Agri-silviculture in tropical America

Peter Weaver

PETER WEAVER is specialized in tropical forest research at the Institute of Tropical Forestry of the US Forest Service, Rio Piedras, Puerto Rico.

Agri-silviculture is a production scheme that supplies wood, foodstuffs and/or animal products from a single management unit where good agricultural practices are complemented by the judicious use of trees. Such a unit could be a farm, a small community or a portion of a watershed.

Despite its numerous benefits, agri-silviculture should not be seen as a substitute for intensive agriculture or forestry on any given terrain. Trees compete for light and water, and unless properly managed, can reduce marketable produce. Agri-silviculture is best viewed as one means to keep certain slopes in permanent production or to rehabilitate lands degraded by poor agriculture practices.

Tropical agriculture

Basic differences exist between temperate and tropical mineral cycling. In colder regions, much organic matter and :many available nutrients are stored in the soil, but in humid tropical forests these are retained in the biomass and recycled organically in the system (Odum, 1971a). Few minerals occur freely in the soil (Went and Stark, 1968). In both regions, humus is essential to maintain soil structure, water movement and crop production, and, in turn, nitrogen often controls the amount of humus produced (Aldrich, 1972).

Agriculture may have originated. In tropical areas where the precipitation/evapotranspiration ratio approached unity. Here soluble nutrients would not have been lost through percolation or runoff (Holdridge, 1959; Tosi and Voertman, 1964). However, in many parts of the tropics today, local people produce food on land better suited for tree cover. This is unfortunate because in tropical montane areas, trees are critical to the stability of the landscape. In tropical monsoon climates, trees are also necessary in nutrient cycling because rainwater percolation during the wet season deposits soil nutrients at a depth that only tree roots can penetrate (Frith, 1955).

Certain limitations on the expansion of mechanized tropical agriculture have been observed. First, the "green revolution" may spark social unrest in developing countries that are already overpopulated. Mechanization displaces small farmers, forcing them into urban areas where there is not enough work, housing, or food (Janzen, 1973). Second, the expense of fuel subsidies must be added to the cost of selected seed sources and technology (Odum, 1971a). Food yields per unit-area can be augmented, but only at exceedingly high costs to remaining resources and energy supplies. Finally, temperate zone agrotechnology cannot simply be "transplanted" into the tropics to meet future food demands; rather, new concepts based on sound ecological principles are needed (Igbozurike, 1971). These encompass moral, economic and legal constraints derived from complete public awareness.

The general lack of concern for subsistence agriculture has directly hindered economic development. Haiti is perhaps an extreme example, but it could be an omen for many other third-world nations (Anonymous, 1977). Erosion here is rampant, land surfaces are covered with rocks, and the water-holding capacity of soils has been diminished. Small farmers need all of their land for foodstuffs, and many feel that they could not afford space for trees. Thus they continue to exploit steep and infertile terrain, causing inundations, sedimentation of reservoirs and major alterations in the water regimen -problems that have directly affected all elements of Haitian society. Addressing these problems today will be costly and will involve diversion of funds that could have been used for industrial development and economic improvement.

Do rational alternatives exist? Given that the developing nations must produce both for vast urban populations and for export, high-yielding varieties could be multiple-cropped by using labour-intensive techniques on a year-round basis under appropriate climatic and soil conditions. But at the same time, these nations must also link forestry and agriculture into a harmonious production system to provide for their own rural areas (King, 1977).

Agri-silviculture

COSTA RICAN FARMERS TENDING YOUNG EUCALYPTS part of the self-sufficiency of a small farm

Several indigenous peoples in -the tropics have developed stable agri-silvicultural systems using annual plants, bushes, trees, vines and livestock (Budowski, 1978). Such systems frequently simulate the natural forest in appearance, remain productive through the entire year, resist plagues and infestations and minimize soil erosion. Microclimates within them are modified by tree cover (Wilken, 1972), and minerals are recycled through natural processes that include organic material from dead plants and manure from livestock. Yields are both diverse and nutritious and include seeds, flowers, fruits, vegetables, leaves, medicines, resins, forage, firewood, lumber and meat. At least eight different agri-silvicultural systems can be identified:

1. Shifting cultivation. Shifting cultivation has been defined as "the use of the forest in the development of agriculture" (Petriceks, 1968). It regenerates soil through the use of trees, and constitutes the predominant use of arable lands in the tropics (FAO, 1957; Watters, 1968a, 1968b, 1971; Petriceks, 1968; Conklin, 1963). After cultivation ceases, the soil passes through a series of alterations (Sanchez, 1972). Secondary growth stores nutrients against percolation losses, absorbs them from the subsoil, and restores them to the surface. Organic matter accumulates on the surface, and, at the same time, the capacity of the soil to store nutrients is augmented (Nye, 1958; Nye and Stephens, 1962).

The system is extremely efficient when populations are disperse. In high-density areas, erosion occurs rapidly when cultivation is prolonged, when large areas are cleared or when steep slopes are employed (Bedard, 1960). Both the forest and its increment are lost, and low productivity of the soil persists (Petriceks, 1968).

2. The "corridor system." In Africa, in response to community necessities (including the desire to export foodstuffs), a series of migratory croppings organized in rotational sequence was developed (Coene, 1956; Newton, 1960). A typical 17-year rotation included two seasonal crops followed by an annual crop, perennial crops and finally secondary vegetation. A 12-year fallow was used to ensure soil fertility during the next five-year cropping sequence. In Ecuador, a similar system with prescribed fallow is under investigation (Bishop, 1978).

Dooryard gardens and field crops are followed by grass-legume pastures containing legume firewood trees. Poultry and livestock roam in the forest-pastoral fallow. Like the system of shifting cultivation, the corridor system uses trees over time as a means of rejuvenating the soil.

3. Taungya. Initiated in Burma during the 1860s, taungya is usually practised on public lands on loan to farmers. King (1968) has listed some 25 names by which the system is known and given guidelines for its implementation. The trees to be used, he said, should be species that grow rapidly, tolerate light, have deep roots and can withstand brief periods of competition for light, water and nutrients. In turn, interplanted agricultural crops should neither produce a dense shade nor demand excessive nutrients. Vines are ruled out entirely. The crops should not be long-term crops, and they should contribute to soil stabilization. Some 80 trees and 40 species of compatible agricultural crops were cited.

In Costa Rica, a taungya plantation of *Eucalyptus deglupta* plus maize (Aguirre, 1977) was found to be not only more economical to establish. but also more resistant to weeds than the control plantation. A plantation of Dalbergia retusa and maize and beans (Espino-Caballero, 1976) proved more efficient in production, probably because the association of plantings used available nutrients more completely than the control.

OVERGRAZED PASTURE IN METÁPAN, EL SALVADOR where forestry can heal the wounds of agriculture

4. Tree intercropping. The intercropping of trees with permanent beverage crops such as coffee (Marrero, 1954, Gutiérrez-Zamora and Soto, 1976) or cacao (Holdridge, 1957) is commonly practiced in the American tropics. For example, species of Leguminosae, *Inga* spp., *Erythrina* spp., *Dalbergia* sp., *Gliricidia septum* and *Pithecellobium saman* are used, frequently in combination with plantains and scattered vegetables and tubers.

Casual intercropping of timber species with subsistence crops occurs near markets or forest industries (Peck, 1976). *Cordia alliodora* was found together with cacao, plantains and pasture near San Lorenzo, Ecuador, and *Cordia, Cedrela* sp., and *Juglans* sp. were observed with cacao, coffee and plantains near Tumaco, Colombia.

Near Turrialba, Costa Rica, I saw *Cordia alliodora* and pejibaye palm as dominants and co-dominants in association with intermediate stems of *Erythrina* sp. and coffee. On the island of Dominica, coconut palms and scattered *Artocarpus* sp. were dominants with intermediate stems of cacao and coffee.

Increases in produce have been attributed to tree intercropping. In Costa Rica, *Hevea brasiliensis* grown with cacao was found far superior to a monoculture of *Hevea* (Hunter and Camacho, 1961). The difference in production was attributed to simulation of the natural forest. In Mexico, the casual association of *Prosopis* sp., *Leucaena esculenta* and /or *Pithecellobium* spp. was thought to increase the production of intercropped foodstuffs (Wilken, 1977). Table 1 gives production estimates for one or more of the components of tree associations with foodstuffs or perennial crops.

5. Simulation of natural succession. Holdridge (1959) offered a sequence of crop management that proceeded at 0.1 ha/yr and terminated in 30 years with the gradual conversion of previously cleared land. Successional stages included subsistence crops. The final stage had *Cordia alliodora* and pejibaye palm as dominant and co-dominant vegetation, cacao as suppressed, while tubers were scattered across the ground.

More recently, Hart (1975) observed that the yield and economic return from a successional polyculture exceeded that from a monoculture in which crop rotation was practiced. He proposed the following cropping sequence, which simulates natural succession: (a) leafy, stem and root plants; (b) bananas and plantains; (c) palms, and, finally, (d) productive forest.

Whereas we observed earlier that such agri-silvicultural systems as shifting cultivation and the corridor system use trees over time, the simulation of natural succession, together with taungya and tree intercropping, uses trees over both time and space.

6. Self-sufficient farms. The development of biological cycles on small farms has been the objective of certain Philippine and Australian researchers (Samaka Service Center, 1973, Mollison and Holmgren, 1978). Many of the units contain livestock, fruit and forest trees, home gardens, pasture, ponds stocked with fish, and fields of multiple crops. Animal wastes are washed into a pond, whose waters are used to irrigate crops. Plant residues and forage are employed as animal feed or green manure.

7. Scattered or row trees. Because of strong, dry, seasonal winds, windbreaks along property boundaries or among cultigens could help prevent desiccation of the soil and erosion in areas like El Salvador. Trees, or "living fenceposts" (Lozano Jiménez, 1962) bordering pastures could enclose livestock, yield forage, provide firewood and obviate the need for recurrent cutting of small trees for replacement of the posts. Scattered trees within pastures provide shaded areas, forage, and-in the case of nitrogen-fixing species-an increase in pasture production (Holdridge, 1951, Sicco-Smit and Venegas, 1965, Sicco-Smit, 1971, Peck, 1 976).

8. Forest blocks. Forested upper slopes and hilltops constitute yet an other system with long-term benefits. Trees thus located in areas where recurrent drought is a problem could provide wood, improve water quality and regimen and, because tree-root systems are deep, utilize solar energy throughout the year. These forest blocks could prolong the growing season directly and consequently raise the productivity of adjacent lower slopes and bottomlands. In Guatemala, the litterfall production of adjacent forests is used to fertilize vegetable plots and improve filth of the soil (Wilken, 1977).

Some rice paddies in the Philippines which are interspersed among parcels of forest have been maintained because of religious beliefs and have been productive for over 1 000 years (Sears, 1957). The function of such trees in nutrient cycling and soil stabilization could be significant.

These last three agri-silvicultural systems - self-sufficient farms, row trees and forest blocks-differ from the others in that they use trees over space but not particularly over time.

Choosing the right system

In emphasizing a variety of approaches to improve subsistence agriculture, I have stressed differences among agri-silvicultural systems. Where a timber market is available, tree intercropping may be easy to promote. Near cities, the introduction of fruit trees may be most convenient. In some places, such as larger farms with lands of variable topography, circumstances may favour the planting of hilltops and upper slopes to timber trees, mid slopes to casual agriculture or row trees and bottomlands to multiple-cropping. Such management would improve the water regimen and provide both food and wood. Climate, topography, soil fertility, land tenure, proximity to markets and population pressure are among the factors that will most influence agri-silvicultural practices.

One other aspect merits particular attention, namely the importance of local innovation in extending agri-silviculture in either time or space. In Spain, foresters used bamboo stakes to irrigate tree seedlings, a practice that brought the survival rate in arid areas up to 85 percent (Kernan, 1966). In El Salvador, farmers planted in excavations, thereby also enhancing survival.

Such localized techniques are important, but even more impressive are agri-silvicultural schemes involving entire communities. For example, in Sri Lanka traditional dry-land farming was practiced in a region of monsoon climate with only 150 mm of rainfall during a six-month period (Abeyratne, 1956). Tributaries were dammed, forming reservoirs, each of which served as a village site or "tank village" with the following scheme of land use: (a) irrigable lowlands planted in rice and grazed by cattle during fallow; (b) the village area around the reservoir intercropped with oranges, limes, breadfruit, peppers, mango, plantain, papaya, coconut, yams, yucca and snakegourd; (c) unirrigable uplands put in shifting cultivation with grains, pulses, oilseeds, vegetables, fibre crops and fallow; and (d) the reservoir stocked with fish.

Each village remained a self-sufficient unit based on a system of land classification developed by the peasants. Each was united socially by laws and customs while being physically situated within a watershed. The traditional mode of cultivation was based on maximum conservation and use of rain-water, land use according to soil type and drainage and the use of tested agri-silvicultural techniques including intercropping of trees with foodstuffs and shifting cultivation with adequate fallow.

The development of an agri-silvicultural scheme

In general, the basic requirements for stable agri-silviculture include: soil and waiter conservation; effective techniques to produce nutritious foodstuffs and wood during the entire year; crop diversification to reduce the risk of plagues, infestations and market fluctuations; emphasis on crops that have low fertility requirements and are easily stored; the production of animal protein from plant products and forage for which man has no direct use; and the production of foodstuffs for sale.

Acquiring an intimate knowledge of local conditions constitutes the first step in the development of agri-silviculture, whether on a single farm, in a community or over an entire region. On small land units, many of the aforementioned agri-silvicultural systems can be adopted directly. In some countries, however, the variety and magnitude of problems related to the production of food and wood demand far more than the simple introduction of a new system; indeed, regional agri-silvicultural schemes under the direction of an appropriate local administrative organization are often needed. Such schemes would consider the following points:

Priorities. On the basis of their productive potential, the populations they serve and their national importance, specific watersheds should be selected for programme emphasis. Each watershed should be divided into zone.. Upper slopes and ridges can be used for both forestry and pasture while conservation measures are applied; slopes at mid-elevations could support both pasture and agriculture with soil protection measures being undertaken. Plains and alluvial valleys should be used for intensive agriculture. In each of these zones, model farms should be developed for educational purposes.

Planning. Management plans based on soil classification and land-use capacities should be developed, especially for the larger farms.

Techniques. Since the intent of agri-silviculture is the joint production of food and wood, both should be given appropriate emphasis on management. units. Specific concerns would include:

- Multiple cropping with high-yield, nutritional varieties on lands capable of sustained production coupled with use of traditional varieties on poorer lands.

- Determination of carrying capacities of rangelands, use of rotational grazing and the construction of trench silos for storage of fodder.

- Intensive management of water through construction of terraces, ponds and canals.

- Recycling of minerals through elimination of fires, use of legumes, planting of trees with deep root systems and application of organic matter and manure.

- Development of techniques for food storage (drying, canning), use of foodstuffs that resist decomposition and raising of small, meal-size animals such as guinea pigs and rabbits.

- Reduction of erosion by minimum tillage techniques on steep slopes.

- The regular use of fruit, vegetable, forage and forest trees on all land units.

Socioeconomic considerations. Successful introduction of the above techniques must involve extension personnel. Access to credit, formation of cooperatives and development of nurseries would be critical to the programme.

Pasture and food crops

Past approaches to agri-silviculture have been concerned with the maintenance of intercropped timber trees, a reasonable concern given the objectives of most programmes. In some areas, however, a daily ration of food and firewood is the farmer's chief worry.

The types of plants useful in agri-silviculture include pasture herbs and grasses, trees and foodstuffs. Here trees will be emphasized, with only brief attention being given to the critical points regarding forage and food crops.

Pasture herbs and grasses. There is much literature which identifies grass and forage species and gives their climatic requisites, areas of origin, productivity and nutritional worth (Whyte et al., 1953, 1959; McIlroy, 1972; Butterworth, 1967, Vicente-Chandler et al., al., 1974; Roseveare, 1948). Perhaps of greatest interest to agri-silviculture, however, are studies that demonstrate (a) increased pasture yield in areas beneath trees capable of fixing nitrogen (Holdridge, 1951), (b) nitrogen-fixing activity in common tropical grasses (Day et al., 1975). and (c) significantly higher yields of more nutritious forage from compatible combinations of range plants (Warmke et al., 1952).

Nutritious foods. Twenty percent of the people in the third world do not receive enough calories, and over 30 percent suffer from protein deficiency (Kracht, 1973; Rehm and Espig, 1976). Among the most useful plants to alleviate this shortage, with their respective mean contents of crude protein, are: grains 10.4 percent, soya 38 percent, oilseeds 19.7 percent, and legumes 23 percent. By comparison, tubers contain only 1.7 percent protein (Rehm and Espig, 1976). *Amaranthus* spp. (amaranth), *Vigna unguiculata* (cowpea), and *Cajanus cajan* (pigeon pea) all have high-protein seeds and leaves. *Hibiscus esculentus* (okra) has high-protein seeds, and *Manihot* esculenta (cassava) and *Ipomaea batatas* (sweet potato) have high-protein leaves. The entire plant of *Psochocarpus tetragonolobus* (winged bean) is edible and high in protein. *Cucurbita foetidissima* (buffalo gourd) and *Colocasia esculenta* (taro) are also high in protein (National Academy of Sciences, 1975a, 1975b; Martin and Ruberté, 1975, 1976; Mortensen and Bullard, 1970; Wittwer, 1974). In addition, several other high-protein tropical plants could possibly serve as new food sources (Martin et al., 177).

Choice of trees

Timber, firewood, fencing and forage. Trees for timber production are usually tall, fast-growing secondary species with straight stems, strong, fine-grained woods and good machining characteristics. The best fuelwoods have a high specific gravity, regenerate easily by sprout or seedling, are fast-drying and easy to harvest and transport, and burn with little or no sparking (FAO, 1977; Burley, 1978). Fence or hedgerow species could include either timber or fuelwood species, but additionally they should be easy to establish, preferably by stakes, and should be fast-growing and resistant to corrosion from nails or wire.

The Leguminosae, as a group, afford many benefits. Several are colonizers that grow rapidly, produce a low-to-intermediate density wood and are adapted to several environmental conditions. Generally, they are fertile at an early age and either produce much seed or sprout easily. Many add nitrogen to the soil and produce protein-rich foliage and seeds that serve as excellent forage and, in some instances, as food for man. Others are cut and used as hay. The bark, flowers, pods and seeds of some, however, are poisonous.

Table 2 contains many valuable species that provide timber products, firewood and forage. The Meliaceae (i.e., *Cedrela* spp., *Swietenia* spp., *Carapa* spp., *Toona* spp. and *Guarea* spp.) are quality timber species used in general construction, carpentry and cabinet and furniture making. They also resist decay and drywood termites. Another important group, the conifers, including *Pinus caribaea*, *P. oocarpa, P. radiata*, *Cupressus* spp. and *Araucaria* spp., serve as valuable sources of sawtimber and pulp.

Table 1. Examples of tree intercroppings in the American tropics for which some production estimates are available

Components of technique	Source	Production estimates or benefits	Location
Cordia alliodora + cacao	Peck, 1976	Natural regeneration of Cordia in plantations of cacao reached basal areas of 18 m²/ha at maturity	Limón, Costa Rica
Cordia alliodora + coffee	Venegas, 1965; Peck, 1976	Natural regeneration of Cordia in coffee plantation reached 20-30 m²/ha at maturity	Chinchona, Colombia (1400 m)
Erythrina poeppigiana + Cordia alliodora + coffee	Beer, 1979	215 stems/ha of Erythrina at 12 years old, 40 m³/ha of Cordia at 3-7 years old, and 320 kg/yr of coffee beans	La Suiza, Costa Rica (600-1200 m)
Cedrela odorata + coffee	Ford, 1979	12 to 19 m²/ha basal area (130-215 m³/ha volume) of Cedrela in 15-20 years on 2 farms	San Carlos (250 m) and Tabarcia (800 m), Costa Rica
Alnus jorullensis + coffee	Fournier, 1979	Tree diameters of 20 cm in 5 years	San Antonio de Coronado, Costa Rica (1300 m)
Pithecellobium saman + Papaya carica + coffee + cacao	Author, pers. obs.	Pithecellobium with 15-20 m² basal area at 25 years	Limbe, Haiti (20 m)
Annona spp. + Citrus spp. + Artocarpus spp. + Inga spp. + Mammea americana + Papaya carica + Persea americana + Mangifera indica + Psidium guava + Guarea trichilioides	Author, pers. obs.	The tree component aver- aged about 20 m²/ha	Plaisance Valley Haiti (150 m)

+ Simaruba sp. + coffee + plantains + coconut palm + sugar cane + maize + royal palm¹			

(¹The royal palm was bored at 10 m above the ground and mounted with crossbar to store maize. Similar continuous intercroppings of trees and foodstuffs or beverage crops have been observed in Dominica Colombia and Venezuela.)

Eucalyptus spp., including *globulus, grandis, robusta* and *deglupta,* have been planted widely because they are fast-growing and easily adapt from dry through wet lowlands to montane sites. They offer opportunities as a source of timber, posts and fuelwood.

Cordia alliodora, found between 15°N and 15°S latitude, is a fast-growing valuable wood prized for furniture, cabinet work, millwork and general construction. It has been used as coffee shade in combination with peji-baye palm, and as a timber crop with cacao.

Casuarina equisetifolia is a prime candidate for fuelwood because of its density, about 0.8, and its adaptability to a wide range of sites. Moreover, it is fast-growing, functions as an excellent windbreak, and fixes nitrogen. *Syzsygium jambos* also provides firewood, charcoal and posts, and produces an edible fruit. The trunk sprouts after cutting or pruning, an'] production has reached 15+ m^2/ha/yr basal area over six years on poor soils (Wadsworth, 1943).

Leucaena leucocephala is one of the most promising multipurpose trees, yielding nutritious forage, firewood, timber, nitrogen, windbreak and shade. Production has ranged from 30-40 m / ha/yr. The "Acapulco" variety, when intercropped, provides overstorey for coffee, cocoa, peppers, and vanilla., and the "Hawaii" variety yields up to eight ton/ha/yr edible dry forage with 25 percent crude protein. Moreover, both young leaves and small pods are edible. The pods also yield a dye.

Albizia lebbek, a fast-growing species, provides a coarse-grained, strong, fairly durable wood used for furniture, panelling, veneer, turnery, general construction posts and fuel. The species is tolerant of salt spray and drought and is widely naturalized throughout the tropics. The leaves and pods also serve as forage.

Gliricidia sepium is particularly useful as living fenceposts. Stakes up to two m in length are capable of sprouting after being "planted" in the ground. The species is fast growing, fixes nitrogen, provides green manure and serves as an excellent nurse crop for cacao and coffee. The wood ifs hard and can be used in construction. The branches are often cut and used as fuel. The leaves serve as forage for cattle but are poisonous to horses.

The tree also functions as a honey plant and can be intercropped with cacao and vanilla.

Prosopis juliflora is a drought resistant species whose leaves and pods serve as forage. The species can be planted in dry lowlands through montane habitats, where it provides a heavy wood that is resistant to decay.

Table 2. Trees for timber, firewood, fencing, and forage

Scientific name	Common name	Special values, habitat
1. Alnus spp.	Alder	Timber, fixes N; cool, moist montane

2. *Anthocephalus chinensis* A Rich. ex Walp.	Kadam	Timber, veneer, cabinetwood; fast growing; moist to wet lowlands and foothills
3. *Bambacopsis quinatam* Dug.	False cedar	Construction timber, fast growing; dry to wet lowlands
4. *Casuarina equisetifolia* L	Australian beefwood	Windbreak, hedge, fuel (dense wood); propagated from cuttings, fixes N; dry to moist lowlands and foothills
5. *Cedrela odorata* L.	Spanish cedar	Fragrant, durable wood, resistant to termites; low elevation, dry to very humid lowlands
6. *Ceiba pentandra*	Kapok	Boxwood, fibre, edible leaves, fast growing; dry to wet lowlands or foothills
7. *Colubrina arborescens* Sarg.	Coffee colubrina	Water resistant construction timber, coffee shade; dry to wet low- lands and foothills
8. *Cordia alliodora* Oken	Capa	Timber, furniture, posts, coffee shade; dry to wet lowlands and foothills
9. *Cupressus lusitanica* Mill.	Mexican cyprus	Timber, pulp; summer rains, foot-hills to montane
10. *Eucalyptus* spp.	Eucalypt	Timber, fuel, rapid growth; individual species adapted to variety of climates
11. *Gmelina arborea* Roxb.	Gmelina	Pulp, posts, fast growing; moist to wet lowlands and foothills
12. *Ochroma* spp.	Balsa	Light wood for construction, fast growing; moist to wet lowlands or foothills
13. *Pinus caribaea* Morelet	Caribbean pine	Timber, pulp; summer rainfall, low elevations
14. Pinus oocarpa	Ocote pine	Timber, pulp; summer rainfall, intermediate elevations
15. *Pinus radiata* Don.	Monterrey pine	Timber, pulp; winter rain and dry summer; low to high elevation
16. Simaruba glauca	Paradise tree	"Living fencepost," fuel, oil for soap; monsoon to rain forest in lowlands
17. *Swietenia macrophylla* King	Honduras mahogany	Timber, furniture, durable wood, resistant to termites; dry to wet lowlands
18. Syzsygium jambos Alston	Rose apple	Fuelwood, charcoal, heavy yield, fruit, dry to moist lowlands and foothills
19. Tectona grandis L.f.	Teak	Timber, furniture; deep soils at low elevations, dry to moist
20. Toona ciliate Roem.	Burma toon	Furniture: moist to wet foothills at mid-altitudes
Leguminosae		
21. *Acacia albida* and other spp.		Forage, drought resistance
22. *Albizia lebbek* Benth. and other spp.	Tibet tree	Fuel, construction wood, leaves and pods as forage; drought resistance
23. Bauhinia spp.	Bauhinia	Forage, fuel
24. Cassia spp.	Cassia	Forage, green manure
25. *Erythrina berteroana* Urban and other spp.	Machette	Forage, living fencepost, fuel, edible leaves
26. *Gleditsia* spp.		Shade, forage, hedges
27. *Gliricidia sepium*	Mother of	Forage, fencing, hedge, sprouts from stakes, edible flowers; widely

Steud.	coca	adapted
28. *Inga* spp.	Spanish oak	Coffee shade, fuel, edible pulp; wet tropics
29. *Leucaena leucocephala* de Wit.	Tantan	Forage, fuelwood, timber, wind break, shade, fast growing high density wood, young pods and leaves as human food, dye from pods; mainly dry tropics
30. *Pithecellobium dulce* Benth.	Blackhead	Forage, hedges, edible pulp, construction wood, tannin, dye; drought resistant
31. *Prosopis juliflora* (Sw.) DC. and other spp.	Mesquite	Fuel, leaves and pods as forage; very drought resistant
32. *Sesbania grandiflora* Pers.	Sesban	Forage or green manure, pods, young leaves and flower parts edible, bark yields fibre, dye from sap, fuel, pulp; common in dry areas
33. *Tamarindus indica* L.	Tamarind	Excellent fuel, fruit and vegetable source; widely adapted

Sources: Golfari, 1963, Little and Wadsworth, 1964, Lamb, 1966; Critchfield and Little, 1966; Grijpma, 1969 Kadambi, 1972; Salazar and Albertin, 1973, 1974; National Academy of Sciences, 1977; Wadsworth, 1943; Roseveare, 1948; Whyte, Nilsson-Leissner and Trumble, 1953.

The species is used for rural carpentry, fuel and production of high quality charcoal. Its bark is used in tanning. The nutritious pods are eaten by children and were at one time a staple for the Indians of the southwest United States. It also is a honey plant.

Sesbania grandiflora is another fast-growing multipurpose legume that yields a variety of products including tender green pods, young leaves and flower parts that are eaten in salads, curries and soups. The high protein content in the leaves makes them an excellent forage or green manure. The bark yields a fibre, and dyes have been extracted from the sap. Moreover, other extracts from the plant have been used medicinally. The tree also serves as a source of fuelwood and pulp.

In addition to the species and genera cited in Table 3, several other tree species in Latin America including *Apeiba, Virola, Zanthoxylum, Jacaranda, Tabebuia, Brosimum, Terminalia, Myristica, Quercus, Dalbergia, Trema, Lauraceae, Acacia, Albizia, Bauhinia, Cassia, Prosopis, Calliandra* and *Erythrina* have served local populations as sources of fuel, fodder, construction timber and shade.

Trees for fruits and vegetables. On very small farming units, preference should be given to fruit and vegetable trees because they provide multiple benefits and are more likely to survive than timber species. Well over 1000 species of fruit and vegetable trees are suitable for use on small properties. Some of the best are cited in Table 3. In general, the species selected should be well adapted and not too large. Moreover, it is advisable to select a combination of trees to supplement nutritional needs. For example, vitamins A and C are found in a wide variety of fruits; oils for cooking are found in coconuts or oil palms; and protein, which is difficult to obtain from fruits, can be derived from nuts. A small farming unit ought to contain trees from each of these three groups. *Carica papaya,* although short-lived, is an exceptional tree. The leaves, pith, roots and flowers can be eaten if properly prepared. The fruits can be cooked when green or eaten ripe. *Psidium guajava* is a versatile tree that bears when young and provides fruits that can be used fresh or dried. The wood is heavy and can be used for fuel or the manufacture of home implements.

Anacardium occidentale, Artocarpus spp., *Mangifera indica, Tamarindus indica, Spondias dulcis, Achras zapota, Annona muricata*, and several species of *Ficus* produce well known fruits and nutritious edible leaves. These are multiple-use plants. *Abelmoschus manihot, Morinda citrifolia and Sauropus androgymous* also have edible leaves both nutritious and good tasting. *Moringa oleifera* and *Cnidoscolus chayamansa* have edible leaves that are high in content. Many species of palms provide fruits and a meristem that can be prepared and eaten as a salad.

Approaching agri-silviculture

These are some of the techniques that may be helpful in approaching the development of agri-silvicultural schemes:

Documentation of agri-silvicultural techniques. A data bank with tile following kinds of' information may be developed for existing agri-silvicultural techniques: species used, location of the operation, production levels for foodstuffs, forage, medicinal plants, fruits and wood; soil nutrient status and soil stability; dietary nutrition; folklore regarding cultigens; planting techniques; methods of treating and storing foodstuffs; and annual income generated.

Method for evaluation of practices. A comprehensive index that measures all inputs and outputs, perhaps in kilocalories or dollars (MacKinnon, 1976, Odum, 1971b), should be developed to evaluate the multiple benefits and environmental costs of maintaining particular agri-silvicultural systems, and for comparing them to alternative cropping technologies.

Multiple-use cultigen lists. Lists of multiple-use cultigens should be compiled, especially for small landholdings, where agri-silviculture is to be promoted.

Model farms. The development of model farms of several sizes on different topographic units should lee made a priority item.

Sustained -yield agri-silviculture. Nutrient recycling should constitute an area of major interest. The rate at which nutrients become available must be balanced by the rate at which they are harvested. The success of known techniques may be attributable to the lack of stress placed on the environment. Cropping systems that simulate the natural forest, as well as the process of natural succession, offer promise.

Specific studies. The effect of plant spacings, plant sequences, intercropped combinations and harvest techniques upon both the nutrient content and the biomass of the produce should be investigated. Also, water use and competition for light among intercropped plants should be evaluated. Finally, the effectiveness of incentives, extension activities and cooperation to promote agri-silvicultural techniques should be monitored.

Table 3. Fruit and vegetable trees

Scientific name	Common name	Special values, habitat
Fruit trees		
1. *Anacardium occidentale* L.	Cashew	Nutritious nut, fruit, leaves edible tolerates drought and poor soils
2. *Artocarpus altilis* Fosberg and other spp.	Breadfruit	Starchy vegetable, long prolific production, leaves edible; widely adapted
3. *Carica papaya* L.	Papaya	Stems, flowers and leaves edible, vitamin A and C content high rapid growing; widely adapted
4. *Citrus sinensis* Osbeck and other spp.	Orange	High vitamin C content; widely adapted
5. *Cocos nucifera* L.	Coconut	High oil content, protein source, highly nutritious; widely adapted

6. *Elaeis guineensis* Jacq.	Oil palm	High oil content; adapted to wet tropics
7. *Macadamia ternifolia* F. Muell.	Macadamia nut	Edible nut high in protein and oil; widely accepted
8. *Malphigia glabra* L.	Barbados cherry	Very high vitamin C content; widely adapted
9. *Mangifera indica* L.	Mango	Vitamin A and C content, delicious fruit, leaves edible; widely accepted
10. *Persea americana* Mill.	Avocado	High oil content, prolific; widely adapted
11. *Psidium guajava* L.	Guava	High vitamin A and C content; widely adapted
12. *Tamarindus indica* L.	Tamarind	Fruit, pulp and leaves edible; widely adapted
13. *Theobroma cacao* L.	Cocoa	High oil content, edible pulp, beverage, widely used
Vegetable trees		
14, *Abelmoschus manihot* Med.	Sunset hibiscus	Edible leaves and shoots, propagated from cuttings
15. *Chamaedorea* spp.	Palm flowers	Inflorescence edible; grown widely in Central America
16. *Cnidoscolus chayamansa* McVaugh	Chaya	Leaves edible and nutritious, propagated from cuttings; dry areas
17. *Guilieima gasipea* L.H. Bailey	Peach palm	Fruits nutritious, palm hearts, multiple trunks; widely adapted
18. *Morinda citrifolia* L.	Indian mulberry	Edible leaves, fruit; grows well at seaside
19. *Moringa oleifera* Lam.	Drumstick tree	Leaves, young pods and roots edible, regenerates from cuttings; dry areas
20. *Oreodoxa oleracea*	Millionaires' salad	Heart of palm; several adapted to many areas
21. *Sauropus androgynus* Merr.	Katuk	Edible leaves, hedge plant, propagated from cuttings

Sources: Ochse, Soule, Dijkman & Wehlburg, 1961; National Academy of Sciences, 1975b, 1977; Martin, Telek & Ruberté, 1977,

Acknowledgements

I am indebted to many for their critical review of this paper: Gerardo Budowski, Head, Forest Sciences Department, Turrialba, Costa Rica; Stanley L. Krugman, Principal Research Forest Geneticist, US Forest Service, Washington, D.C.; Franklin W. Martin, Horticulturist, Mayaguez Institute of Tropical Agriculture, Mayaguez, Puerto Rico; and Janis Petriceks, Professor, SUNY College of Environmental Science and Forestry, Syracuse, New York.

Helmut Haufe, Regional Forestry Official for Latin America and the Caribbean (FAO), provided much useful information and enthusiasm during the early stages of this work.

References

ABEYRATNE, E.L.F. 1956. Dry land farming in Ceylon. *Tropical Agriculturist*, 112: 191-229.

AGUIRRE, C.B. 1977. *Comportamiento inicial* de Eucalyptus deglupta *Blume, asociado con maíz (sistema "Taungya"), en dos espaciamientos con y sin. fertilización*. Tesis Mag. Sc., UCRCATIE, Turrialba, Costa Rica. 130 p.

ALDRICH, S.R. 1972. Some effects of crop-production technology on environmental quality.

Bioscience, 22: 90-95.

ANONYMOUS. 1977. The edge of disaster. *West Indies Chronicle*, 90 (1538): 6, 7, 15.

BEDARD, P.W. 1960. Shifting cultivation - benign and malignant aspects. In *Fifth World Forestry Congress,* 3: 2016-2021.

BISHOP, J.P. 1978. The development of a sustained yield tropical agro-ecosystem in the upper Amazon. *Agro-Ecosystems*, 4: 459-461.

BUDOWSKI, G. 1978. *Food from the forest*. Eighth World Forestry Congress, Djakarta, Indonesia. 20 p.

BURLEY, J. 1978. *Selection of species for fuelwood plantations*. Eighth World Forestry Congress, Djakarta, Indonesia. 14 p.

BUTTERWORTH, M.H. 1967. The digestibility of tropical grasses. *Nutr. Abstr. Rev*., 37: 349-368.

COENE, R. DE 1956. Agricultural settlement schemes in the Belgian Congo. *Trop. Agric. (Trinidad),* 33: 1-12.

CONKLIN, H.C. 1963. The study of shifting cultivation. *Curr. Anthrop*., 2: 27-61.

CRITCHFIELD, W.B. AND E.L. LITTLE, JR. 1966. *Geographic distribution of the pines of the world*. US Dept Agric. For. Serv., Misc. Pub. 991. Washington, D.C. 97 p.

DAY, J.M., M.C.P. NEVES AND J. DOVER-LEINER. 1975. Nitrogenase activity on the roots of tropical forage grasses. *Soil Biol Biochem.*, 7: 107-112.

ESPINO-CABALLERO, R.F. 1976. *Productividad de maíz* (Zea mays L.) *y frijol de costa* (Vigna sinensis *Endl.) asociados dentro de una plantación forestal en Turrialba, Costa Rica*. Turrialba, Costa Rica. 78 p.

FAO. 1957. Shifting cultivation. *Trop. Agric. (Trinidad),* 34: 159-164.

FAO. 1977. *Forestry for local community development.* FO:MISC/77/ 22. Rome, Italy. 113 p.

FRITH, A.C. 1955. No man's land. *Emp. For. Rev*., 34: 179-187.

GOLFARI, L. 1963. Climatic requirements of tropical and subtropical conifers. *Unasylva*, 17: 33-42.

GRIJPMA, P. 1969. *Eucalyptus deglupta* Bl, una especie forestal prometedora pare los trópicos húmedos de America Latina. *Turrialba*, 19: 267-283.

GUTIÉRREZ-ZAMORA, G. AND B. SOTO. 1976. Arboles usados como sombra en cafe y cacao. *Revista Cafetalera*, 159: 27-32.

HART, R.D. 1975. A bean, corn and manioc polyculture cropping system. II. A comparison between the yield and economic return from monoculture and polyculture cropping systems. *Turrialba*, 25: 377-384.

HOLDRIDGE, L.R. 1951. The alder, *Alnus acuminata*, as a farm timber tree in Costa Rica. *Carib. For.,* 12(2): 47-53.

HOLDRIDGE, L.R. 1957. Arboles de sombra para el cacao. In *Manual del Curso de Cacao*. Edicion Provisional. IICA, Turrialba, Costa Rica. 11 p.

HOLDRIDGE, L.R. 1959. Ecological indications of the need for a new approach to tropical land use. *Econ. Bot*., 13: 271 280.

HUNTER, J.R. AND E. CAMACHO. 1961. Some observations on permanent mixed cropping in the humid tropics. *Turrialba*, 11: 26-33.

IGBOZURIKE, M.U. 1971. Ecological balance in tropical agriculture. *Geogr. Rev*., 61: 519-529.

JANZEN, D.H. 1973. Tropical agroecosystems. *Science,* 182: 1212-1219.

KADAMBI, K. 1972. *Silviculture and management of teak*. Bulletin 24, Sch. of For., Stephen F. Austin State University. Nacogdoches, Texas. 137 p.

KERNAN, H. 1966. *Reforestation in Spain*. College World Forestry Series No. 3. SUNY Coll. For., Syracuse, New York. 52 p.

KING, K.F.S. 1968. *Agri-silviculture (the taungya system).* Dept. For., Univ. Ibadan, Nigeria. 109 p.

KING, K.F.S. 1977. *Forests for people: a challenge in world affairs*. SAF and the Mexican Association of Professional Foresters. Albuquerque, New Mexico.

KRACHT, U. 1973. New high-protein foodstuffs to improve the consumption of protein in developing countries. *Plant Res. and Dev.*, 1: 121-130.

LAMB, F.B. 1966. *Mahogany of tropical America: its ecology and management*. Univ. Mich. Press, Ann Arbor, Michigan. 220 p.

LITTLE, E.L. AND F.H. WADSWORTH. 1964. *Common trees of Puerto Rico and the Virgin Islands.* US Dept Agric., For. Serv. Handb. 249. Washington, D.C. 548

LOZANO JIMÉNEZ, O.R. 1962. Postes vivos pare cercos. *Turrialba*, 12: 150-152.

MAcKINNON, J.C. 1976. Design and management of farms as agricultural ecosystems. *Agro-Ecosystems,* 2: 277-291.

MARRERO, J. 1954. Especies del género *Inga* usadas como sombra de café en Puerto Rico. *Carib. For*., 15: 54-71.

MARTIN, F.W. AND R.M. RUBERTÉ. 1975. *Edible leaves of the tropics*. Mayaguez Inst. Trop. Agric., Mayaguez, Puerto Rico. 235 p.

MARTIN, F.W. AND R.M. RUBERTÉ. 1976. *Survival and subsistence in the tropics*. (Unpublished book) Mayaguez Inst. Trop. Agric., Mayaguez, Puerto Rico.

MARTIN, F.W., L. TELEK AND R. RUBERTÉ. 1977. Some tropical leaves as feasible sources of dietary protein. *J. Agric. of the Univ. Puerto Rico*, 61: 32-40.

MCILROY, R.J. 1972. *An introduction to tropical grassland husbandry*. Oxford University Press, London, England.

MOLLISON, B.C. AND D. HOLMGREN. 1978. *Permaculture 1- A perennial agricultural system for human settlements*. Transworld Publishers Pty. Ltd. Melbourne, Australia. 128 p.

MORTENSEN, E. AND E.T. BULLARD. 1970. *Handbook of tropical and subtropical horticulture*. Dept of State Agency for Int. Dev., Washington, D.C. 186 p.

NATIONAL ACADEMY OF SCIENCES. 1975a. *The winged bean, a high-protein crop for the tropics*. Washington, D.C. 41 p.

NATIONAL ACADEMY OF SCIENCES. 1975b. *The underexploited tropical plants with promising economic results*. Washington, D.C. 188 p.

NATIONAL ACADEMY OF SCIENCES. 1977. *Leucaena, a promising forage an tree crop for the tropics*. Washington, D.C. 115 p.

NEWTON, K. 1960. Shifting cultivation and crop rotations in the tropics. *Papua New Guinea Agric. J.,* 13: 81-118.

NYE, P.H. 1958. The relative importance of fallows and soils in storing plant nutrients. J. West. Agric. Sci. Assoc., 4: 31-49.

NYE, P.H. AND D. STEPHENS. 1962. Sail fertility. In *Agriculture and land use in Ghana*, J.B. Wills. ed. Ghana Ministry of Food and Agriculture (Oxford University Press). London, England. p. 127-143.

ODUM, E.P. 1971a. *Fundamentals of ecology*. W.B. Saunders Company, Philadelphia, Pa. 574 p.

ODUM, H.T. 1971b. *Environment, power and society*. Wiley Interscience, New York. 331 p.

OCHSE, J.J., M.J. SOULE, JR., M.J. DIJKMAN MAN AND C. WEHLBURG. 1961. *Tropical and subtropical agriculture*. Vols I and II. The Macmillan Company New York. 1 446 p.

PECK, R. 1976. *Sistemas agro-silvopastoriles como una alternativa para la reforestación en los trópicos americanos*. II Seminario Nacional de Plantaciones Forestales. Sociedad Venezolana de Ingenieros Forestales. Mérida, Venezuela. 13 p.

PETRICEKS, J. 1968. *Shifting cultivation in Venezuela*. Ph.D. thesis. SUNY College of Forestry at Syracuse University. Syracuse, New York. 327 p.

REHM, S. AND G. ESPIG. 1976. Plant sources of protein in the tropics. *Plant Research and Development*, 4: 7-15.

ROSEVEARE, G.M. 1948. The grasslands of Latin America. imperial Bureau of :Pastures and Field Crops. *Bulletin* 36: 164-178. Aberystwyth, UK.

SALAZAR, F., R. AND W. ALBERTIN. 1973. Requerimientos edáficos y climáticos pare *Pinus caribaea* var. *hondurensis* Barr. and Golf. *Turrialba*, 23: 444450.

SALAZAR, F., R. AND W. ALBERTIN. 1974. Requerimientos edáficos y climáticos pare *Tectona grandis L. Turrialba*, 24: 66-71.

SAMAKA SERVICE CENTER. 1973. *The Samaka guide*. Manila, Philippines.

SANCHEZ, P.A. 1972. Soil management under shifting cultivation. In *A review of soils research in tropical Latin America*, P. Sanchez, ed. North Carolina Agricultural Experiment Station in Cooperation with USAID. p. 46-67.

SEARS, P.B. 1957. *The ecology of man.* Condon Lectures. Univ. Oreg. Press. 61 p.

SICCO-SMIT, G. 1971. Notas silviculturales sobre el *Alnus jorullensis* de Caldas, Colombia. *Turrialba*, 21: 83-88.

SICCO-SMIT, G. AND L.T. VENEGAS. 1965. *Informe forestal del Departamento de Caldas,* *Colombia*.

TOSI, J.A. AND R..F. VOERTMAN. 1964. Some environmental factors in the economic development of the tropics. *Econ. Geog*., 40: 180-205.

VICENTE-CHANDLER, J., F. ABRUÑA, P. CARO-COSTAS, J. FIGARELLA, S. SILVA AND R.W. PEARSON. 1974. *Intensive grassland management in the humid tropics of Puerto Rico*. Bulletin 233. Univ. Puerto Rico, Rio Piedras. 164 p.

WADSWORTH, F.H. 1943. Pomarrosa, *Jambosa jambos* (L.) Millsp. and its place in Puerto Rico. *Carib. For*., 4: 183-193.

WARMKE, H.E., R.H. FREYRE AND J. GARCIA. 1952. Evaluation of some tropical grass-legume associations. *Trop. Agric. (Trinidad)*, 29: 115-121.

WATTERS, R.F. 1968a. *La Agricultura Migratoria en México IFLAIC*. Mérida, Venezuela.

WATTERS, RF. 1968b. *La Agricultura Migratoria en Perú IFLAIC.* Mérida, Venezuela.

WATTERS, R.F. 1971. *Shifting cultivation in Latin America* FAO Forestry Development Paper No. 17. Rome, Italy.

WENT, F.W. AND N. STARKE. 1968. Mycorrhiza. *Bioscience*, 18: 1035-1039.

WHYTE, R.O., T.R.G. MOIR AND J.P. COOPER. 1959. *Las Gramíneas en la Agricultura.* FAO Estudios Agropecuarios No. 42. Rome, Italy. 464 p.

WHYTE, O., G. NILSSON-LEISSNER AND H.C. TRUMBLE. 1953. *Legumes in agriculture*. FAO Agricultural Studies No. 21. Rome, Italy. 367 p.

WILKEN, G.C. :1972. Microclimate management by traditional farmers. *Geogr. Rev*., 62: 544560.

WILKEN, G.C. 1977. Integrating forest and small-scale farm systems in Middle America. *Agro-Ecosystems,* 3: 291 -302.

WITTWER, S.H. 1974. Maximum production capacity of food crops. *Bioscience*, 24: 216-224.
