Chapter 6

Management of Terrestrial Resources: Agriculture, Agroforestry, and Forestry

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Chapter 6

Management of Terrestrial Resources: Agriculture, Agroforestry, and Forestry

AGRICULTURAL DEVELOPMENT IN THE U.S.-AFFILIATED ISLANDS

Few areas in U.S.-affiliated islands remain unmodified by man. Most are or have been managed to some extent to provide for human needs, and many land areas have been degraded in the process through deforestation, soil erosion, and nutrient depletion. Terrestrial resources and resource systems still supply many subsistence needs on the Pacific islands, but subsistence agriculture has been declining in many areas of the Pacific, and has not been a significant activity on the Caribbean islands in this century.

Semicommercial and/or intensive commercial agriculture (on smallholder or larger scales) can play a significant role in the islands' economic development and progress toward greater self-sufficiency. Development of agriculture or forestry on any scale must, however, be sustainable and commercial operations will require considerable expertise and probably importation of new technologies. Developmental research also may be required. Subsistence systems, where they exist, can be protected and fostered and/or made more productive and de-

Photo credit: C. Hodges

Eighty percent of the American Samoan population provides or supplements family nutrition through subsistence agriculture.

veloped to semicommercial scale. Which strategy is selected as appropriate will depend on the geographic, environmental, economic, and social characteristics of individual islands.

Terrestrial resource sustainability will depend on several supportive technologies for minimizing soil erosion and crop losses and for improving the productivity of nutrient depleted soils. Revegetation programs (including reforestation efforts) could also be considered.

Pacific Agriculture

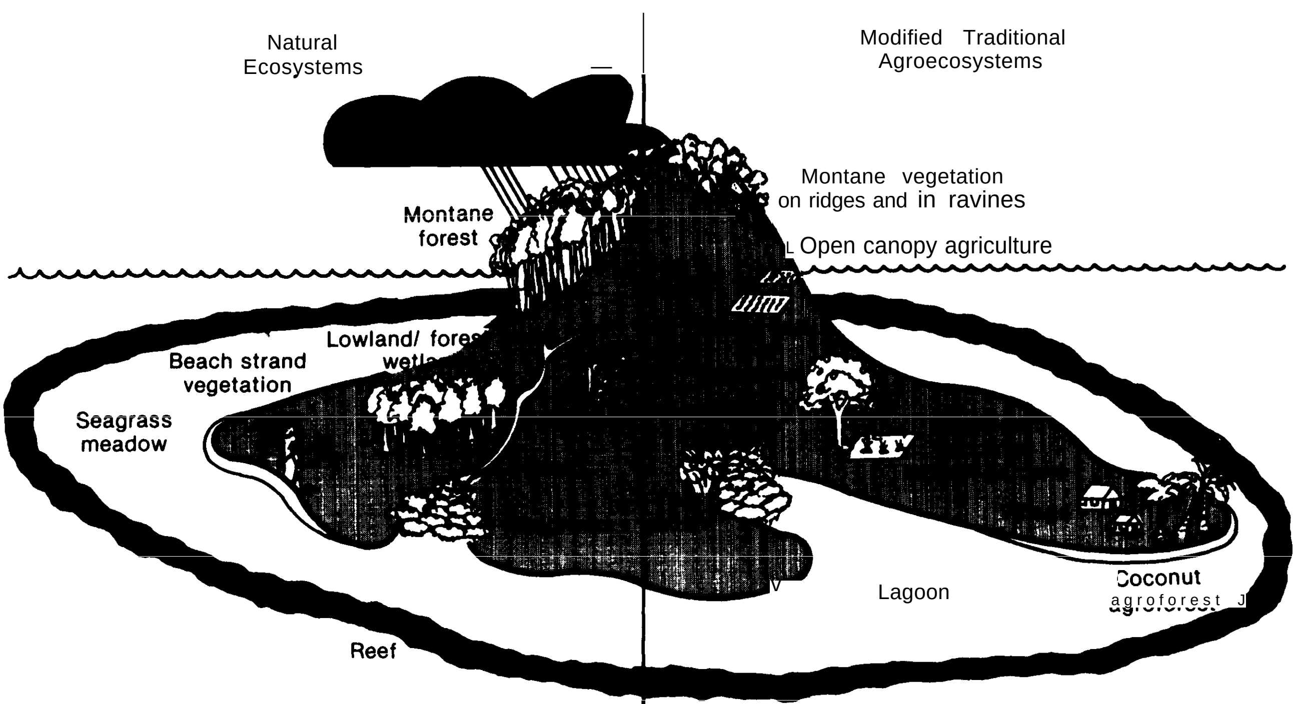
The maintenance of an environment meeting the needs of Pacific islanders involved a complex system of integrated resource management. Rather than rearrange the environment and expend great amounts of energy, people's activities were directed to the most effective use of microhabitat and natural phenomena. This "technology" can be classified as being "nature-intensive," and can be contrasted with what might be classified as "Asian labor-intensive agriculture" and "Western energy- and chemical-intensive agriculture. " Many traditional practices had conservation value resulting from technological limitations of natural materials, taboos and religious beliefs, territoriality, and stratified societies (23).

Traditional Agricuture[1]

The terrestrial activities of early inhabitants of Caroline and Samoan high islands, whether by design, necessity or both, seem to have modified the vegetation of the freshwater runoff filtering systems to meet human needs without altering their basic functions (figure 6-l). For example, swamp forests and low areas inland of mangroves were converted to taro patches which maintained their function as silt traps. Traditional agriculture activities further inland under conditions of low population pressure probably also produced minimal increases in

1 A review of traditional Micronesia high island practices **currently is underway at the University of Guam Water and Energy Resources Institute** (45).

Figure 6=1.—Traditionai Agriculture on a Typicai Micronesia High Voicanic island



SOURCE: Office of Technology Assessment, 1987.

soil erosion *(24).* Atoll agricultural practices were developed to protect crops from salt spray and to place them in proximity to the freshwater lens.

Traditional agriculture systems still can be found throughout the Pacific territories, although some areas have developed these to a greater extent than others. Common systems are:

- culture of wetland tare,
- atoll pit taro culture,
- mixed "tree gardening, "
- intermittent tree gardening,
- "lanchos" and backyard gardens, and
- traditional open canopy culture.

The tree gardens and taro patch systems offer stability and the intermittent gardens offer variety, resilience, and a means of adapting to each year's weather conditions.

Taro Patch Systems.—Species and varieties of food plants in the family Araceae, generally thought of as "tare," can be grown in wet or relatively dry situations. The latter are dealt with in the section on mixed gardening. Culture of wetland taro generally involves preparation of taro patches and management of water and is considered here as a distinct system.

Sites chosen for taro patches are mostly marshy lowland areas such as exist in swamp forests just inland of mangroves. These are deepened as needed and water is generally directed to flow through the patch. *Cyrtosperma* taro is more shade tolerant than *Colocasia* ("true tare"), and is thus more compatible with tree culture, and is an integral part of the agroforestry system of Yap. Taro patches are generally managed on an individual or family basis, the individual taro patch having been handed down from one generation to the next. Where taro patch habitat is extensive, the area is subdivided into separately tended subplots (22).

Palau appears to have the most highly developed cultural methods for *Colocasia* tare. There, the development of a taro patch involves the clearing of a suitable area, in many or perhaps most instances, the site of a previously worked patch. The area may be drained and soil is dug up and leaves, twigs, seagrasses, and other locally available forms of "green manure" are laid down and covered with soil. The patch is then thoroughly mixed and "cultured" to obtain a nutrient-rich muck of desired consistency. planting material consists of small corms or the tops of corms which have previously been harvested. These are planted in depressions and soil is mounded about developing corms to encourage large growth.

A considerable body of expertise exists involving the choice of green manures; choice of cultivar suitable for the site and intended use; management of water; and planting and tending the plant in order to obtain the desired shape, size, and consistency of the corm. Palauan taro patches are divided into sections in which the intensity of management is related to the end product: a fairly intensively worked area to provide for a families' caloric needs, a section with optimal conditions for producing especially high-quality corms for special people or occasions, and sections which are worked less intensively for reserve supplies *(107).*

Colocasia is harvested from 6 months to a year after it is planted depending on the variety and other conditions. The harvested product will not keep long, so only as much as can be consumed is harvested. A continuous supply is provided by successive plantings throughout the year. Once a *Colocasia* patch has been established, it is not necessary to repeat the process of moving soil and adding large amounts of green manure unless the quality of the growing media declines.

Culture of *Cyrtosperma chamissonis* is less labor-intensive than that of *Colocasia* and seems to rely more on the natural transport of nutrients in water directed through the taro patch. Green manure is not commonly added, and cultural methods involve the periodic removal of fallen vegetative material and debris in order to maintain the flow of water through the system. Replanting of *Cyrtosperma* is done at the same time as harvesting, and there is no hiatus required to recondition and replant the patch.

Atoll Pit Taro Culture.–Atoll soils are largely made up of sand and silt-sized particles of limestone and are typically low in organic carbon, nitrogen, and potassium. The soil has a low water-holding capacity because of its coarse texture, and the activity of soil microorganisms is limited *(102).*

Cultivation of giant taro *(Cyrtosperma chamissonis)* on atolls involves excavating pits down to the level of the freshwater lens, commonly several feet, inserting a bottomless basket made of woven twigs, and filling it with mud mixed with leaves and other organic matter. Then cuttings of giant taro are planted in the muddy substrate in the basket *(41,148).* Fertilizers are derived from composted leaves, coconut fronds and husks, manures, dried starfish or shark, or rotted sea cucumber *(22,102).* Thus, taro pit culture is effectively similar to container agriculture, wherein the water and soil management efforts are concentrated in a small area.

Placing the taro plants in pits allows their roots closer access to freshwater and provides some protection from salt spray. Bananas may be planted on the margins of taro pits to take advantage of the higher organic content in nearby soils *(102),* further protecting taro plants from sea spray.

Tree Gardens.—One special form of Micronesia agriculture is the tree garden, found throughout the high islands of Micronesia, and containing a high proportion of food producing species. In their simplest form, such gardens consist of a mix of coconut (Cocos *nucifera)* and breadfruit *(Artocarpus* spp.) with occasional other trees. Such areas are extensive in Truk.

More complex systems developed on other high islands in the Pacific. Tree gardens on Yap involve about 50 tree species, including betel nut *(Areca catechu),* a wide variety of bananas Musa spp.), mangoes *(Mangifera indica),* many varieties of *Citrus* spp., cacao *(Theobroma cacao),* papayas (Carica papaya), guava *(Psidium guajava),* and other food trees mixed with timber and wild tree species, and with an understory of shrubs and herbs useful for food, fiber, medicine, condiments, ornamentation, etc. (22). Animals maintained in Yapese village tree gardens include penned or tethered pigs and chickens and feral chickens in the bush. Fruit bats may forage in these areas at night.

Within the crop and tree species that have long been cultivated by Yapese, there are numerous locally recognized varieties. There are, for example, 21 names for coconut varieties, 28 names for breadfruit, and 37 names for varieties of bananas. Such tree gardens represent a considerable collection of genetic diversity.

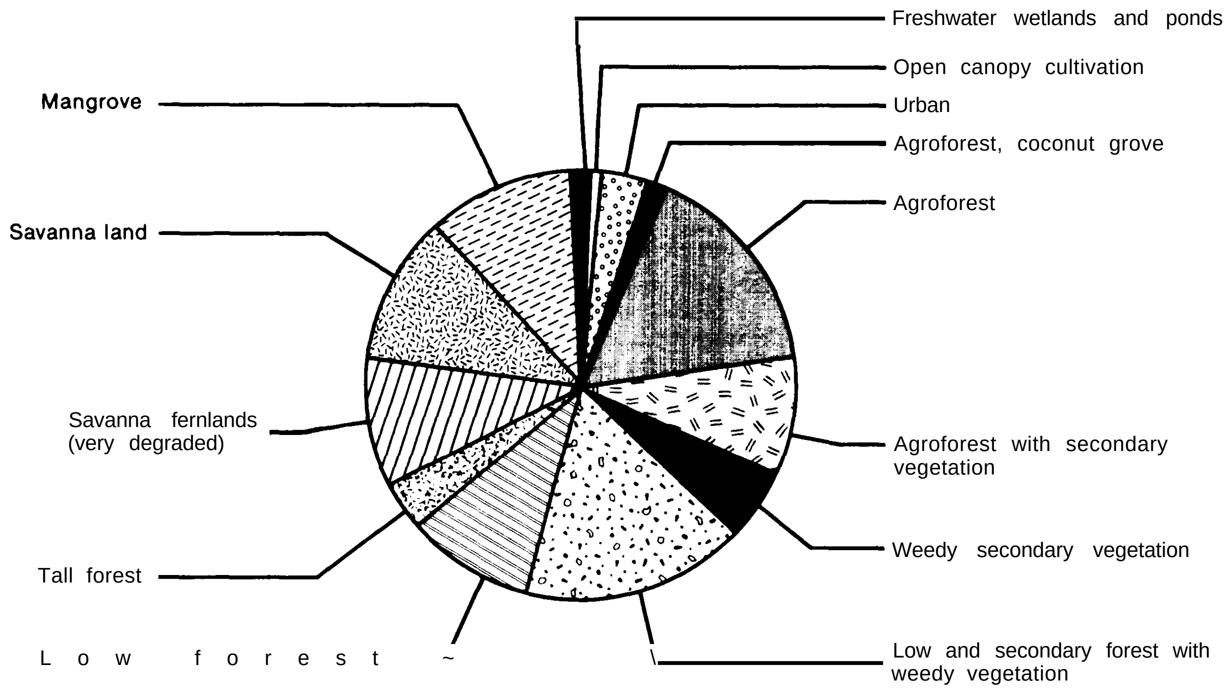
Unlike temperate seasonal agriculture, traditional tree gardens are a permanent fixture and take years to develop. Existing natural vegetation is gradually manipulated into agroforest *(22,94).* The likely process on Yap was the planting of food trees and other useful trees about homesteads, and in the drained areas created by the excavation of taro patches and construction of paths between homes and villages. Backyard and pathside tree gardens became confluent and today make up about 27 percent of Yap's vegetation (figure *6-2).*

The objective of traditional tree gardening systems is to achieve a permanent, long-term, stable agroforestry system, primarily on poorer/marginal lands. Tree gardening can be considered a long-term investment, taking up to a lifetime to complete, with large initial labor and energy inputs for planting and maintenance. Once a stable-state tree garden system is established, little labor and energy are expended for activities other than harvesting (99).

Tree gardens recycle nutrients through leaf falls. They are maintained largely by the pruning activities of their owners, who select for desired trees by cutting or girdling those trees that are not desired. Many of the trees propagate themselves by root growth (as with breadfruit), or seed. Fruit bats aid seed dispersal in some cases. People preserve certain volunteer species as well as planting other desired varieties and species.

Intermittent Gardens.—Areas around and generally inland of villages are used for gardens of yams and other crops generally grown in mixed, multilayered culture and alternated with a fallow period in which secondary forest growth develops. Mixed culture of yams and other food crops is practiced on most high Pacific islands, especially on Pohnpei where culture of especially large or old yams can pro-

Figure 6-2.—Main Categories of Land Use and Vegetation on Yap

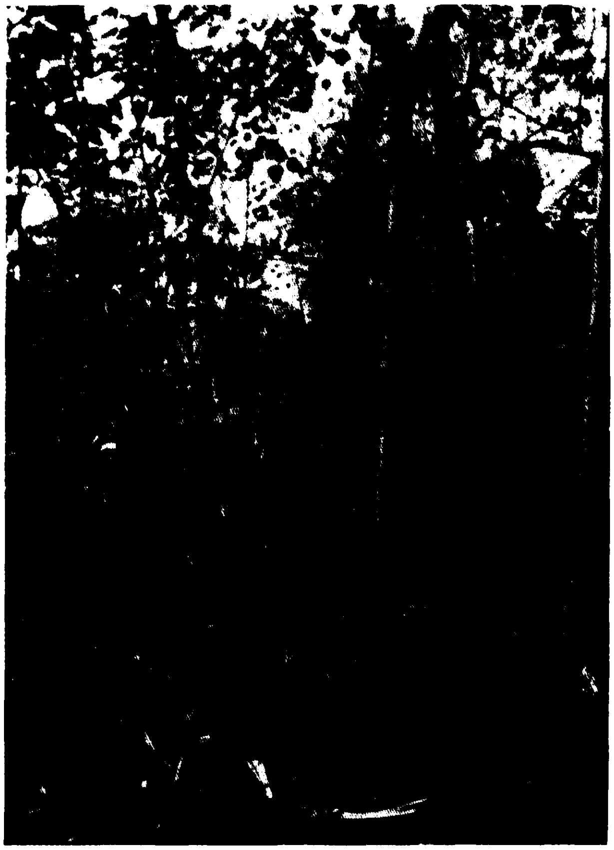


SOURCE: M.C.V. Falanruw, "Traditional Agriculture and Resource Management Systems in the High Islands of Micronesia," OTA commissioned paper, 1986.

vide the grower social status. Four general types of areas are typical:

1. *Early second-growth forest fallow:* Areas on the outskirts of villages which have become covered with a characteristic set of small second-growth trees and often with an understory of ferns. Such areas are generally the site of a previous garden (and are indicated as weedy, replacement vegetation in figure *6-2).*
2. *Advanced second-growth forest fallow:* Areas on the outskirts of villages which are covered with secondary forest consisting of a characteristic set of tree species (indicated as low and secondary forest with weedy vegetation in figure *6-2).*
3. *Bamboo gardens:* Areas on the outskirts of villages which are covered with a mix of secondary vegetation and two species of bamboo. These areas resulted from the planting of bamboo in earlier days when the large and small bamboo were needed in house construction, and the large bamboo was used to build rafts, the most common type of water transport. Now that rafts are used less, other building materials are available, and the style of houses built by young couples is less traditional, areas of bamboo are often burned to be used as gardens.
4. *Special-purpose yam gardens:* Areas within villages where neat raised beds are constructed and bamboo poles brought in to build a series of yam trellises. These areas generally are the work of a group of women growing yams to present on a special occasion. Such gardens are limited in size, more labor-intensive, and do not generally have a variety of other crops planted in the same site.

Sites chosen for intermittent gardens are relatively well-drained areas of secondary vegetation (often the sites of previous gardens) *within* the land available to the family or borrowed for such use. The soil in areas of secondary forest are richest and there is a nearby supply of poles for trellises, so such areas are preferred.



The first step in making a garden is to open a "skylight" in the canopy by clearing herbaceous vegetation. This is piled about trees and burned. Sometimes trees may be girdled before being burned. Standing logs and surrounding vegetation commonly are left to shade young plants, or the canopy may be removed gradually so that young plantings are shaded the first part of their lives.

The major crop grown in such gardens are yams of the genus *Dioscorea*. The tops of tubers which have been previously harvested, as well as small whole yams are planted. A border of fallen logs often is formed about the yam plantings and mulch is piled within this area. Trellises of poles, often of bamboo, provide pathways for yam vines to grow up into the sunlight and produce large tubers. In areas rich in bamboo, trellises may consist of tall "teepees" of three or more poles tied together at the top. In Pohnpei, vines are trained to climb trees along a string, often made of *Hibiscus* bark, which is tied to a stone and thrown up to the first branches of the tree. When the yam vines reach the first branches, additional strings may lead the vine to higher branches. The tree may be injured or killed so that it drops part or all of its leaves as the vine covers the tree. This new vegetation forms a canopy similar to that furnished previously by the tree.

After yams are planted in the choicest microhabitat, the rest of the garden area is filled in with a mix of other crops, generally in a predictable succession: pumpkins *(Cucurbita* spp.) and wax gourds *(Benicasa hispida)* which grow fast in the ash fertilizer and form a protective layer of vegetation over the soil. These often die back by the time the yams and other crops have made their major vegetative growth. Sweet potato vines may be planted in raised mounds although they are more often planted in open areas.

Pineapples and sugarcane maybe planted in suitable areas. Other crops include certain taro species, bush spinach *(Abelmoschus manihot),* and winged beans *(Psophocarpus tetragonolobus).* Banana may be planted and weeds that are cleared from the garden piled about the trees as mulch. Papaya, passionfruit, and luffa vines may grow voluntarily or from old plantings in the area. Sometimes a few fruit trees from nearby agroforests may be present.

These crops grow rapidly so that a multistoried canopy of leaves is formed by the time the rainy season starts. Intermediate crops are harvested as they mature and yams are harvested at the end of the growing season. The garden may then be replanted if the soil remains fertile, otherwise it is only sporadically tended to harvest tree crops and other long-term crops, and gradually is abandoned. Gardens are seldom used for more than 3 consecutive years.

After gardens are abandoned, they go through a series of successional stages as the wild canopy reforms. They are invaded first by herbaceous weeds followed by woody species. Seed dispersal commonly is aided by birds and fruit bats (21).

"Lanchos" and Backyard Gardens.—Traditional agricultural activities in the Marianas are not well documented. However, wild food plants found in the Marianas indicate that the original inhabitants ate the food found on other high islands of Micronesia (22). The neotraditional agriculture system of the Marianas was the development of "lanchos" or "ranches" where food was grown by people who resided in village areas. Lanchos were generally located in rural wooded areas and consisted of a simply built cooking and sleeping house surrounded by food trees, chickens, pigs, and gardens.

Although many lanchos still are in use on Guam (84], they are harder to find in the Marianas where population increases, division of family lands, economic development, and food stamp programs result in competitive uses for land and decrease the need to raise one's own food. Fresh local produce remains important for fiestas, however, and is reflected in poaching of deer and fruit bats and importation of traditional foods from other islands (22).

Traditional Open Canopy Agriculture.—Crops grown in openland areas include sweet potatoes, cassava, and vegetables. Garden beds are reconditioned by clearing or burning unwanted vegetation from the site. Debris is piled on the garden, sometimes with additional mulch such as seagrass. Ditches are dug or deepened around the garden bed and the soil piled on top of the mulch. The result is drainage of the garden, suppression of weeds and development of a "sandwich" of soil, mulch, soil. Cuttings may be planted directly or in raised rows (22).

Commercial Agriculture Developmemt

After western contact, traditional agricultural technologies were modified to varying degrees by voluntary incorporation of methods or implements introduced by settlers, missionaries, and colonial governments. Few wholly subsistence farmers remain.

In Micronesia, numerous attempts have been made to develop commercial agriculture, beginning with the development of the copra trade by the Germans in the late 19th century. Coconut palms were planted on many islands and villagers were organized to process dried coconut meat (copra) for export to Germany (86).

The Japanese expanded commercial agriculture through the cultivation of sugarcane in the Northern Marianas; cassava, sweet potato, coffee, and other crops in Pohnpei; and various other commercial farming and related industries throughout Micronesia. Agricultural colonies were established, generally with imported Asian workers. The Japanese provided support for agriculture through provision of materials, technical advice and assistance, selection of technologies that maximized use of local resources, and a comprehensive marketing program. Both the German and Japanese efforts primarily served the colonial power and natives were used mainly for unskilled labor.

With the advent of the U.S. administration at the end of World War II, the Japanese-supported commercial agriculture development—which had led Micronesia to become a self-supporting part of the Japanese Empire—quickly disappeared. Initially, exploitation of existing island resources was a very low priority with the new U.S. administration; securing military interest was a primary goal. Without expatriate managers, shipping services and markets, most commercial agriculture was soon abandoned and the islands again returned to subsistence food production (94).

Commercial agriculture development in American Samoa, which became a U.S. possession in 1900, has progressed even less than in Micronesia. Although a small copra industry was developed, most agriculture activity is still at a subsistence level (94).

Within the last 30 years, there have been renewed efforts to develop commercial agriculture, but progress has been slow and results disappointing. Several crops have been designated for commercial development in Micronesia, notably cacao in the late 1950s and early 1960s, ramie in Palau, and banana on some high islands. More recently, efforts have been directed to developing a black pepper industry on Pohnpei and introducing vegetables throughout Micronesia *(99,103,105)*. Efforts in American Samoa have been mainly directed at increasing local food production with some effort made to introduce commercial vegetable production. All have been introduced as small-scale projects for limited-resource farmers and many have been unsuccessful for reasons including: *1)* lack of markets or low market prices, 2) technologies dependent on imported inputs, 3) lack of management skills among farmers, 4) diseases and pests, and 5) a general lack of commitment by farmers and U.S. and local governments *(94)*.

The most persistent efforts of the Pacific island government Departments of Agriculture, at least during American Administration, seems to have been the encouragement of open canopy vegetable gardens involving crops such as Chinese cabbage, green peppers, tomatoes, and corn, and introduction of western techniques of clean-field gardening using fertilizers, pesticides, etc. Several farmers successfully operate enterprises on Guam and in the Commonwealth of the Northern Mariana Islands (CNMI) and the numbers are increasing as farmers become more adept at cultivation practices and techniques *(84)*. However, many attempts have been unsuccessful due to high ratio of input cost to output value; soil degradation; and invasion of noxious weeds, such as the spiny *Mimosa invisa*, which are difficult to clear. Nonetheless, outside advisors continue to recommend such technology and outside funding continues to be made available for such efforts (22).

The incidence of soil erosion is probably greatest in clean-cultivated vegetable gardens where the soil must be made friable and vegetative growth does not provide adequate protection against heavy rainfall or invasion by weeds. An increasing number of pests hinder sweet potato culture, and the repeated burning, depletion of soil nutrients, and changes in soil texture associated with cassava culture results in soil degradation (22).

The environmental impact of the multilayered mixed gardens varies with the extensiveness and intensity of burning. Today, more forest and secondary vegetation is burned than is used. Part of this is due to careless gardeners and part to arson. There appears to be little concern for controlling fires that have gotten out of hand, and local fire departments tend to respond only when residences or other infrastructure are threatened (22).

The expected result from too many attempts at open canopy gardening, too frequent burning of garden lands with too short fallow periods is a decrease in forest fallow areas, use of preferred sites to exhaustion and degradation of the soil. The end result of prolonged degradation of soils seems to be swordgrass savannas or *Gleichenia* fernlands. On Yap, extensive areas of degraded soil bear the sign of too-frequent burning and over-intensive use, and the island's genetic heritage of wild endemic species is small compared to surrounding islands (22).

Current Status of Agriculture

The diets of Pacific Islanders, in general, consist mainly of starchy foods, probably reflecting the kinds of crops which have been adapted to the local environments. Principal commodities produced in the U.S.-affiliated Pacific islands are listed in table *6-1*. On most islands, tare, coconut, banana, and breadfruit are grown in large quantities, primarily for home consumption. In American Samoa and the Compact States, the coconut is used for food, drink, and for making tools and utensils important in the household.

In areas such as Guam and CNMI, where western and Japanese influence has been greatest, meat and vegetables have become more important parts of the diet. Pork and chicken are popular throughout the Pacific Islands, and are raised mainly for home consumption. Pigs and chickens are raised in most rural areas *(108)*. In most of the territories eggs are produced in small volume for the market, but per capita consumption is small compared with Hawaii and

Table 6-1.—Principal Crop and Livestock Commodities in the U. S.-Affiliated Pacific Islands

	Commodity	
Islands	Crop	Livestock
American Samoa	Banana, breadfruit, coconut, taro	Chicken, eggs, pork
Marshall Islands	Banana, breadfruit, coconut, pandanus	
Federated States of Micronesia	Banana, black pepper, breadfruit, cassava, citrus, coconut, mango, pandanus, papaya, sweet potato, taro, yam	Eggs, pork
Northern Marianas	Avocado, banana, breadfruit, cassava, cucumber, mango, other melons, papaya, sweet potato, tare, yam	Beef, eggs, milk, pork
Guam	Avocado, banana, breadfruit, cassava, chinese cabbage, cucumber, eggplant, green beans, head cabbage, melons, papaya, sweet potato, tare, tomato, watermelon, yam	Chicken, eggs, pork

SOURCE: R. Lucas, "Role of Smallholders in Agricultural Development in the U. S.-Affiliated Islands," OTA commissioned paper, 1986.

continental U.S. consumption. Backyard gardening in urban as well as rural areas is a popular means to supplement the diet and income of wage earners.

No shortage exists of people in Micronesia, especially young people, to form a labor pool. It is likely that the ratio of children to adults has never been as high as today. However, it is difficult for mothers of young children to care for their babies and do the strenuous work of gardening or gathering. With considerable time now spent in school, where traditional agriculture is not taught, and with motherhood coming at an early age, young women sometimes do not learn and experience all that is needed to be effective gardeners. A number of young women work in town, and leave small children with relatives, thus reducing the available work force of experienced food producers (22).

Caribbean Agriculture

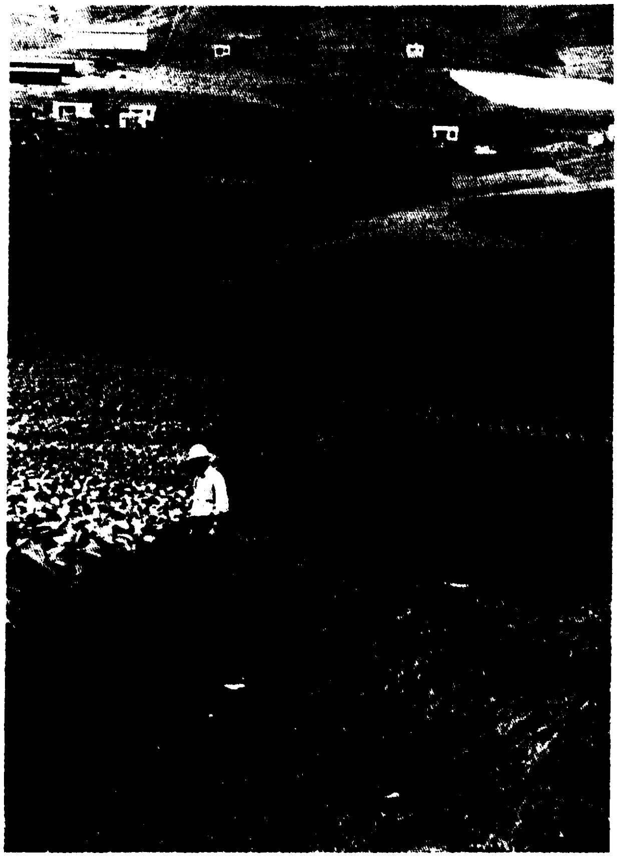
Because of diverse factors, there is relatively little heritage of traditional, subsistence agriculture in the U.S. Caribbean. In Puerto Rico, traditional shifting agriculture was adopted by subsistence farmers of European descent and later by those of African extraction. This subsistence sector continued into the early 20th century, but little remains today. The Virgin Islands were unpopulated at the time of colonization, thus there was no tradition of indigenous agriculture passed onto later inhabitants as occurred in Puerto Rico *(116)*. In addition, these areas experienced an extended period of agricultural production for export to colonial powers, continuing well into this century.

Puerto Rico

Early in Puerto Rico's nearly 400-year history of colonization, the forests were cut and up to 90 percent of the plains and mountains were tilled, largely for sugarcane, coffee, tobacco (131) and, to a lesser extent, for bay trees *(Pimenta racemosa) (11)*. The island was no longer self-sufficient in wood and paper products as early as *1830 (131)*.

Even **50** years ago, Puerto Rico had an agricultural economy based primarily on sugarcane and, to a lesser extent, on coffee, tobacco, and cattle. With the notable exceptions of rice, beans, and codfish (dietary staples), most food was produced locally. Heavy hillside soil erosion severely hindered tobacco cultivation and contributed to reduction in already economically stressed sugar operations. The sediment laden runoff silted water supply facilities; seven major reservoirs lost a total of *32,500* acre-feet of storage capacity and two were totally filled and had become grazing areas (131).

Hillside tobacco and sugar land was abandoned as the profit margin decreased. The land returned to scrub brush and tree cover having little economic value. Sugarcane cultivation on flat coastal lands continued. Substantial reduction in damage to land and water resources has occurred over the last *25* years primarily be-



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cause of natural revegetation of abandoned croplands, and aided by some adoption of conservation practices such as strip and contour cropping, drainage, grazing and brush management, and spring development (131).

Harvested land in Puerto Rico declined from 724,000 acres to 283,851 acres between 1959 and 1978 (157). Abandoned farms commonly belong to persons over 50 years of age who may farm part-time, but who derive much of their income from sources outside farming. The causes of abandonment include lack of working capital, advanced age of the owner, or a preferred course of income outside the farm (10). Economic and sociological studies (8,31, 64) have shown that family-sized farms are rarely profitable due to their limited size; steep, unproductive soils; and lack of credit, entrepreneurial abilities, and technical assistance with production and marketing. Sometimes beef cattle are raised on grass-covered abandoned lands.

In 1950, agriculture provided 215,000 jobs (36 percent of total employment) and contributed 18 percent of the commonwealth product. There are now 40,000 jobs in agriculture, which accounts for 5 percent of the commonwealth product. Production at the farm level is valued at about $580 million with a retail value of about $1.2 billion. Sugarcane production has fallen 90 percent since 1952, and tobacco production has almost disappeared. Coffee producers still provide for three-fourths of local consumption, but they are protected from competition with imported coffee by locally set tariffs (143).

Puerto Rican diets also have changed significantly in recent decades. Despite declining per capita consumption of starchy vegetables, the total amount of food consumed per capita has increased (131). Production of milk, eggs, poultry, and pork has more than doubled since 1952 (table 6-2) (89,90,143). Meat and dairy products now comprise 60 percent of the value of farm output in Puerto Rico. Approximately 600,000 acres are used for pasture, however, approximately 500,000 tons of feed for cattle, pigs, and poultry are imported yearly, mostly from the U.S. mainland; none is produced locally (143).

The Puerto Rican Government has instituted a number of measures to increase and improve local agriculture. Farmers are exempt from 90 percent of local income taxes. Land taxes are low and land used for intensive agricultural production is exempt. Agricultural land also is exempt from inheritance taxes (143). Of the approximately 1,500 college-trained agriculture specialists on the island, 800 are employed by the government in agencies related to agriculture.

The Puerto Rican Government also has made a number of costly and largely unsuccessful efforts to develop modern, large-scale farming in several parts of the island. A local rice industry was developed on government lands on

Table 6-2.—Trends in Production of Selected Commodities in Puerto Rico

Commodity	Product ion 1951-52 (thousands)	Production 1981-82 (thousands)	Consumption[a] 1981-82 (thousands)	Imports (thousands)
Sugar (tons)	1,360	103	140	37
Tobacco (lbs.)	61,949	3,527	—	—
Coffee (lbs.)	52,249	55,115	85,979	30,864
Fresh milk (qts)	48,305	395,318	401,660	6,342[b]
Beef (lbs)	24,700	38,000	114,000	76,000[c]
Pork (lbs)	18,800	40,000	113,000	73,000[d]
Poultry (lbs).	12,600	52,500	195,000	142,000
Eggs (doz)	9,500	21,900	39,400	17,500
Pineapple (tons)	22	42	3	—
Plantains (thousands).	170	330	330	—
Bananas (thousands)	1,120	720	720	—
Tanier (lbs)	95,239	52,910	91,491	38,581
Sweet potatoes (lbs)	61,729	46,297	70,547	22,046
Yams (lbs)	56,438	70,768	70,768	287
Oranges (thousands)	144	162	192	3 1[e]
Grapefruit (thousands)	16	7	9	2
Citron (lbs.)	16,094	19,621	—	—
Pumpkins (lbs)	40,124	100,750	100,750	—
Tomatoes (lbs)	39,683	14,991	77,822	62,831
Pepper (lbs)	17,416	17,637	30,203	13,228
Cabbage (lbs)	14,550	17,637	37,478	23,369
Pigeon peas (lbs)	25,573	24,251	27,558	3,307
Taro (lbs)	25,353	16,535	16,535	—
Cassava (lbs).	28,660	13,228	18,739	5,523
Potatoes (lbs)	—	—	291,669	291,669
Rice (lbs)	—	22,046	683,426	661,380
Beans (lbs)	—	1,764	97,002	94,798
Onions (lbs).	—	—	78,704	81,570
Corn (lbs.). ..,...	—	—	992,070	992,070
Grapes (lbs).	—	—	5,100	5,100
Garlic (lbs)	—	—	3,600	3,600
Cocoa (lbs)	—	—	—	I0,000[f]

[a]Exports from Puerto Rico to the USVI and to others account for some of the discrepancies between imports, local production and consumption
[b]The equivalent of about 158,550,000 quarts are imported in dry or condensed form.
[c]28,000,000 pounds from the U.S. and 48,000,000 pounds from foreign countries.
[d]Plus 28,000,000 pounds of ham.
[e]Plus 4,000,000 gallons of concentrate,
[f]Plus 15,000,000 pounds of chocolate candies,

SOURCE: Vicente-Chandler J., "Assessment of Agricultural Production Technologies for U.S. Caribbean islands;" OTA Commissioned paper 1988.

the north coast in 1978. A rice mill was constructed and the lands were precision-leveled at considerable cost in time and money (143). However, the rice project has not become self sustaining.

Seven years ago, the Government of Puerto Rico started a modern vegetable industry on about 5,000 acres on the south coast by leasing lands and providing credit and facilities to two large Israeli companies and 13 local farmers. Approximately 2,500 acres now have drip irrigation systems and two packing plants were constructed. Crops were grown for both local and export markets with some success. However, in 1986 one project (April-Agro) reportedly was foreclosed by the Puerto Rican Government due to nonpayment of a large government loan although some of its activities are continued. The remaining operation—ISPRAC—continues operation.

Today, Puerto Rico annually imports about 1.2 billion dollars' worth of food (with a retail value of $1.8 billion), and about 400 million dollars' worth of wood products. About 29,840 Puerto Rican farms comprise a total of l,259,700 acres (135). Several large processors of agricultural products exist in Puerto Rico but, with few exceptions, they depend almost exclusively on imported materials and are not interested in processing small periodic agricultural surpluses (143).

Agriculture at present is generally characterized by low yields, high production costs, older farmers (averaging 55 years of age with a fifth grade education), and inefficient marketing systems. Attitudes are generally negative toward farming on the part of technicians, farmers, leaders, and the general public (143).

Young, well-trained, and motivated farmers are scarce in Puerto Rico, probably due to the way agriculture developed on the island. Sugarcane, coffee, and cattle plantations were developed with cheap labor; landholders often delegated responsibilities to poorly trained managers. As the island's economy boomed, many landholders preferred land speculation to learning new techniques and investing in agriculture. Their offspring generally entered other professions; higher wages are paid in manufacturing, tourism, and construction. Children of subsistence farmers went to work elsewhere or migrated to the U.S. mainland. Consequently, agricultural work is considered of low status.

U.S. Virgin Islands

Early colonial land modification in the U.S. Virgin Islands (USVI) included clearing of forests both for the establishment of export crop plantations and for their commercially valuable timber species. Early in this century, St. Thomas and St. Croix were severely deforested and consisted largely of secondary scrub growth characterized by small woody shrubs. The scrub-covered land consisted of thin soil with many rock outcropping. The removal of timber species and subsequent burning damaged the soil further reducing its fertility.

Historically, the majority of desirable land has not been available for small-scale subsistence agriculture. Initially, the majority of the highest quality land was held in large plantations and later, with the emergence of the tourism industry, land speculation and increased real estate prices has made much of the land inaccessible (117,143).

Since 1930 there have been sharp decreases in average farm size, harvested cropland, and agricultural employment and marked increases in the percentage of operators engaged in off-farm work. In the context of waning farm effort and acreage, there have been three major adjustments in the structure of USVI agriculture (80 percent of which is concentrated on St. Croix). First, an increase in mechanization and use of fertilizers; second, the noticeable shift away from cropping toward livestock; and third is a growing bimodal structure in which there are a large number of small farms alongside a few large commercial farms. Over the past century, USVI agriculture has adapted to resource encroachment basically by reducing farm effort and size, replacing capital-intensive inputs, and changing the composition of output from export crops to domestic fruits, nuts, and vegetables. Small-scale holdings largely are secondary income-earners. The largest commercial tracts now specialize in cattle and dairy products (56).

There have been some clear increases in the production of fruits, nuts, rootcrops, sheep, goats, and cattle since 1970, in part because of inflation of the prices of imported goods, slowdowns in tourism growth associated with economic recessions, and new farm efforts by Rastafarians and West Indian migrant workers who have become a permanent component of the local work force. These gains, however, occur in the long-term context of continuing reduction in farm scale and reduction in farm sales (56). Some landowners among the French agriculturists of St. Thomas have begun to sell land for residential development and many young people are looking to alternative livelihoods (117).

COMMON CONSTRAINTS TO AGRICULTURAL DEVELOPMENT IN U.S.-AFFILIATED ISLANDS

Major constraints to agricultural development which apply to all of the U.S.-affiliated islands generally fall into the following categories: biophysical, economic, social and cultural, and infrastructural, Major biophysical constraints are low soil fertility, limited or irregular water resources, and limited arable land of suitable soil types and level topography. Economic constraints include the small size of domestic markets for agricultural products, availability of high-paying government jobs and ready emigration opportunities, high cost of imported livestock feed and other inputs and, in tourism-dominated islands, the relatively low value of agricultural lands vis-a-vis nonrural residential or commercial real estate uses. The arduous nature and declining status of agricultural employment provide social constraints to agricultural development on some islands (13), and land tenure systems characterized by fragmented landholdings and clan influence over use rights can be primary cultural constraints to commercial development. Constraints posed by undeveloped infrastructure include lack of rural farm roads in high islands, scarcity of transportation from rural and outlying areas to central markets, and costly and irregular transportation to overseas markets (43).

The degree to which the above constraints apply to U.S.-affiliated islands varies but, nevertheless, is significant in all of them, For example, cultivable land is sparse on all islands. However, there is more arable land in Pohnpei and Palau relative to population than in the Marshalls, Truk, and American Samoa (table 6-3). In all of these areas, available arable land typically is owned in relatively small parcels, few areas have flat terrain, and contiguous soils of a given type (i.e., soils suitable for a given crop) are not common.

Some constraints tend to apply only to certain of the islands, for example, some islands have significant dry seasons while other islands receive evenly spread rainfall. In areas experiencing dry periods, lack of irrigation capabilities compounds limitations on farm productivity. The incidence of destructive typhoons and other tropical storms, although experienced by the majority of the U.S.-affiliated islands, tends to be much greater in the Marianas and western Caroline Islands (43).

Biophysical Constraints

Biological and physical (biophysical) considerations include availability of land and

Table 6-3.—Comparison of Population Density and Arable Land Acreages in the U.S.-Affiliated Pacific Islands

Islands	1984 Population[a]	Arable area (acres)[b]	Population density per arable acre
American Samoa	35,300	14,000	2.45
Guam	119,800	6,900[c]	16.41
CNMI	18,600	30,000[d]	0.65
Marshalls	34,900	n/a	n/a
FSM:			
Kosrae	6,300	17,900	0.35
Pohnpei	26,900	57,700	0.47
Truk	44,600	13,500	3.30
Yap	10,600	21,500	0.43
Palau	13,000	63,500	0.20

SOURCES:

[a]*Land Use Planning Report,* 13(46):365, November 25, 1985; U.S. Department of State, *1984 Trust Territory of the Pacific Islands,* report to the United Nations on administration of the Trust Territory of the Pacific Islands, 1985; R Lucas, "Role of Smallholders in Agricultural Development in the US.. Affiliated Islands," OTA commissioned paper, 1986

[b]Data derived from U.S. Department of Agriculture, Soil Conservation Service tysoil surveys of American Samoa (1984), Kosrae (1983), Ponape (1962), Truk (1983), Yap (1983), and Palau (1983), except where otherwise noted,

[c]Arable area is based on a soil survey of lands designated as potential agriculture lands (9,920 *acres) by the Guam Bureau* of Planning, and exclude a large portion of Guam controlled by the military, as well as lands designated for urban and conservation use

[d]CNMI arable acreage is based on surveys sponsored by the Trust Territory government and cover only Saipan and Tinian Most of the acreage would need irrigation to be considered good in terms of productivity for agriculture,

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water resources, soils, topography, and climate. In general, land is in short supply on all of the U.S.-affiliated islands, but particularly in the majority of the Pacific islands and the USVI. Additionally, the quality of soils, population density, land tenure, and topographic circumstances determine the degree to which land is a constraint (43).

Tropical soils in the territories have a number of limitations. Natural fertility is low compared to the nutrient needs of high-yielding crops. High rainfall in many areas leaches out basic plant nutrients and erodes the soil. Thus, conservation methods such as terracing, contouring, and conservation tillage practices become critically important. Maintaining forest canopy and vegetative cover stems erosion and maintains soil fertility by returning organic matter to the soil through the natural plant lifecycle. In clean-tilled crop production, soils are more susceptible to loss of fertility through erosion, leaching, and loss of organic matter. To overcome soil fertility problems associated with clean-tilled crop production, use of compost and organic fertilizers, return of crop residue to soil, application of lime, mulching, and crop rotation commonly are required. On coral atolls and single coral islands, soils are very porous, consisting mainly of sand and, while conducive to growing coconut palms, are not suited for most other crops (127).

Annual rainfall is generous in many areas, with a fairly even distribution during the year. However, in the northern Marshalls and, to a lesser extent in Yap, Truk, the Marianas, and the Caribbean, there is a more distinct dry season which can bring drought conditions harmful to crop production. Lack of water is the main physical factor limiting agriculture in the U.S. Virgin Islands; there, evapotranspiration greatly exceeds precipitation (143). The volume of water supplies, while limiting the potential growth of the arid agricultural sector of Puerto Rico, presently does not constrain production in other areas of the island (61).

Storms and torrential rainfall creates problems as well. Watersheds of high islands typically are comprised of steep valleys flanked by sharp ridges. Even if vegetated, flooding and landslides occur posing considerable hazards to agriculture and populations located in the coastal valleys. During the rainy season, cyclonic storms frequently occur in some areas. Atolls and low islands, as well as the coastline areas of high islands, frequently experience flooding and saltwater damage to crops caused by storms and storm surges (43).

The interiors of high volcanic and continental islands are mountainous; much of the land area consists of steep slopes that preclude cultivation of most crops other than tree crops. For example, almost all of the land on St. Thomas and St. John is very steep to strongly sloping, representing problems for agricultural pursuits. Many agricultural areas on these islands have been terraced or planted with fruit trees (143). Land improvement, such as grading of steep slopes, improvement of drainage and irrigation, is generally quite costly.

Social and Cultural Constraints

Social and cultural factors may provide opportunities or constraints to agriculture, depending on the development strategy pursued. Those that are commonly perceived to constrain commercial agricultural development include land tenure and clan value systems, acquired tastes for western foods, and attitudes towards farming as an occupation.

Traditional values of Micronesians and Samoans place great prestige on land and other resource use rights. Within the clan or extended family, the cultivation and gathering of crops such as tare, breadfruit, yams, and coconuts is determined by communal needs rather than by the economic return which could be obtained by marketing production. Decisions on land use are made by the clan or family head, and land use is an integral part of the social system. For example, slaughtering pigs for feasts or social gatherings involving the extended family is part of fulfilling social obligations. The high prestige value placed on land results in increasing fragmentation of parcels over time, as ownership is retained in families that have increased in size (46,47). Acquiring land for commercial use—where the products of the property are not to be used for subsistence and sharing—may be difficult or impossible (22). Alternatives, such as making landowners part-owners, eligible for dividends from earnings from development projects on their lands, may be required.

High social value placed on land is accompanied by clan system values which require the sharing of production with clan members. The sharing extends to individual wage earnings as well. These traditional values toward land and the sharing of wealth and income tend to inhibit individual initiative towards commercial farming. Reluctance to sell or lease land also makes it difficult to consolidate land into larger parcels to enable larger scale farm operations (43).

In areas such as Guam and the CNMI, leasing and selling land has become more prevalent, along with western economic values, as most households have become integrated into the wage economy (43). However, residents no longer have access to one-third of Guam's land, which is controlled by the U.S. military. Considerable amounts of food could be produced if areas suited for farming that are not actively used by the military are opened for short-term leases with rates comparable to those offered by the local government (113).

Land reform has long been a matter of great importance in the Caribbean. The 1940s "Land Law" of Puerto Rico successfully relocated squatters on small plots where they could build homes and cultivate small farms (143). Attempts at land redistribution in the USVI occurred in the 1930s with a "homesteading" program, but the program met with only limited success.

With large increases in public employment and wage income related to U.S. Government expenditures in the Pacific Islands, western consumption standards—particularly for convenience foods—have been increasingly adopted. Rice, flour, canned meat and fish, sugar, and beverages such as soda and beer are large import items. Prestige attached to western foods, convenience in preparation of processed foods, and lack of education on the nutritional value of fresh foods have all been contributing factors in the popularity of imported food. In addition, the influence of U.S. Department of Agriculture (USDA) school lunch and disaster relief food programs, which have distributed large amounts of surplus processed foods to the islands, have contributed to preferences for imported processed foods on most islands. Preferences for some imported foods lessen demand for locally grown crops, and have had a detrimental effect on nutritional status (109).

Farming as an occupation is generally held in low esteem by the younger generation in many of the islands. Availability of secure, high-paying government jobs with career advancement opportunities and fringe benefits (e.g., retirement pensions, low-interest housing loans, medical insurance), and education systems which emphasize white-collar occupations result in little interest by youth in agricultural occupations (43). Well-trained, young, motivated farmers are scarce in Puerto Rico and the USVI; many young people opt for more lucrative or more highly esteemed professions (61,143). In the CNMI, where young farmers consider agriculture a potentially profitable undertaking, alien laborers from the Philippines are hired at $150 per month (80).

Attitudes towards traditional agriculture systems and official and unofficial government policies range from benign approval to benign neglect. In the U.S. Pacific, it is commonly considered good to produce as much of one's food as possible, although in practice no specific programs are designed to help with traditional agriculture, perhaps because it is so much a part of Micronesia lifestyles that it is overlooked (22). Puerto Rico's attempt to encourage a small-farm sector through the establishment of family farms (1940s Land Law) largely was unsuccessful.

Economic Constraints

Small domestic markets, high wage structures, USDA food programs, and lack of appropriate technology are major economic constraints to an expanded agriculture (43). Insufficient economic resources also may seriously constrain sustainable development of renewable resources. They particularly affect research, public education, and project implementation (15).

While development of local food production and markets may be important to local food supply and nutrition, it is limited by the amount of local demand and competition with imported foodstuffs (94). Local markets can absorb relatively little local produce in the Freely Associated States (FAS) and American Samoa as most consumers also are producers; expatriate workers and urbanized locals make up the market on most islands. In some areas, a considerable demand for traditional crops exists, but problems with transport, spoilage, and inconvenience of preparation hinder their marketing (22).

Markets for locally supplied commodities in the U.S.-affiliated Pacific are situated in the capital areas. However, they generally account for a small part of total commodity sales. Inadequate marketing facilities contributes to small volume, but a more basic problem is the lack of steady supply by farmers committed to growing for the market on a regular basis, i.e., lack of commercial and semicommercial farmers, as opposed to subsistence growers (43). Generally, outlets consist of combination retail/wholesale/importer market operations.

Small market size is a major constraint inherent in island economies located at great distance from large population centers (e.g., Honolulu, Tokyo). Territory populations represent a small market demand for any given commodity; commercial farmers using modern technologies can produce all that can be sold on relatively few acres. For example, in Guam it has been estimated that with modern farming practices, including irrigation, only 226 acres would be required to supply almost 11 million pounds of fruits and vegetables (19 different commodities) per annum (14). In Guam, however, where many people buy a large percentage of their food, most prefer the convenience of imported produce and food products to local produce.

In addition, locally grown products also must compete on local markets with products imported from the United States and other developed countries with more efficient agricultural systems, and with imports from nearby developing countries that have lower labor costs. Imports in the USVI offer almost insurmountable competition since they are available in large quantities throughout the year and are generally of good quality although expensive (143). Puerto Rico is similarly constrained by competition from lower wage areas as well as mainland U.S. imports of commodities such as poultry, eggs, dairy products, and meats (98). In Puerto Rico, a tax on imported coffee serves to protect the local industry and increase the incentive for local production. Similar systems may be needed to support development of other agricultural enterprises faced with low-cost import competition (67).

Another disincentive to producing for the local market is the availability of USDA surplus food, which is free and available to many people through the extended family. In the CNMI and Guam, food stamp and school lunch programs distribute large quantities of food. For example, in Guam some 22,600 persons participated in the food stamp program in 1983, and received coupons worth $18 million in food purchasing power, The majority of the food obtained from markets with the food stamps is processed food imported from the United States.

Micronesians are focusing efforts on economic development, including agriculture. The only advice available for development of food and fiber production, however, refers to nonindigenous systems (22). Many recommended projects involve large capital outlays on the part of the farmer or the government, and require outside expertise, imported energy and chemicals, and technology. These systems commonly are suited to parcels of land larger than those generally available to individuals or groups in the islands. The experts, generally on short-term assignments, frequently leave before problems arise from droughts or storms, delay in arrival of inputs, changes in personnel, lack of markets, lack of cooperation, or vandalism, that effectively end the program (22).

Infrastructural Constraints

Constraints to development imposed by lack of infrastructure exist in varying degrees in all of the U.S.-affiliated islands. The main kinds of facility shortfalls are: farm roads, irrigation systems, water storage and distribution, power generation and distribution, transport facilities and service, and storage/refrigeration capacity (43),

In the high islands, such as Palau and Pohnpei, farm roads are needed to enable cultivation of areas which currently are underused. In the CNMI, Palau, Yap and the northern Marshalls, reservoirs, or other sources of water, and distribution systems are needed to increase crop yields (43). In the Virgin Islands, provision for water supply infrastructure is necessary for agricultural development (61).

Transportation infrastructure in the Caribbean islands generally is quite good, with well-developed roads and regular air and sea transportation to the United States and other Caribbean islands. In those Pacific territories with populations dispersed over a number of atolls and islands, however, inter-island surface transportation typically is inadequate to provide farmers with market access and farm inputs such as livestock feed and fertilizers.

In remote U.S. Pacific islands, unreliable shipping has caused shortages of agriculture supplies, forcing producers to ration imported products and to substitute local products for imported supplies, sometimes resulting in reduced production. Because advance orders tie up cash and inventory can be slow to move, some suppliers tend to be unwilling to purchase supplies in advance (80). A combination of the shortages and unwillingness to advance order may cause a "shortage mentality," which results in rationing of these agriculture supplies even when they are available.

Inter-island shipping services and associated harbor docking/storage facilities need to be upgraded to enable an expansion of agriculture in the U.S.-affiliated Pacific islands. Likewise, potential for intra-regional commodity exports and exports to Hawaii and Asian countries may not be realized without improved transportation services—particularly in the FAS and American Samoa. There is little or no regularly scheduled surface shipping between the FAS and Asian-Pacific cities outside Micronesia. The same situation exists in American Samoa (43).

Storage and refrigeration facilities are scarce in all Pacific areas, particularly in the FAS. These facilities are needed to facilitate development by providing for an increased and steady supply of domestic commodities and to improve quality (43).

OPPORTUNITIES FOR AGRICULTURE DEVELOPMENT

The constraints discussed above represent formidable obstacles to agriculture development, but potential opportunities exist for increased crop production. Opportunities available to enhance island economic development include: 1) import substitution, 2) potential for increased local production, and 3) potential for export development for at least a few high-value commodities (43).

Import Substitution

Food imports are substantial in every territory. For example, in American Samoa food imports averaged $18.6 million in the 1981-83 period (4). The CNMI imports more food per capita by value than anywhere else in the Pacific despite its relatively low population density (13); food valued at $23.2 million was imported in 1983 (12). Also in 1983, Federated States of Micronesia (FSM) food imports were $11.2 million (26), and in Palau, $3.4 million (140).

In the Marianas, the USVI, and Puerto Rico, a wide range of fruit and vegetables already are grown commercially (34,43). Although traditional local crops still are favored in the FAS, urban populations are consuming increasing amounts of nontraditional fresh fruits and vegetables. The non-Micronesian population in the urban centers account for part of this demand, but prestige attached to imported foods and greater awareness of nutritional benefits of fresh produce may also be contributing factors (43).

A large proportion of the fresh fruit and vegetable commodities which are imported could be produced on most high islands of the territories. Examples are pineapple, papaya, cucumber, eggplant, bell pepper, citrus, sweet corn, tomatoes, avocados, green onions, Chinese cabbage, and head cabbage in Pohnpei (47). The Soil Conservation Service (SCS) has determined on the basis of its soil surveys that most of these commodities also can be grown in Kosrae (128), Truk (127), Yap (128), Palau (129) and American Samoa (125).

Puerto Rico is self-sufficient in plantain, bananas, pumpkin, and tare, and at least 60 percent of products such as raw sugar, coffee, freshmilk, eggs, taniers (cocoyam taro), sweet potatoes, yams, oranges, and grapefruit are locally produced. Opportunities still exist to substitute some locally grown vegetables for currently imported produce (143), but those that can be imported cheaply from the mainland United States and that require large acreages of land are not good candidates for import substitution (78). The USVI is nearly self-sufficient in egg and milk production (56).

Increased Subsistence and Commercial Production

In addition to increased domestic production for import substitution, there is substantial scope for increasing subsistence and commercial agricultural production of traditional crops, as well as other crops which are not imported but could be grown locally if domestic demand could be developed.

Although semicommercial and commercial farming can be expected to become proportionately larger given a sustained agricultural development program, initially packages of practices for traditional crop and livestock commodities could be developed to raise subsistence productivity. With respect to commercial farming, modern technology already available in other tropical areas can be adapted to selected locally produced commodities.

Export Development

Large export markets potentially are accessible by island producers: primarily Japan for western Pacific islands and the U.S. mainland for U.S. Caribbean islands. In order to penetrate these markets, several hurdles must be overcome. Export marketing requirements include regular, significant volume shipments of high-quality products; prices competitive with similar products—locally produced and imported—in the export market; and, for fresh produce, pest- and disease-free products that can pass the commonly strict animal and plant quarantine regulation of importing countries. Depending on the product exported, reliable and cheap transportation may be a requirement.

Generally, successful export crops are characterized by high value per unit weight, superior quality, low production cost, and low cost and relative ease of transport. Pohnpei black pepper, which is characterized by these qualities, was able to penetrate the U.S. gourmet market (29). Ornamental plants, honeydew melons, and mangoes are exported successfully from Puerto Rico. Other high-value commodities which might be grown in the U.S. high islands include coffee, cacao, nuts, spices, and essential and perfume oils (94,126,127,128, 129,130).

Opportunities for intra-regional trade also are possible for certain commodities such as sweet corn, bananas, pineapple, papaya, and selected vegetables. Coordinated agricultural development planning among Pacific and Caribbean islands would enable some degree of specialization for areas with a comparative advantage for particular commodities (43).

AGRICULTURAL DEVELOPMENT STRATEGIES

Commercial agriculture development continues to be emphasized as desirable for the U.S.-affiliated islands. Goals of such development include increasing employment opportunities in the rural and outlying areas, stemming migration to over crowded urban centers, building the private sector through development of local renewable resources, increasing local food production, replacing imported food items and build self-reliance, and generating cash for the island economies (94).

A basic premise underlying commercial agricultural development is that, in every territory, the private sector must be made more productive to support standards of living to which residents have become accustomed. Further, that economic development options other than agriculture are sufficiently limited so that territorial governments cannot ignore agriculture's development potential. Since imports constitute the bulk of island consumption, for territories to improve economic self-sufficiency they must either produce the goods they consume locally or generate overseas earnings (through commodity or services exports) to pay for the imports. Given the currently large food imports in most of the territories, domestic agriculture can contribute to the ultimate goal of overall economic self-sufficiency by producing for import substitution or for export—in either case, agriculture would have to become increasingly commercialized (43).

However, in view of the pervasive nature and severity of the constraints to agricultural development, and the present levels of standards of living, consumption, and expectations, total self-sufficiency or even near self-sufficiency in domestic food production is unlikely on most islands. An alternative goal might be optimal use of lands best suited to crop production taking into account other land use requirements; large amounts of arable lands may not be farmed where other uses are deemed more socially important (43).

Characteristics of Sustainable Tropical Island Agriculture

Successful tropical island agricultural systems generally exhibit ecological characteristics which mimic and extend natural processes by providing for water and nutrient flow, and maintaining a canopy to protect and enhance soil quality at critical periods, especially during times of heavy rainfall. An agricultural system which incorporates a diversity of crop species and varieties strengthens the system's resilience to disruption from pests and disease outbreaks and, further, provides the farmer with a variety of products throughout the year even where erratic weather patterns exist. For such systems to be readily adopted, they may need to be based on traditionally used systems and should require minimal exotic nonrenewable inputs such as fossil fuel energy or derived chemicals (22), Sustainable agricultural systems commonly:

- mimic natural tropical systems;
- emphasize or incorporate perennial crops;
- emphasize optimization of components rather than maximization of yield;
- emphasize recycling of locally available nutrients;
- emphasize incremental changes from extant systems; and
- provide farmer and consumer security in areas prone to natural disasters.

Mimic Natural Tropical Systems

The major mechanism through which sustainable tropical agricultural systems mimic natural tropical systems is through maintaining a multistoried vegetative soil cover. The vegetation protects the soil from erosion and provides soil organic matter in the form of leaf fall and roots. The growth and recycling of organic matter is similar to that occurring in tropical forests. In agroecosystems, these benefits can be generated through polyculture systems, planting a polyculture—a diversity of plant species and varieties—can increase yields by reducing plant competition, by taking advantage of differences in microhabitat, by reducing the intensity of pest and disease infestations, and through beneficial plant interactions. Thus, sustainable tropical agriculture emphasizes managing biotic interactions within the agroecosystem rather than divorcing the agroecosystem from natural factors and replacing them with imported nonrenewable resources.

Monoculture. —The cultivation of a single crop on a unit of land has been the main commercial cropping technology introduced to the islands to date. Historically, colonial powers in the Pacific and the Caribbean have favored the monoculture approach (e.g., in the Pacific: the Germans with coconut plantations, the Japanese with sugarcane, rice, cassava, sweet potato, etc. and the Americans with cacao, rice, banana, ramie, black pepper; in the Caribbean: the Danes and Spaniards with sugarcane). Traditionally, however, very few cases of monoculture existed originally in local agriculture practices *(94).*

Benefits of monoculture are many and, thus, large agricultural systems have been built around this technology. The main advantage of monoculture is uniformity—in planting, fertilizing, cultivating, and harvest—thus favoring intensive use of inputs such as improved and hybrid cultivar varieties, chemical fertilizers and pesticides, and mechanization (94). This uniformity in product and harvest period also simplifies large-scale processing. Monoculture systems also are simpler to research and develop than polycultures, whose permutations can appear infinite.

These advantages do not translate easily to small-scale farming systems with limited available resources. Capital often is not available to invest in the improved inputs needed to sustain successful monoculture. Labor, needed for tillage, planting, and harvesting, which tend to be concentrated into peak periods, rarely is available to farmers who must depend mainly on family labor. The uniform harvest and greater yield requires adequate storage, processing, and marketing facilities which currently are lacking on some U.S.-affiliated islands. Monoculture also encourages the spread of pests and diseases in the absence of natural barriers found in more diverse ecosystems. Also, in monoculture, as in any cropping system that needs total land-clearing and regular tillage, erosion can be a serious problem, even when terraces and contour-farming are practiced.

All of these factors can add up to a generally unlikely and risky prospect for many island farmers. Few small-scale, limited-resource farmers, who must depend on their farm for their family's food, are willing to take such risks. Another factor, which planners and agriculturists tend to overlook, is that a small farmer, faced with decisions on how best to use his extremely limited land resource, is likely to avoid any technology that will entail tying up a large percentage of land to grow a single crop (94). Thus, monoculture are likely to be undertaken only when markets are guaranteed, when competition is restrained (e.g., if farmers agree to specialize on certain crops) or if crop harvests are staggered *(80).*

Monoculture does, however, hold some possibilities for further development in Micronesia, especially in those areas where landholdings are relatively large (e. g., on government leased lands). Ponape Agriculture and Trade School on Pohnpei has been running a 20-acre mechanized commercial farm for nearly 10 years based on monoculture of sweet potato, corn, cassava, banana, and beans (94). Farmers in Guam and the Northern Marianas also have developed successful vegetable monoculture systems. Each of these systems depends on excellent tillage and cultivation (generally mechanized), well-planned crop rotation schemes, and imported commercial fertilizer and pesticides. Also, markets in these areas are fairly well developed.

New methods of monoculture have been developed in Africa and the United States designed to reduce erosion and/or capital investment by replacing tillage with herbicides. Proponents of these systems claim that the dead mulch left after herbicide treatment helps keep soils cool, suppresses weed growth, encourages water retention and growth of soil building organisms, as well as reducing erosion to as little as 2 percent of that of clean-tilled fields (151). However, with the extremely high cost and irregular availability of herbicides imported into Micronesia, dangers of pesticide misuse and the general reluctance of farmers to practice monoculture technologies, it is unlikely that any of these systems will support commercial agriculture in Micronesia (94).

Polyculture.—Concurrent mixed cropping of two or more crops on a unit of land is the form of most traditional agriculture in the U.S.-affiliated islands. A common form of polyculture is intercropping, the planting of two or more crops together at the same time by row, strip, or in a seemingly random mixture. Another form is relay cropping, with a second crop being planted into the original crop before the latter's harvest. This allows growth of a second crop without tillage.

Agroforestry–a mixture of annual and woody perennial species, sometimes including animals —is the basis of traditional agriculture in the Pacific. Agroforestry systems depend on creation and maintenance of a multistoried, semipermanent stable system. The productivity of the system is based on the positive interactions between the plants (and between plants and animals) giving the farmer a continuous food supply over the long term (94).

Alley or avenue cropping is another form of agroforestry which consists of planting trees, usually a fast-growing, nitrogen-fixing legume species in rows, with annual crops planted in the alleys or avenues. The deep-rooted trees, which act as nutrient pumps and erosion barriers, are pruned at short intervals and the prunings are plowed into the alleys as green manure.

A complex form of polyculture is "Energy Integrated Farming" or "Biogenic Farming. " These systems incorporate livestock production with algae and fish ponds, annual and tree crop production, and a biogas digester, the effluent of which is used as fertilizer and irrigation water (see ch. 8). These systems are highly energy efficient. Systems have been operational on an experimental level in the Northern Marianas and Yap, but have not been widely adopted on the U.S. Pacific islands (94). Such systems are in operation in Puerto Rico (2).

Polyculture systems offer a number of benefits, particularly important in the tropics, that are not available from monoculture systems. The mixture of crops and animals tends to discourage the spread of pest and disease infestations, and the multi-story plant canopy decreases erosion, increases capture of solar energy for photosynthesis, and shades and cools the soil. The varied geometry of root systems exploits the soil profile and nutrients more fully than monoculture systems. Overall production per unit of land often is higher than in monoculture systems, although the yield of individual crops per land unit may be lower (30,115).

The increased variety of crops and livestock, as well as beneficial interactions between different species result in a more sustainable agricultural system than monoculture (94). Also, because polyculture outputs closely approximate local consumption requirements, there also is inherent stability in the market or pattern of demand, in contrast to the instability characteristic of internationally sensitive monoculture markets (e.g., sugar, copra) (56). Finally, some farmers may practice polycultures not only because they are traditional in the islands but because the farmers are willing to sacrifice some amount of product yield and quality to save in expenditures on fertilizers and pesticides (80).

Polyculture has not been developed for large-scale commercial agriculture mainly because it does not lend itself well to mechanization or increased fertilizer and pesticide inputs. Polyculture systems also require more research, planning, and management than monoculture if they are to become fully competitive with monoculture in the short-term, since several different crops must be cared for on the same land unit (94).

Emphasizes or Incorporates Perennial Crops

In addition to incorporating a number of crop species and varieties, traditional agricultural systems commonly are comprised of crops with staggered planting and harvest periods. Perennial crops, usually shrub or tree crop species, are typical members of traditional polyculture systems. Although developing a traditional Yapese agroforest or "tree garden" may take years, once established relatively little input is required for their maintenance and food and other products can be harvested essentially in perpetuity. Developing a modern agroforest, in which species' spacing is carefully planned and individuals are planted rather than allowed to volunteer, can take considerably less time.

Most major tropical "plantation crops" also are perennial crops, such as coconuts, coffee, and cacao. Permanent crops are estimated to occupy at least 8 percent of the total arable area in developing countries *(69)*. One of the most widely grown tropical tree crops is the coconut palm, covering some 15 million acres, although it is mostly grown on smallholdings in densely populated areas *(69)*. Smallholders commonly intercrop coconuts with annual crops during the early stages of plantation establishment, but modern plantations generally maintain their traditional characteristics: "monocultural production of an export crop, extensive and, in some cases, underutilization of land, and a high manual labour input" *(69)*. With increasing populations and the need for intensification of land uses, planners and policymakers are increasing their attention to the potential of integrating plantation crops, annual crops, livestock raising, and forestry *(69)*.

Emphasizes Optimization of Components Rather Than Maximization of Yield

A sustainable tropical agricultural system places primary emphasis on maximizing agroecosystem stability through managing biotic interactions and minimizing demand for human and industrial inputs *(42)*. For example, intercropping and crop and field rotations are commonly practiced in tropical subsistence farming systems to minimize weeds and pest infestation and to maintain soil fertility. This is not to say that crop yield per land unit cannot be as high as those in temperate systems, in fact biomass yields may be higher due to the year-round growing season. However, the primary goal of these systems is to derive as many benefits as possible from natural actions and interactions, thus reducing input and labor costs of managing the systems to produce goods for human consumption or sale.

Emphasizes Recycling of Locally Available Nutrients

Traditional agriculture in the islands relied heavily on infusions of green manures to provide plant nutrients to infertile soils. Agricultural inputs are derived from composted leaves and other organic materials and manures, or even from dried starfish or rotted sea cucumber (22,102). On resource-poor islands such as atolls, the ubiquitous coconut fronds and husks are used to supplement the meager organic matter content of soils for crop cultivation *(102)*. In recent years, introduced agriculture implements and chemicals (fertilizers and pesticides) also have been incorporated into the traditional cultivation systems.

Reliable information on the types, amounts, and availability of various organic wastes useful for improving the productivity of agricultural soils is lacking on many islands. Successful planning and implementation of organic recycling programs requires such information as a first step. Several common types of waste that can be used are: 1) animal manure; 2) crop residues and cut vegetation; 3) algae, seagrasses and marine animal products (e.g., starfish, sea cucumber); 4) sewage sludge; 5) food processing wastes (e.g., rum brewery byproducts); 6) organic industrial wastes (e.g., some pharmaceutical wastes); 7) logging and wood manufacturing wastes; and 8) municipal refuse. Information is needed on the quantity currently generated, present and potentially competitive uses, value as fertilizer, and problems and constraints affecting use.

Emphasizes Incremental Changes From Extant Systems

Although farm size, type of technologies applied, and farming goals are not directly related, agriculture in the U.S.-affiliated islands can be classified into four general types that make up a continuum of farming systems:

1. Subsistence *smallholder:* Family (or clan) member(s) producing solely for family consumption, although "surplus" commodities may be sold. Traditional cropping or gathering techniques commonly are used, and the number of crops produced is usual1y greater than in commercial smallholding systems.
2. *Semicommercial smallholder:* Individual or family members regularly producing commodities for the market, but only on a part-time basis. Farming mayor may not be regularly directed to home consumption (farmer may have a full-time wage job in the money economy). Commodities may or may not be produced using modern[2] technology.
3. *Commercial smallholder:* Individual or family member(s) producing solely or substantially for the market. Commercial smallholders typically are full-time producers who derive their principal livelihood from farming. Commodities are normally produced using modern technology. The range of crops is much narrower than for the subsistence smallholder. The commercial smallholder may have a few wage employees, but most would rely solely on unpaid family labor.
4. *Large-scale commercial farming:* Usually is characterized by significant investment in operation, and use of paid wage and salary workers. Ownership commonly would be corporate in form, with production using modern, high-input technology. Output per unit of land or labor would tend to be much higher than for smallholder agriculture.

"Large-scale" commercial farming on the islands is not large by U.S. standards (tables *6-4* and *6-5).* In the United States, farms average *416* acres acres *(132),* whereas in the U.S.-affiliated islands large farms can be considered those with more than *50* acres in the Caribbean and more than *20* acres in the Pacific. Small farms in the United States can be defined as those selling less than *$20,000* worth of agricultural products in one year *(119).* While **8.5** percent of Puerto Rican farms exceed this, under this definition, virtually all farms in the USVI and the Pacific islands can be considered small.

[2]Modern technology is defined to be the package of practices (agronomic methods and procedures, as well as use of labor and material inputs) developed by scientifically based institutions [experiment stations, agriculture departments, specialized institutes) for use in tropical and semitropical areas. A package of practices relates to a given farm commodity or enterprise, and tends to be unique to a particular region. Packages of practices based on modern technology enable a farmer to obtain yields maximized with respect to the scarcest resource (e.g., per acre per crop, if land is scarce; per manhour, if labor is scarce) (43).

Table 6-4.—Comparison of U.S. Mainland and Island Farm Sizes by Acreages

Farm size (acres)	United States[a]	Puerto Rico[b]	USVI[c]	Guam[d]	American Samoa[e]	CNMI[f]
Less than 10	8.3% (187,643)	45.5% (9,837)	62.4% (189)	93.8% (1,868)	94.7% (1,260)	66.9% (200)
10-19	(included below)	21.1% (4,554)	10.6% (32)	3.2% (63)	3.6% (48)	18.4% (55)
20-49	20.0% (449,184)	18.2% (3,937)	11.2% (34)	1.8% (36)	1.3% (17)	8.0% (24)
50-99	15.3% (343,715)	7.2% (1,549)	5.9% (18)	1.3% (25)[g]	0.5% (6)[g]	6.7% (20)[g]
100-174	16.4% (367,734)[h]	3.0% (658)	4.0% (12)			
175-259	9.4% (211,384)[i]	1.7% (372)	1.7% (5)			
260 and more	30.3% (679,640)	3.3% (712)	4.3% (13)			

SOURCES:
[a]U.S. Department of Commerce, Bureau of the Census, 1982 Census of *Agriculture:* Summary, vol. 1, part 51, (Washington DC: U.S. Government Printing Office, 1984).
[b]U.S. Department of Commerce, Bureau of the Census, 1982 Census *of Agriculture; Puerto* Rico, vol. 1, part 52, (Washington DC: U.S. Government Printing Office, 1984).
[c]U.S. Department of Commerce, Bureau of the Census, 1982 Census *of Agriculture: U.S. Virgin Islands,* vol. 1, part 54, (Washington DC: U.S. Government Printing Office, 1983).
[d]U.S. Department of Commerce, Bureau of the Censis 1982 Census of Agriculture: Guam, vol. 1, part 53, (Washington DC: US. Government Printing Office, 1983).
[e]U.S. Department of Commerce, Bureau of the Census, 1978 Census of Agriculture: American Samoa, vol. 1, part 55, (Washington DC: U.S. Government Printing Office, 1981).
[f]U.S. Department of Commerce, Bureau of the Census, 1978 Census *of Agriculture: Northern* Mariana *Islands,* vol. 1, part 58, (Washington DC: U.S. Government Printing Office, 1981).
[g]Data include farms with 100 to 179 acres.
[h]Data include farms with 50 acres or more.
[i]Data include farms with 180 to 259 acreSs

Table 6-5.—Comparison of Farm Sizes by Sales Class

Value of sales	United States[a]	Puerto Rico[b]	USVI[c]	Guam[d]	American Samoa	CNMI
$1 to $99	(included below)	n/a	2.3% (6)	13.2% (45)	n/a	n/a
$100 to $499	(included below)	9.0 "/0 (1,964)"	25.7% (68)	31.9% (109)		
$500 to $1,199	(included below)	33.2% (7,236)	26.0% (69)	15.5% (53)		
$1,200 to $2,499	23.9% (536,437)	20.5% (4,474)	20.4% (54)	12.9% (44)[f]		
$2,500 to $4,999	12.4% (278,208)	15.1% (3,293)	10.2% (27)	26.9% (92)[f]		
$5,000 to $7,499	7.50/0 (168,483)	6.0% (1,302)	3.0% (8)			
$7,500 to $9,999	5.0% (1 13,319)	3.0% (651)	1.5% (4)			
$10,000 to $19,999	11.5% (259,007)	4.8% (1,043)	10.9% (29)[g]			
$20,000 to $39,999	11.1% (248,825)	2.4% (529)				
$40,000 to $59,999	6.6% (148,272)	0.9% (190)				
$60,00 or more	21.6% (484,859)	5.2% (1,138)				

SOURCES:
[a]U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: Summary,* vol. 1, part 51 (Washington, DC: U.S. Government Printing Office, 1984).
[b]U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture; Puerto Rico,* vol. 2, part 52 (Washington, DC: U.S. Government Printing Office, 1984).
[c]U.S. Department of Commerce, Bureau of the Census, 1982 Census *of Agriculture; U.S. Virgin Islands,* vol. 1, part 54 (Washington, DC: U.S. Government Printing Office, 1983).
[d]U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: Guam, vol.* 1, part 53 (Washington, DC: U.S. Government Printing Office, 1983).
[e]Includes all farms in sales class less than $499.
[f]Includes all farms with sales of $2,500 or more.
[g]Includes all farms with sales of $10,000 or more.

Even the definitions used by the U.S. Bureau of the Census reflect the wide disparity in farm sizes between the United States mainland and the islands. Farms in the States are defined as a place that produces and sells, or normally would have sold, at least $1,000 worth of agricultural products per year (132). Enumeration in Puerto Rico covers:

> . . . all places from which $500 or more of agricultural products were sold, or normally would have been sold, during the 12-month period, . . [and] places of 10 cuerdas (9.7 acres) or more from which $100 or more of agricultural products were sold, or normally would have been sold (135).

Farms in the USVI include all those with 3 acres or more on which any field or forage crops or vegetables were harvested, livestock managed or having 10 or more poultry, and places of less than 3 acres if agricultural sales amounted to at least $100 (133). In Guam, a farm is:

> a place on which any crop, vegetable, or fruit was harvested or gathered during 1982, or on which there was any livestock or 15 or more poultry at the time of enumeration (134).

The amount of marketed agricultural produce is small relative to total food consumption in all the U.S.-affiliated Pacific islands; most farming is of subsistence and semicommercial scale. Approximately 3,000 persons in the Marshall Islands were estimated to be active in subsistence agriculture, forestry and fisheries in 1980 (49), and 38 percent of gross domestic product in the FSM was attributable to the subsistence sector in 1983. In Palau, an estimated 20 percent of the 1976 work force was in subsistence agriculture and fishing, and many in the wage economy farmed on a part-time basis for home consumption (43].

Truly sustainable agriculture probably should represent an integration of traditional techniques with modern scientific theory and with modern technologies. Progress will ultimately depend on the development of technology and understanding of the fundamental processes underlying soil fertility (42).

POTENTIAL STRATEGY: Support Nonmarket Agriculture

Traditional cultural practices are labor- and nature-intensive, maximizing the use of local resources and mimicking the local natural environment. In the U.S. Pacific islands, a variety of subsistence crop cultivation systems are practiced including root crop cultivation, agroforestry, and backyard or home garden agriculture. These systems have been adapted to varying island environmental conditions.

Traditional cropping practices in many U.S. Pacific islands are strongly rooted in the sociocultural practices of the communities. Some crops and animals play an important role in traditional exchanges. In Micronesia, specially cultivated taro and yams, and pigs are prepared for significant social and cultural events such as births, marriages, funerals, dedication ceremonies, and for traditional feasts (22,94,108). In urban centers these traditional practices are gradually disappearing.

Although subsistence farming sometimes may not result in highly uniform yield, it provides a number of benefits:

- stable system producing on a sustainable basis;
- ecologic compatibility with the local environment;
- beneficial environmental services (e.g., soil stabilization, habitat protection);
- compatibility with local culture and land tenure systems;
- high crop diversity and phased harvest enhance nutrition; and
- generally does not depend on costly and often unreliable imported resources a-rid inputs (e.g., agrichemicals, feed, spare parts, equipment, experts).

Subsistence farming systems are gradually abandoned and generally neglected by young farmers because these systems are considered inferior and may involve excessive manual work, However, much can be learned from these time-tested traditional systems because they incorporate certain resource conservation practices and operate on a sustainable basis suitable for islands (22).

On the other hand, although these practices are well suited to island conditions, crop yields may not meet the needs of increasing populations on some islands. Traditional root crop cultivation has been gradually abandoned in recent years because it is labor-intensive and relatively low returns are no longer compatible with social and cultural aspirations among young farmers. Because most modern agricultural systems are heavily dependent on imported agrichemicals and have been economically unstable and ecologically unsustainable, in the long run, subsistence agriculture systems probably will not disappear on the islands. They are likely to persist to the greatest extent in situations in which capital is not readily available to farmers or where islanders consider subsistence agriculture practices a manifestation of their cultural identity.

No consistent measure of nonmarket production has been derived for the separate territories. Indicators of agricultural production both entering and not entering the money economies of U.S.-affiliated Pacific islands, are listed in table 6-6. The terms subsistence and commercial (or market) agriculture are used in a gen-

Table 6“6.—Indicators of Subsistence and Commercial Agricultural Production in the U.S.-Affiliated Pacific Islands

Islands	Measures of subsistence production	Measures of production for the market
American Samoa	1,405 acres (81%) in subsistence crops	330 acres in commercial crops
Guam	More than 1,000 family gardens, usually <5 acres	85 commercial farms <5 acres
Northern Marianas	Approximately 20°/0 of total production is for home consumption	Approximately 80°/0 of total production is for market
Marshall Islands	n/a	n/a
Federated States of Micronesia. ... , ., . ..	$40.59 million is imputed value of subsistence agriculture and fisheries	Market production valued at $4.32 million
Palau	n/a	n/a

SOURCE: R. Lucas, “Role of Smallholders in Agricultural Development in the U.S.-Affiliated Pacific Islands,” OTA commissioned paper, 1986 eral sense, but the specific island context is important. For example, in Guam, nonmarket production is largely of the home garden variety but, except for scale and use of machinery, the technology for producing commodities does not differ substantially from the commercial grower whose output is marketed. Virtually all Guamanian households area part of the money economy, and few depend on farming for the food they eat. In contrast, in an area such as Palau, subsistence farming typically not only means use of a different technology but also, for many families, is the main source of the family's food (43).

Little true subsistence agriculture exists in the U.S. Caribbean. However, rural and urban backyard gardens are common in Puerto Rico and the U.S. Virgin Islands, and several groups practice a sophisticated combination of subsistence and semicommercial agriculture.

Opportunity: Project Currently Functioning Traditional Agriculture Systems

Without a conscious effort to retain existing food producing systems, it is likely some traditional practices and varieties will become rare or disappear. Because present-day Micronesians have inherited relatively self-sustaining food production systems developed by more dense populations of their ancestors, complacency about continued maintenance presents a danger; without inputs, even relatively stable systems will run down. For example, the productive lifespan of a coconut tree is about 60 years; under good conditions, breadfruit trees produce for about 50 years (103). These plant lifespans are close to the productive years of each human generation. If present-day island populations do not do their part to maintain the systems, the next generation may not realize what it had until it's gone (22).

Many traditional systems already are declining. On Guam, for example, the percentage of persons involved in fishing and farming declined from 90 percent in 1941 to 6 percent in 1950 to less than 1 percent in 1970. The traditional lancho system has declined precipitously. This was accompanied by a concurrent increase in dependence on food stamps (22).

Without conscious efforts to protect currently functioning traditional agriculture systems, local production of food can be expected to decrease. With increases in prices and population, nutritional problems may be expected to result (110,111). Another byproduct would be the loss of Micronesia's genetic heritage: the wealth of adapted varieties of food plants and other species developed over a great many years by ancestors of the present generation. Further, the collective body of traditional knowledge relating to the use of island resources could be lost (22).

Consideration of development project impacts on currently functioning agricultural systems could be made prior to investment, followed by actions to mitigate adverse impacts. For example, road construction has altered drainage patterns and affected water circulation in some taro patches. In some cases the impact is obvious: the taro becomes buried in silt. In other cases the microbiology of the substrate is changed, generally towards more anaerobic conditions (22). This is particularly important on islands where government economic development strategies favor nonagricultural sectors which will eventually lead to competition for and encroachment on agricultural lands (56).

Opportunity Support and Increase Backyard Agriculture

Backyard or home gardens, as the name indicates, are located immediately adjacent to permanent dwellings. Backyard agriculture is widely practiced in Pacific and Caribbean islands and it maybe considered as an adjunct to subsistence and semicommercial agriculture. Except for scale, many characteristics of subsistence agriculture systems apply to backyard gardening. Generally it is characterized by mixed cropping of a variety of trees and short-term crops, high crop diversity, and labor-intensive cultivation of a small plot of ground (commonly less than 1 acre). In general, produce from backyard gardening is for subsis-

Photo **credit:** *Office of Technology Assessment*

Although more intensive than other traditional cultivation methods, backyard gardens also commonly rely on minimal soil disturbance and locally available materials such as these bamboo trellises.

tence use, although surplus crops or certain cash crops (e. g., spices and herbs) sometimes are sold. As in subsistence field cropping, backyard gardening activities have few market constraints. However, in cultures based on extended family sharing, backyard subsistence gardens may effectively reduce the market for commercial farmers' products (63,80).

Backyard gardening in rural areas commonly is an extension of subsistence cropping and backyard gardens may serve as a convenient recycling site for organic wastes. They also may serve as trial plots of wild plants or new crop varieties grown under reasonably controlled conditions (22,110,152). Where space is limited or when the soil is extremely poor, crops can be cultivated in containers. When good soil is not available, chopped up fibers from coconut husks and fronds mixed with fertilizer, compost, or animal wastes can be used as substrate in container cultivation for vegetables (46).

Backyard gardening in urban areas may contribute significantly to supplementing diets of wage earners. It also may improve the nutritional and economic well-being of increasing numbers of urban dwellers (110). In recent years, primarily in urban areas, backyard gardens are becoming commercialized. Some backyard gardeners use drip irrigation systems, greenhouses, shadehouses, or even hydroponics (10).

On some islands where agricultural production costs or land values are high, backyard gardening is popular for part-time, semicommercial cultivation of vegetables and fruits. Backyard gardening is popular in the USVI because it requires low capital investment, is suitable for small parcels of land, affords little economic risk, and provides flexibility in choice of crops or cultivation methods to meet changing local market conditions (16).

Backyard gardening, in general, is highly adaptable and can be implemented under varying environmental conditions and social settings (51). Backyard gardening has a number of characteristics making it suitable for the U. S.-affiliated islands including:

- flexible technology adaptable to varying physical, social, and environmental conditions;
- useful for subsistence, semicommercial, and some intensive commercial ventures;
- generally little capital outlay required;
- generally little economic risk;
- could be applied in rural and urban settings;
- little land area needed;
- simple agricultural methods are applicable;
- varied choices in use of agriculture inputs (e.g., organic composts, agrichemicals);
- variety of crops can be grown; and
- provides flexibility in switching crops or cultivation methods to meet changing demands or market conditions.

Opportunity: Enhance Game Wildlife Management Practices

Proper management of game may enhance supplemental food supply and nutrition of island inhabitants. Depending on the island, wild game may include feral pigs, goats, and deer, pigeons, fruitbats, and land crabs. Apart from regulating the harvesting of game, appropriate resource management such as setting aside hunting preserves is essential in order to manage and maintain game species populations. In addition to allowing management and harvest of game populations, restriction of some of these animals, particularly feral goats and deer, to carefully defined areas can protect indigenous vegetation from overgrazing.

Other methods, such as introduction of certain species to uninhabited islands or wildlife ranching of certain species, are ways of supplementing local food supplies. Traditional practices, still adhered to on some Pacific islands, commonly include rules and restrictions that conserve resources. For example, small uninhabited islands are set aside as sanctuaries where turtles and sea birds, and their eggs, can be harvested at certain times and in certain quantities. However, these practices are declining in effectiveness as traditional values and authorities are disappearing (40).

Today, on most islands, local governments regulate the harvesting and management of game species. Generally, they cover three areas: endangered species, hunting laws, and protected habitats. Endangered species protection laws commonly involve a fine for violation. For example, the CNMI Endangered Species Code, based on the U.S. Endangered Species Act of 1973, carries a fine of $2,000 or imprisonment for a maximum of 30 days or both for illegal taking of species listed under the act. Hunting laws may establish harvest quota limits, restrictions based on size or sex for certain species, and provide for exemptions if it is determined that curtailment of harvest of restricted fish and game may result in hardship or malnutrition to the taker or his/her immediate family. However, such regulations are generally difficult to enforce. In some cases, especially on small islands where extended family ties remain strong, violations carry little sanction.[3]

POTENTIAL STRATEGY: Develop Smallholder Agriculture

Development of smallholder agriculture would take advantage of the already existing subsistence, semicommercial and part-time farmers in the U.S.-affiliated islands, and is likely to be more compatible with the present land tenure systems than would be a policy of promoting large-scale farming. Smallholders also tend to produce a large range of commodities which may mitigate some marketing constraints in small size markets. If increased market supply were in import substitution commodities that could be profitably sold at lower prices than the competing products, commodity prices would be reduced.

Semicommercial farming could provide opportunities to increase income for part-time farmers or to generate cash incomes for subsistence farmers. Introduction of new technologies or new crops to extant semicommercial agriculture systems could increase income, yield, and make more efficient use of islands' scarce resources. Furthermore, introduction of semicommercial farming systems may become an effective method for relatively unsophisticated subsistence farmers to gradually learn the operation of commercial farming systems.

Among the three types of smallholder agriculture (subsistence, semicommercial and commercial), competition for resources is not likely to be a concern. Moreover, the three types of agriculture have many characteristics in common, such as relatively modest acreage requirements per operation, generally heavy reliance on family labor, and significantly less capital requirements per operation compared with large-scale agriculture.

Smallholder development policies could seek to achieve a gradual transition from nonmarket production to semicommercial and, ultimately, to commercial agriculture. For example, policies could seek to raise productivity in the subsistence sector, particularly in outlying areas which have arable land but lack transport and other infrastructure needed for market access. Concurrently, efforts could be initiated to strengthen urban markets for the products of semicommercial farmers, and to develop more productive packages of practices for selected import substitution commodities (43).

[3]For example, on one United Nations Day celebration on Yap, a Palauan fisherman whose catch included a turtle won first prize in the spear-fishing contest, even though it was against the law to kill turtles at that time of year (20).

Opportunity: Enhance Existing Nonmarket and Semicommercial Systems

Many constraints to resource management and development do not limit production to provide for personal needs and sharing, while they do limit commercial development. This suggests an initial strategy of encouraging production to meet family needs and, once these are met, surplus production may be marketed. Of course, should employment in nonagricultural sectors remain stagnant, then satisfying extended family needs would effectively satisfy the market (63).

The primary goal of enhancing existing nonmarket agricultural systems would be to increase productivity so that surplus could be marketed. In this way, the farmer would earn income and learn the skills needed for commercial agriculture. Methods of increasing nonmarket agricultural productivity include introducing improved cultivars of traditional crops and assisting women gardeners. In addition to these, a number of methods and crops have been introduced successfully on some islands for semicommercial operations. Methods of enhancing extant semicommercial systems include: improving cultural practices for cash cropping, promoting underutilized crops and animals, introducing suitable new crops, and introducing new technologies.

Introduce Suitable Improved Cultivars Into Extant Systems.—Specialization in agricultural systems and in culture of various crops is found within Micronesia islands and in other tropical areas. Information exchanges among these groups could provide much useful information (22). Similarly, although little is known about ethnobotanical crops or cultivation practices in the U.S. Caribbean, identification of local cultivars and information exchange with non-U.S. Caribbean islands could prove beneficial.

In Micronesia, a number of local crop varieties have been introduced from island to island. For example, varieties of coconut are recognized from the size, shape, and color of the nut; number of nuts per bunch; flavor of the coconut milk and meat; and tree sizes (86). At least seven tall and four dwarf coconut varieties are recognized in the Marshall Islands (104), One high-yielding, tall coconut ("thifow"), originally from Yap, produces twice as much copra as the commonly grown variety. This variety has been successfully introduced to other Micronesia islands including the Marshalls (86).

Prior to introduction of varieties from outside Micronesia, an effort could be made to collect and maintain existing varieties.[4] These varieties may be directly transferable among Micronesia islands and can provide germplasm for cultivar improvement programs. Screening systems and facilities for tissue culture probably are needed to ensure provision of disease-free planting material (22).

New cultivars could be developed that effectively extend the growing season of seasonal crops. In addition, unusual climatological events, such as the 1982-83 El Niño, have been related to gaps in yearly food production on some islands. With improved predictability of weather patterns, new cultivars and new technologies might be developed to fill some of these gaps.

Assist Women Farmers.—Women are the agriculturists on many Pacific islands. Extension services directed to collecting and disseminating information to these women could complement more traditional technology transfer systems. Women extension agents might speed this process. Methods of assisting these women with childcare also could increase time available for production and for passing on their experience to other women (22).

Improve Culture of Current Cash Crops.—Most cash crops currently grown on tropical islands are perennial: coconut, coffee, cacao, and sugarcane, Research efforts for many of these tropical "plantation crops" have resulted in considerable yield increases (e. g., rubber, "the average yield of which has increased over seventeenfold in a century"). On the other hand, the yield of crops like the coconut palm has re-

[4]Mechanisms to maintain crop and livestock varieties and wild plants and animals are assessed in an OTA report on *Technologies To Maintain Biological Diversify*, OTA-F-330 (Washington, DC: U.S. Government Printing Office, March 1987) (118).

mained low (69). This is due to a lack of research attention and, in part, to lack of maintenance by island smallholders.

For example, although copra production represents the only major cash crop for most Pacific islands, very little regular maintenance and replanting is practiced. In the Marshalls, brush growing between coconut palms occasionally is cleared and burned along with fallen coconut fronds and accumulated husks, although commonly they remain on the ground for considerable periods of time. These provide breeding sites for the Rhinoceros beetle, rats, and mosquitos. Fertilizers are not used, and old trees are not thinned. New trees are planted only in conjunction with government programs which subsidize the planting by providing seednuts and mechanized equipment (86). Inadequate maintenance of coconut palms and replanting programs results in reduced yields.

Since coconut palms have a very long economic life (60 years), understory cover management is critical. Manual clearing or control using herbicides generally are expensive or impractical. An alternative would be to keep livestock under coconut palms to graze understory vegetation or to intercrop coconut with other crops. Well-managed intercropping increases the productivity of the land, improves income distribution over time, increases return on investment, and thus may increase farm income (100). It could also increase employment. In some instances, pastures under coconuts can be improved by fertilization or planting nitrogen-fixing plants such as *Centrosema pubescens, Desmodium trifolium,* and shade-tolerant grasses.

Although no accurate copra production figures are available for U.S.-affiliated islands, it generally is lower than yields in Asian countries. For example, about 6,000 nuts are required to produce one short ton of copra in the Marshall Islands (86) as compared to only 4,000 nuts in the Philippines (35). Low yield is partly due to improper maintenance or lack of maintenance, and partly due to the use of low-yielding coconut varieties.

Many stands of coconuts in the U.S.-affiliated Pacific islands, and particularly in the Marshalls, were planted during the German administration of the islands and are now senescent. Little planned replanting is occurring. Although technologies to improve coconut production are available, people are reluctant to replant for several reasons:

1. the substantial investment of time and effort required,
2. the length of time before trees bear fruit (5 to 7 years),
3. unattended nuts will sprout and grow by themselves,
4. the government is likely to provide superior seednuts and replanting assistance (86),
5. in some cases it is more lucrative to plant short-term crops than to plant coconuts (63), and
6. substantial migration from outer islands makes it uncertain whether planters will be able to collect benefits of replanting (13).

Yet, techniques as simple as changing spacing from a rectangular to a triangular arrangement may substantially increase yield per acre (86).

Promote Underutilized Crops and Animals.– Every island has indigenous or naturalized species, either gathered from the wild or raised in small farms, that have been used traditionally for food, fuel, medicine, livestock feed, construction, fiber, and other purposes. These potentially marketable resources may be ignored by some planners in favor of introduced “western” crops, livestock breeds, and methods (121). In recent years, however, there is renewed interest in the potential for developing such resources (22,40,76,94).

Many crops and animals now found on U. S.-affiliated islands were introduced after western contact. Many have adapted to the local environment and are now considered local resources, including crops such as sweet potato, cassava, papaya, mango, and soursop; and animals such as goat, deer, water buffalo, and rabbit.

Systematic introduction of crops reached its peak during the Japanese administration in

Micronesia. A total of 157 varieties of plants producing food, medicinal, and fiber crops were field-tested in Palau; 88 varieties remained after World War 11 (53). Crops include cassava, pineapple, jackfruit, limes, oranges, groundnut, soybean, coffee, cacao, clove, nutmeg, cinnamon, teak, mahogany, ebony, and others, some of which are still present today. Mahogany planted during the Japanese period has largely replaced native hardwood *(ifil)* used in traditional woodcarvings (storyboards). Other crops have potential to provide marketable products

Benefits are obtained from using indigenous or naturalized plants and animals because they are adapted to the local environment conditions and stresses. For example, indigenous crops have adapted to local soil types, climate, and terrain and animals have adapted to local food sources. These indigenous species are efficient users of minimal available resources, and also tend to be resistant to local diseases and pests. Thus, using indigenous crop and animal species adapted to suit the local environment can effectively replace some inputs (e.g., pesticides) which are designed to change the environment to suit the crops or animals (121).

Some indigenous plants offer opportunities for commercial-scale development if markets are available. For these, improved cultivation methods to increase production may be economically justified. However, to develop the potential of native plants, more effort needs to be devoted to identifying potentially valuable species (121).

Introduce Suitable New Cash Crops.—Cash crops (i. e., crops usually providing raw materials for processed products and grown primarily to generate income) can be cultivated on islands for either local or export markets. Local crop varieties generally are preferable to supply local markets, because they are palatable to the local taste and have a number of advantages over introduced crops (22). However, introduced cash crops can provide the means to develop export products.

Characteristics of crops providing products suitable for export markets include: 1) high value of product per unit weight, 2) ease of cultivation and harvest, and 3) ease of processing and transport (43). Pohnpei black pepper, which has these characteristics has been successfully exported in small quantities to the U.S. gourmet market; potential exists for increased production. Other high-value crops that appear suitable to the Micronesia high islands include clove, cacao, cinnamon, nutmeg, vanilla, cashew nuts, and coffee (126,127,128,129,130). All are present in the islands (25).

Introduction of new crops and animals must be carefully weighed against potential undesirable effects on the local environment. For example, introduction of nitrogen-fixing plants generally is considered favorable because they provide an essential nutrient usable by other plants, are fast growing, and can grow on marginal lands. However, giant *Leucaena,* because it grows so rapidly, can effectively outcompete and shade out other, desirable species (22).

POTENTIAL STRATEGY: Integrate Characteristics of Traditional Agriculture Into More Productive Systems

“Neotraditions” of resource use may, in some cases, be suitable for fulfilling local and extended family needs, thus allowing sale of surplus production in local markets. These would involve technologies adapted, via a combination of traditional knowledge and experience and modern science, to today’s conditions (22). This would require evaluation of existing systems to determine which characteristics enhance their productivity and sustainability. Few data currently are available on the productivity or even extent of traditional agriculture systems. One attempt was made to census traditional agriculture production in Micronesia (116), but the results are unreliable (22).[5]

Once existing production systems have been evaluated, they can be compared with other systems and enhanced as needed. Comparisons of caloric and other inputs and production by

[5]Planning for Micronesia agroforestry and subsistence agricultural systems research is underway at the University of Guam (45).

extant and introduced technologies could indicate technologies which could be improved and evaluate needs for new technology. Concurrently, guidelines for development that would assure at least sustainability of a subsistence base of resource uses and foster sustainability of economic development projects are needed (22).

Several common characteristics of traditional systems might be integrated with modern practices to arrive at more productive, sustainable systems. Two of these are interplanting trees with crops and incorporating animals in cropping systems.

Opportunity: Incorporate Trees in Cropping Systems

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, etc.) are used on the same land management unit as nonwoody crops or animals. In agroforestry systems there are both ecological and economic interactions between the different components. The goal is to achieve an efficient use of space, to optimize crop combinations so as to maximize overall productivity, to optimize the ecological balance of the system and, at the same time, to achieve a sustainable yield (121). In addition to products derived from agroforests, agroforestry systems serve as sanctuaries for wild plants and animals and provide recreation areas. Agroforestry also can retain much of the flood and erosion control services provided by forested watersheds, thereby protecting the productivity of the land.

Traditional Pacific agriculture largely is based on tree crops and on preserving the environmental services of trees in cropping systems. Commonly, only small areas of land are cleared at any one time, forest trees and shrubs are selectively cut, and useful plants (producing food, medicines, or building materials) are mulched with leaves and twigs of unwanted species.

In the Caribbean, Puerto Rico's shade-coffee system can be categorized as an intermediate agroforestry system (121). Several plantings in western Puerto Rico, sampled in 1959, contained shade, fruit, and valuable timber species (114). Charcoal, prepared from annual shade tree prunings had a value of $3 million and accounted for over half of the total charcoal produced on the island in 1949 (106). The coffee "forest" production system was probably the start of modern agroforestry practices in Puerto Rico. Other agroforestry technologies practiced in Puerto Rico include coconut/pasture in coastal regions, mangoes/papaya, plantains and bananas intercropped with rootcrops and citron (87).

In the Virgin Islands, with the exception of bay tree plantations, traditional subsistence agroforestry incorporated root crops; vegetables; fruit trees; livestock; and forest species for charcoal, firewood, and construction. The most prevalent type of subsistence agroforestry is found in backyard gardens, which typically have a mixture of perennial fruit tree crops interplanted with short-term food crops. A more specialized agroforestry system is practiced by French farmers who grow herbs and spices along with fruit trees that serve as windbreaks and mark field (87).

Opportunity: Incorporate Animals in Cropping Systems

A primary means of increasing and enhancing local food production is by incorporating livestock in small-scale cropping systems. Island livestock generally are of mixed breed, resistant to diseases and parasites, and suited to island environments.

On some islands, particularly in the FAS, chickens, pigs and, more rarely, goats may be allowed to roam and forage in or near villages. On more developed islands such as in Puerto Rico, Guam, Saipan, and the USVI, free-roaming husbandry of animals other than chickens generally is not practiced (9,app. F).

Free-roaming livestock require minimal care and feeding and, thus, cost little to raise. However, productivity of free-roaming livestock is low compared to yield from more intensively raised livestock. Free-roaming livestock also may present a health hazard, by carrying and spreading diseases.

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Moreover, free-roaming animals can seriously threaten endemic flora and gardens. They also can denude island watersheds, causing serious degradation of "downstream" habitats and structures. Most Pacific island vegetation did not evolve with herbivore pressure and does not contain defenses such as thorns, bad taste, or protective alkaloids. Introduced herbivores may thus feed preferentially on native species and provide inroads for the loss of native species and spread of exotic vegetation (7).

Penning these animals would permit greater control of their diets, can provide an easily accessible supply of manures for comporting or direct application to soils, and would protect valuable endemic species and natural ecosystems. Considerable labor is required to care for penned animals (e.g., feed procurement, feeding, and waste disposal), which may hinder adoption of this technique. Penned animals currently are fed with leftover food, crop wastes, and forage such as *Leucaena* leaves *(108),* which might otherwise be used as soil amendments and conditioners. However, because manures are more decomposed than food and crop wastes, their nutrients are more readily available to plants.

In addition to penning, the yield and efficiency of livestock production can be increased by using improved breeds, better feeds, and more intensive husbandry. Although imported, improved breeds may increase production, most Micronesians prefer local livestock over imported breeds (93). The high costs of both imported and locally produced feed concentrates hamper widespread adoption of this technique. Since most livestock raised in the U. S.-affiliated Pacific islands are for subsistence use, farmers generally will not invest in processed commercial feed. Little research has been conducted on improving livestock productivity on those islands and much is unknown about its performance under intensive management.

Grazing of livestock on pastures grown under coconuts is a major land use activity in many parts of the tropics, especially the Pacific islands (69). Cattle or goats can be raised on natural or managed grasses and legumes. The carrying capacity of both improved and unimproved pastures varies widely depending on the type of forage plants, climate, age and density of the coconut stand, etc. The effects of grazing under coconuts has been studied by the Coconut Research Station in Sri Lanka, indicating that grazing will have no depressive effects on nut yields if fertilizers are applied to both palms and intercrops (69). Primarily because coconut palms are shallow rooting, the potential competition for nutrients with other, interplanted forage crops is considerable, requiring careful management to maintain high productivity of both. However, where enough land is available to rotate the animals among "fields," goats, in particular, can help to reduce weeds that also compete with coconut palms for nutrients.

POTENTIAL STRATEGY: Develop Intensive Commercial Farming

Conditions in the U.S. Pacific and, to a lesser extent, in the U.S. Caribbean islands generally are not favorable for large-scale commercial agriculture development. Constraints include relatively poor resource bases, small land areas, poor and/or expensive transportation services, and relatively high wages compared to labor productivity. In addition, land tenure systems in U.S. Pacific islands and high land prices in the U.S. Caribbean islands are not conducive to large-scale commercial development (43,61, 87,143).

Despite these hindrances to commercial agriculture, some opportunities for development exist. Profitable commercial agriculture development is generally accomplished through the use of modern technologies and careful selection of crops. Technologies range from intensive field farming to containment of crops in hydroponics and greenhouse systems. More specifically, some techniques used in intensive, large-scale farming can be adapted to the U. S.-affiliated islands, including mechanization, irrigation, and agricultural drainage.

Photo credit: A. Vargo

Increased mechanization appropriate to small-plot semicommercial and commercial farms, such as roto-tillers, is a goal of agricultural development on most U.S.-affiliated islands.

Mechanization. —Increased mechanization gives the farmer the ability to prepare farmland with less labor or to farm larger amounts of land. Given islanders' relatively high wage rates and the difficulties of hard physical labor in tropical areas, mechanization probably will be an agricultural goal in the U.S. Pacific (94) and Caribbean (10). Guam has large areas of flat, well-drained, cleared, and accessible land, as do Saipan, Tinian, and Rota, which can support large-scale mechanization. Pohnpei and Palau and, to some extent, American Samoa also have such areas.

Primary tillage—loosening the soil surface to disrupt weed growth–by hand is extremely labor-intensive and arduous, and is not a common practice in the U.S.-affiliated Pacific islands. Animal power has been, for the most part, bypassed in the U.S. Pacific except for carabao (a Southeast Asian water buffalo introduced during Spanish administration) which are used mainly for transport. A project to breed and train carabao in Palau by the TTPI government did not meet with success despite determination that carabao seemed to be the only sensible farm power for hilly, shallow soils and capital-poor farmers (94).

Small-scale rototillers and tractors have met with some success in the U.S. Pacific islands, although few farmers own farm machinery. Several farmers on Guam and Saipan own tractors, discs, and boom-sprayers (84). On some islands, rototillers and other small machinery are loaned to farmers. Some FSM State Agriculture Divisions till land for a nominal fee using government equipment. A Pohnpei State program provides farm clearing and bed preparation at subsidized rates of $10 and $6 per hour respectively. This program has been responsible for an estimated 152 farms cleared and 10 miles of farm roads completed in 1984 alone. Demand is such that farmers may wait 6 months before they receive machine service (94).

A 12-horsepower rototiller should be able to handle up to 5 acres of crops per year, more than sufficient for the average farmer in the U.S. Pacific, Capital investment in this type of tillage machinery is not prohibitive (about $2,000-$3,000) and machinery could be purchased cooperatively.

Secondary mechanization—seeders, sprayers, harvesting equipment, processing equipment, chainsaws, grass-cutters, pumps for irrigation, etc.—may need to be tested and made provisionally available as agriculture develops. Private business could eventually be encouraged to import and sell farm machinery, but the local government could do the initial evaluation and selection of suitable equipment. Cooperative ownership, as with the black pepper processing machinery on Pohnpei, may increase the availability of equipment to local farmers (94).

Irrigation.—Irrigation services are needed for commercial production on islands experiencing a dry season, such as Puerto Rico, the USVI, Guam, Yap, and the CNMI. In traditional agriculture, planting usually coincides with the rainy season, while harvest coincides with the dry period. Only Guam, the Northern Marianas, Puerto Rico, and the USVI have developed notable irrigation systems (61,94). In the U. S.-affiliated Pacific islands most irrigation systems are multiple-user, government-subsidized systems (94), while small-scale irrigation systems are common in the Caribbean (59).

Major irrigation technologies are flood, furrow, sprinkler, and drip irrigation systems. Flood irrigation is practiced in level areas and is well suited to rice and taro production. This type of system was practiced by the Japanese in some areas. Of all the systems however, flood irrigation requires the greatest amount of water, and is relatively ineffective on rolling lands.

Furrow irrigation involves planting on raised beds on level or leveled land and irrigating in furrows on each side of the beds. Furrow irrigation seems applicable to the CNMI with large level areas of land where sufficient water storage can be developed (94). Furrow irrigation has two main drawbacks: high operation costs because more water is pumped than is necessary and low crop yield because water cannot be applied evenly and at optimum frequency. However, in southern Puerto Rico, furrow irrigation helps maintain a stable groundwater balance because excess irrigation water reinfiltrates the aquifer; the only net loss of water caused by irrigation is due to evapotranspiration (61). Interestingly, infiltration of irrigation water has provided a greater volume of groundwater recharge than rainfall along most of Puerto Rico's south coast (28,59).

Sprinkler irrigation is more suited to sloping and hilly lands. The system also is suited to annual, perennial, or polyculture systems. This technology requires a water source, a pumping system and movable pipes with sprinklers. This system is used to some extent in Guam and the CNMI, especially where water is available through government irrigation projects (94).

Drip or trickle irrigation is the most versatile system in that it can be applied to all kinds of crops or crop mixtures, on sloping or flat

Pboto credit: Office of Technology Assessment

Rainwater is collected from outbuilding rooftops and pumped to a water tower on this Taiwan-sponsored agricultural research station on Majuro (Marshall Islands), using gravity flow to distribute it to the crops during dry periods.

lands, and even in greenhouses. This system requires a water source under some pressure (gravity can be sufficient in some cases) fed into a series of hoses or pipes that have small openings or drip nozzles feeding water near the base of the crop plants. Drip irrigation uses much smaller amounts of water than the other systems, and waters only the crop plants, thus reducing weed infestations between crop plants. Fertilizer and other nutrients can easily be fed into the system. No energy or labor is required to move the system once in place, and a biodegradable drip hose has been developed in Hawaii that can be plowed into the field after crop harvest. However, drip irrigation systems are costly, and water flow must be continually monitored to ensure effectiveness (94).

Construction of irrigation systems in the U. S.-affiliated Pacific islands seems limited to large-scale farm development projects primarily due to the high cost of underlying water storage and distribution systems (94). There are 72 irrigated acres on government land on Tinian made available for farmers during the dry season; Rota has a water system that 20 farmers are using and Kagman Station on Saipan provides irrigation to nearly 35 farmers from a well on the Station grounds. In Guam, municipal water is available to farmers for irrigation at 25 percent of cost, but supplies are insufficient. No other areas have irrigation systems operating at present, although infrastructure—canals and ditches—are still left from the Japanese occupation on some Micronesia islands. Considering the existing situation in U.S.-affiliated islands—lack of water storage and distribution systems, limited capital, and sloping land—drip irrigation seems to hold the greatest possibility for future development (94).

Agricultural Drainage.—Although a less common problem than arid lands, some agricultural lands on the high islands, particularly in the Carolines, are constrained by water saturation. Because the roots of most cultivated crops will not penetrate saturated soil and oxygen uptake is hindered, poor drainage can result in a shallow root spread and a commensurate reduction in plant size, stability, and yield. Water-saturated lands also promote surface runoff of rainwater, inducing erosion and increasing the problem of flooding on downslope land (123).

Surface drainage can channel water through shallow-grassed ditches and into outlets, reducing erosion on sloping soils and surface ponding on flat soils. To lower the water table, subsurface conduits, or tiles, must also be used. Drained soils allow surface water to infiltrate the soil, reducing erosion and can help control health hazards to man and livestock such as mosquito and fly-borne diseases. Drainage of wet cropland also can enhance crop production significantly; wet soils often have high potential productivity because they contain more organic matter than soils that are not as wet (123). However, drainage has been specifically exempted from most USDA cost-sharing programs, primarily because of its adverse impacts on mainland wetland wildlife. Adverse impacts also could accrue to island endangered species such as the Guam Gallinule and migratory waterfowl (113).

Opportunity: Intensive Smallholder Commercial Agriculture

Commercial small-scale farms outnumber large-scale farms in both the U.S. Pacific and U.S. Caribbean islands. In Puerto Rico, the average farm size is 33 acres with an average of 16 acres for each farm worker (37). Commercial farm size on Puerto Rico's south coast varies from 25 to 2,000 acres, but only 10 percent are more than 50 acres (135). In the USVI, commercial farm sizes average less than 1 acre per farm, and only three commercial farms in St. Croix consist of more than 100 acres (61).

To be competitive in the market place, small-scale commercial agriculture has to be made highly productive, This can be achieved in several ways:

- increased agricultural inputs in field farming and improved pasture systems;
- increased efficiency in methods for delivering agriculture inputs (e. g., irrigation, hydroponics); and
- cultivation in controlled environments (e.g., greenhouses, shadehouses, soil-less agriculture).

These technologies also are ways to overcome constraints posed by land scarcity, high land prices, scarcity of fresh water, unpredictable weather, and pest and disease outbreaks. The technologies have several things in common: capital outlays can be considerable, most require mechanization, and nutrients and energy have to be continuously supplied or replenished from outside the system. In addition, to implement the systems successfully, the operator must have both technical and business skills, and access to skilled labor and market outlets.

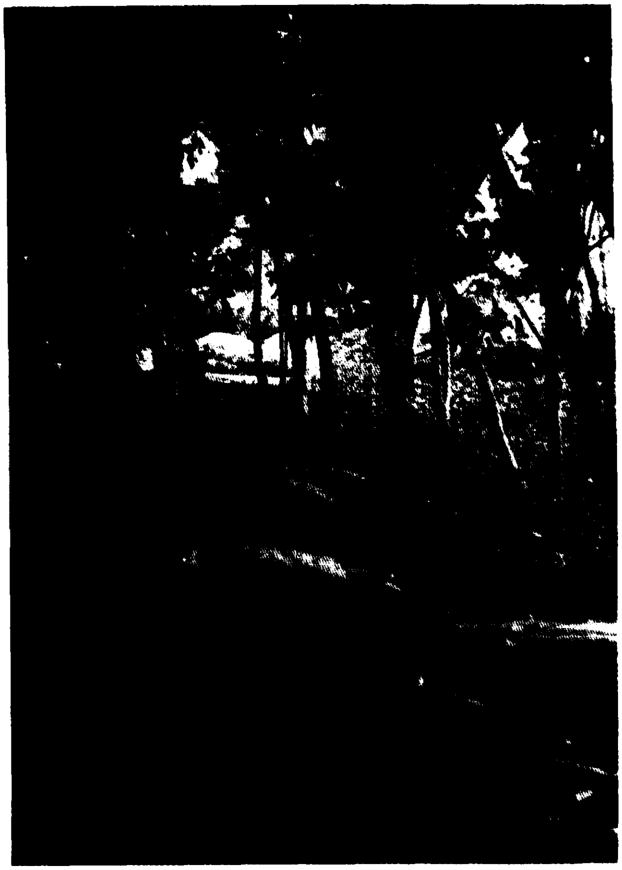
Although increased agricultural inputs commonly increases yields, they may not be sustainable. Yields may suffer if agricultural chemicals are not applied properly or in sufficient quantities. Furthermore, supply shortages, sudden price increases, changes in credit policies, or unreliable transportation services may also contribute to economic instability. High levels of agricultural chemicals applied to fields also may contribute to degradation of nearby environments.

Agriculture development may be constrained by the availability and the willingness of people to work in agriculture. The number and skill requirements of agriculture workers required for intensive small-scale commercial agriculture technologies vary and, thus, different systems have different employment-generating effects. Generally, small-scale farming requires more labor per acre than large-scale farm operations.

Several small-scale commercial agriculture ventures have been implemented on U.S.-affiliated islands with varying degrees of success. Technologies tried include high-input, intensive field cropping systems, hydroponics, cultivation in greenhouse or shadehouse, and intensive backyard gardening.

Intensive Field Farming Systems.—A number of improved agricultural practices have been proven profitable, have increased productivity, have exhibited reduced soil erosion rates as compared to clean-tilled fields, and have been successfully implemented on islands. Examples include intensive "sun-coffee" and plantain cultivation systems in the humid mountain regions of Puerto Rico.

In the past, coffee was cultivated under shade trees. However, research has shown that high density plantings of heavily fertilized coffee, grown without shade, produces higher yields per acre, and is economically profitable (144). A government-sponsored rehabilitation program for the coffee industry, based on intensive cultivation and providing financial assistance for new plantings, fertilizer, and hurricane insurance has met with some success. About 10,000 acres of intensively managed sun-coffee now yield 1,200 to 1,500 pounds/acre. On about 20 farms, harvesting is done with plastic nets rather than by hand; this reduces costs and loss



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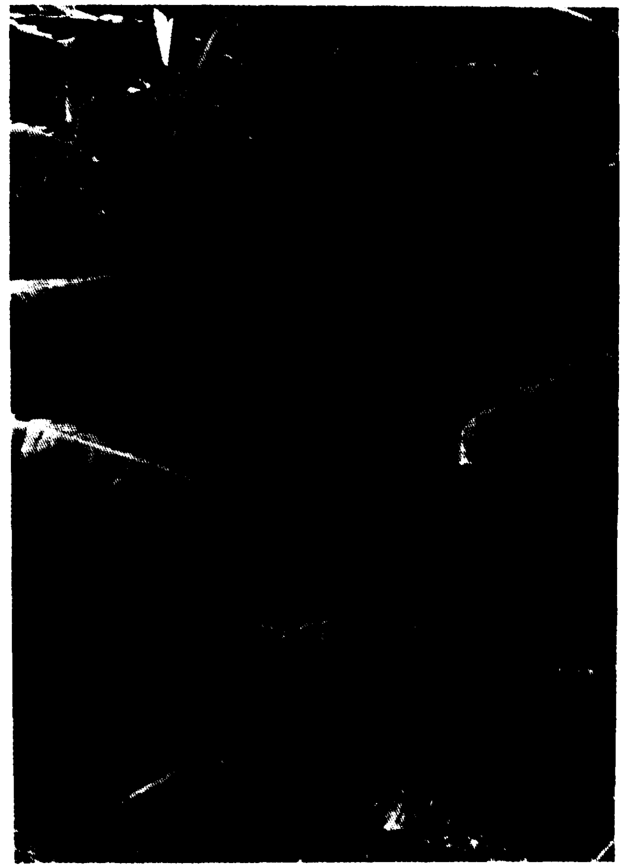

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of berries and effectively increases production. Intensive cultivation methods apply to semi-commercial as well as commercial development. In recent years, small-scale growing of coffee on a part-time basis has become popular among public servants in Puerto Rico.

As is the case for sun-coffee, plantain can be grown in high-density, intensive cultivation, even on relatively steep slopes, using heavy fertilization and intercropping *(143).* In the semi-arid areas of Puerto Rico, plantains can be grown commercially year round by employing drip irrigation systems.

Plantain can also be interplanted as a temporary shade tree and a source of income while permanent crops, such as sun-coffee and cacao, are being established (143). Vegetables can also be interplanted between plantain rows, at least for the first few months after plantain planting. Using appropriate techniques, plantain cultivation can be compatible with conservation *(147).*

Plantains are suitable for family-size commercial farms in the humid mountain regions of Puerto Rico since they provide a high return, do not require mechanization and are drought tolerant. About 3.3 million plantains are produced on *15,000* acres, mostly in small farms in the mountain regions of Puerto Rico, all of which are marketed and consumed locally *(143).*

While increased yields are achieved in both sun-coffee and high-density plantain systems, the high levels of agricultural chemicals required may have adverse effects on island water supplies. The cumulative effect of this is not known. It is likely that nutrients levels in rivers and streams will increase due to fertilizer run-off, increasing eutrophication in ponds and streams and, possibly, adversely accelerating spread of aquatic weeds such as the water hyacinth. Increased water hyacinth growth has been associated with such adverse effects as hindering fishing and fish culture, clogging rivers and canals, and increased schistosomiasis infestations, resulting in increased flood and disease control expenditures (72).

Container Agriculture. -Among the most intensive systems of commercial crop production are greenhouse, hydroponics, and container cropping. These production technologies hold the greatest promise in areas where soils are not productive, as in urban areas or on atolls where high alkalinity and saline conditions preclude standard cultivation practices. These technologies also hold promise for cultivation of some high-value crops that are limited by pests and disease.

When yields are calculated on a per-acre basis, yields from container agriculture are commonly very high and sometimes sensational. A yield of only 3.5 ounces of edible produce from a 0.1-square-yard pot is approximately equal to a yield of 4 tons/acre, a good yield in conventional agriculture. Container agriculture can be used for subsistence or commercial production of salads, herbs, cooked greens, and other vegetables for variety in the diet (50).

Small containers suitable for use in urban areas or on atolls, can be derived from old milk cartons, plastic garbage bags, cans, tires, and other receptacles as long as containers are 1 gallon or larger. Containers made from porous materials lose water through evaporation and thus, although they may require more frequent watering, are more suitable for plant growth in the tropics than nonporous materials (50). Large, permanently located containers allow use of more conventional techniques for plants grown in the ground.

Photo credit" Office of Technology Assessment

Containers for intensive agriculture can take nearly any form and size, although use of abandoned boats for container agriculture, such as on Ulithi Atoll (Yap), can be considered rather unusual.

Soil fertility must be maintained and as much of the plant as possible must be used to make commercial container cropping worthwhile (94). Greenhouses are a special site for container agriculture. Plants in greenhouses are protected from wind and driving rain, but may be exposed to high temperatures, high humidities, and infestations by insects that find greenhouse conditions comfortable (50). If care is taken to ensure that enough water is available in the soil, excess heat radiated from nearby walls or other structures can be reduced by shielding the plants with screen or shade covers.

A friable soil is best for container agriculture it has good aeration and drainage, may have a high organic content and is likely to relatively free of pests and diseases. Coconut husk fiber can improve aeration and peat and sphagnum moss will increase moisture-holding capacity. Crushed shells (including eggshells), coral or limestone, and coral beach sand can be added to neutralize acid soils.

Because relatively small amounts of soil must furnish the nutrients needed in container agriculture, soil fertility must be enhanced by adding commercial fertilizers, liquid fertilizers, or compost. Composted organic material is preferable to raw organic material such as garbage or fresh manure because the latter must deteriorate before they are useful to plants. If the organic content of the soil is high, it will contain a wide variety of micro-organisms, most of which are beneficial (50). When plants have been harvested and removed from their containers, the soil should also be removed and refertilized. Large containers will be needed to store soil to be used in pots, soil to be recycled, and finished compost.

Container agriculture's main requirement is water. Plant size, container size, location, and weather all affect the amount of water needed. Watering devices can be purchased that can water a pot continuously for as much as 1 or 2 weeks; or ropes can be used to absorb and transport water from a basin below the container to any part of the container (50).

plants most suitable to commercial container agriculture are those that can be harvested frequently over along period of time. Some plants, such as leaf vegetables, can be crowded and, thus, profitably planted several to a container. These tend to produce large quantities of edible materials over a long period of time and some act as perennials in the tropics. Many spices and herbs tested also grow well with one to five plants per container. Others, such as tomatoes, produce better when planted only one per pot (and commonly do better outdoors where they have access to greater root areas). Weeds should be removed as soon as they are noticed, before they produce seed or otherwise spread (50).

Greenhouse and Shadehouse Cultivation Systems.—Greenhouse systems were developed in temperate zones to produce fruits, vegetables, and flowers during the cold winter season. In the tropics the greenhouse allows farmers to control irrigation and disease. Crops are cultivated in flats or containers to which water is delivered. Irrigation systems include sprinklers, automatic drip irrigation systems and, for certain ornamental plants, "plant misting" devices. Many crops cannot be grown under heavy rainfall typical of the tropics. By growing these crops in a greenhouse, foliage can be kept dry and soil sterilized.

Greenhouses in the tropics usually have only roofs which are vented to emit excess heat. Materials such as fiberglass, plastic, or polyethylene netting, or saran "shade-cloth" are used for walls and roofs (10). It also is possible, by using canvas dark cloth, to simulate short day lengths, making it possible to grow crops that are day-length sensitive (94).

Shadehouses also are used throughout Micronesia, especially for tree and perennial crop propagation. A shadehouse consists of a wooden or metal frame covered with wood slats or fine netting or commercially available "shade cloth" to allow part of the sunlight to enter. Shadehouses have the dual advantage of subdued light, important for rooting of perennials, and lower temperatures. Shade houses also may be used to grow cool-season crops sensitive to high temperatures and day-length (94).

Although cultivation in greenhouses and shadehouses requires high initial capital outlays, it has a number of advantages over conventional field cultivation methods. It overcomes the need for large tracts of lands, scarcity of fresh water, and can ameliorate seasonal and climatic fluctuations. Types and size of crops that can be cultivated commercially are dependent on the size of greenhouse. And, as in any other commercial venture, business and marketing skills are critical for success.

Insular government agricultural experiment stations in the U.S. Pacific all have greenhouses, mainly for seedling propagation. At Ponape Agriculture and Trade School (PATS), a greenhouse was used for growing tomatoes for a number of years. The project was eventually terminated because of the high labor requirements (the entire soil of the greenhouse had to be sterilized after every production run) and the relatively low demand for tomatoes (94). The high capital costs of building a greenhouse probably limits its use to only high-value vegetable crops.

In Puerto Rico, growing ornamental plants in greenhouses or shadehouses can offer a high investment return, depending on the building design, the type of ornamental plant grown, and the cultural practices used. However, the initial capital outlay for such an enterprise is relatively high, and growing ornamental plants in greenhouses or shadehouses is labor-intensive (lo).

Hydroponic Culture Systems.–Hydroponics are totally controlled systems where plants are grown in a sterile, artificial media—commonly sand, perlite, or gravel—with a premixed nutrient solution continually pumped throughout the system, usually inside of a greenhouse type structure. Crops are grown in containers which, for commercial cultivation, commonly are either long troughs covered with wire meshing or plastic (PVC) pipes with perforations on the top side. Crops are placed in the holes of the perforated PVC pipes or held in place by wire netting that is placed over the containers. Water, plant nutrients, and other agrichemicals are circulated throughout the grow-out containers. Foliage and stems above the water may be treated by spraying.

Most advantages of greenhouse/shadehouse cultivation methods also apply to hydroponic cultivation methods. Hydroponically grown crops commonly are of high quality and crop yields are higher than conventional field cropping methods. For example, yield of hydroponically grown tomatoes is about 10 times greater than tomatoes grown under drip irrigation, and 25 times greater than tomatoes grown using conventional field cultivation methods (10).

Within limits, hydroponic systems are flexible. Varying types and qualities of water may be used as the substrate for growing crops. For example, water that was used for aquiculture can be recirculated and reused for hydroponic cultivation. Research on such an integrated hydroponic-aquiculture system is being conducted at the College of the Virgin Islands (CVI) (92,141).

Photo credit: A. Vargo

A highly specialized form of container agriculture is the hydroponic greenhouse. While greenhouses and hydroponic systems provide a number of benefits individually and in combination, the high capital outlays required largely restrict them to production of high-value crops unsuitable to field agriculture.

The CVI system, based on tilapia and tomatoes or lettuce (92) recirculates water collected on a one-quarter-acre plastic rainwater catchment. The water is directed into freshwater tilapia grow-out tanks, channeled through the hydroponics system, and any surplus is used to irrigate a nearby garden, Combined fish culture with hydroponics systems probably is more economically viable than either hydroponics *or* fish culture alone (5,91). Because of marketing constraints, however, this technology may not be applicable outside of high-demand urban areas.

Hydroponic systems are technically suitable for atolls and high islands in the U.S.-affiliated Pacific, as long as adequate water supplies are available. Hydroponics were used to produce food for soldiers stationed on atolls during World War II (33). Currently, six hydroponic farms produce vegetables, mostly tomatoes, in Guam; one hydroponic farm grows tomatoes on American Samoa and The Gardens Hydroponic Farm on Majuro (Marshalls) grows cucumbers, tomatoes, and peppers commercially (94).

Because of high capital outlay and operation costs, choice of crops is critical for profitability of commercial operations (10). As a result, hydroponically-grown produce typically is more expensive than field-grown produce. Thus, crop choice commonly focuses on a few very specialized crops and is directed toward upper-income specialty markets, such as English cucumbers in Puerto Rico (60). In the U. S.-affiliated islands, crops grown in hydroponic systems largely are restricted to high-value vegetables and herbs. While hydroponics probably will not have a significant impact on the overall produce market, especially in view of the yield-increasing technologies being applied to field-grown crops (e.g., drip irrigation), it has potential for satisfying some specialty market demands currently fulfilled by imported products.

Opportunity: Develop Spices, Essential Oils, and Other Specialty Crops for Export

Historically, spices, perfume and flavoring oils, and specialty crops such as tea and coffee have been highly sought after crops worldwide and evidence exists that markets are growing. For example, the American Spice Trade Association estimates that U.S. annual per capita spice consumption has risen from 10 ounces in 1932 to 36 ounces today, growing 33 percent in the last 10 years (88). Most species are native to warm tropical regions similar to the U. S.-affiliated Pacific and Caribbean islands. Yet, few of these islands grow spices for commercial sale.

With the small size of Micronesia landholdings (usually less than 5 acres), relatively high labor costs compared to the rest of the Pacific, and general high expectations of farm financial returns, spices, essential oils, and other specialty crops seem to hold potential for future commercial development. Numerous spice and specialty crops have been introduced into Micronesia, among them allspice, nutmeg, pepper, vanilla, ginger, and coffee. Moreover, several local and introduced plants can undergo extraction to produce high-priced oils which can be used in soaps, perfumes, etc. (94).

Black pepper was introduced to Pohnpei in 1959 and has become an increasingly important crop for the island's farmers with nearly 70 farmers growing from one-quarter to 1 acre or more. Nutmeg also is produced from six trees growing at the Kolonia Agricultural Station. Ginger is grown commercially at the Protestant Mission at Ohwa. Coffee is grown in the Sokehs area, propagated from the remainder of a Japanese plantation, and the Agriculture Division is investigating the possibility of introducing high-yielding coffee varieties from Costa Rica. Japanese and Fijians have expressed interest in importing sakau (a drink made from *Piper methysticum)* from Pohnpei in the near future. Other local beverages are being investigated for commercialization (94).

A perfume oil from a tree that grows wild on Pohnpei, Ylang-ylang *(Cananga odorata),* has been successfully processed at Ponape Coconut Products at PATS and samples of the oil have received favorable reception in Paris and New York (97). Other crops such as *Fragraea sair* and citrus oils also could provide high-value, low-volume products. In areas with a considerable expatriate or urban population, crops such as ornamental plants or Norfolk Island pines (for Christmas trees) may provide a potential local specialty crop (94).

All of these specialty crops give a high return to labor and management and can be profitable in small plantings. However, because of the small volumes each island could produce, development of spices, essential oils, and specialty crops probably should aim for the gourmet or health food markets where small quantities of product can demand high prices.

While there are little or no duties on dried spices imports into the United States, spice company quality specifications are among the highest in the world (88). The U.S. gourmet spice market is almost entirely controlled by large spice companies such as Spice Islands and McCormick & Co. (36). Even through these companies, however, "gourmet-quality" spices can sell for as much as five times the price of standard spices (57).

Production of gourmet-quality spices depends partly on site conditions and cultivation practices (box 6-A), and partly on handling, processing, and packaging. Some spices are collected from the wild, others are semicultivated and still others, like pepper, take careful cultivation and tending. Those spices harvested in the wild commonly pass through several parties before being sold at the port to a spice company representative. The spice sold at the port, therefore, is a blend of the harvests of many smallholder farmers (57). The more a spice is handled the greater the chance of its contamination with dirt and insects. The final seller must clean the spice before sale to rid it of foreign matter and pests. The harvests of larger producers pass through fewer hands and therefore, are likely to be cleaner and more desirable to the final buyer.

Penetration of the gourmet-quality spice market, then, entails strict quality control and processing standards, which may require farmer cooperative, private joint venture or government oversight during startup. Spice industries also are especially well suited to vertically integrated contract farming (see ch. 8).

For example, black pepper exports from Pohnpei have declined in recent years, partly due to sale of poor quality product; the Pohn-

Photo credit: Office of Technology Assessment

Black pepper has become an increasingly important crop for the farmers and economy of Pohnpei (FSM). Because of its special characteristics, it is estimated that Pohnpei pepper could capture as much as 5 percent of the U.S. gourmet-quality pepper market, even though it currently is grown on plots of 2 acres or less. Other spices may have similar potential.

Box 8-A—Spice Cultivation Research

The quality of a spice (its taste) is believed to be related to a variety of characteristics of the natural site where the spice grows. Rainfall amounts and its timing, soil fertility or lack of it, and cloud cover to mention a few, probably play a role in the taste of a particular spice, but little more is known. Research into the effects of the ecological setting on spice quality is woefully lacking. In addition, improved research on the disease-resistance of spice-bearing plants is needed to offset significant crop losses that occur in the tropics. The U.S. spice industry is only now beginning to conduct the necessary research to help answer such questions (57).

Further, there is little ability to predict the properties a spice will exhibit when it is milled. For instance, nutmeg from one locality will grind to a fine particle size easily and will be easy to handle whereas nutmeg from another site may agglomerate into large particles when ground. Such characteristics play an important role in whether a given spice can find a market. Again, appropriate research could help solve such problems.

While spice companies buy, process, and sell spices, they conduct little research for the use of the grower. The grower or potential grower must seek this information elsewhere or pay for it themselves. Small farmers of the U.S.-affiliated islands are not likely to be able to afford this research. Further, trees that produce many spices can take 6 to 8 years before producing a crop; there is no assurance that the product will be of the quality required to compete in the spice market. Few farmers can take such risks.

In addition, careful market research must precede investment in spice production. For instance, the cinnamon preferred by Europeans is not the same cinnamon preferred in the United States. The first is *Cinnamomum zeylanicum*, whereas the U.S. favorite is *C. cassia* (57). Were a farmer to raise the European favored cinnamon for a U.S. market without knowing of the differences in taste preference the results could be disastrous.

USDA has only general information on growing tropical spices because this is not seen as a major research area. Although some research related to disease resistance, ecological controls, and agronomic practice goes on at certain international and foreign tropical agriculture research centers (e.g., FAO, Spice Research Center in India), little of the information seems to reach insular spice farmers. Extension of this information is a weak link in improving spice farmer's production and the crop's quality.

Research on certain spice, oil, and specialty crops (e.g., pepper, ylang-ylang) is underway at the Ponape Agriculture and Trade School in the FSM. Preliminary results from this research indicate a significant potential from development of spice and essential oil crops. However, further research and strong farmer extension programs will be necessary to develop insular spice, oil, and specialty crop industries fully (95).

pei State government has plans to repossess the government-purchased processing equipment so that it can be more closely supervised (94). To date, the centralized dryer on Pohnpei has provided a check point for quality control but also has proved to be an impediment to farmers in outlying regions; research is underway on solar dryers which would allow initial processing to occur on the farm (38).

Despite the relatively small quantities of product that might be produced on U.S.-affiliated islands, this could have a significant impact on the livelihood of the islands' smallholder farmers. Under current cultivation practices, Pohnpei pepper could capture as much as 5 percent of the U.S. gourmet-quality pepper market with product grown on only 80 acres of land (36), or eight times the acreage currently devoted to pepper on Pohnpei. At present an estimated 70 farms ranging from 0.1 to 2 acres produce pepper (38); growth of this industry could support, at least partially, numerous other smallholder farmers,

Opportunity: Develop New Products From Extant Crops

Local processing of crops can provide higher returns to growers, compared to exporting raw materials, and can provide import substitution opportunities. Major opportunities for development of new products from locally available crops are coconut oil products, fruit juices, and animal feeds.

The major commercial crop in the U.S. Pacific is the coconut, from which copra is made. Copra oil processing plants exist on Majuro, Moen (Truk), Palau, and Pohnpei. Yap is in process of building a plant, The Pohnpei Coconuts Products plant has developed a line of products—laundry and bath soap, dish soap, cooking oil, body oils, and shampoo—for the local and tourist markets, Plants on Truk and Yap will offer similar products, mainly for import substitution. Copra oil is a potential substitute for diesel oil, but its cost ($4.00/gallon) compared to imported diesel oil ($1.50/gallon) is prohibitive at present (94).

Surplus fruit crops can be made into jams and jellies, juiced and bottled, or used in production of fruit ices, currently popular in areas having refrigeration, Small-scale juicing machinery, suitable for small quantities, are available and are employed on other Pacific islands. Through a successful Yap government sponsored radio campaign, coconut milk has replaced large amounts of imported canned beverages; similar campaigns could promote locally produced juices (94).

Opportunity: Support Large-Scale Farming Systems

Large-scale field farming operations need large tracts of uniform soils suitable for the chosen crop. For row-cropping, soil topography should be fairly level to accommodate mechanization and other farm management practices necessary for high uniform productivity. Large parcels of land of uniform type soil are scarce in most of the Pacific territories. While relatively large parcels of uniform lands are available in the U.S. Caribbean islands, land prices are exorbitantly high *(87,143).*

Conventional, mechanized, clean-tilled field farming that characterizes most large-scale commercial farming generally requires considerable levels of agricultural chemical inputs, such as fertilizers and pesticides, to maintain crop yields. In addition, large-scale conventional field-cropping of short-term crops generally entails greater risks of soil erosion and other ecological damage than other systems such as smallholder farming *(22,43,94).*

Finally, large-scale commercial farming requires large markets to absorb production volume. Since local markets on islands are small or the local buying power is low, large-scale producers generally export the products. While export potential exists, it is difficult to achieve *(43).*

Despite these constraints, opportunities for large-scale commercial farm development exist, particularly in Puerto Rico. Careful selection of technologies and crops is crucial for profitable large-scale commercial operations. Business and operational skills, marketing skills and careful timing (e. g., to supply fruits and vegetables to the U.S. mainland "winter market") also are essential.

Increased agriculture yields in field farming generally is achieved by intensifying agriculture inputs or using highly efficient input delivery systems, such as drip irrigation. However, under certain circumstances, improved management of crop production alone will increase yields. For example, low yield of sugarcane in Puerto Rico is primarily due to inefficient drainage and irrigation systems, inadequate pest control, and poorly timed and inefficient harvesting operations (143). In other cases, new technologies may be needed to increase productivity and product quality *(61,143).* In addition to the intensive cultivation of sun-coffee and high-density plantain, large-scale intensive pasture improvement for commercial cattle rais-

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ing has been successfully accomplished in Puerto Rico (9,143).

Conventional Field Farming Systems.–Conventional field cultivation systems are characterized by mechanized operations, clean-tilled fields, and monocultural crop cultivation. To maintain high crop yields, chemical fertilizers and pesticides are used. Gravity (furrow) or sprinkler irrigation systems are common. In Puerto Rico, principle crops cultivated this way include sugarcane, plantains, pumpkin, pigeon peas, pineapple, and some vegetables (61).

Due to high production costs, conventional field cropping for most crops is not economical. High production costs are related to high energy cost, relatively high labor cost (compared to neighboring non-U.S. islands and countries), low labor productivity, and the application of inefficient agricultural technologies. For example, gravity irrigation is considered inefficient compared to the sprinkler or drip irrigation systems, in terms of the amount of water used for irrigation. Although mechanized, clean-tilled agriculture systems have several advantages, given the vulnerability of most tropical soils to erosion from heavy rainfall, the overall effect can be long-term soil impoverishment.

High-Input, Improved Pasture Technologies. —Large-scale, high-input improved pastures have been used in cattle ranching in Puerto Rico. Pasture improvement is instrumental in increasing beef and dairy milk production.

Cattle can be raised on unimproved or improved pastures. Ranching on unimproved pastures is practiced in areas where few alternative land uses exist, such as the semiarid areas of southern Puerto Rico and the USVI (9). Raising cattle on unimproved pastures requires little capital investment and labor. Some landowners in the USVI raise beef cattle on unimproved pastures for investment and tax purposes until these lands can be developed for other uses and sold at a profit (9).

However, raising dairy or beef cattle on improved pastures is considered by some to be the best land use of idle lands in Puerto Rico's mountain regions. Well-managed tropical pastures in steep mountain regions helps protect soil against erosion (145). Soil losses on intensively managed pastures amounted to only 1 ton/acre/year; the lowest for any current mountain agricultural practices in Puerto Rico (101,146).

In Puerto Rico, as much as 100,000 acres of mechanizable land are in intensively managed pastures—primarily for dairy cattle—and an additional 500,000 acres are in less-intensively managed pastures for beef cattle production. Five thousand acres of improved pastures are reportedly being used for dairy in the USVI, 8,000 acres for beef production, and 12,000 acres are in unimproved grassland (9,81,82, 143). However, only part of this pasturage is truly productive; many smallholders apparently graze a small number of animals on their few acres in order to receive tax reduction accorded to "farms"; when the price of land rises high enough such land may be sold for condominium development (56).

Cattle pastures occupy about 22,500 acres in the Northern Marianas (primarily on Tinian), about 170 acres on Guam, 350 acres on American Samoa, and less then 1,000 acres in various other Pacific islands (12,46,134,135,137). Considerable opportunity exists to expand livestock production in the CNMI (84).

Drip Irrigation on Semiarid Lands.–Semiarid lands comprise about 20 percent of the land area of the U.S. Pacific islands (primarily on atolls) and about 40 percent of the land area of the U.S. Caribbean islands, including 60,000 acres in southern Puerto Rico (61,143,150). Semiarid lands are generally associated with high salt and alkali levels in soils, brackish water intrusion into groundwater and, on atolls, salt spray. These undesirable conditions make conventional agricultural practices difficult.

One way to make these lands more productive is through irrigation. Drip irrigation is a particularly efficient and water-thrifty method of water use for crop production; it is 13 percent more efficient than the sprinkler irrigation, 31 percent more efficient than pipe irrigation, and 56 percent more efficient than conventional furrow irrigation systems (10). In some cases, drip irrigation systems can reduce fertilizer costs by about 25 percent. Although total water purchase costs can be reduced from 30 to 50 percent (154), the cost per unit of water delivered to each plant (which includes preapplication filtration, higher pumping costs to provide higher pressure and equipment amortization, as well as water purchase costs) typically is higher in drip irrigation than other irrigation systems (59). The systems can be applied on small or large scales and in manual or automated operations, with varying complexity of hardware, capital investments, and severity of freshwater constraints.

Crop yield is higher under drip irrigation than under conventional rainfed field cropping. In semiarid lands of southern Puerto Rico, drip irrigated crops produced two to three times higher yields than conventional small-scale commercial field cropping (table 6-7) (61). However, the total net value of products is basically the same due to the high initial capital investment and high operation costs for drip irrigation systems.

Installation of drip irrigation systems in Puerto Rico costs between $1,500 to $2,000 per acre for a typical farm (32) compared to $1,000 to $1,400 in the Western United States (6). Sophisticated and costly filtering and backflushing systems commonly are required to keep the systems from clogging due to suspended particles in the water. Because of the high costs, only crops with assured markets can be grown economically.

Opportunity: Develop Commercial Forestry

Reliable information on the original extent of island forests does not exist, but forests probably covered most of the islands. Most of the islands have been largely deforested at some time during their colonial histories, and some are naturally regenerating second-growth forest on abandoned lands. Today, at least one-third of Puerto Rico is again under forest cover; much of this land is too steep for other uses (121).

Some wood products are harvested on most U.S.-affiliated islands, such as fuelwood, wood for charcoal production, poles, and home construction materials. However, most wood products are imported. For example, American Samoa imports nearly all wood products except fuelwood from nearby independent Western Samoa and from the United States and New Zealand. In 1981, Puerto Rico produced about 100,000 board feet of hardwood timber with a

Table 6-7.—Comparison of Yields under Drip and Conventional Irrigation Systems in Semiarid Zones of Puerto Rico

	Drip irrigation				Conventional irrigation	
	Agricultural experiment station		Private growers		Private growers	
Crop	(Box/Ac)	(Tons/Ac)	(Box/Ac)	(Tons/Ac)	(Box/Ac)	(Tons/Ac)
Vegetables:						
Tomatoes	669	10.0	1,000-2,000	15-18.7	600	7.5
Peppers	528	10.5	800-1,000	20-30	400	8.0
Eggplant	668	13.3	1,000	20	400	8.0
Cucumbers	921	18.4	500-1,000	12-25	250	6.0
Squash	—	20.0	—	10	—	6.0
Watermelon	—	12.7	—	2-3	—	3.0
Cabbage	—	15.6	—	10	—	5.0
Onion	—	10.4	—	10	—	5.0
Tree crops:						
Plantain [a]	35,000	21.0	40,000	24	30,000	18.0
Bananas	1,200	24.0	1,000-1,300	20-26	700	14.0
Papaya	—	—	—	40	—	25.0
Avocado	—	3.5-5.0	—	4-5	—	3.0-4.0

[a]Yield computed based on 0.6 lb/fruit *average* weight since this crop is normally sold on a count basis rather than by weight.

SOURCE: G. L. Morris, and D J. Pool, "Assessment of Semiarid Agricultural Production Technologies for the U, S.-Affiliated Caribbean Islands," OTA commissioned paper, 1966

Photo credit: Office **of Technology Assessment**

Although forestry research is being conducted on most U.S.-affiliated islands, including this experimental plot at an Agricultural Experiment Station on Pohnpei (FSM), most wood products continue to be imported to the islands.

retail value of about $200,000, while the island's imports of forest products totaled $410 million (121).

Until recently, the forests in the U.S.-affiliated islands have not been managed actively. In fact, while overexploitation is not now a problem in most areas, poor land uses in the past have left the islands with significant amounts of abandoned agricultural land and relatively unproductive secondary forests. Development and implementation of appropriate forestry technologies could help alleviate rural unemployment, provide local substitutes for some imported products, and help protect land and nearshore resources against erosion, floods, sedimentation, and similar environmental damage.

One method to derive economic benefits from forest resources without disrupting their environmental services is to promote the profitable and sustainable use of animals and plant products other than wood. The potential to develop such products is not large in Puerto Rico and the USVI, but some opportunities exist, such as small-scale production of honey, bamboo products, and eucalyptus leaves and oil (121). Because gathering activities are a normal part of subsistence life on the Pacific islands, this sort of development has considerable potential. With careful management to avert the threats posed by gathering activities to indigenous animal and plant life, harvest of products such as essential oils and mangrove aquatic organisms can continue on a subsistence and semicommercial scale without causing forest degradation.

Relatively little potential for full-scale industrial logging exists in the U.S.-affiliated islands due to limited acreages, topographical factors, competing land uses, small landholdings, high land prices, and uncertain land tenure. Significant potential for commercial forest plantations exists only for the larger islands of Puerto Rico, American Samoa, Guam, Pohnpei, and Palau. However, standard timber stand improvement techniques, such as enrichment planting (wherein higher value species are underplanted in natural second-growth forests) could result in valuable future timber stands on these islands (121). Some of these techniques are being used in the Puerto Rican National and Commonwealth forests. Subsequent harvest provide income for the Puerto Rican Division of Forestry and supports further management of the Caribbean National Forest.

Considerable potential does exist for small-scale industries that can serve domestic markets (121). For example, portable sawmills were introduced to Puerto Rico in 1982. Teak, mahogany, and Caribbean pine have been successfully and economically thinned, milled, and marketed by the Puerto Rico Forest Service. portable sawmills, combined with regulation

Photo credit C. Whitesell

Small portable or stationary sawmills (shown here on Pohnpei, FSM), combined with reforestation and regulation of exploitation, probably are the best-suited timber harvesting systems for the U.S.-affiliated islands because they can support rural industries and yet can be temporarily retired without significant economic disadvantage.

of exploitation; are probably the best-suited harvesting systems for the western Pacific as well, because they can be used as needed and temporarily retired without significant economic disadvantages. Because they can be pulled to the harvest site behind small vehicles, they cause less harm to thin soils than larger systems. They do not require an extensive road system and they leave bark and branches on the site, thus reducing nutrient loss.

Moreover, small-scale sawmills in rural areas can stimulate development of local workshops with corresponding effects on rural employment. These effects could be expanded by introducing facilities such as simple and inexpensive solar kilns or wood preservation equipment. This type of forest industry can be upgraded as workers improve their skills, local management masters the task, and local markets grow to absorb the increased production.

Even though managed second-growth forest is not likely to become a major land use in the U.S. insular areas, it merits consideration as an improvement over unmanaged, low-quality brush or forest land unsuitable for agriculture (121). In Puerto Rico, managed second-growth forests can provide a first harvest before conversion to plantation forestry or increase the value of land deliberately held out of intensive production (e.g., recreation sites).

The most pronounced impacts of forest degradation in the U.S. tropical territories are on island streams and coastal resources. Deforestation has caused permanent streams on some islands to disappear and contributes to increased runoff, flooding, water shortages, and erosion. Siltation has harmful effects on lagoons and reefs, affecting fish and other marine resources important to island people. Increased financial and political support for insular forestry programs could foster reforestation, development of plantation and second-growth forest management, and build local forest industries. Further, science and environmental education in primary schools could direct students towards an understanding of the importance of forests to quality of island life and encourage them to enter relevant fields of study.

TECHNOL0GIES SUPPORTING AGRICULTURAL SUSTAINABILITY

Agriculture cannot be a productive sector of island economies if soils become too nutrient-depleted or if erosion cannot be controlled. Thus, many technologies supportive of agricultural sustainability are aimed at restoring or improving soil quality, or at minimizing soil loss through erosion. Terracing and contour farming, cultural practices and crop choice, conservation tillage, and revegetation can all be used to control erosion. This will have the additional beneficial impact of reducing sedimentation in shallow coastal waters—probably the single greatest cause of coral reef degradation around high Pacific islands (40). Soil amendments and composts, use of nitrogen-fixing intercrops, and salt-resistant crops can increase productivity on infertile soils. Lengthened fallow periods allow natural soil organic matter recovery and growth of regenerated vegetation helps prevent erosion. Finally, reducing crop losses from pests can reduce the extent of land and intensity of use required to meet a production goal.

POTENTIAL STRATEGY: Minimize Soil Erosion and Degradation

Before human intervention, most lands in the U.S.-affiliated islands were forest-covered. Although tropical soils are diverse and variable, in general, few tropical forest soils can sustain productive agriculture over the long term. The presence of either heavily leached soils of low fertility, thin erosion-prone soils, or dry soils makes the establishment of permanent sites extremely difficult. Although soils on certain deltas, young volcanic materials, and flood plains may be fertile, most soils in hot, wetlands have significant fertility problems caused primarily by leaching of nutrients from rock and soil mineral particles. Often, such soils have a poor ability to hold common plant nutrients; if such nutrients are added to the soil as fertilizer they can be expected to be leached away rapidly (121)

In arid/semiarid areas, such as Puerto Rico's southern coastal plain and the USVI, nutrients needed by many plants commonly are in the soil, but become available to the plants only if sufficient water is available. If most of the water evaporates rather than percolating through the soil, dissolved solids or salts can accumulate at or near the land surface in concentrations that few plants can tolerate (121).

Tropical mountainous soils are, in general, rocky, thin, and easily eroded (121). U. S.-affiliated tropical high islands tend to have substantial areas of steep ridges and deep valleys; mountain slopes are extremely steep. For example, about half of Puerto Rico consists of slopes of 450 or more (137), and only 30 percent of American Samoa has slopes less than 30° (138). Thus, minimization of soil erosion and degradation are integral to maintain productive agriculture in the U.S.-affiliated islands.

Soil erosion is greatest in conventional row-cropping, where soil is loosened and exposed to weathering. For example, studies of test plots in Puerto Rico indicate that, on sloping lands, improved pastures suffer the least (1 ton/acre/year) and clean-tilled cultivated crops the most (17 tons/acre/year) soil losses (101,146). Row crops grown under clean-tilled agriculture commonly do not provide soils with adequate protection against heavy rainfall. Depletion of soil

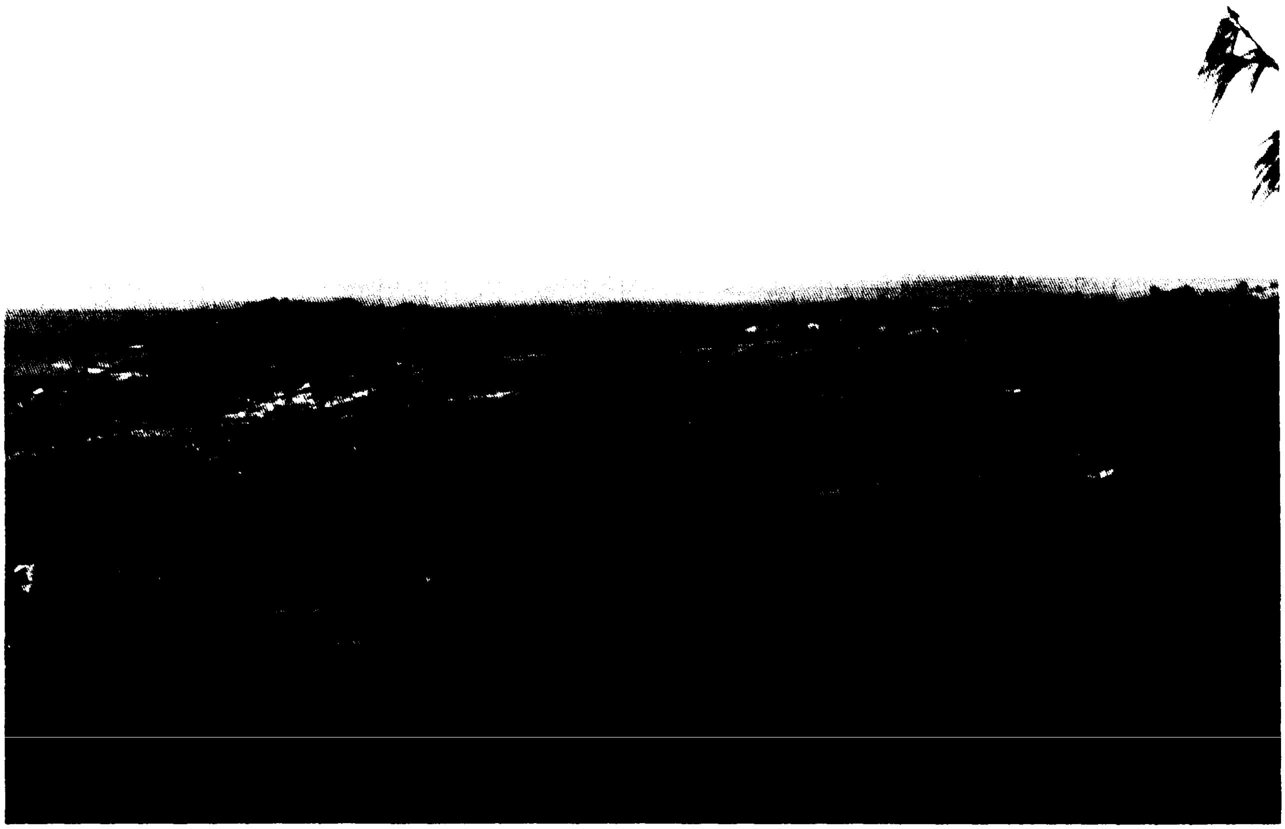


Photo credit: Office of Technology Assessment

These degraded volcanic soils on southern Guam illustrate the potential for reduction in development options caused by uncontrolled soil erosion; few species can survive under these conditions. Revegetation of these lands with more desirable species will be a difficult, costly, and lengthy process.

nutrients through erosion and leaching and changes in soil texture associated with clean-tilled cultivation methods result in soil degradation.

Soil degradation also can be the result of shortened fallow periods. Shortening of fallow periods can "short-circuit" the natural regenerative capacity of the ecosystem. Natural vegetation contributes organic matter to the ecosystem, and gradual accumulation of this organic matter allows the land to recuperate and become productive.

In Micronesia, degraded lands are characterized by depauperate vegetative cover consisting of savanna dominated by swordgrass *(Miscanthus)* or *Gleichenia* ferns and *Pandanus* trees. Frequent deliberate burning of vegetative cover make these lands increasingly unproductive (22,121).

Ways to prevent land degradation or to improve marginal and degraded lands include the following:

- lengthen fallowing periods,
- restrict and control burning,
- implement soil conservation measures,
- apply soil conserving cultural methods, and
- enhance reforestation programs.

Opportunity Lengthen Following Periods and Restrict Burning

It is well known that shortened fallow periods will degrade tropical soils because organic input into the soil from regenerated vegetation is curtailed (121). Furthermore, too frequent burning of old garden sites, shortened fallow periods, and open field row-cropping practices without sufficient addition of organic matter will rapidly deplete soil fertility (22). Severely depleted soils will support little vegetative growth. Soils with little vegetative cover are prone to erosion and leaching by heavy rainfall and strong wind.

Normal fallowing periods might be shortened by planting nitrogen-fixing legumes. Woody species might also provide useful products such as posts and fodder. However, care must be taken in choosing varieties; for example, giant Leucaena can be difficult to control and can grow tall quickly enough to shade out fruit trees (22).

Opportunity: Implement Soil Conservation Measures

Contour cultivation and terracing on sloping lands and covering freshly prepared soil with mulch may reduce soil erosion problems (143).

Terracing. —A classic example of soil conservation measures for cultivated lands is terracing of steep lands. One example of terrace farming is perennial herb cultivation on rock terraces in the USVI. Herbs and spices are grown essentially clean-tilled on narrow, irrigated rock terraces along with fruit trees that serve as windbreaks and also mark field boundaries (52).

Other terraces have been constructed on steep slopes using contour rows of closely spaced fast-growing trees. Trunks are allowed to stand, serving as retaining walls with the new growth regularly cut and piled horizontally above the trunks. At regular intervals soil is piled up on top of the organic debris for gradual formation of bench terraces. Hardy, tall grasses also have been used to form bench terraces. Both terracing and contours increase water infiltration and organic matter accumulation as well as control soil erosion (52).

Terraces are earth embankments, channels, or combinations of embankments and channels built across the slope of the land at suitable spacings and with acceptable grades (box 6-B and figure 6-3). They provide maximum retention of moisture for crop use and reduce soil erosion by removing surface runoff at a nonerosive velocity and/or reducing peak runoff rates (123). Terraces may also facilitate irrigation and drainage, as well as cultivation. Benches can improve drainage by concentrating runoff at the inside of the bench and then draining it along a controlled lateral gradient to a protected waterway. They are suited to annual, semipermanent and mixed crops and can be applied on slopes up to 300 (122). Through these mechanisms water quality in adjacent streams may be enhanced.

Terraces may trap up to 85 percent of the sediment eroded from the field, although they cannot stop erosion between terraces. Terrace construction may cause surface compaction and remove topsoil from large areas of the field. Uneven drying, pending, and severe erosion in different parts of the same terrace channel are also common, especially for the first 3 to 5 years after construction. In addition, misalignment of terraces may result in problems with maneuverability of machinery and maintenance of grass waterways.

The design and construction of a terrace system is labor-intensive and often expensive, and may require skilled professional assistance. Further costs include loss of land to terrace backslopes, loss of crops during construction year, higher labor and energy costs to work terraced fields, and costs of controlling insect pests that may be harbored in backslope grass strips. In addition, maintenance is mandatory to retain an adequate terrace cross section for proper functioning of the system (123).

The applicability of terracing in island areas may best be illustrated by example. During the Danish control of the USVI, the islands were nearly covered with stone terraces, allowing extensive cultivation of sugarcane on steep slopes. This method fostered a sugar economy that persisted for nearly 100 years. Similarly, early inhabitants of some of the Micronesia islands created terracing for agricultural purposes. Remnants of stone terracing still remain in Palau and the Marianas.

Box 6-B.--Terracing

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

- Bench terraces: A series of level strips running across the slope supported by steep risers. These can be used on slopes up to 25° and are mainly used for upland crops.
- Hillside ditches: A discontinuous type of narrow, reverse-slope bench built across the hill slope in order to break long slopes into many shorter ones. The width of the cultivable strips between two ditches is determined by the slope of the land. They are inexpensive, flexible, and can be built over a period of years. This treatment can be applied to slopes up to **25°**.
- Individual basins: Small, round benches for planting individual plants. They are particularly useful for establishing semipermanent or permanent tree plots to control erosion. They should normally be supplemented by hillside ditching, orchard terracing, and crop covering.
- Orchard *terraces:* A discontinuous type of narrow terrace applicable on steep slopes up to 300, Spacing is determined by *distance between trees. Spaces between* terraces should be kept under permanent grass or legume cover.
- Intermittent terraces: Bench terraces built over a period of several years.
- Convertible terraces: Bench ter**with the spaces between**s planted with tree crops.
- Natural terraces: Constructed initially with contour embankments (bunds) 20 inches high on slopes not over 7° and on soils having high infiltration rates.
- Hexagons: Special arrangement of a farm road that surrounds or envelops a piece of sloping land treated with discontinuous terraces which are accessible to four-wheeled tractors. This treatment is primarily for mechanization of orchards on larger blocks of land and on slopes of up to 20°,

Contour Farming.—The practice of planting on a line perpendicular to the slope of the land is termed contour farming. This practice is relatively inexpensive, basically only requiring a reorientation of planting patterns. The effectiveness of contouring however, decreases as the inherent potential for erosion increases. Some climatic, soil, or topographic conditions may limit the application of contour farming,

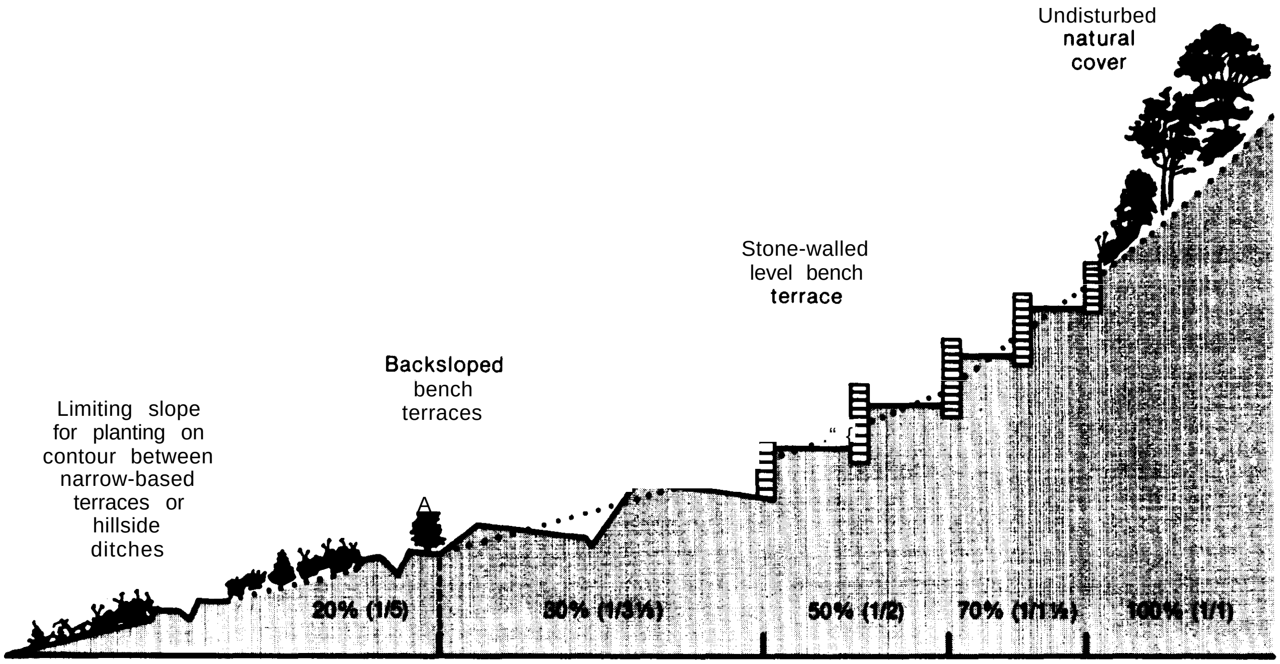
A variation of contour farming is contour stripping in which relatively narrow strips of crops are interplanted with close growing pasture grasses. The strips are oriented approximately on the contour and perpendicular to the slope. Similarly, strips of erosion-resistant crops can be alternated with strips of erosion susceptible crops, The actual width of the strips varies with the topographic features such as length, degree of slope, and exposure of the slope to winds, and with factors affecting field erodibility, e.g., soil texture, roughness, wind velocity, frequency, and direction (122).

Contour strip cropping may significantly reduce soil erosion beyond regular contour farming. The grass strips serve to slow the velocity of the runoff and further reduce soil loss, Contour strips are relatively inexpensive to install, however, some acreage is lost to the maintenance of the grass strips, headlands, and waterways, thus reducing productive acreage.

Many tropical areas suffer from severe soil erosion and implementation of some variation of these cropping schemes may serve to decrease soil loss. However, rainfall levels and soil depth may limit the effectiveness of these practices.

Mulching.—Mulches, nonvegetative, and processed covers can protect areas from severe soil erosion, and contribute to soil moisture reten-

Figure 6-3.—Slopes and Appropriate Conservation Measures



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

red W.

Terraces can be designed for varying farming scales and systems, and to fit differing availability of labor and capital, ranging from handmade stone terraces such as on this communal farm on St. Thomas (USVI) to large, grass-backed bench terraces developed at the Mayaguez Tropical Agriculture Station (Puerto Rico) in the 1930s.

tion. Mulches contribute to retention of soil moisture by reducing loss by evaporation as well as discouraging weed growth.

Organic (grass, leaves, etc.) and inorganic (plastic) materials may be used as mulch. Soil quality is enhanced by decomposing organic mulches. Further, organic mulches contribute to reducing soil temperature and thus keep root systems cool (102, 122). Plastic mulches, while more durable, may increase soil temperature.

Fertilizer application becomes more difficult in mulched fields; fungi growth may be encouraged in more moist areas and insect pests may become established in the mulch requir-

Photo credit: A. Vargo

Mulching is a common agricultural practice on the U. S.-affiliated islands to reduce weed infestations, help retain soil moisture, and provide soil cover. Organic mulches, which also provide nutrients as they decay, can be applied by simply cutting weeds on the site and planting through them after they have dried.

ing some pesticide application or biological control. However, appropriate mulching techniques, such as leaving space around the stem of the plants to reduce fungi and pest attack of the stem, can be employed to offset inherent problems with mulching.

Costs often prohibit widespread application of this method of erosion control. However, it may be appropriate for some open field crop lands, specialty crop lands, and "hot spot" erosion problems in large dryland agricultural areas (122) such as the south coast of Puerto Rico.

Land Leveling.—Land is often leveled or benched for purposes of water erosion control, irrigation, and moisture conservation. Land leveling may facilitate drainage and mechanization and reduce wind erosion by shortening field lengths and reducing slope (122).

However, land leveling is expensive and is profitable only for high-value crops. Puerto Rico employed precision land leveling to prepare approximately 5,000 acres for rice production in 1978. The effort was costly in both time and money. Currently, only 2,500 acres are producing (143).

Opportuntiy: Apply Soil-Conserving Cultural Practices

Careful selection of crops and cultural practices can minimize soil losses. Well-managed pastures and, to a lesser extent, certain cultivation methods of plantain, banana, coffee, and cocoa may offer varying degrees of protection against soil erosion on sloping lands. Conservation tillage (e. g., no-till farming) can reduce erosion. However, polyculture is the primary means to minimize the adverse environmental impacts of cropping on sloping lands. Interplanted shrubs or trees also can protect crops from wind damage and salt spray.

Soil-Conserving Crops and Intercrops.—Groundcover legumes such as Centrosema *pubescens, Desmodium trifolium,* and *Pueraria phaseoloides* can be grown to provide fast vegetative recovery on bare soil. These plants fix atmospheric nitrogen, add organic matter (green manure and forage), and shield the bare soil surface from erosion (74). In Papua New Guinea, winged bean traditionally is grown on stakes for pods and seeds or grown unstaked for tubers and as an effective ground cover. Every part of the plant is edible and contains high levels of protein (77).

Tree crops are the primary means for limiting soil erosion in tropical agriculture. These can be intercrops, or as boundary "hedgerows" on clean-tilled agriculture.

Conservation Tillage.—Conservation tillage involves allowing approximately one-third of the mulch from previous crop harvest to remain above the soil surface after planting (120). This cropping system is designed to reduce soil erosion and aid in soil moisture retention by absorbing the impact of rainfall and protecting the soil surface from wind abrasion. Further, the crop residue contributes to the decrease of soil temperature.

In addition to erosion control benefits, economic incentives for adoption of this technology exist. Reduced labor requirement—less time is required to till the fields; reduced preharvest fuel requirement—fewer passes across the field are required; lower machinery costs—

lighter, and thus less expensive, machinery can accomplish the tillage, and benefits of reduced soil erosion allow expansion of cropping onto sloping lands.

However, the crop residue which remains may also offer habitat for insect pests as well as plant diseases. While disease-resistant crop varieties may be available, increased pesticide applications may be required to control insect pests. In poorly drained soils conservation tillage may prove undesirable.

This tillage method also relies heavily on herbicides for weed control which may have far--reaching ecological impacts (120). Most herbicides do not attack the root systems of weeds, thus in tropical areas where the growing season is year long, frequent application of herbicides may be necessary.

Conservation tillage schemes have proven successful in reducing sedimentation from agricultural runoff. However, the increased chemical pollutants and nutrients may adversely affect water quality and aquatic life. Additions of nutrients accelerate plant growth in aquatic systems which in turn reduces oxygen concentrations. This accelerated eutrophication can significantly affect fish survival. Increased herbicide and pesticide applications may infiltrate groundwater supplies (120). Since the freshwater lens beneath islands is small, the contamination can be significant, affecting the entire island's freshwater supply. Contaminants contained in runoff and carried to streams and nearshore waters may damage associated aquatic life.

The net result of conservation tillage on nutrient pollution of surface water and groundwater will vary under different conditions. For example, losses for either system can be quite high if rainfall occurs shortly after fertilizers or pesticides are applied. Tropical regions generally receive abundant rainfall, thus increasing the chance for higher pollution rates, as well as necessitating increased fertilizer and pesticide applications since much would be lost in runoff.

Hedgerows and Shelterbelts.—Hedgerows (windbreaks) and shelterbelts which reduce field length and windspeed also help control soil erosion from wind and water (120,123). Further, they enhance water retention in the soil and improve associated stream water quality by capturing sediment from runoff. An early Danish conservation law (1840) in the USVI involved the maintenance of fruit tree stands as shelterbelts to enhance water retention. Applications such as this provide both ecological and economic benefits.

The effectiveness of any barrier depends on the wind velocity and direction and on the shape, width, height, and porosity of the barriers. Nearly any plant that reaches substantial height and retains its lower leaves can be used effectively as a barrier. Tree windbreaks have most application on sandy soils and in areas where there is substantial rainfall. Typically, on atoll islands where crops are extremely vulnerable to wind and saltspray damage, the beach strand vegetation is maintained on the seaward side of the island to function as a windbreak. Narrow rows of of tall-growing field crops, perennial grass barriers, solid wooden and rock walls also may serve as windbreaks (121). Windbreaks may interfere with large machinery, however, they should be applicable for small-scale agricultural operations.

Maintaining vegetated riparian zones along streams is important for maintenance of water quality and associated aquatic life. Streamside vegetation helps moderate water temperature fluctuations, filters sediments and nutrients harmful to aquatic life, and may provide habitat for fish spawning and breeding (120).

POTENTIAL STRATEGY: Enhance Revegetation Programs

A primary cause of land degradation is forest clearing, leaving the cleared land without

6 Degradation of tropical land is a physical, chemical, and biological process set in motion by activities that reduce the land's inherent productivity, This process includes accelerated erosion and leaching, decreased soil fertility, diminished natural plant regeneration, disrupted hydrological cycle, and possible salinization, waterlogging, flooding, or increased drought risk, as well as the establishment of weedy plants that displace more desirable plant species. Evidence that the degradation process is advancing includes, for example, a reduction in the water-holding ability of the soil, a decrease in the amount of soil nutrients available to plants, a reduction of the soil's ability to hold nutrients, or soil compaction or surface hardening.

means to replenish soil nutrients. Because the major soil nutrient supply is in the vegetation, productivity of degraded lands could be improved, in part, by revegetation. Methods to enhance vegetative inputs to replenish soil nutrients include traditional and commercial agroforestry, short- or long-rotation forestry, or growing ground covers such as grasses or nitrogen-fixing legumes.

Choice of vegetation type for reestablishment depends on the objectives of revegetation. For exampIe, if lands are to be used for pasture, grasses and leguminous groundcovers maybe most appropriate. If direction of surface runoff into water catchments is a primary goal, grasses are probably preferable to trees, which transpire considerable amounts of water. However, if the watershed is steeply sloping, the greater erosion control afforded by brush and tree cover may be required to increase the longevity of the catchment. Further, on degraded lands where weeds easily can outcompete most smaller species, tree species that can shade them out may be necessary,

Selection of plant species is critical. Early succession species need to be highly competitive pioneers, able to outcompete weed species, and should have a dense and effective root system to minimize leaching and erosion (7). Many degraded soils commonly retain less moisture than protected soils (147), thus, early succession tree species may need to have tap roots—roots that rapidly grow deep into the soil that allow them greater access to soil moisture than shallow-rooted trees. In addition, tree species chosen to increase organic matter in degraded soils must be those that allow establishment of some undergrowth. Therefore, trees such as certain eucalypts probably should be avoided as allelopathic chemicals released by the trees into nearby soils preclude growth of understory plants.

Opportunity: Establish Forest Plantations

Rotation ages of tropical forest species vary and depend on the product to be harvested. Short-rotation species (first harvest in less than 6 years) like *Gliricidia, Leucaena,* and *Sesbania* can be harvested every few weeks for forage or green manure or every 6 months for forage and fuelwood. Harvest of poles from the Caribbean pine can take place several years after planting. Conventional long-rotation forestry of hardwood timber trees, such as teak or mahogany, can require 60 to 100 years before first harvest.

Nitrogen-fixing legumes possess favorable characteristics for both short-rotation forestry systems and for improving degraded land. Fast growing nitrogen-fixing shrubs such as *Sesbania* and *Crotalaria (27)* or nitrogen-fixing trees such as *Leucaena leucocephala, Casuarina* and *Acacia* are suitable for planting on degraded lands (70,71,75). For example, it is estimated that nitrogen-fixing *Leucaena* can supply 500 to 1,300 lbs of nitrogen per acre per year (75). Moreover, a variety of nitrogen-fixing trees can be used as fuelwood, fodder, nurse trees, timber/pulpwood, food, gum and medicines, or for shade trees. However, many of the fast-growing legumes can become pests in certain cases (e.g., Guam). This needs to be considered before species introduction is undertaken (7).

Reforestation of degraded lands provides benefits apart from products. Forests provide many environmental services such as reducing the force of wind, creating cool understory microclimates, protecting and, in some cases, improving the soil's productive potential. Foliage dropped by forest plants provide organic matter which, as it decays, improves soil fertility. Forests control soil erosion, regulate soil moisture, and mitigate flooding. Furthermore, forests may serve as sanctuaries of wild plants and animals and, therefore, increase and maintain greater species diversity.

Opportunity: Improve the Productivity of Degraded Grass and Fern Savanna Lands

Degraded lands have become quite extensive in the U.S.-affiliated islands, especially in southern Guam and the western Carolines. These lands commonly are no longer used for agriculture, although some may be used when more fertile areas are not available. The grass *(Miscanthus)* and fern *(Gleichenia)* species which predominate on degraded insular lands are aggressive species. Their dense networks of roots crowd out many other species and deprive them of moisture during dry seasons. Plowing and burning may allow temporary use of these lands for grazing, but commonly only encourage further grass and fern growth and expansion.

Grass and fern savanna lands could be afforested (or reforested) to increase wood, food, fodder, and fiber production. Trees protect soil from the effects of tropical heat, rain, and wind. Soil temperatures are lower under tree canopies, permitting reaccumulation of organic matter that restores soil structure and microbiota and enhances moisture- and nutrient-holding abilities. Bacteria on the roots of some tree roots can convert soil minerals to useful forms. In dry areas, trees can help to prevent the rise of saline groundwater. Where surface soils are dry or infertile, deep tree roots can tap underground reservoirs of nutrients and water and bring them to the surface. Tree species selected for reforestation of savanna lands should possess the following characteristics to counter those factors that allow grass and ferns to dominate:

- easy establishment,
- rapid early growth in poor soil conditions,
- deep rooting,
- dense crown to shade out grasses and ferns,
- nitrogen-fixing and soil-improving characteristics, and
- fire resistance (122).

Acacia, Calliandra, Gliricidea, and *Leucaena* species have been used successfully to reclaim such lands. Best tree growth occurs if the grass is cut and burned prior to planting, and if large seedlings are used to withstand competition with the grass (122).

Once an area of such species have been established and soil productivity regenerated, enrichment planting and other second-growth forest management techniques can gradually improve the economic value of the stand. Eventually, agroforestry and agriculture maybe introduced into the area.

Steps involved in reclamation might include:

1. inventory of degraded lands to classify them into subtypes;
2. protection of suitable areas of endemic communities;
3. development of fire prevention programs, including construction of firebreaks, public education programs, and improving the means to fight fires and enforcing fire laws; and
4. establishment of reforestation plantings on selected degraded lands using local species as well as selected exotics and development of plans for controlling aggressive exotic species and conversion of areas to more useful species (22).

POTENTIAL STRATEGY: Develop Local Soil Amendments

In traditional systems, nutrients cycle within the system and few nutrients are removed by harvest. In commercial technologies, especially monoculture, these natural cycles are broken and there is a larger resultant nutrient drain on the system. Introduction of additional nutrients is needed, either through manure, organic fertilizers (sea cucumbers, seaweed, dead grass and leaves, compost), or commercial fertilizer. Because most soils in the islands are relatively nutrient poor due to leaching, erosion, and other factors, the need to use soil amendments to obtain commercially acceptable yields is imperative (94).

Numerous fertilizer trials have been carried out in the U.S.-affiliated islands, and the use of commercial fertilizer is widespread. Most fertilizer technology has been adopted directly from the United States, despite evidence that tropical soils respond much differently to fertilizer than temperate soils. There also is growing concern about the potentially adverse impacts of fertilizer use on insular groundwater and marine ecosystems (94).

The U.S. Soil Conservation Service (SCS) has completed comprehensive soil surveys for all U.S. Caribbean islands; similar studies have been completed for all major U.S. Pacific islands. However, adequate soil testing to determine nutrient deficiencies is limited to Guam where a soils laboratory was set up by the University of Guam in 1975. Few other islands currently make use of this service. Implementation of this information may depend on further training of agriculture department personnel. Research also is needed on other methods of maintaining soil fertility such as green manuring, intercropping with legumes, fallow periods, and crop rotation (94).

Organic Matter.—Many organic materials contain components other than nitrogen, phosphorus, and potassium which can contribute significantly to increased crop yields, including secondary and micronutrients and, sometimes lime. The crop yield response to an organic amendment, however, follows the "law of diminishing returns"; the capacity of organic matter to elicit yield responses declines with succeeding crops (83).

USDA has identified a number of ways that organic matter could be used more effectively as soil amendments:

1. improve methods of manure collection, storage, and processing (e.g., comporting) to minimize nitrogen losses that often occur in these operations;
2. apply wasted manures to lands;
3. apply wasted crop residues to lands;
4. increase use of sewage sludge on land; and
5. increase use of the organic/compostable fraction of municipal refuse (83).

It is well established that microorganisms are beneficial to soil structure and that soil aggregation can be increased by the addition of crop residues presumably due to resultant soil microbial activity during the decomposition process (19). Burning crop residues in place instead of comporting destroys much of the nitrogen contained in the residue, Burning may result in soil erosion problems, destroy any soil-conditioning effects of the residues, and modify the ecological effects of the residue on the soil microflora. In some cases it causes the soil surface to become hydrophobic which can reduce infiltration and water storage (19).

It is unlikely that organic fertilizers will totally replace commercial fertilizers, nor should that be the goal. Evidence indicates that higher crop yields are possible when organic wastes are applied in combination with commercial fertilizers than when either one is supplied alone. Thus, organic amendments may increase the efficiency of commercial fertilizers *(83),*

Soil Microorganisms.—Soil particle aggregation and, therefore, erosion control can be effected by a range of polysaccharides and other gums that are produced by soil microorganisms (44). The size and composition of the microbial mass present determine the degree of the effect.

Mycorrhizae, a group of fungi associated with plant roots, often promote more efficient use of applied fertilizer *(62).* For example, in several experiments on tropical soils, legumes responded little to the addition of rock phosphate unless they were mycorrhizal. Uptake of minor elements with slow soil diffusion rates, like copper and zinc, also can be increased by mycorrhizal presence.

In naturally regenerating degraded tropical soils, the new vegetation will consist predominantly of nonmycorrhizal plants *(62).* Finally, it is well documented that plants with mycorrhizal associations transplant better than nonmycorrhizal.

Composts.—Composting is the biologic conversion of organic wastes to humus, a nutrient-conserving process carried out by a complex of aerobic organisms and microorganisms that occur naturally in soils. In simple systems, soil, manure, and plant residues, or a combination of animal, human and crop wastes, are layered in a pen or bin. The pile heats as the waste decays and is turned manually and rewetted as needed. The process commonly is complete in 4 to 12 weeks. More complex systems are more labor-, material-, and cost-intensive (73).

USDA recently developed a highly successful method for comporting sewage sludge, animal manures, municipal refuse, and pit latrine wastes called BARC (Beltsville Aerated Rapid Comporting). This method has been adopted widely in the United States and in some lesser developed countries. It is simple, effective, inexpensive, and allows considerable trade-off between labor and capital.

After compost is applied to fields, waste nutrients and nutrients from the organisms themselves are slowly released, allowing long-term uptake by plants. Compost also improves the physical structure of soil and its water-holding capacity.

Inorganic Soil Amendments.—One strategy with potentially significant applications to agriculture on U.S.-affiliated islands involves "turning rocks into fertilizers" using naturally and widely occurring inorganic materials as agricultural inputs.

The potential for agricultural uses of natural materials like zeolites and rock phosphates, and for increasing yields by mixing these inorganic materials with organic manures and composts containing soil microorganisms is thought to be considerable (65]. Geologists in Canada and the U.S. Geological Survey who have been studying some of the natural fertilization systems are enthusiastic about their potential uses in a number of countries where the economic and environmental costs of conventional fertilizers are prohibitive.

Zeolites are a family of common silicate minerals that often occur in or are associated with volcanic rock. Zeolite minerals participate in chemical exchange reactions that have been shown to increase crop yields in experimental systems and field trials. These minerals can take in nitrogen from manures and other sources and release it slowly in soils in a form plants can use (i.e., they have a high ion-exchange capacity). They can induce the breakdown of rock phosphate, making another important nutrient available to crops. Laboratory tests in Guelph, Ontario (Canada), have shown that zeolite treated rock phosphate releases its phosphate into soils up to 100 times faster than rock phosphate alone (112). Because of their high ion-exchange capacity and water retentivity, natural zeolites have been used extensively in Japan as amendments for sandy soils (65).

A variety of microorganisms are known to solubilize different insoluble inorganic phosphates, permitting their uptake by plants. Although the relation of these organisms to crop yield has been a subject of much controversy, recent research (58) demonstrated that yields of two study crops were higher after application of composts enriched with rock phosphate than after application of rock phosphate or of composts alone. Phosphate-enriched composts were associated with higher yields than even superphosphate, with its extremely high levels of water soluble phosphate. This may be because of the the slow release of phosphorus from enriched composts.

Opportuntiy: Introduce Salt-Tolerant Crops and Systems

Salt spray and saline soils are a significant production constraint on atolls and shorelines of larger islands. Research has been conducted on Tarawa, Kiribati, on the salt tolerance of crops and on technologies to minimize salt effects on crops. A variety of strategies, including raised beds, windbreaks, organic matter amendments, and drip irrigation have been suggested to minimize salt damage to crops. Table 6-8 lists the salt-tolerance of some common crops. Further, selecting or engineering strains of highly salt-tolerant crops could permit the expansion of agriculture onto currently unusable lands.

Photo credit: A. Vargo

Pandanus, or screw pine, is a common beach strand plant on Pacific islands due to its tolerance of salt spray and saline groundwater. Fiber for weaving is derived from the fronds, and the fruit is eaten on some islands.

Table 6-8.—Salt Tolerance of Certain Common Crops

Hi ah	Medium	Low
Arrowroot	Broccoli	Alocasia taro
Asparagus	Cabbage, head	Banana
Beet	Cantaloupe	Bean
Coconut	Carrot	Breadfruit
Kale	Cauliflower	Celery
Pandanus	Corn	Colocasia taro
Papaya	Cucumber	Radish
Spinach	Cyrtosperma taro	
	Lettuce	
	Onion	
	Pea	
	Sweet pepper	
	White potato	
	Squash	
	Tomato	

SOURCE E Soucie, *Atoll* Agriculture, Ponape Agriculture and Trade School, Pohnpei, Federated States of Micronesia 1983

Photo credit A Vargo

Depredation by the imported Giant African Snail hinders vegetable cultivation on several U.S.-affiliated Pacific islands. Research to develop an integrated pest management (1PM) strategy is being conducted at the American Samoa Community College.

POTENTIAL STRATEGY: Reduce Agricultural Crop Losses

Major crop and livestock losses in the tropics are due to diseases, pests, and weeds prior to and after harvesting. Accurate data for postharvest losses are not available for most U.S.-affiliated islands (99). However, crop losses probably are similar to estimates given for the tropics, which is around 30 to 40 percent (155, 156).

Application of appropriate pest, disease, and weed control may reduce losses, effectively increasing yields. Various control methods have been applied to combat agricultural pests, weeds, and diseases in U.S.-affiliated islands, including: use of pest-resistant crops; chemical, biological and cultural pest and disease control methods; and integrated pest management.

Opportunity: Use of Pest- and Disease-Resistant Crops and Livestock

Cultivation of pest-and disease-resistant varieties of crops and livestock is a common traditional method of protection from pests and disease (94,142). The use of pest-resistant crop varieties or plants serving as pest repellents make cultural control methods more effective in preventing pest and disease infestations.

As with cultivation methods, use of pest-resistant crops is effective in avoiding pest and disease infestations, is inexpensive, easily transferable to small-scale farmers, and has little adverse environmental impact. Although this strategy holds promise for widespread application on islands, it is constrained by high costs for research, field trials, and development, Furthermore, little scientific data is available on the performance of resistant crops and livestock on islands (142).

Opportunity: Cultural Control

Cultural control is the avoidance or reduction of pests and diseases through the use of certain cultivation or husbandry methods. Cultural control methods, such as the traditional cropping systems, provide the most common method of pest and weed control by subsistence farmers on the U.S.-affiliated Pacific islands (22,41,94,142). Cultural practices which serve to control pests and weeds include: polycropping, field and crop rotation, time of planting, and irrigation methods. Although cultural controls alone may not eradicate pests, they often can reduce pest populations and enhance other control methods (124).

In polyculture, some plants may serve as physical barriers partially concealing or protecting susceptible crops from pests. Other plants may emit or secrete repellents or provide favorable environments for predators or parasites of pest species (3). For example, in American Samoa, taro armyworm may be controlled by intercropping taro with *Coleus blumea* which serves as insect pest repellant (142). Further, low crop density inherent to polycropping may attenuate the spread of diseases.

It is well known that crop and field rotations may suppress pest and weed infestations. Irrigation and regular flooding in wetland taro cultivation (55) and drip irrigation system in semiarid row cropping (61) also reduce pest infestations.

Cultural control methods are effective (especially when combined with the use of resistant crops), inexpensive, easily transferable to small-scale farmers, and have little adverse environmental impact. However, development of new cultural control methods is constrained by high costs for research and development and by lack of documentation of local knowledge.

Opportunity: Chemical Control

This involves application of chemical agents to control pests, diseases, and weeds. Chemical biocides are easily applied and generally have an immediate effect. In the United States, pesticides play a major role in pest control, increase crop yields and give about a fourfold return on investment (85). However, the presence of disease, pests, or weeds does not indicate that chemical application of control is needed, because many potentially harmful insects can be controlled by parasites and natural predators. Unnecessary chemical application may destroy the natural balance and lead to further serious pest outbreaks.

Under certain circumstances, chemical control may be the only effective method of dealing with pest infestations, for example for crop pests and diseases in greenhouses (10) or cattle tick control (9). However, little is known on the proper chemical application or formulation for tropical crops and on the long-term effects of these chemicals on the environment (142). Further, on U.S.-affiliated islands, application of chemical pest control is expensive due to costly importation of agriculture chemicals (43,94).

Although chemical control has immediate results, its effectiveness is generally short-lived, and it is an inefficient way to control pests in the field. Often, only a small quantity (less than 0.1 percent) of pesticides applied to field crops reaches target pests and the rest of the pesticides remain in the environment to contaminate the land, water, and air (85). Pests may acquire resistance and some chemicals may adversely affect nontarget organisms (124). Resistant pests make subsequent application of the same chemical ineffective. Since extension workers on some islands are few or inadequately trained, pest resistance or upset of natural predator balance may not be noticed (99).

On U.S.-affiliated islands, the Environmental Pesticide Control Act of 1972 requires the registration of agriculture chemicals for sale and extends control to actual application by the user. Certain restricted chemicals may only be applied by certified personnel, and penalties may be levied against those who misuse chemicals. Most pesticides, however, are not registered for use on tropical crops. Therefore, under U.S. regulations, special registration is required. This is done by field trials and monitoring of biocide residues in compliance with EPA regulations. These procedures require funds and skilled staff, and thus are beyond the capacity of most existing island institutions (99).

Since most U.S.-affiliated island are small, inappropriate application of chemical control may have very serious adverse environmental impacts.[7] Contamination of water lenses by the use of agriculture chemicals on small islands is of major concern (66); limiting or improving agriculture chemical applications may reduce contamination of the environment.

Opportunity: Locally Produced Pesticides

Certain local products may be able to take the place of some imported agrichemicals. For example, soap sprays were principal insecticides during the early 20th century in the

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[7] A pesticide spill on Truk resulted in a fish kill estimated at 20 tons and another on Ulithi (Yap) may have contaminated the water supply; however, no tests have been run (24).

United States (17). Soap sprays are biodegradable, may kill enough pests to prevent serious damage to plants yet leave sufficient numbers to provide food and, thus, build beneficial populations of natural predators. Coconut oil soaps may be an effective pesticide against some insects and are readily available on most U. S.-affiliated islands. However, little research has been done on formulations, effectiveness, or tolerance by various tropical plants.

Pesticides also can be derived from certain plants that can be locally grown. Crude extracts from plants have been used as pesticides for thousands of years, and a recent compilation of plants used for pest control listed 700 species (l). Twenty-five species possess characteristics making them particularly suitable for propagation and use by resource-poor farmers (e.g., perennial species requiring little space, labor, water, or fertilizer with an easily processed product and possessing complementary uses).

The neem tree *(Azadirachta indica)* seems particularly promising for pesticide production on the U.S.-affiliated islands. The neem is native to the Indo-Pakistan region but has spread throughout the tropical world, including the Pacific and Caribbean islands. A group of biologically active constituents found in neem leaf, fruit, bark, and seed reportedly provide antifeedant, growth regulatory, repellant, hormonal, or pesticidal control in more than 100 pest species (l).

Neem leaves, neem seed oil, and the "cake" resulting from oil extraction can all be used for pesticide. The cake can be worked directly into the soil and neem oil can be spread through a simple sprayer. A number of other products, such as livestock feed, soap, and cosmetic oils can also be produced from the neem. The neem is salt-tolerant, can be grown on relatively infertile soils, and has been demonstrated effective at improving such soils. Research on neem tree cultivation and uses is being conducted by USDA, including the Tropical Agricultural Research Station at Mayaguez, Puerto Rico.

Opportunity: Biological Control

Biological control is a method whereby a predator, parasite, or disease agent is used to combat undesirable pests, diseases, or weeds. Identification of biological agents involves intimate knowledge of both pest and control agent, requiring considerable research, experimentation, and field trials (66).

Although biological control of pests and weeds may hold promise, development is costly and time-consuming. It requires funds, special facilities, and skilled staff; and thus it is beyond the capacity of existing island institutions (99,142).

Biological control works best on long-term crops, such as trees, which allow the control agent ample opportunity to become established. Biological control has been implemented in the U.S.-affiliated Pacific islands with varying success for eradication of fruitfly (66), the giant African snail (18), and rhinoceros beetle (79,99, 142).

In 1963, USDA succeeded in eradicating both the oriental fruitfly *(Dacus dorsalis)* and the melon fruitfly *(Dacus cucurbitae)* from Rota island (CNMI) by a method of "male annihilization" (killing male flies with a toxic attractant) and the sterile male technique (flooding the area with large number of sterile males). However, in recent years, the melon fruitfly has reappeared on Rota (66) possibly due to an ineffective quarantine program. Recently, introduction of an insect *(Pareuchaetes pseudoinsulata)* has proved effective in controlling a notorious weed *(Chromolaena odorata)* on Guam (66).

Generally, biological control is simple to implement once precise control procedures and control agents have been identified. Sometimes introduction of biological agents may have reverberating adverse effects after the target pest has been controlled. For example, the marine toad *Bufo marinus* was introduced both intentionally and accidentally through much of the Pacific islands during the last 50 years. The toad was thought to be a good biological control agent due to its large size and wide adaptability. It was introduced to Guam from Puerto Rico through Hawaii originally for insect and garden slug control and rapidly spread over the island. Later it was introduced throughout the remainder of Micronesia and American Samoa. While the toad did reduce slug and other pest populations, it also reduced populations of beneficial insects; contaminated drinking water; killed freshwater fishes, pets and, reportedly, some humans (18).

Opportunity: Integrated Post Management-

Integrated pest management (1PM) refers to the management of pest, diseases, and weeds using a combination of control methods. It relies on a balance of biological and chemical controls, and cultural practices, such as polyculture or timing of irrigation. Its goal is to coordinate multiple pest management technologies to assure stable crop production and maintain pest damage below the economic injury level while minimizing hazards to humans, animals, plants, and the environment (124). 1PM is considered the best long-term control strategy, both economically and environmentally. Under 1PM, chemical controls are used only when a predetermined economic level of damage has been reached.

Effective pest and disease control programs may increase productivity, quality, and thereby marketability of crops and livestock. High-quality products can be exported to metropolitan markets with little difficulty. For example, the occurrence of melonfly on Rota (CNMI) and Guam prevent fruit export from these islands to Japan as well as to other islands (66). For subsistence farmers, where the major bulk of the crop is consumed locally and little enters the market sector, reduction of crop losses results in greater security against lean years.

On U.S.-affiliated islands, the major stumbling block for the implementation of pest management is neither lack of technologies nor lack of funding, but lack of highly skilled and motivated agricultural staff and good agriculture extension services. Although some pest control methods, such as cultural control and 1PM, hold great promise for effective pest control on islands, government subsidies that lower the costs of agrichemicals may undermine other pest control methods which have less detrimental effects. Furthermore, islands lack aggressive quarantine programs to prevent reinfestation and reintroduction of pests. Strong policy commitments of local administrators to implement an effective pest control together with an effective quarantine program are also absent (66,142).

Pest control methods will have little effect on islands without concurrent efforts to prevent reintroduction of pests and diseases from other areas via incoming cargo such food imports from high risk areas. The USDA Animal and Plant Health Inspection Program (APHIS) operates on most U.S.-affiliated islands (43,142) and is administered by local Departments of Agriculture. However, the current program lacks an integrated preventive program (68), which might include:

- public education on the importance of plant and animal quarantine;
- rigorous inspection of incoming cargo, both by ship and air;
- inspection of planes and ships for insects and other pests;
- definitions of which countries are high risks for new pests;
- a list of crops to be protected and from what organisms; and
- continuous education programs to increase skills of inspectors.

APHIS, the University of Guam, and the United Nations' Food and Agriculture Organization (FAO) have developed training programs in plant protection and quarantine, and the FAO project on Strengthening Plant Protection and Root Crops Development in the South Pacific has recently reviewed plant quarantine programs in the FSM, Marshall Islands, CNMI, and Palau (39).

Quarantine regulations made along political rather than geographical boundaries also may unnecessarily restrict export of some agricultural products. For example, a quarantine on export of all citrus products was imposed on the FSM while its cause—the citrus moth—is reported to be found only in the western Caroline Islands. Thus, although unaffected, exports also were prohibited from the eastern Caroline Islands (39). USDA entomologists and plant pathologists could conduct surveys of pests of economic importance in the U.S.-affiliated islands, review quarantine and fumigation regulations, facilities and procedures for each major exporting island. Such surveys should result in better information for use by both USDA and island governments in their agricultural inspection and quarantine activities. This also may open U.S. and other markets to previously restricted agricultural commodities from the islands (39).

SUMMARY

A variety of agricultural methods are practiced in U.S. insular areas. However, significant constraints hinder application of certain agricultural technologies and agricultural development in many U.S.-affiliated islands. Factors that support and hinder application and implementation of sustainable agricultural technologies for U.S.-affiliated islands are many and vary between regions, islands, and polities,

Small land areas and population, fragmented land masses, great distances between islands, and isolation from major markets are not conducive to modern commercial development. Land tenure systems characterized by small parcels also make some forms of commercial development unlikely. Small farm size, however, does not constrain subsistence agriculture development and some forms of smallholder commercial agriculture.

Additional major constraints for modern agriculture development in the U.S. Pacific islands are limited arable land areas and low soil fertility. Limited fresh water on low islands and on semiarid regions of islands is constraining to conventional cropping methods. Environmental factors such as droughts and typhoons, and constant threat of pest and disease outbreaks are serious problems for agriculture. Furthermore, costly and irregular transportation services, poor storage facilities, and small markets on U.S.-affiliated islands compound the problems.

Universally high energy costs and expensive imported goods and supplies make application of energy-intensive commercial agricultural technologies uneconomical for most small tropical islands. This is especially true for adoption of typical U.S. mainland field cropping technologies which is based on a temperate climate, scarce and expensive labor, large-scale and highly mechanized operations, and abundant land.

Availability of high-paying government jobs and generous U.S. social support programs, make it difficult to find skilled farm workers at reasonable wages. For some islands, strong traditional social support and extended family welfare systems tend to hinder motivation toward working in low-paying "unprestigious" agriculture jobs or entering into risky commercial agricultural enterprises. Low labor productivity together with application of inefficient agricultural technologies make commercial farming uneconomical.

In U.S. Pacific islands, modern commercial agriculture development is further complicated by the heavy influence of traditional customs. Many islanders are caught between their own aspirations for higher levels of material living, which they hope to attain through commercial development, and the demand for observing customary kinship and family practices. Commercial agriculture often requires regular and long periods of work, prescribed schedules, and also accurate accounting of expenditures and income, Yet, demands to meet customary obligations to share with relatives are difficult to ignore, especially when farmers are dependent on regular reciprocal assistance. Under this system commercial enterprises are likely to operate under suboptimal conditions.

Opportunities

Despite these constraints, most islands have conditions that are conducive to development of certain types of crops, livestock, or "agricultural packages" (a combination of resources and methods that is productive and can be applied profitably at an acceptably low economic risk) for development.

Sustainable agriculture technologies maximize the use of abundant (inexpensive) or renewable resources and minimize the use of scarce (expensive) or nonrenewable resources. For the technologies to be readily adopted, they should maximize output per unit input of the scarcest resource. For example, if labor is expensive or scarce, labor productivity should be increased (e.g., by use of labor-saving equipment); if land is the most limiting factor, land yields should be increased through the use of intensive practices. Similarly, if water is scarce, water use efficiency should be increased through water management practices such as drip irrigation systems or hydroponics.

Technology packages should also be tailored to the local ecological, climatic, and sociocultural conditions. Characteristics of crops that generally are appropriate to U.S. island conditions include crops that: 1) are resistant to pests, diseases, and weeds; 2) thrive in poor soils; 3) require little or no irrigation; 4) require relatively little nonrenewable agricultural inputs; 5) require relatively little labor; and 6) produce high yields (48]. Crops should recover rapidly or suffer minimal damage from occasional adverse weather conditions such as cyclonic storms and droughts. For export, crops should be high quality, high value, low weight and bulk, or have a long shelf life. Characteristics of livestock appropriate to tropical islands include those that are resistant to diseases, pests, and parasites; that thrive on poor feed and forage; require little care; and that can adapt to variable weather conditions.

Few or no crops or livestock are so ideal as to fulfill each of these requirements. However, these desired characteristics can serve as objectives in crop, cultivar, and livestock choices. Because conditions vary among and within islands, ranking of objectives must be made on a case-by-case basis.

Some intensive, high-yielding farming systems are suitable for the larger islands. However, for the most part, agriculture systems on smaller and more remote U.S.-affiliated islands systems should be simple and nearly self-sustaining, including:

- systems that use minimal mechanization, thus avoiding expensive repairs, spare parts, and fossil fuel imports. Where mechanization is required, use of small-scale or simple equipment should be developed;
- systems which require little skilled labor, but which generate employment;
- systems that maximixe use of local renewable resources and minimize use of nonrenewable resources; and
- systems which maintain the productivity of local and "downstream" environments.

Agricultural Development

Great diversity in agriculture systems is likely to persist on U.S.-affiliated islands. While opportunities for large-scale farming may be exploited by outside investors willing to bear the high risks for the potentially high returns associated with a successful export commodity, development of smallholder agriculture provides a greater likelihood of success and breadth of benefit distribution. Compared with large-scale farming, the benefits associated with smallholder agricultural development include:

- less risk of adverse impacts on traditional social systems (especially for U.S. Pacific islands);
- less dependence on foreign capital;
- larger employment-generating effects;
- broader distribution of increased farm income;
- greater compatibility with island ecological conditions;
- less dependence on imported production inputs;

- more widespread nutritional benefits; and
- potentially greater agricultural stability resulting from greater agricultural diversification (43).

Common characteristics of smallholder farming systems include the relatively modest acreage requirements per operation, heavy reliance on family rather than hired labor, and significantly lower capital requirements per operation compared with large-scale agriculture. Also, a strategy which is likely to emphasize import substitution (at least in the early stages of development) probably is more likely to succeed and be less costly than attempting to promote large-scale export-oriented farming (43).

POTENTIAL STRATEGY: Improve Research and Extension Services

In order to accelerate agriculture development, research programs need to be directed to specific goals clearly relevant to island development. Although the need for research is widely recognized, the capacity of most U.S. Pacific island institutions is limited. Furthermore, effective research is hampered by inadequate or unavailable baseline data and skilled research staff. Levels of research needed for agriculture development include (48):

- *operational research* at the farm level to increase productivity and profitability of farm operations through monitoring and experimentation in farms;
- field *trials* at field experimental stations for testing new varieties, fertilizers, pest management, and new technologies;
- *strategic research* on broad agricultural development issues affecting many areas, including social and economic issues; and
- *basic research* on agriculture problems with no predetermined practical application in mind.

The on-farm operational research and field trials are best done onsite at each island institution. However, since the capacity of small island institutions to support complex research is limited, basic and strategic research maybe more effectively conducted at large institutions (48) such as the University of Hawaii or the University of Puerto Rico. Although agriculture research has been conducted in the U.S. Pacific islands, many research activities are not designed to apply directly to the development needs of the islands. Further, research results are commonly not presented in a format usable for development planners or decisionmakers.

Although island governments should focus on research that is critical to their special local needs, this should be supplemented by taking advantage of research done at similar institutions at neighboring islands. Research performed by the South Pacific Commission, Caribbean Agriculture Research and Development Institute, and other regional research institutions may provide useful information (48, 87). It would be to the advantage of small island governments to establish cooperative relationships with international research institutions or major universities who can help broad strategic and basic research (48). Integrated development planning of island renewable resources cannot be effectively achieved because research and planning of renewable resources are not well coordinated in island polities (87),

After appropriate technology and strategy have been formulated for implementation, extension agents communicate this information to the farmers. Ideally, extension agents should be supported by an extension station with skilled professional staff in various fields. Although this condition may exist on large, well-developed islands, provision of agriculture extension services to the widely scattered farmers on U.S. Pacific islands is extremely difficult (48]. Lack of trained and motivated extension staff or the wrong kinds of extension agents may hinder effective communication with farmers. In some areas (e.g., Yap and Palau) where subsistence farmers are women, male extension agents are ineffective because it is considered inappropriate for men to teach women. In such situations, female extension agents would be more effective and appropriate to convey information to farmers (48).

Although extension services in Puerto Rico and the USVI are relatively well developed, transfer of modern technologies to Puerto Rico's farmers remains slow. This may be due to the relatively small size of the agriculture sector and scattered geographical location of farmers, and also because extension workers rarely have appropriate prior experience with modern technologies to guide farmers (61).

Research knowledge in certain areas (e.g., semiarid agriculture in Puerto Rico) lags significantly behind commercial practice. Generally, the agriculture experiment stations have made little or no effort to incorporate the results of commercial experience in their technology packages. Furthermore, existing links between research and extension, and the present level of funding are inadequate to address the magnitude of the problems which exist in the U.S. Caribbean islands (61). If research is to be effective, the gap of knowledge between researchers and commercial farmers must also be closed.

One of the ways of overcoming this problem is to conduct on-farm agronomic research trials. On-farm research provides documentary evidence of the nature and magnitude of biological, technical, economic, and social constraints. Moreover, on-farm research can provide baseline data for extrapolation to other farms where conditions are similar. Finally, on-farm trials make the process of research and development more understandable and accessible to other farmers, decisionmakers, and service organizations.

POTENTIAL STRATEGY: Improve Education in Agriculture

Apart from agriculture extension services, a need also exists for education and training programs for future farmers on most islands. On U.S. Pacific islands, agricultural education is inadequate. Two schools in Pohnpei offer agricultural education, three island institutions offer programs at the junior college level (Palau, CNMI, and American Samoa), and the University of Guam offers college-level courses. In the U.S. Caribbean islands, agricultural education programs and facilities are adequate. However, strong negative attitudes toward agricultural trade hampers participation of people in agriculture development, especially among the youth. Students also commonly lack hands-on experience with farming.

Although agricultural education programs exist, improvement is needed to enhance their effectiveness, particularly for the less-developed islands. In general, constraints to agricultural education in the U.S.-affiliated islands stem from lack of funding, qualified teachers, and of interest on the part of students due, in part, to the status attached to high-paying jobs with the government (app. F). Agricultural education effectiveness could be achieved through improving education in general, providing training for farmers, and providing public education programs.

Opportuntiy: Improve Education in General

All island areas have public education systems which can accommodate nearly all school age children through the secondary level. However, the educational programs generally do not prepare the students to fill employment needs for island development such as agriculture. Generally, emphasis has been on academic pursuits or preparation for white-collar employment. This has led to outmigration of high-school graduates and persistent shortages of manpower in agriculture trades and other such occupations. Interest in agricultural occupations might be enhanced if ecology and agriculture courses or on-farm training were offered at all educational levels.

Opportunity: Provide Training for Farmers

Low educational levels of most farmers may pose a problem. In this case, education and training can be presented through nonwritten communication methods with audio-visual aids. Effective education and training may be accomplished by using local examples and by showing rather than telling. Workshops and on-the-job practical training for farmers may also bean effective way to convey information. Involvement of farm organizations in agricultural development programs may enhance farmers' awareness of new agricultural programs and activities (48).

Opportunity: Provide Public Education Programs

Public awareness campaigns through the media or agricultural fairs may also be an effective way to convey the importance of the agriculture sector to the general public, and to counter the general negative attitude young people have toward farming as a trade. Agricultural fairs also can serve to introduce new crops or new products to the public and a means of testing public acceptance. The U.S. Virgin Islands holds an annual agriculture and food fair on the two larger islands, St. Croix and St. Thomas (153).

Photo credit: USFS-ITF

Youth conservation worker programs can introduce local people to basic principles of ecology and help strengthen environmental understanding while providing needed labor for such programs as reforestation and protected area management. Here, Young American Conservation Crops enrollees plant mahogany in a Puerto Rican public forest.

CHAPTER 6 REFERENCES

1. Ahmed, S., and Grainge, M., "Potential of the Neem Tree (*Azadirachta indica*) for Pest Control and Rural Development," *Economic Botany* 40(2):201-209, 1986.
2. Alexander, A. G., "Assessment of Energy-Integrated Farming Technologies for U.S. Insular Areas," OTA commissioned paper, 1986.
3. Altieri, M., and Letourneau, D., "Vegetation Diversity and Insect Pest Outbreaks," *Critical Reviews in Plant Sciences* 2(2):131-169, 1984. *In:* Vargo, 1986.
4. American Samoa Economic Development and Planning Office, *Statistical Bulletin* 1984, Government of American Samoa, 1984. *In:* Lucas, 1986; Vargo, 1986.
5. Barnaby J. W., and Busch, R. L., "Tropical Production of Tilapia and Tomatoes in a Small-Scale Recirculating Water System, " *Aquaculture* 41:271-283, 1984. *In:* Morris and Pool, 1986.
6. Bassett, C.A. "Arid West Trying Drip Irrigation," New *York Times*, June 3, 1983.
7. Buck, M., Resource Evaluation Forester, Hawaii Division of Forestry and Wildlife, personal communication, September 1986.
8. Calero, R., et al., "Estudio Socioeconomic del Programa de Fincas Individuals del Titulo VI de la Ley de Tierras," Estacion Experimental Agricultural, University of Puerto Rico, Boletin 236, 1974. *In:* Vicente-Chandler, 1986.
9. Caro-Costas, R., "Assessment of Livestock Production Technologies in the U.S.-Affiliated Caribbean Islands," OTA commissioned paper, 1986.
10. Castillo-Barahona, F., and Bhatia, M. S., "Assessment of Agriculture Production Technologies in Puerto Rico, " OTA commissioned paper, 1986.
11. Childers, N, F., et.al., "Bay Oil Production in Puerto Rico," USDA Agricultural Experimental Station, Circular No. 30, 1948. *In:* Pool, 1986.
12. Commonwealth of the Northern Mariana Islands, Planning and Budget Office, *Overall Economic Development Strategy* 1984, 1984. *In:* Lucas, 1986.
13. Connell, J., University of Sydney Department of Geography, personal communication, September 1986.
14. Decision Analysts Hawaii, Inc., *Agriculture, Municipal and Industrial Water Demand and Benefit Parameters on Guam,* prepared for the U.S. Army Corps of Engineers, Pacific Ocean Division, 1983. *In:* Lucas, 1986.
15. Diaz-Soltero, H., and Oxman, B., "Organizations Dealing With Renewable Resource Development and Management in Puerto Rico and the U.S. Virgin Islands, " OTA commissioned paper, 1986.
16. Dillingham, E. "Agriculture Development Needs and Opportunities in the U.S. Virgin Islands," OTA commissioned paper, 1986.
17. Dorschner, C., "Soap Sprays Can Control Pests Safely," *National Gardening* 9(6):20-22, 1986.
18. Eldredge, L., "Case Studies of the Impacts of Introduced Animal Species on Renewable Resources in the U. S,-Affiliated Pacific Islands, " OTA commissioned paper, 1986.
19. Elliott, L. F., and Papendick, R. I., "Crop Residue Management for Improved Soil Productivity," *Biological Agriculture and Horticulture* 3(2/3):131-142, 1986.
20. Falanruw, M. V. C., Director, Yap Institute of Natural Sciences, personal communication, July 1986.
21. Falanruw, M. V. C., "On the Status, Reproductive Biology, and Management of Fruit Bats of Yap," Institute of Pacific Islands Forestry (in press).
22. Falanruw, M. V. C., "Traditional Agriculture/ Resource Management Systems in the High Islands of Micronesia," OTA commissioned paper, 1986.
23. Falanruw, M. V. C., "People Pressure, Management of Limited Resources on Yap, " prepared for the World National Parks Congress, Bali, October, 1982 (appendix to Falanruw, 1986).
24. Falanruw, M, V. C., "Marine Impacts of Land-Based Activities in the Trust Territory of the Pacific Islands," presented at a seminar on *Marine and Coastal Processes in the Pacific: Ecological Aspects of Coastal Zone Management,* Motupore Island Research Centre, University of Papua New Guinea, UNESCO, July 14-17, 1980, *In:* Falanruw, 1986.
25. Falanruw, S., Director, Yap Department of Resources and Development, personal communication, July 1986,
26. Federated States of Micronesia, National Plan Task Force, *First National Development Plan, 1985-1989: Working Draft,* Federated States of Micronesia (unpublished draft), 1984. *In:* Lucas, 1986,
27. Fosberg, R., Department of Botany, Smith-

sonian Institution, personal communication, September 1985.
28. Giusti, E. V., "Water Resources of the Juana Diaz Area, Puerto Rico: A Preliminary Appraisal, 1966," *Water Resources Bulletin,* U.S. Geological Survey, Water Resources Division, San Juan, 1968. *In:* Morris and Pool, 1986.
29. Glenn, M., "An Analysis of Black Pepper Production in Ponape,'' OTA commissioned paper, 1986.
30. Goldsmith, W. W., and Vietorisz, T., "A New Development Strategy for Puerto Rico: Technological Autonomy, Human Resources, A Parallel Economy, " Program on International Studies on Planning, Cornell University, Ithaca, NY, January 1978.
31. Gonzalez-Villafane, E., et al., "Analysis Economico de 151 Fincas Establecidas a Traves de la Administration de la Explotacion Economica de Fincas de Cafe con un Area Total de 200 Cuerdas o Mas,'' Estacion Experimental Agricultural, University of Puerto Rico, Pub. 74, 1972. *In:* Vicente-Chandler, 1986,
32. Goyal, M.R. "Annual Report No. 3, 1983-1984 Trickle Irrigation in Humid Regions, Puerto Rico," University of Puerto Rico Agricultural Experiment Station, 1984. *In:* Morris and Pool, 1986.
33, Gruelach, V. A., *Botany Made Simple* (Garden City, NY: Doubleday & Co., 1968). *In:* Raynor, 1986.
34. Guerrero, N. M., "Natural Resources in the Northern Mariana Islands: A Wealth of Underdeveloped Potential," *Proceedings of the Year of the Pacific,* Saipan, 1983, pp. 48-56.
35. Hagenmaier, R. D., *Coconut Aqueous Processing* (Cebu City, Philippines: San Carlos Publications, University of San Carlos, 1980). *In:* Poison, 1986,
36. Hanes, R., Senior Vice-President, Specialty Brands Inc., personal communication, September 1985.
37. Hill, M. T., "A Preliminary Assessment of the Economic Situation of Puerto Rico's Agriculture," *Puerto Rico Business Review,* special supplement, 8(5):1-17, May 1983.
38. Hydeman, M., and Raynor, B., "Research on Solar Drying of Black Pepper at PATS," *PATS Agri-Industrial Bulletin,* Ponape Agriculture and Trade School, Pohnpei, Federated States of Micronesia, May 1986.
39. Jackson, G., Director, Kosrae State Department of Conservation and Development, personal communication., September 1986.
40, Johannes, R., "The Role of Marine Resource Tenure Systems (TURFS) in Sustainable Nearshore Marine Resource Development and Management in U, S.-Affiliated Pacific Islands," OTA commissioned paper, 1986.
41. Klee, G., "Oceania," *World Systems of Traditional Resource Management, G.* Klee (cd.) (New York, NY: V.H. Winston& Sons and Edward Arnold Publishers, 1980), pp. 245-285.
42. Lopez-Real, J. M., "Sustainable Agriculture: the Microbial Potential — the Microbiologist's Challenge," *Biological Agriculture and Horticulture* 3(2/3):143-152, 1986.
43. Lucas, R. L., "Role of Smallholder in Agriculture Development in the U, S.-Affiliated Pacific Islands," OTA commissioned paper, 1986,
44, Lynch, J, M., "Rhizosphere Microbiology and Its Manipulation," *Biological Agriculture and Horticulture* 3(2/3):143-152, 1986.
45, Manner, H., University of Guam Department of Anthropology and Geography, personal communication, September 1986.
46. Mark, S. M., *Development of the Agricultural Sector in the American-Affiliated Pacific Islands,* Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii, 1982.
47. Mark. S. M., and Lucas, R, L., "The Pohnpei Agricultural Development Plan, " Pohnpei State Economic Development Authority, December 1984 (unpublished). *In:* Lucas, 1986.
48, Mark, S. M., and Plasch, B. S., *Strategy Outline for Accelerated Agriculture Development of American-Affiliated Pacific Islands,* Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii, 1982.
49, Marshall Islands Office of Planning and Statistics, "First Five Year Development Plan 1985-1990: The Initial Phase of a Fifteen Year Development Program," (unpublished document), Republic of the Marshall Islands, 1984.
50. Martin, F, W., and Ruberte, R. M., *Growing Food in Containers in the Tropics,* U.S. Department of Agriculture, Agriculture Research (Southern Region), Science and Education Administration, Agricultural Reviews and Manuals, ARM-S-13, New Orleans, LA, January 1981.
51. Martin, F, W., and Ruberte, R. M., *Techniques and Plants for the Tropical Subsistence Farm,* U.S. Department of Agriculture, Science and Education Administration, Agricultural Reviews and Manuals, ARM-S-8, New Orleans, LA, July 1980.

52. Matuszak, J. M., "Terracing in 1984–Building Soil and Feeding Families," *Proceedings of the Fourth Annual St. Thomas/St. John's Agriculture Fair,* sponsored by the St. Thomas and St. Johns' Farmers' Association and the College of the Virgin Islands Cooperative Extension Service, 1984, pp. 7-8. *In:* Pool, 1986.
53. Mayo, H, M., "Report on Plant Relocation Survey and Agricultural History of the Palau Islands," (Saipan, Commonwealth of the Northern Mariana Islands: Trust Territory of the Pacific Islands, 1954).
54. McClymonds, N, E., and Diaz, J, R., "Water Resources of the Jobos Area, Puerto Rico, " *Water Resources Bulletin, No. 13,* U.S. Geological Survey, Water Resources Division, San Juan, Puerto Rico, 1972. *In:* Morris and Pool, 1986.
55. McCutcheon, M., "Reading the Taro Cards: Explaining Agricultural Change in Palau, " *FoodEnergy in Tropical Ecosystems,* D.J. Cattle and K.H. Schwerin, (eds.) (New York, NY: Gordon & Breach Science Publishers, 1985), pp. 167-188.
56. McElroy, J. L., Department of Business Administration and Economics, St. Mary's College, IN, personal communication, July 1986.
57. Miller, T., Vice President - Procurement, McCormick & Co., Inc., personal communication, June 1986.
58. Mishra, M. M., and Bangar, K. C., "Rock Phosphate Comporting: Transformation of Phosphorus Forms and Mechanisms of Solubilization, " *Biological Agriculture and Horticulture,* vol. *3, 1986,* pp. *331-340.*
59. Morris, G. L., Consulting Hydrologist, personal communication, September 1986.
60. Morris, G. L., Consulting Hydrologist, personal communication, February 1986.
61. Morris, G, L., and Pool, D. J., "Assessment of Semiarid Agriculture Production Technologies for the U.S.-Affiliated Caribbean Islands," OTA commissioned paper, 1986.
62. Mosse, B., "Mycorrhizae in a Sustainable Agriculture, " *Biological Agriculture and Horticulture* 3(2/3):191-209, *1986.*
63. Mueller-Dombois, D., University of Hawaii, Department of Botany, personal communication, July 1986.
64. Muler-Manzanares, L., and Santini, J. E., "Estudio Socioeconomic de 29 Fincas Individuales del Titulo VI de la Ley de Tierras Distribudas de 1967 a 1970," Estacion Experimental Agricultural, University of Puerto Rico, Boletin 241, 1976, *In:* Vicente-Chandler, 1986.
65. Mumpton, F. A., "Using Zeolites in Agriculture, " *Innovative Biological Technologies for Lesser Developed Countries* U.S. Congress, Office of Technology Assessment, OTA-BP-F-29 (Washington, DC: U.S. Government Printing office, 1985).
66. Muniappan, R., Associate Director, University of Guam Agricultural Experiment Station, personal communication, January 1986,
67. Munoz-Roure, J. O., Director, Caribbean Fishery Management Council, personal communication, September 1986.
68. Nafus, D., "Strengthening Plant Protection and Root Crops Development in the South Pacific" (Suva, Fiji: United Nations Food and Agriculture Organization in association with the South Pacific Commission, 1985).
69. Nair, P. K. R., "Agroforestry With Coconuts and Other Tropical Plantation Crops," *Plant Research and Agroforestry,* P.A. Huxley (cd.) (Nairobi, Kenya: International Council for Research in Agroforestry, 1983), pp. 79-102.
70. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, Casuarina: *Nitrogen-Fixing Trees for Adverse Sites* (Washington, DC: National Academy Press, 1984).
71. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, Mangium *and Other Fast-growing* Acacias *for the Humid Tropics* (Washington, DC: National Academy Press, 1984).
72. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, *Making Aquatic Weeds Useful* (Washington, DC: National Academy Press, 1984),
73. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, *Food, Fuel and Fertilizer From Organic Wastes* (Washington, DC: National Academy Press, 1981).
74. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, *Tropical Legumes: Resources for the Future* (Washington, DC: National Academy Press, 1979).
75. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, *Leu-*

caena: Promising Forage and Tree Crop for the Tropics (Washington, DC: National Academy Press, 1977).

76. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, *Underexploited Tropical Plants With Promising Economic Value* (Washington, DC: National Academy Press, 1975).
77. National Academy of Sciences, National Research Council, Board on Science and Technology for International Development, *The Winged Bean: A High Protein Crop for the Tropics* (Washington, DC: National Academy Press, 1975).
78. Ortiz-Daliot, J., Director, Puerto Rico Federal Affairs Administration, personal communication, September 1986.
79. Owen, R., former Chief Conservationist of the Trust Territory of the Pacific Islands, personal communication, March 1985.
80. Pangelinan, M., Executive Director, Saipan Farmers Cooperative Association, personal communication, July 1986.
81. Park, W. L., and Park, R. L., *Potential Returns From Sheep and Goat Enterprises,* Virgin Islands Experimental Station Report No.7, 1974. *In:* Caro-Costas, 1986.
82. Park, W. L., and Park, R. L., "Profitability of Beef Production in St. Croix, " U.S. Virgin Island Agriculture Experiment Station Report No.3, 1974. *In:* Caro-Costas, 1986.
83. Parr, J, F., Papendick, R. I., and Colacicco, D., "Recycling of Organic Wastes for a Sustainable Agriculture, " *Biological Agriculture and Horticulture* 3(2-3):115-130, *1986.*
84. Perry, J., Resource Conservationist, U.S. Soil Conservation Service, personal communication, September 1986.
85. Pimentel, D., and Levitan, L., "Pesticides: Amount Applied and Amount Reaching Pests," *Bioscience* 36(2):86-91, *1986.*
86. Poison, S., "The Marshall Islands Coconut Industry: Prospects for Expansion and Developmerit, " OTA commissioned paper, 1986.
87. Pool, D. J., "Forestry and Agroforestry Technologies: Development Potentials in U.S.-Affiliated Caribbean Islands, " OTA commissioned paper, 1986.
88. Przybyla, A. E., "America's Passion for Spices," *Food Engineering 58(6):70-71,74-76,78,* June 1986.
89. Puerto Rico Department of Agriculture, "Anuario Estadisticas Agricolas de Puerto Rico, " Department de Agriculture de Puerto Rico, 1982. *In:* Vicente-Chandler, 1986,
90. Puerto Rico Department of Agriculture, "Consumo de Alimentos en Puerto Rico 1950-1974, " Department de Agricultural de Puerto Rico, Publication Especial, 1978, *In:* Vicente-Chandler, 1986.
91. Rakocy, J. E., College of the Virgin Islands Agricultural Experiment Station, personal communication, July 1985.
92. Rakocy, J. E., "A Recirculating System for Tilapia Culture and Vegetable Hydroponics in the Caribbean," paper presented at Auburn University Fisheries and Aquiculture Symposium, Sept. 20-22, 1984. *In:* Morris and Pool, 1986.
93. Raynor, W., Ponape Agriculture and Trade School, Pohnpei, Federated States of Micronesia, personal communication, September 1985.
94. Raynor, W., "Commercial Crop Production Technologies and Development Potentials for The U.S.-Affiliated Pacific Islands," OTA commissioned paper, 1986,
95. Raynor, W., and Soumetaw, L., "Report on PATS Ylang-ylang Project, " *PATS Agri-Industrial Bulletin,* Ponape Agriculture and Trade School, Pohnpei, Federated States of Micronesia, February 1986,
96. Reynolds, S. G., "The Use of Local Resources for Vegetable Production in South pacific, " *Proceeding for Planning and Organization Meeting: Fertilizer I.N.P. U. T. (Increase Productivity Under Tight Supplies) Project* (Honolulu, HA: Food Institute, East West Center, 1975), pp. 169-180.
97. Sam, C., Ponape Coconut Products, personal communication, April 1985.
98. Sanchez-Nieva, F., "Assessment of Food Processing Technologies for U.S.-Affiliated Caribbean Islands," OTA commissioned paper, 1986.
99. Schreiner, I., University of Guam Agricultural Experiment Station, personal communication, February 1986.
100. Sefanaia, S., et. al., " A Review of Recent Research on Intercropping Under Coconut, " *Fiji Agric. Journal* 44(1):31-36, *1982.*
101. Smith, R. M., and Abruna, F., "Soil and Water Conservation Research in Puerto Rico, 1938-1947, " *University of Puerto Rico Agriculture Experimental Station Bulletin No. 1241955. In:* Vicente-Chandler, 1986.
102. Soucie, E. A., S. J., *Atoll Agriculture for Secondary Schools* (Pohnpei, FSM: PATS Education Foundation of Micronesia, Inc., 1983).

103. Sproat, M. N., *A Guide to Subsistence Agriculture in Micronesia,* Agriculture Extension Bulletin No. 9, Trust Territory of the Pacific Islands Publications Office, Saipan, Northern Mariana Islands, 1968. *In:* Falanruw, 1986; Polson, 1986; Raynor, 1986.

104. Sproat, M. N., "Coconut Varieties in Micronesia," Agriculture Extension Circular No. 4, Division of Agriculture, Department of Resources and Development, Trust Territory of the Pacific Islands, Saipan, Marshall Islands, 1965. *In:* Poison, 1986.

105. Sproat, M. N., and Migvar, L., *TTPI Agricultural Development Operations* TTPI Agricultural Extension Bulletin No. 1, January 1964, *In:* Raynor, 1986.

106. Stella, C., and Olivieri, J. A., "Costos y Practicas para Elaborer el Carbin Vegetal en la Zone Cafetalera de Puerto Rico 1952 -1953," Boletin 124, Estacion Experimental Agricultural, University of Puerto Rico, 1954. *In:* Pool, 1986.

107. Sugiura, K. "Taro Culture of Palauans," *Geogr. Res.* 1(8):1017-1035, 1942. *In:* Falanruw, 1986.

108, Szentkiralyi, M., "Assessment of Livestock Production Technologies in Micronesia and Feasibility Study for Locally Produced Pig Feed on Ponape," OTA commissioned paper, 1986,

109. Thaman, R, R., *Pacific Islands' Health and Nutrition: Trends and Areas for Action* (Honolulu HA: East-West Center, June 1985). *In:* Lucas, 1986.

110. Thaman, R. R., "Deterioration of Traditional Food Systems, Increasing Malnutrition and Food Dependency in the Pacific Islands," *Journal of Nutrition* 39(3):109-121, 1982. *In:* Falanruw, 1986.

111. Thaman, R, R., "Food Scarcity, Food Dependency and Nutritional Deterioration in Small Island Communities," *Proceedings of the 10th New Zealand Geographical Conference and 49th ANZAAS Conference,* W. Moran, P. Hosking, and G. Aitken (eds.) (Auckland, New Zealand: N.Z. Geographical Society Conference Series No. 10, 1979), pp. 191-197. *In:* Falanruw, 1986.

112. Toomey, G., "Agrogeology: Rocks in the Service of Soil," *IDRC Reports,* July 1986, pp. 12-13.

113. Torres, E., Director, Guam Department of Agriculture, personal communication, September 1986.

114. Tosi, J. A., Jr., "Forest Land Utilization in Western Puerto Rico, " Ph.D dissertation, Clark University (Ann Arbor, MI: University Microfilms Inc., 1959), *In:* Pool, 1986.

115. Trenbath, B. R., "Biomass Productivity of Mixtures," *Advances in Agronomy* 26:177, *1974.*

116. Trust Territory of the Pacific Islands, Office of Planning and Statistics, "Consumption and Production in the Traditional Sector of the Trust Territory of the Pacific Islands," 1981, pp. 102-116. *In:* Falanruw, 1986.

117, Tyson, G., Caribbean historian, personal communication, July 1986.

118. U.S. Congress, Office of Technology Assessment, *Technologies to Maintain Biological Diversity,* OTA-F-330 (Washington, DC: U.S. Government Printing Office, March 1987).

119, U.S. Congress, Office of Technology Assessment, *Technology, Public Policy and the Changing Structure of American Agriculture,* OTA-F-285 (Washington, DC: U.S. Government Printing Office, March 1986).

120, U.S. Congress, Office of Technology Assessment, *Technologies to Benefit Agriculture and Wildlife,* OTA-BP-F-34 (Washington, DC: U.S. Government Printing Office, May 1985).

121, U.S. Congress, Office of Technology Assessment, *Technologies To Sustain Tropical Forest Resources,* OTA-F-214 (Washington, DC: U.S. Government Printing Office, March 1984).

122. U.S. Congress, Office of Technology Assessment, *Reforestation of Degraded Lands,* Background Paper No, 1, OTA-BP-F-18 (Washington, DC: U.S. Government Printing Office, May 1983).

123. U.S. Congress, Office of Technology Assessment, *Impact of Technology on U.S. Cropland and Rangeland Productivity,* OTA-F-166 (Washington, DC: U.S. Government Printing Office, August 1982).

124. U.S. Congress, Office of Technology Assessment, *Pest Management Strategies in Crop Production,* vol. 1, NTIS PB80-120-017 (Springfield, VA: National Technical Information Service, October 1979).

125, U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey of the American Samoa,* February 1984.

126, U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey of the Island of Kosrae, Federated States of Micronesia,* March 1983.

127, U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey of the Islands of Truk, Federated States of Micronesia,* March 1983.

128. U.S. Department of Agriculture, Soil Conservation Service, Soil *Survey of the Islands of Yap, Federated States of Micronesia,* March 1983.
129, U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey of the Island of Palau, Republic of Palau,* March 1983.
130. U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey of the Island of Ponape, Federated States of Micronesia,* January 1982.
131, U.S. Department of Commerce, *Economic Study of Puerto Rico, 2* vols., report prepared by the Interagency Task Force (Washington, DC: U.S. Government Printing Office, 1979).
132, U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: U.S. Summary* (Washington, DC: U.S. Government Printing Office, 1984).
133. U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: Virgin Islands of the United States* (Washington, DC: U.S. Government Printing Office, 1983).
134. U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: Guam* (Washington, DC: U.S. Government Printing Office, 1983).
135. U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: Puerto Rico* (Washington, DC: U.S. Government Printing Office, 1983).
136, U.S. Department of Commerce, Bureau of Census, 1978 *Census of Agriculture: Northern Mariana Islands* (Washington, DC: U.S. Government Printing Office, 1981).
137. U.S. Department of Commerce, Bureau of the Census, 1978 *Census of Agriculture: American Samoa* (Washington, DC: U.S. Government Printing Office, 1981).
138. U.S. Department of Commerce, Office of Coastal Zone Management, *American Samoa Coastal Management Program and Final Environmental Impact Statement,* (Washington, DC: National Oceanic and Atmospheric Administration, 1980).
139. U.S. Department of Commerce, Office of Coastal Zone Management, *Puerto Rico Coastal Management Program and Final Environmental Impact Statement* (Washington, DC: National Oceanic and Atmospheric Administration, 1978).
140. U.S. Department of State, *Thirty-Seventh Annual Report to the United Nations on the Administration of the Trust Territories of the Pacific Islands, 1984. In:* Lucas, 1986.
141. U.S. Virgin Islands Agricultural Experiment Station and Cooperative Extension Service, 1983-1984 *Report of College of Virgin Island Land Grant Programs* St. Croix, U.S. Virgin Islands, October 1985.
142. Vargo, A., "Economic Pests and Pest Management Technologies Suitable for U.S.-Affiliated Pacific Islands," OTA commissioned paper, 1986.
143, Vicente-Chandler, J., "Assessment of Agricultural Production Technologies for U.S. Caribbean Islands," OTA commissioned paper, 1986.
144. Vicente-Chandler, J. *Conceptos, Plan* y *Programa Para una Agricultural Moderna en Puerto Rico,* Special Report to the Secretary of Agriculture of Puerto Rico, 1978. *In:* Pool, 1986; Caro-Costas, 1986; Morris and Pool, 1986.
145. Vicente-Chandler, J., et al., "Production *y* utilizacion intensiva de las Forrajeras en Puerto Rico," *University of Puerto Rico Agriculture Experimental Station Bulletin No. 271, 1983. In:* Vicente-Chandler, 1986; Caro-Costas, 1986.
146. Vicente-Chandler, J., and Figarella, J., "Experiments on Plantain Production with Conservation in the Mountain Region of Puerto Rico, " *University of Puerto Rico Journal of Agriculture* 46(3):226-236, *1962. In:* Vicente-Chandler, 1986.
147, Vicente-Chandler, J., Irrizary, H., and Llorens, A. A., "Costos e Ingresos en la Production Intensive de Platanos en la Region Montanosa de Puerto Rico, " Estacion Experimental Agricultural, Publication No. 137, 1980. *In:* Vicente-Chandler, 1986.
148. Vickers, M. E. H., "The Cultivation of Taro Cyrtosperma chammissonis Schott.," *Taro Cultivation in the Pacific* M. Lambert (cd.), Noumea, New Caledonia, South Pacific Commission Technical Bulletin No. 22, 1982, pp. 90-97.
149. West, N, E., "Desertification or Verification?" *Nature* 321(5):562 June 1986.
150. Wiens, H. J., *Atoll Environment and Ecology"* (Brookhaven, NH: Yale University Press, 1965).
151, Wijewardene R., and Waidyanatha, P., *Conservation Farming: Systems, Technologies, and Tools*, Department of Agriculture, Sri Lanka and the Commonwealth Consultative Group on Agriculture in the Asia-Pacific Region, 1984. *In:* Raynor, 1986; Vargo, 1986.
152. Wilkens, G. C., "Role of Traditional Agriculture in Preserving Biological Diversity, " OTA commissioned paper for assessment of *Technologies to Maintain Biological Diversity,* OTA-F-

330 (Washington, DC: U.S. Government Printing Office, March 1987),

153. Williams, P., USVI Commissioner of Agriculture, personal communication, November 1986.
154. World Development Forum, "Dripping Fertilizer, " *World Development Forum* 4(2):4, January 1986.
155. Wortman, S., *To Feed This World* (Baltimore MD: The Johns Hopkins University Press, 1984). *In:* Stiles, 1986,
156. Youdeowei, A., and Service, M. W., *"Pest and Vector Management in the Tropics"* (New York, NY: Longman Inc., 1983). *In:* Vargo, 1986.
157. Zapata, J. Z., et al., "El Mercado de Trabajo en la Agricultural y las Caracteristicas Socio-Economicas do 10S Obreros Agricola en Puerto Rico, " Agricultural Experiment Station, October 1983. *In:* Castillo-Barahona and Bhatia, 1986,