of the failures of forest plantations and tree-planting activities in agroforestry programs can be traced to the selection of inappropriate species. Use of the following criteria may improve the selection process.

Adaptation to Site Conditions Climate, soils (especially structure and depth), water regime, and so forth, must be known. A site classification should be made, and results should be laid out in maps and supported by aerial photography. Based on this data, the site characteristics can be matched with the requirements of the trees considered.

Easy and Safe Establishment, Low Inputs Seeds of selected quality should be obtained. Vegetative propagation may be possible. Preference should be given to species direct seeding. A special effort should be made to keep costs low for establishment and maintenance (for example, reducing cost of production, pesticides, fertilizer).

Fast Growth, High Yields Multiple-use suitability may be essential, including the possibility of intercropping. Growth and yield often are not the only considerations.

Compatibility with Other Land Use This is important under agroforestry management and also in mixed stands within the forest. The species selected should not negatively affect crops, grazing, farmland, or installations, and should not attract insects, fungi, birds, rats, or other pests harmful to agricultural crops.

Plantations with exotic tree species should be limited to sites where the natural tree vegetation evidently fails to meet present or future demands. There are a number of reasons for this recommendation. First, the full use (or use potential) of local plants is not yet sufficiently known or statistically recorded. It may well be that their replacement by exotics will result in permanent, seasonal, or occasional deficiencies (for medicines, for example) which may impair or even threaten the chances for survival of man or his livestock.

Second, the introduction of new species implies increasing ecological and management risks. Exotic species should be thoroughly evaluated in terms of performance and on-site consequences of their planting before they are extensively used in a new region. It is not easy to identify exotic tree species whose overall benefits can be compared to those of the local species. Third, the conversion to a plantation forest or even enrichment planting (and maintenance) is more expensive than natural forest management on a sustained-yield basis, making use of natural regeneration.

There are, however, a number of exotic species that should be tested in the Sahel, primarily for use in afforestation projects on land now without forest cover, for specific benefits that cannot be obtained from local species and that can best be provided by planting outside the forest, in villages, along roadsides, and on particularly degraded or endangered sites, within the context of agroforestry.

The multiple uses of local and introduced tree species are indicated in Table A-1, which begins on page 66.

TABLE A-1 Multiple-use Tree Species for Sahelian Agroforestry Systems

\+ main use
o use indicated
. no information
– no use

		Fuelwood, charcoal	Utility wood	Food	Fodder	Medicine, repellents, poisons	Various raw materials	Protection, soil improvement	Village/urban plantation	Cultural values
3,4,5	Acacia albida	o	o	–	+	o	o	+	o	+
	Acacia ataxacantha	o	o	–	o	o	o	–	o	–
	Acacia dudgeoni	o	o	–	o	o	o	–	–	–
1	Acacia ehrenbergiana	o	.	–	o	.	–	–	–	–
	Acacia gourmaensis	o	.	–	o	o	o	–	–	–
	Acacia laeta	+	o	–	o	.	o	–	–	.
	Acacia macrathyrsa	o	o	–	o	o	–	–	–	–
	Acacia macrostachya	o	o	o	o	+	o	–	o	.
3	Acacia mellifera	o	o	–	o	.	o	–	–	–
1,5	Acacia nilotica	+	+	o	o	+	+	o	–	.
	Acacia pennata	o	–	–	o	o	o	–	–	–
5*	Acacia polycantha	o	o	–	.	o	o	–	–	.
1,3,5	Acacia senegal	+	o	o	+	o	+	+	–	.
1,3	Acacia seyal	+	+	o	+	o	o	o	–	.
5	Acacia sieberiana	o	+	–	o	o	o	o	o	–
1,3	Acacia tortilis	+	o	–	+	o	o	o	–	.
5	Adansonia digitata	–	–	+	+	+	o	o	+	+
	Adenium obesum	–	–	–	–	+	–	–	o	o

5	Albizia chevalieri	o	o	o	o	.	o	–	–	–
1,3	Albizia lebbeck	o	o	–	o	o	o	o	+	–
5	Anacardium occidentale	o	–	+	o	o	o	+	–	–
	Annona senegalensis	.	o	+	o	+	o	–	–	o
5	Anogeissus leiocarpus	o	+	o	o	o	o	–	–	.
1,5	Azadirachta indica	+	+	o	o	+	o	o	+	o
2,5	Balanites aegyptiaca	+	+	+	+	o	o	–	o	o
	Bauhinia rufescens	o	o	o	+	o	o	o	o	.
	Bombax costatum	.	o	o	o	o	+	–	–	–
5	Borassus aethiopum	o	+	+	o	o	o	–	–	o
	Boscia angustifolia	o	o	o	+	o	.	–	–	–
	Boscia salicifolia	o	–	o	o	.	–	–	–	–
	Boscia senegalensis	o	.	+	o	o	–	–	–	–
5	Butyrospermum paradoxum	o	o	+	o	o	o	–	–	+
	Cadaba farinosa	o	–	o	+	o	–	–	–	–
	Cadaba glandulosa	.	.	.	o	.	o	–	–	–
	Calotropis procera	o	o	–	o	+	o	–	–	.
	Capparis corymbosa	o	–	o	o	o	.	–	–	–
	Capparis decidua	.	–	o	o	o	.	–	–	–
	Capparis tomentosa	.	–	.	o	o	.	–	–	–
	Cassia occidentalis	–	–	o	–	+	o	–	–	–
1,5	Cassia siamea	+	o	–	o	o	o	o	+	–
	Cassia sieberiana	o	o	–	.	+	o	o	+	–
1	Casuarina equisetifolia	o	o	–	–	o	–	+	o	–

		Fuelwood, charcoal	Utility wood	Food	Fodder	Medicine, repellents, poisons	Various raw materials	Protection, soil improvement	Village/urban plantation	Cultural values
	Celtis integrifolia	o	o	o	o	o	o	o	-	-
	Combretum aculeatum	o	-	o	+	+	-	-	-	o
	Combretum glutinosum	+	+	-	.	+	o	-	-	-
2	Combretum micranthum	o	o	+	.	+	o	o	-	o
	Combretum nigricans	o	o	o	-	o	o	-	-	-
	Combretum paniculatum	.	o	o	-	o	-	-	o	-
	Commiphora africana	o	o	-	o	+	o	-	-	-
	Crateva religiosa	o	o	o	o	o	o	-	-	-
	Dalbergia melanoxylon	o	+	-	o	o	-	-	-	+
	Dichrostachys glomerata	o	o	o	+	+	o	o	.	-
	Diospyros mespiliformis	+	+	o	o	+	o	o	-	-
	Entada africana	.	o	-	o	+	o	-	-	-
3	Erythrina senegalensis	.	-	-	o	+	-	-	o	o
1,5	Eucalyptus camaldulensis	+	+	-	o	o	-	o	+	-
	Euphorbia balsamifera	-	-	o	.	+	-	o	+	.
	Feretia apodanthera	-	o	o	o	o	-	-	-	-
	Ficus capensis	-	o	o	.	+	-	-	.	+

	Ficus gnaphalocarpa	.	o	+	o	+	–	–	.	o
	Ficus ingens	–	–	.	.	o	–	–	–	o
	Ficus iteophylla	o	.	o	o	o	–	–	–	–
	Ficus platyphylla	.	.	o	.	o	o	o	+	.
	Ficus thonningii	.	.	.	.	o	o	o	+	o
	Ficus vogelii	.	o	o	.	+	o	o	+	.
	Gardenia aqualla	.	.	.	o	.	.	.	.	.
	Gardenia erubescens	–	o	o	o	o	o	–	–	–
	Gardenia sokotensis	o	.	–	.	.	–	–	–	–
	Gardenia ternifolia	o	o	.	.	o	o	–	o	o
	Grewia bicolor	.	o	o	o	o	o	–	–	–
	Grewia flavescens	–	–	o	.	o	.	–	–	–
	Grewia mollis	o	o	o	.	o	o	–	–	–
	Grewia tenax	–	–	o	o	.	o	–	–	–
	Grewia villosa	–	o	o	o	o	o	–	–	–
5	Guiera senegalensis	o	o	–	o	+	–	–	–	–
	Hyphaene thebaica	o	+	+	o	o	o	–	–	–
	Khaya senegalensis	o	+	–	o	+	o	o	+	o
5	Lannea acida	o	o	+	o	o	o	–	–	–
	Lannea microcarpa	o	o	+	o	o	o	–	–	–
	Leptadenia spartium	–	–	o	o	o	o	–	–	–
1,3	Leucaena leucocephala	o	o	o	+	o	o	o	o	–

		Fuelwood, charcoal	Utility wood	Food	Fodder	Medicine, repellents, poisons	Various raw materials	Protection, soil improvement	Village/urban plantation	Cultural values
	Maerua angolensis	.	o	o	+	o	-	-	o	-
	Maerua crassifolia	.	o	o	+	o	-	-	-	-
	Mangifera indica	o	o	+	o	+	o	o	+	o
	Maytenus senegalensis	o	o	o	.	o	o	-	-	-
	Mimosa pigra	.	o	-	-	o	-	-	-	-
	Mitragyna inermis	+	+	-	o	o	o	o	-	o
	Moringa oleifera	o	o	+	o	+	+	-	o	-
5	Parkia clappertoniana	o	+	+	o	+	o	o	o	+
1,5	Parkinsonia aculeata	o	-	o	o	o	-	+	+	-
	Phoenix dactylifera	o	+	+	o	.	o	o	o	+
	Piliostigma reticulatum	o	.	.	+	o	o	o	-	-
	Piliostigma thonningii	o	o	o	+	o	o	o	-	-
5'	Prosopis africana	+	+	o	o	+	o	.	-	-
1,5	Prosopis juliflora	+	o	o	o	o	.	+	+	-
3	Pterocarpus erinaceus	+	+	o	+	+	o	o	o	o
	Pterocarpus lucens	+	o	o	o	o	-	-	-	-
	Salvadora persica	o	o	o	+	o	+	-	-	-
	Sclerocarya birrea	+	+	o	o	+	o	-	o	-

	Securidaca longepedunculata	o	+	−	o	+	o	−	o	+
	Securinega virosa	o	o	o	.	+	−	−	o	−
	Sterculia setigera	o	o	+	o	+	o	−	o	+
	Stereospermum kunthianum	.	o	−	.	o	o	−	+	−
	Strychnos spinosa	o	o	o	o	+	−	−	−	−
3,5	Tamarindus indica	o	+	+	o	+	o	o	+	+
	Tamarix senegalensis	.	−	−	.	o	.	o	−	o
	Terminalia avicennioides	o	o	−	o	o	o	−	−	−
	Terminalia macroptera	o	o	−	.	o	o	−	−	−
	Vitex diversifolia	.	.	o	.	o	.	−	−	−
	Vitex doniana	.	o	o	o	o	o	−	−	−
	Ximenia americana	o	o	+	.	o	o	−	o	−
	Zizyphus mauritiana	o	o	+	o	+	o	o	+	.
	Zizyphus mucronata	o	o	o	o	o	o	−	−	−
5	Zizyphus spina-christi	o	o	o	o	o	.	o	+	−

1--National Academy of Sciences. 1980. Firewood Crops: Shrub and Tree Species for Energy Production. National Academy Press, Washington, D.C., USA.

2--National Academy of Sciences. 1983. Firewood Crops Supplement. National Academy Press, Washington, D.C., USA.

3--National Academy of Sciences. 1979. Tropical Legumes: Resources for the Future. National Academy Press, Washington, D.C., USA.

4--National Academy of Sciences. 1975. Underexploited Tropical Plants with Promising Economic Value. National Academy Press, Washington, D.C., USA.

5--Weber, Fred R. 1977. Reforestation in Arid Lands. Manual Series Number 37E. Volunteers in Technical Assistance, Mt. Rainier, Maryland, USA.

Descriptions of the species listed in this appendix are contained in the above publications as indicated by the numerical code associated with each listing. The publications also contain additional readings and research contacts.

These publications can be ordered free of charge by readers in developing countries. To order publications 1-4, write:

Board on Science and Technology for International Development (BOSTID)
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418 USA

To order publication 5, write:

Volunteers in Technical Assistance (VITA)
1815 N. Lynn Street
Arlington, Virginia 22209 USA

APPENDIX B

Methodology for Diagnosis and Design of Agroforestry Land Management Systems

John Raintree

If agroforestry is to live up to current expectations concerning its capacity to solve problems, significant improvements will have to be made in the methodology for relating research and development efforts to the actual needs and potential of tropical land use systems. This paper highlights the principal features of the core logic of an evolving diagnostic and design methodology that is intended to serve as a reliable tool for arriving at effective and adoptable agroforestry solutions to local land use problems the world over.

WHY DIAGNOSIS IS NECESSARY

The ultimate practical aim is to improve agroforestry land management systems and technologies with specific capabilities to solve land management problems. Unfortunately, technologies implicitly designed for conditions that prevail at research stations, "high access" farms (Rolling 1980), and forest management units are often completely unsuitable when extended to the majority of land users in the same agroecological zone. The problem is not that the biophysical features of the zone have not been taken into account--on the contrary, they are usually well understood--but that discipline-focused researchers often fail to perceive that the existing land use system has its own internal organization and its own unique set of operational constraints and potentials.

The problem with an ad hoc approach to designing or prescribing technologies is that the technologists are rarely equipped to address the full set of design criteria. Rather than designing technology on the basis of only a partial set of criteria and then treating the nonadoption of the resulting technology as an "extension problem," it will almost always be more useful to place the onus of responsibility squarely on those developing the technology, recognizing that in the first instance, there is a design problem and no substitute for good design. This objective requires coordinated contributions from an interdisciplinary team of professionals as well as from the intended users of the eventual technology product.

A problem-oriented diagnostic approach to agroforestry design is the most direct and logical route to effective and adoptable agroforestry technologies and land management systems. A long, drawn-out survey process is neither necessary nor useful. The aim is to develop a practical, effective, and quickly accomplishable diagnosis and design method that can prove its usefulness by the results it obtains in a wide range of environments.

THE LOGIC OF AGROFORESTRY DIAGNOSTIC AND DESIGN METHODOLOGY

The success of the methodology will be judged not by the number or the elegance of resulting agroforestry technologies but by the impact it has had on the landscape, that is, how effective it has been in transforming landscapes into more productive and sustainable land use systems. A successful methodology must somehow guide the user toward agroforestry technologies that embody three essential attributes: productivity, sustainability, and adoptability.

The first two criteria are virtually axiomatic. Agroforestry is an approach that seeks to improve the productivity and sustainability of land use systems and has significant potential for achieving both objectives simultaneously. Productivity and sustainability are the most effective criteria by which to measure problems of existing land use systems and evaluate potential agroforestry alternatives. No matter how efficiently or elegantly a technology may solve a problem, however, it will have little impact unless it is adopted by a significant percentage of the intended users. In agroforestry diagnosis and design, there are many factors beyond technological irrelevance that may limit the adoptability of an otherwise promising technology.

Most of the possible adoption constraints have to do with the level of available resources and management skills in a given system, or with the incompatibility of the potential technology with existing practices or certain cultural factors associated with the general technological tradition of the area. It may be difficult, or even impossible, to diagnose all of the potential constraints on adoption before undertaking farm trials of the proposed technologies, but the process can be guided initially by the commonsense assumption that the ability to solve a problem begins with the ability to define it (Steppler 1981, Steppler and Raintree 1981).

There are two practical implications for a strategy that focuses attention on the solution of perceived problems in existing land use systems. In the diagnostic phase, it becomes even more essential to involve the land users in the process inasmuch as only they can shed light on their perceived problems. Hence, it is important to emphasize analysis of perceived management problems and strategies at the household or unit management level.

In the design phase, not all of the problems that constrain the productivity and, particularly, the sustainability of a household land management system are clearly perceived by the manager; and even when the problem is perceived, its solution may not rank high in the farmer's priorities, and technologies designed to solve the problem may fail to awaken any adoption interest. Although often viewed as an "extension" or "education" problem, again it may be more productive to regard it as a design problem.

The multifunctional nature of many potential agroforestry technologies may enable the designer in such cases to find some attractive way to link the not necessarily wanted conservation function to some desirable production function of a well-chosen multipurpose technology.

For example, in Kenya, farmers with little or no present interest in erosion control (a severe problem in dry hill areas) nevertheless appear very interested in hedgerow planting of fast-growing leguminous trees to satisfy household fuelwood needs. By planting dense hedgerows of coppicing fuelwood trees on the contour with row spacings selected for effective erosion control, both problems can be solved with a single, adoptable design. Other farmers in Kenya, on the other hand, have expressed a definite and immediate interest in hedgerows for erosion control, but there is no currently perceived problem with fuelwood supply. Where trend analysis indicates a potential fuelwood problem, these farmers, with potential fuelwood production systems already in place, could then begin to manage the hedgerows for fuelwood. These two examples of cleverly designed multipurpose agroforestry systems illustrate the kinds of design considerations that follow from a diagnostic approach.

In making the analysis, it is helpful to distinguish between constraints and potentials of existing land use systems and those that pertain to the appropriateness of potential agroforestry technologies. These two levels of evaluation (dealing with constraints and potentials of different types) are part of a sequence of analyses outlined below:

Diagnostic Phase

1. Characterize the essential features of structure and function in the existing land use system and identify the output subsystems.
2. Evaluate the performance of the subsystems (that is, identify problems).
3. Determine what constraints limit the performance of the subsystems.
4. Identify general potentials for performance-improving (constraint-removing) interventions of an agroforestry nature (candidate technologies).

Design Phase

5. Determine constraints that condition the appropriateness of candidate agroforestry technologies (components and practices).
6. Identify remaining potentials for specific agroforestry technologies (existing or to be developed).

The following section discusses details of the logic of agroforestry diagnosis and design and considers what is needed at each of the above steps.

Identification of Output Subsystems

In analyzing land use systems, initial attention must be directed to the evaluation of the resource base. Subsequent priority should be given to the definition of land management units (or their equivalents) as the primary decision-making units and reference systems. Defining land use subsystems in terms of their output seems most appropriate because it is (a) the least restrictive modeling possibility, (b) the most compatible with various techniques of input-output analysis, and (c) the most consistent with the way in which land users manage their land--that is, to produce desired outputs. A "major output subsystem," then, may be defined as the set of activities, resources, and other land use factors that are involved in the generation of an output intended to satisfy one of the basic production objectives of the household.

In deciding specifically what output categories to consider as "basic," it is important, for a widely applicable methodology, to satisfy two general requirements: (1) general applicability, and (2) adequate representation of the idiosyncracies of local land use systems. To satisfy both requirements and to facilitate ready linkage with categories of agroforestry technologies, it is fruitful to follow a "basic needs" approach. The output categories considered basic to the economic well-being of households everywhere are:

1. Food

2. Energy

3. Shelter--all forms of shelter (housing for people, livestock, and personal belongings; shade, windbreaks, etc.) and enclosure (fences, kraals, boundary markers, etc.)

4. Raw materials for home industry--all raw materials for household or village manufacture of everything from clothes and kitchen implements to medicinal preparations--that is, all locally manufactured consumer items, whether for home consumption or sale

5. Cash income

6. Community integration--all forms of "social" production and consumption (feasting, gift-giving, brideprice, taxes, education, etc.).

This approach assumes that (1) the needs identified in the list are basic and universal; (2) local systems will display great variety with respect to the preferred forms in which these needs are satisfied (food and fuel preferences, shelter types, etc.), but that these will all be variations on the same universal themes; and (3) local and regional land use systems are organized to produce goods aimed at satisfying these basic needs (whatever else they might also do). The way in which they do this will, of course, vary from system to system. In commercial land use systems, cash crop production for purchase of the basic commodities will be the predominant household strategy. In more subsistence-oriented economies the household land use system will be organized to satisfy the basic needs more directly.

The use of the term "basic needs" does not imply any restriction on the level of economic development. The needs that have been highlighted are basic in type, not necessarily in level of satisfaction.

Problem Identification

Once the basic needs subsystems have been identified, problems in the productivity and sustainability of the basic production subsystems can be identified by conducting intensive interviews with farmers. The following example from Kathama, Machakos District, Kenya, illustrates the application of the methodology to a semiarid zone, mixed farming system in the midlands of East Africa.

Problems in Household Basic Needs Supply Subsystems

1. Food. Seasonal staple food shortages are normal, and deficits must be made up by purchases; drought-related crop failure requiring famine relief occurs on the average of once every five years; low milk and meat production results from dry season feed shortage for livestock.

2. Energy. Insufficient fuelwood produced from personally owned land requires purchase for household and cottage industry uses; large trees for brick kilns are not available.

3. Shelter. Lack of construction-quality timber and poles requires purchase of expensive supplies; lack of large trees for brick making; lack of fencing and shade trees; problems with wind desiccation of crops.

4. Raw materials. Must purchase expensive fuelwood supplies for butchery and brick making.

5. Cash. Low net household income due in part to cash drain for staple foods, fuelwood, and construction wood; earning and savings potential of livestock enterprise limited by dry season feed gap.

6. Community integration. Difficulty in meeting expectations for cash contributions to numerous "harambee" community self-help projects; difficulty in meeting educational expenses.

Analysis of Land Use Constraints

Once the problem subsystems and the general nature of the supply problem have been identified, analysis of the land use system traces out the causes of the supply problem. In the Kathama example, the causal factors are:

Crop land

1. Low fertility and declining yields
2. Lack of manure
3. Soil or wind erosion and water loss due to poor infiltration and heavy runoff of rainwater
4. Waterlogging on low spots
5. Labor bottleneck at ploughing and weeding time
6. Pests

Grazing land

1. Small grazing area
2. Insufficient dry season feed production
3. Overgrazing and soil erosion
4. Uneven distribution of water supplies

In the first approach, the analyst has intensive discussions with the farmer to probe the cause of the problem and also observes the farm. Additional objective measures are also being developed to supplement interview and observation data with more quantitative measurements of land use problems. This approach provides (1) a spot diagnosis, and (2) sufficient information to establish a structural model of the problem's causes. With respect to the latter, a causal network diagramming technique (Figure B-1) is a useful tool in analyzing interrelationships among land use problems and identifying the critical constraints that limit the productivity and/or the sustainability of the system.

Identification of Potential Agroforestry Interventions

The resulting model or models of problem etiology, such as the partial model of cropping system constraints shown in Figure B-1, then serve as the basis for identifying points in the system where interventions could remove, reduce, or bypass specific constraints. The analyst simply studies the causal diagram(s) and, for each node in the causal network, asks "Is there anything trees can do to solve or mitigate this problem?" Ideally, this exercise should be an interdisciplinary brainstorming session about possible land use alternatives.

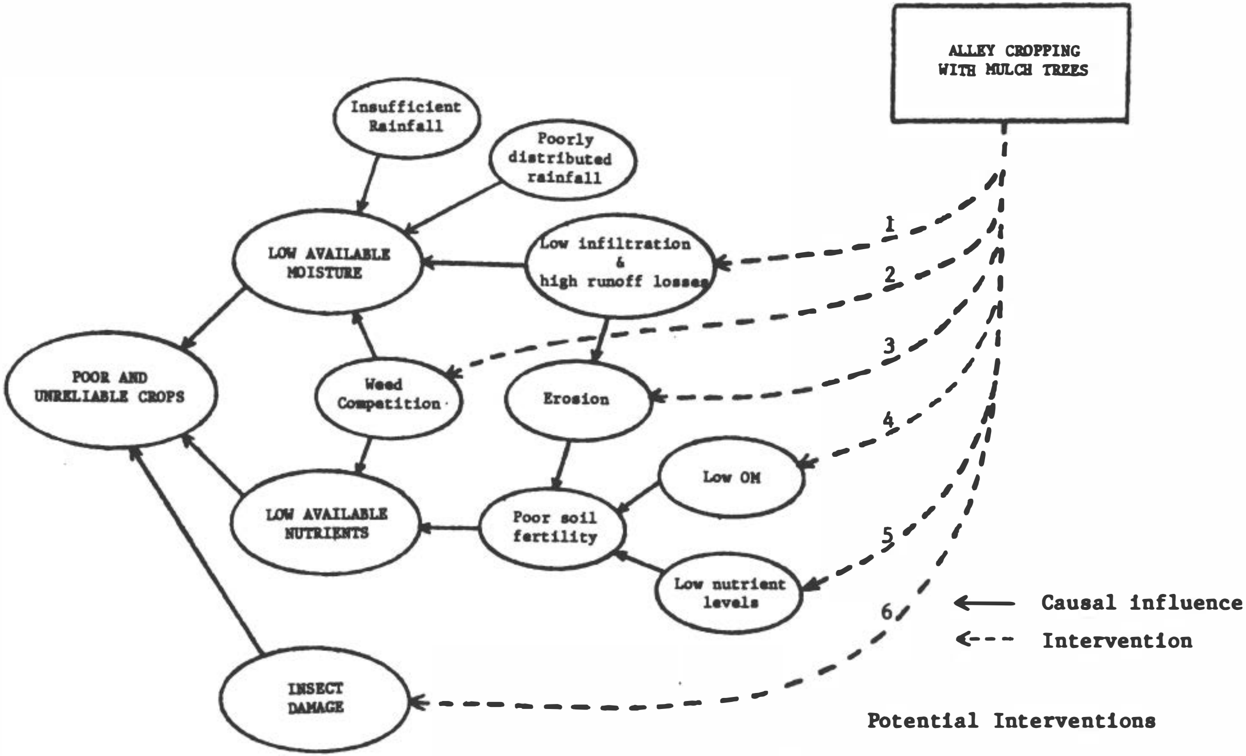
Nonagroforestry alternatives should also be considered. In certain situations, for example, traditional approaches to land use other than agroforestry may be more appropriate than agroforestry systems. Where these are clearly superior to agroforestry alternatives, they should be recommended. Agroforestry is not the solution to every land use problem, and there is simply too much real agroforestry work to be done in the world to squander resources trying to force agroforestry technologies into land use systems where they have no clear and significant role to play.

FIGURE B-1 Partial causal network model of cropping system problems in Kathama, Machakos District, Kenya (semiarid zone, mixed farming system). (International Council for Research in Agroforestry)

At a minimum, the diagnosis and design team identify agroforestry technologies that can solve land management problems by addressing specific end-use or service potentials in the system. Design indications are drawn from the Kathama example previously cited.

Specific Problem-Solving Agroforestry Alternatives

1. Alley cropping/mulch farming with leguminous and other suitable trees to control erosion, increase rainwater infiltration, reduce runoff, conserve soil moisture, improve soil fertility and structure, reduce the traction requirements for tillage (or the tillage requirement in general, by minimum tillage management), lessen the labor requirement for weeding, and possibly provide some measure of pest control through use of insect-repelling mulch species such as neem (see Figure B-2 for the logic of this intervention in the form of a causal network diagram).



Potential Mulch Trees

N-fixing:
- *Leucaena leucocephala*
- *Mimosa scabrella*
- *Sesbania bispinosa*

Insect-repellent:
- *Adhatoda vasica*
- *Azadirachta indica*
- *Derris indica*

Potential Interventions

1. Improved infiltration, reduced runoff
2. Weed control with reduced labor
3. Reduced splash and runoff erosion
4. Increased organic matter
5. N-fixation and nutrient pump action of deep penetrating roots
6. Use of insect-repellent mulch species

FIGURE B-2 Alley cropping as a potential solution to cropping system problems in Kathama, Machakos District, Kenya. (International Council for Research in Agroforestry)

2. Elimination or reduction of the dry season feed gap by planting multipurpose fodder trees in grazing areas and as hedgerows in and around crop fields with concomitant erosion control and windbreak benefits and fuelwood and mulch coproduction possibilities; the improved feed situation should potentially allow dry season plowing and planting.

3. Hedgerows and living fences of high-yielding fuelwood species and fruit-producing thorn bushes for better livestock control; appropriate plantings can also function as a safeguard against famine in bad years and as a source of supplementary livestock feed in average years.

4. Multistory fruit tree plantings with undersown grass/legume pasture.

5. Cut-and-carry fodder trees for increased pen feeding of livestock to improve dry season nutrition and increase the amount of collectible manure.

Identification of Constraints on Potential Agroforestry Interventions

The next step is to evaluate which of the agroforestry technologies identified in the previous step are promising in the context of a detailed analysis of site constraints. Gathering detailed data on site and land management characteristics can now be limited to those necessary to evaluate particular technological possibilities. This is done by eliminating those components rendered inappropriate by topography, soil, or other factors. For example, in the Kathama case, the presence of large termite populations renders inappropriate any mulch species that provide a good habitat for these pests; and it encourages the use of mulch species that have the ability to repel or discourage termite infestation (for example, *Azadirachta indica*, *Adhatoda vasica*, *Derris indica*).

Next, the process identifies those practices that are unlikely to be adopted by virtue of their incompatibility with the local farming system because of resource requirements, labor bottlenecks, management incompatibilities, or conflicting government laws and regulations or the manner in which they are enforced. For example, in Kathama the establishment technique initially used to plant out the first round of alley-cropping farm trials was found to be incompatible with the local practice of plow weeding, which tended to bury the young tree seedlings under a heavy layer of soil. As in this case, it may not always be possible to identify all of the potential constraints prior to actual farm trial of the candidate technology, but such identification should be the aim of pretrial screening.

It may be possible to modify the local farming practice somewhat to accommodate the new technology (for example, a modified plow-weeding practice seems to be acceptable to the farmers in Kathama), or it may be necessary to look further for a suitable agroforestry alternative. A basic understanding of constraints on potential agroforestry interventions is of considerable importance in the planning process.

Finally, following this elimination process, we arrive at a set of feasible agroforestry alternatives that may be compared with each other, with existing land management practices, and with nonagroforestry alternatives to determine which, if any, should be incorporated into site-specific, problem-solving agroforestry designs.

Farm Trials and Field Station Follow-up

The "rapid appraisal" diagnostic and design procedures outlined above are merely the beginning of the technology research and development (R&D) cycle. For project development they should be followed, depending on the state of readiness of the technology in question, by immediate farm trials of "best bet" agroforestry technologies and/or by on-station R&D to develop "notional" or "preliminary" technologies for later incorporation into on-farm trials. These activities entail their own methodological needs. The International Council for Research in Agroforestry (ICRAF) intends to collect, develop, and disseminate information and methodologies for the full range of biophysical and socioeconomic research questions related to the development of agroforestry's potential as a solution to global land use problems (International Council for Research in Agroforestry 1982b).

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Technology Options for Developing Countries

8. **Ferrocement: Applications in Developing Countries.** 1973. 89 pp. Assesses state of the art and cites applications of particular interest to developing countries—boat building, construction, food and water storage facilities, etc.

14. **More Water for Arid Lands: Promising Technologies and Research Opportunities.** 1974. 153 pp. Outlines little-known but promising technologies to supply and conserve water in arid areas. (French language edition is available from BOSTID.)

21. **Making Aquatic Weeds Useful: Some Perspectives for Developing Countries.** 1976. 175 pp. Describes ways to exploit aquatic weeds for grazing, and by harvesting and processing for use as compost, animal feed, pulp, paper, and fuel. Also describes utilization for sewage and industrial wastewater treatment. Examines certain plants with potential for aquaculture.

28. **Microbial Processes: Promising Technologies for Developing Countries.** 1979. 198 pp. Discusses the potential importance of microbiology in developing countries in food and feed, plant nutrition, pest control, fuel and energy, waste treatment and utilization, and health.

31. **Food, Fuel, and Fertilizer for Organic Wastes.** 1981. 150 pp. Examines some of the opportunities for the productive utilization of organic wastes and residues commonly found in the poorer rural areas of the world.

34. **Priorities in Biotechnology Research for International Development: Proceedings of a Workshop.** 1982. 261 pp. Report of a 1982 workshop organized to examine opportunities for biotechnology research in developing countries. Includes general background papers and specific recommendations in six areas: 1) vaccines, 2) animal production, 3) monoclonal antibodies, 4) energy, 5) biological nitrogen fixation, and 6) plant cell and tissue culture.

Biological Resources

16. **Underexploited Tropical Plants with Promising Economic Value.** 1975. 187 pp. Describes 36 little-known tropical plants that, with research, could become important cash and food crops in the future. Includes cereals, roots and tubers, vegetables, fruits, oilseeds, forage plants, and others.

22. **Guayule: An Alternative Source of Natural Rubber.** 1977. 80 pp. Describes a little-known bush that grows wild in deserts of North America and produces a rubber virtually identical with that of the rubber tree. Recommends funding for guayule development.

25. **Tropical Legumes: Resources for the Future.** 1979. 331 pp. Describes plants of the family Leguminosae, including root crops, pulses, fruits, forages, timber and wood products, ornamentals, and others.

37. **The Winged Bean: A High Protein Crop for the Tropics.** (Second Edition). 1981. 59 pp. An update of BOSTID's 1975 report of this neglected tropical legume. Describes current knowledge of winged bean and its promise.

47. **Amaranth: Modern Prospects for an Ancient Crop.** 1983. Before the time of Cortez grain amaranths were staple foods of the Aztec and Inca. Today this extremely nutritious food has a bright future. The report also discusses vegetable amaranths.

Innovations in Tropical Reforestation

26. **Leucaena: Promising Forage and Tree Crop for the Tropics.** 1977. 118 pp. Describes *Leucaena leucocephala*, a little-known Mexican plant with vigorously growing, bushy types that produce nutritious forage and organic fertilizer as well as tree types that produce timber, firewood, and pulp and paper. The plant is also useful for revegetating hillslopes, providing firebreaks, and for shade and city beautification.

27. **Firewood Crops: Shrub and Tree Species for Energy Production.** 1980. 237 pp. Examines the selection of species suitable for deliberate cultivation as firewood crops in developing countries.

35. **Sowing Forests from the Air.** 1981. 64 pp. Describes experiences with establishing forests by sowing tree seed from aircraft. Suggests testing and development of the techniques for possible use where forest destructions now outpaces reforestation.

40. **Firewood Crops: Shrub and Tree Species for Energy Production.** Volume II. 1983. A continuation of BOSTID report number 27. Describes 27 species of woody plants that seem suitable candidates for fuelwood plantation in developing countries.

41. **Mangium and Other Fast-Growing Acacias for the Humid Tropics.** 1983. 63 pp. Highlights ten acacia species that are native to the tropical rain forest of Australasia. That they could become valuable forestry resources elsewhere is suggested by the exceptional performance of *Acacia mangium* in Malaysia.

42. **Calliandra: A Versatile Small Tree for the Humid Tropics.** 1983. 56 pp. This Latin American shrub is being widely planted by villagers and government agencies in Indonesia to provide firewood, prevent erosion, yield honey, and feed livestock.

43. **Casuarinas: Nitrogen-Fixing Trees for Adverse Sites.** 1983. These robust nitrogen-fixing Australasian trees could become valuable resources for planting on harsh, eroding land to provide fuel and other products. Eighteen species for tropical lowlands and highlands, temperate zones, and semiarid regions are highlighted.

Managing Tropical Animal Resources

32. **The Water Buffalo: New Prospects for an Underutilized Animal.** 1981. 118 pp. The water buffalo is performing notably well in recent trials in such unexpected places as the United States, Australia, and Brazil. Report discusses the animal's promise, particularly emphasizing its potential for use outside Asia.

44. **Butterfly Farming in Papua New Guinea.** 1983. 36 pp. Indigenous butterflies are being reared in Papua New Guinea villages in a formal government program that both provides a cash income in remote rural areas and contributes to the conservation of wildlife and tropical forests.

45. **Crocodiles as a Resource for the Tropics.** 1983. 60 pp. In most parts of the tropics crocodilian populations are being decimated, but programs in Papua New Guinea and a few other countries demonstrate that, with care, the animals can be raised for profit while the wild populations are being protected.

46. **Little-Known Asian Animals with a Promising Economic Future.** 1983. 133 pp. Describes banteng, madura, mithan, yak, kouprey, babirusa, Javan warty pig and other obscure, but possibly globally useful wild and domesticated animals that are indigenous to Asia.

General

29. **Postharvest Food Losses in Developing Countries.** 1978. 202 pp. Assesses potential and limitations of food-loss reduction efforts; summarizes existing work and information about losses of major food crops and fish; discusses economic and social factors involved; identifies major areas of need; and suggests policy and program options for developing countries and technical assistance agencies.

30. **U.S. Science and Technology for Development: Contributions to the UN Conference.** 1978. 226 pp. Serves the U.S. Department of State as a major background document for the U.S. national paper, 1979 United Nations Conference on Science and Technology for Development.

The following topics are now under study and will be the subjects of future BOSTID reports:

- **Leucaena: Promising Forage and Tree Crop for the Tropics** (Second Edition)
- **Jojoba**

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