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Flying Beans, Botanical Whales, Jack's Beanstalk, and Other Marvels

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Preface

While a developing country is generally aware of the problems it faces in the process of development, it frequently is not in a position to avail itself of all the benefits advanced technologies can offer for solutions to these problems. Indeed, these technologies may often be inappropriate to the particular circumstances in developing countries, and it has become fashionable to identify or devise "appropriate," "intermediate," or "adaptive" technologies for such situations. What is often more to the point, however, is the identification of technologies that may be dormant or utilized in a different fashion in the United States or other developed countries, but that could be applied quite usefully in developing countries. This problem of identifying and transferring innovative uses of technology—and of fostering the related research and development activities—to developing countries remains, for the most part, unsolved. This is responsible for a very serious gap in the assistance programs that developed countries are providing.

To respond to this need, the Board on Science and Technology for International Development, under the chairmanship of Roger Revelle, established an Advisory Committee on Technology Innovation (ACTI) at the request of the Agency for International Development. This com-

mittee was organized in 1971 and held its first meeting in September of that year.

The program supervised by this committee has two specific objectives:

1. The generation of ideas for innovative applications of current technology to immediate problems of developing countries; and
2. The identification of research that could shorten the time characteristic of the usual progression of scientific discovery to application.

It was in this context that ACTI initiated a continuing series of studies of underexploited tropical plants of potential economic value. These plants were described by Dr. Revelle in a recent paper published in the 1978 Annual Report of the National Research Council.

This paper is the first effort to bring together information from that series of plant studies. Therefore, we are reprinting it in the hope that it will reach a wider audience.

VICTOR RABINOWITCH, *Director*
Board on Science and Technology
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Agriculture is mankind's basic industry. Where it has been successful over the past several millennia, civilizations flourished and populations grew, many other kinds of industries developed, and men freed from drudgery were able to practice such liberal and useful arts as scientific research and wide-ranging technical invention. These activities in turn were reflected in agriculture, which became an ever more scientific and productive enterprise. Where the natural environment made it difficult to practice productive agriculture, human populations were sparse, the arts of civilization lagged, and the people were backward and poor.

Agriculture is easiest in the temperate and subtropical semihumid climatic zones, where seasons of adequate rainfall alternate with dry seasons, and the soils are deep and rich. Starting with a few wild grasses, tubers, beans, and fruits, the farmers of these zones have produced, by an essentially evolutionary process of selection that fascinated Charles Darwin, a diversity of crop plants for many different human purposes and particularly suited to many microenvironments. Some of these crop species,

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such as maize, exhibit as much variety as the domestic dog, and like it are incapable of living without human beings.

Of the hundreds of thousands of plant species, only about a hundred have been domesticated, in the sense that they have undergone genetic changes to make them more useful for man. An even smaller number of species, some thirty in all, provide eighty-five percent of the weight of food eaten by human beings and ninety-five percent of calories and protein. Three-fourths of all human food energy and protein consumption comes from eight species of cereals—wheat, rice, maize, barley, oats, sorghum, millet, and rye. Three of these—wheat, rice, and maize—make up three-quarters of the total weight and calorie and protein content of cereals. All thirty species have been brought by scientific research and practical experimentation to an astonishingly high level of productivity, ten or twenty times the productivity of a few centuries ago.

The humid tropics, where rain falls throughout the year, and the arid and semiarid lands where rainfall is highly erratic, are both areas where man historically found it very difficult to develop a productive agriculture. Long and unpredictable droughts were the curse of the dry lands. Highly leached, acid soils, which could retain little water or nutrients, forced the peoples of the humid tropics to leave most of their land fallow for intervals of many years, until trees and other wild vegetation had captured a meager supply of plant nutrients that could be released by clearing the jungle and burning the debris. It is estimated that some 250 million people still practice this "slash and burn" agriculture.

NEGLECTED BUT USEFUL

The humid tropics contain about 500 million hectares of land that could be cultivated. Provided environmental difficulties can be overcome, three crops could be grown each year on this land, giving a gross cropped area of 1,500 million hectares—considerably more than the total area now cultivated on earth. Alternatively, and this is more likely, trees and treelike plants that can live on their own debris, even in a sterile soil, could be developed to produce useful crops. During the colonialist period, much scientific and technical effort was devoted to developing such tree crops as oil palm, cocoa, bananas, and rubber, whose products were desired by the people of the rich countries but yielded little that the local people could eat

or use. The end of colonialism and the rise of many new nations in the tropical zone, with populations growing at an unprecedented rate, have brought a new need for agricultural plants that can provide food and other necessities for the people of these countries.

In recognition of this need, the National Academy of Sciences, under the inspiration of Noel Vietmeyer, a staff member of the Office of the Foreign Secretary, convened an *ad hoc* panel in 1974 to identify neglected but possibly useful tropical plants, both wild and domesticated, that might be widely introduced throughout the tropics. The panel was co-chaired by Edward S. Ayensu and Richard E. Schultes. Out of 400 promising plants nominated by scientists around the world, 36 were selected for more detailed examination. The properties of these plants are summarized in Table 1.

TROPICS

To meet basic human needs in the humid tropics, several kinds of agricultural development are essential. The supply of carbohydrates, protein, vitamins, and mineral nutrients must be increased, and a greater variety of foods should be produced to provide a more diversified diet. New export crops need to be developed to raise rural incomes. With growing populations it is essential to shorten the cycle of slash and burn agriculture, that is, to reduce and, if possible, to eliminate the need to leave most of the land fallow for long periods to replenish nitrogen and other nutrients. This can be partially accomplished by introducing leguminous plants that, because of their fruitful symbiosis with certain species of bacteria, are able to extract and chemically "fix" nitrogen from the air. Crops that yield an abundant harvest in as short a time as possible after they are planted are highly desirable. It should be possible to store or otherwise preserve the edible products for extended periods. Indigenous fibers are required as well as food, and the supply of nutritious feed for livestock and poultry should be greatly increased.

The plants listed in Part A of Table 1 have been selected with one or more of these qualities in mind. Cocoyam, peach palm, taro, and dasheen are known to yield large quantities of carbohydrates per hectare. The edible products from peach palm (*Guilielma gasipaes*) and cocoyam (*Xanthosoma* spp.) have an adequate quantity of protein relative to carbohydrate.

TABLE 1 Little Used but Potentially Useful Plants

Common Name	Scientific Name	Useful Portion	Potential Use	Present Growing Areas	State of Cultivation	Present Yield Per Hectare Per Year	Time to First Harvest
A. Humid Tropics							
Cocoyam	*Xanthosoma sagittifolium*	tuber	carbohydrate, protein	Tropical Americas, West Africa	domesticated	30–60 tons wet weight	3–10 months
Peach palm or pejibaye	*Guilielma gasipaes*	fruit and stem	carbohydrate, oil, protein, "heart of palm"	Central and Northern South America	domesticated	3 tons	6–8 years
Taro and dasheen	*Colocasia esculenta*	tuber	carbohydrate	Egypt, Philippines, Hawaii, Caribbean	domesticated	22–30 tons wet weight	6–18 months
Buriti palm	*Mauritia flexuosa*	fruit kernel, shoots, trunk and leaves	oil, starch, vitamins A and C, timber, cork, fiber, "heart of palm"	Amazon Basin, Venezuela, Guianas	mostly wild	?	?
Babassu palm	*Orbignya martiana*	fruit and kernel	oil, protein, fuel	Amazon Basin	mostly wild	1.5 tons	10–15 years
Pequi tree	*Caryocar brasiliensis*	fruit and kernel	oil, fuel	Amazon Basin, Central Brazil, Guianas	mostly wild	?	9 years
Seje palm	*Jessenia polycarpa*	fruit	oil resembling olive oil	Amazon Basin	wild	22 kg/tree per year	?
Winged bean	*Psophocarpus tetragonolobus*	pods, beans, tubers, foliage	protein, oil, carbohydrate, livestock feed	Papua New Guinea, Southeast Asia, Sri Lanka	domesticated	2.5 tons of dry beans	10 weeks
Durian tree	*Durio zibethinus*	fruit	carbohydrate, fat, vitamins, flavor	Southeast Asia	haphazardly cultivated	?	7 years
Mangosteen tree	*Garcinia mangostana*	fruit	highly prized flavor	Southeast Asia	domesticated	50 kg/tree per year	15 years
Pummelo tree	*Citrus grandis*	fruit	large citrus fruit	Southeast Asia	domesticated	?	several years

Soursop tree	*Annona muricata*	fruit	fruit and juice	Southern China, Australia, Africa, tropical Africa, West Indies	domesticated	6–10 tons	?
Uvilla tree	*Pourouma cecropiaefolia*	fruit	grapelike fruit	Western Amazon	wild	?	3 years
Chaya bush	*Cnidoscolus chayamansa*	leaves	vitamin-rich leafy vegetable	Mexico and Central America	domesticated	?	2–3 months
Ramie herb	*Boehmeria nivea*	stems and foliage	fiber and livestock feed	East and Southeast Asia, Brazil	domesticated	1.4 tons fiber, 20 tons feed	2 months
Cauassu herb	*Calathea lutea*	leaves	commercial wax	Amazon Basin, Central America	wild	0.8 tons of wax	9 months
Leucaena	*Leucaena leucocephala*	leaves, wood, pods, seeds, bark	livestock feed, timber, fuel, paper, soil fertilizer, dye stuffs, human food, erosion and watershed control, nurse tree, fire and wind breaks	Central America, Mexico, Southeast Asia, Northern South America, Australia, Hawaii, East and West Africa, Papua New Guinea, Caribbean, India	domesticated and wild	12–20 tons of forage, 20–50 tons of wood	less than 1 year to more than 3 years, depends on variety planted
B. Semiarid and Arid Tropics and Subtropics							
Channel millet	*Echinochloa tunerana*	seed, leaves, and stems	carbohydrate, protein, livestock feed	Central Australia	wild	?	several months after heavy rain
Buffalo gourd	*Cucurbita foetidissima*	seed, root	oil, protein, starch	Mexico, Southwestern United States	mostly wild	2.5 tons of seed, 22 tons starch	2 years
Guar (cluster bean)	*Cyamopsis tetragonoloba*	seed, leaves, and stem	gum, protein, oil, livestock feed	United States, Pakistan, India, Australia, Brazil, South Africa	domesticated	18–24 tons green fodder, 0.9–2 tons seed	3–5 months

TABLE 1—Continued

Common Name	Scientific Name	Useful Portion	Potential Use	Present Growing Areas	State of Cultivation	Present Yield Per Hectare Per Year	Time to First Harvest
Apple-ring acacia tree	*Acacia albida*	leaves, shoots, pods, seeds	livestock feed, human protein	Tropical and Southern Africa	wild	200 kg protein	several years
Ramon tree	*Brosimum alicastrum*	leaves, twigs, nuts	livestock feed, carbohydrate, protein	Central America, Southern Mexico, Caribbean Islands	mostly wild	?	several years
Cassia shrub	*Cassia sturtii*	leaves	livestock feed	Australia, Israel	wild and cultivated	1/2 ton dry weight	1–1.5 years
Saltbush	*Atriplex* spp.	leaves and shoots	livestock feed	worldwide in warm arid zones	wild and cultivated	1–1.5 tons	2 or 3 years
Candelilla shrub	*Euphorbia antisyphilitica*	stems and leaves	hard wax	United States and Mexican deserts	wild	?	2–5 years
Tamarugo tree	*Prosopis tamarugo*	pods and leaves	high protein, livestock feed	Atacoma desert of Chile, Canary Islands	cultivated	10–20 sheep	5 years
Jojoba shrub	*Simmondsia chinensis*	seeds	liquid wax identical to sperm oil	United States and Mexican deserts, Israel	mostly wild	2 tons	3–5 years
Guayule shrub	*Parthenium argentatum*	whole plant	natural rubber	United States, Mexican deserts, Spain, Turkey	mostly wild	0.33 ton	1 year
C. Mountain Environments of Low Latitudes							
Grain amaranth	*Amaranthus caudatus*, etc.	seed, leaves	high lysine, high protein, starch, vitamins	Andean region of South America	domesticated	higher than maize	several months

Quinua (grain)	*Chenopodium quinoa*	seed	protein, carbohydrate	Andean region of South America	domesticated	?	5–6 months
Peruvian parsnip	*Arracacia xanthorrhiza*	tubers, stems, leaves	carbohydrate, livestock feed	Andean region of South America	domesticated	?	10–14 months
Naranjilla shrub	*Solanum quitoense*	fruit	fruit and juice	Central and Northern South America	domesticated	1–2 tons of fruit	6–12 months
Winged bean	*Psophocarpus tetragonolobus*	pods, beans, tubers, foliage	protein, oil, carbohydrate, livestock feed	Papua New Guinea, Southeast Asia, Sri Lanka	domesticated	2.5 tons of dry beans	10 weeks
D. Saline Environments							
Eel grass	*Zostera marina*	seed	carbohydrates, protein	tidal flats and estuaries in all latitudes	wild	?	?
Pummelo tree	*Citrus grandis*	fruit	citrus fruit	brackish marshy areas in Thailand	domesticated	?	several years
Saltbush	*Atriplex* spp.	leaves and shoots	high protein, livestock feed	worldwide, including salty soils and saline irrigation waters	mostly wild	1–1.5 tons	2 or 3 years
Tamarugo tree	*Prosopis tamarugo*	pods and leaves	high protein, livestock feed	Atacama desert of Chile, Canary Islands	cultivated	10–20 sheep	5 years
Silt grass	*Paspalum vaginata*	leaves and stems	livestock feed, sand stabilization	seacoasts from Australia to Spain, Argentina to Baja California	mostly wild	?	1 or 2 years
Spirulina, blue-green algae	*Spirulina platensis* *Spirulina maxima*	entire alga	poultry feed, very high protein human food	Lake Chad, Valley of Mexico	cultivated	3 tons protein	several days

Cocoyam tubers can be maintained in edible condition by leaving them in the ground (for as long as two years in fairly dry soil), or they can be stored in a cool, dry place for several months. Dasheen (*Colocasia esculenta*) can be stored at ten degrees centigrade for up to six months, and taro (*Colocasia esculenta*) fields can, in various stages of maturity, contain plants that can be harvested the year round. The fruits and kernels of the buriti (*Mauritia flexuosa*), babassu (*Orbignya martiana*), seje (*Jessenia polycarpa*) palms, and the pequi tree (*Caryocar* spp.) contain abundant oil, which could provide an export crop, as could the preserved fruits and juices of the durian (*Durio zibethinus*), mangosteen (*Garcinia mangostana*), pummelo (*Citrus grandis*), soursop (*Annona muricata*), and uvilla (*Pourouma cecropiaefolia*). These fruits, together with the leaves of the chaya bush (*Cnidoscolus chayamansa*), can give variety to the diet of local people. Ramie fibers (*Boehmeria nivea*) are several times as strong as cotton or silk, and much more durable than cotton. The cauassu herb (*Calathea lutea*) has very large quantities of a commercially valuable wax. Cocoyam, taro and dasheen, chaya, ramie, and cauassu have growing seasons measured in months, unlike the fruit and palm trees that require years before reaching maturity. The palm trees, however, have very modest soil requirements. They live largely on their own debris, as is generally true of the plants of the rain forest.

Much research is needed on most of these plants. For cocoyam, taro, and dasheen, the principal problem is infection of the tubers and roots by viruses, transmitted when the tubers are planted. Virus-free tubers could be produced if it were possible to reproduce the plants either by tissue culture or by seeds. Researchers at the University of Florida have recently grown cocoyam from seed, but there has never been a breeding program for taro and dasheen, either for removing pathogens or for genetic improvement. Taro grown in flooded paddies now requires long hours of hard work in muddy, flooded fields. Mechanical methods for planting, cultivating, and harvesting taro are badly needed and offer a great challenge to agricultural engineers.

In spite of its admirable qualities, ramie fiber is little used outside East Asia. In the harvested plant the fiber is covered with a tenacious, inert gum, which at present is best removed by tedious manual labor. This makes ramie fiber relatively expensive even in developing regions with an abundant supply of underemployed labor. More efficient and economical degumming methods must be developed. This will require research by

organic chemists on the structure of the gum and ways to dissolve it, and by microbiologists to find microorganisms capable of consuming the gum without weakening the fiber.

A similar problem exists with cauassu. Chemical and engineering research are needed to develop more economical techniques for separating the valuable wax from the leaves.

For the palm and fruit and nut trees listed in the table, the principal problems of economic development are the long times required before a first harvest can be obtained, and the consequent tying up of land and capital for many years without a profitable return. Research and development to shorten the growing times of these species, or alternatively to find ways of interplanting them with other crops that do give an early return, could pay off handsomely.

THE FLYING BEAN

Perhaps the most remarkable and potentially useful food crop listed in the table is the winged bean (*Psophocarpus tetragonolobus*), which may have a greater capability for relieving the protein hunger of people throughout the humid tropics than any other known plant. It is a perennial legume, now grown by farmers only in Papua New Guinea and Southeast Asia as far west as Sri Lanka. The plant produces edible green pods within two and a half months after planting, and beans after four months. It continues to provide nutritious and tasteful food indefinitely, though the yields decline after several months, so that farmers usually treat it as an annual crop.

The winged bean resembles an ordinary runner bean, a bushy pillar of greenery with wirelike shoots that twist upward searching for support to hold the plant upright. The pods containing the beans vary from six to sixty-six centimeters in length, depending upon the variety, with four green flanges or "wings" running the length of the pod. The dried beans contain up to twenty percent oil and thirty-seven percent protein, with an amino acid balance and nutritive value equal to the protein of soybeans. Yields can be nearly as large as those of soybeans and much larger than other tropical legumes, over three and a half tons of dry beans per hectare in experiment station plots. The protein component of a mixed diet of winged beans and maize has as high a nutritive value as the protein in milk. Like soybean oil, winged bean oil is polyunsaturated and therefore presumably

better for human health than saturated fats and oils. Some varieties produce protein-rich tubers that can be eaten like potatoes; the flowers and leaves are also nutritious and tasty.

Present varieties of the winged bean appear to be photosensitive, requiring a short day to flower, so that the plant produces seeds only at latitudes within twenty-five degrees of the equator. On the other hand, unlike most cultivated tropical plants it tolerates a wide range of altitudes. In Papua New Guinea it is grown from sea level to over 2,000 meters. For this reason, we have listed it both in Parts A and C of Table 1, as a potentially valuable source of protein and oil for human food and as a livestock feed.

In the future, the winged bean could become as important a crop plant as the soybean. Our knowledge of its genetics, physiology, agronomic requirements, and potential uses is about the same as knowledge of soybeans sixty years ago. Present varieties are grown mainly by home gardeners for family consumption or for sale in local markets. Larger-scale commercial production is less practicable, because the plants must be supported by stakes to produce high yields and the beans must be harvested over many months.

Research on the winged bean is needed to develop strong-stemmed dwarf varieties that will not require staking, and whose beans mature and can be harvested at about the same time. Fermentation and other food-processing technologies for preparation of curd, milk, gruel, and other foods similar to those obtained from soybeans should be investigated.

A report, *The Winged Bean, a High Protein Crop for the Tropics,* was published in 1975 by an international panel of the Advisory Committee on Technological Innovation of the Board on Science and Technology for International Development. Under the chairmanship of Richard E. Schultes, specialists from ten countries contributed to the preparation of this report, which describes the present state of knowledge concerning the winged bean, its promise as a crop plant, significant data gaps and research needs, and a proposed strategy for international cooperation in research and testing. The report contains a list of researchers known to be working with the winged bean and a bibliography of nearly fifty references. One of the panel's recommendations was that an informal international newsletter should be published, and such a newsletter, "The Winged Bean Flyer," published by the Department of Agronomy, University of Illinois, now appears semiannually.

Part C of Table 1 lists five little-known species that might be used to enrich the diets of the peoples of tropical highlands. One of these, the winged bean, has already been described. The remaining four are native to the highlands of tropical South America. One, quinua (*Chenopodium quinoa*), is a food grain that was a staple of the ancient Incas. Another, the Peruvian parsnip (*Arracacia xanthorrhiza*), is a starchy tuber that is less expensive to plant and harvest than the potato. A third, the naranjilla (*Solanum quitoense*), the "golden fruit of the Andes," has a sweet-sour flavor reminiscent of pineapples and strawberries. It is used in Ecuador and Colombia as a dessert fruit and to make a delicious juice. One hectare of naranjilla can produce one to two tons of fruit within a year of planting.

The grain amaranths (*Amaranthus caudatus, A. cruentus, A. hypochondriacus*) appear particularly promising as a source of carbohydrates and protein for highland peoples. They are reported to show a higher yield per hectare of seeds—containing about fifteen percent protein and sixty-three percent starch—than maize grown on adjacent plots. The lysine content—one of the essential amino acids usually deficient in cereals—of the protein is about the same as that of soybeans and milk. At the time of the Spanish conquest, amaranths were major grain crops in the tropical highlands of the Americas, where they played an important role in Indian religious ceremonies. In their efforts to eradicate the native religion, the Spaniards suppressed amaranth cultivation and introduced barley, a low-lysine cereal, in its stead, thereby improving the Indians' souls at the expense of their nutrition. During the last century grain amaranths were introduced in Asia, where they have become important to some hill tribes.

The lack of roads and vehicles restricts the cash crops that can be grown by the farmers of tropical highlands to high-value, small-volume materials that can be carried for long distances on human backs. A search needs to be made for essential oils and spices, medicinal plants, gums, and other natural products for industry that can be grown in the hills and mountains of the poor countries. Descriptions of some plants of this type, which might be suited to the highlands of Sri Lanka at heights up to 2,000 meters, are given in *Natural Products for Sri Lanka's Future,* the report of a workshop jointly sponsored by the National Science Council of Sri Lanka and the National Research Council in 1975. Some fifty scientists from Sri Lanka and nine from the United States participated in this workshop. Carl Djerassi chaired the American group.

Part D of Table 1 lists seven species that are now cultivated or might be used in beneficial exploitation of areas of saline water or soil. One of the most interesting of these is spirulina (*Spirulina platensis, S. maxima*), a blue-green algae that was grown by the Aztecs in the shallow lakes of the Valley of Mexico as one of their principal sources of protein. It is still cultivated near Mexico City as a high-protein, high-carotene additive to chicken feed. Spirulina also grows wild in Lake Chad, where it has been eaten by the local inhabitants for many generations. The microorganism is relatively large, and the Chad villagers recover quantities of spirulina by filtering the lake water through muslin. The material is then sun-dried in cakes, stored until needed, and cooked and eaten as a green vegetable. Seventy percent of the dry matter is protein with a relatively satisfactory balance of essential amino acids; the vitamin B_{12} content is also high.

The Seri Indians of Tiburon Island in the Gulf of California found that the common eelgrass (*Zostera marina*) produces seeds that can be used as a food grain. They threshed the sun-dried plants with wooden clubs, winnowed the grain, and ground it into flour. Recent tests have shown that this bland-tasting flour contains about thirteen percent protein and fifty-one percent starch, which compares favorably with wheat or rice. Applied marine biological research might develop eelgrass into an agricultural crop that could be grown in saline paddies.

DROUGHT AGRICULTURE

Many of the world's poorest people live a precarious existence in the semiarid and arid tropics and subtropics. They have the same needs as the populations of the humid tropics for increased supplies of carbohydrates, proteins, and other nutrients, and for agroindustrial products that could provide incomes. But there are two major differences: Crop plants for unirrigated arid or semiarid lands must be able to withstand long periods of drought and be able to grow vigorously during rainy seasons. Livestock husbandry is often the most economically efficient way to utilize the abundant land and scarce water resources of arid lands; consequently, plants that can provide a greater quantity and better quality of livestock feed are highly desirable.

Part B of Table 1 lists seven plants, now grown only in a few regions, that might be used principally to provide livestock feed in other semiarid or

arid regions. Four other plants have promising agroindustrial potentials, and several could provide carbohydrate and protein for human food.

One of the latter is the buffalo gourd (*Cucurbita foetidissima*), a vigorous long-lived perennial that grows wild on wastelands in the deserts of Mexico and the southwestern United States and is now being cultivated in Lebanon. Its abundant fruits enclose a prodigious quantity of seeds, which can be easily threshed out when the fruit dries. One hectare of plants can produce 2.5 tons of seeds, containing up to thirty-four percent of an edible polyunsaturated oil and thirty to thirty-five percent protein. The seeds have been eaten for centuries by North American Indians. The buffalo gourd's enormous root can weigh thirty kilograms after just two growing seasons; in three years it can be twice as large as a man. The roots are fifty percent starch. Very little is known about the plant's variability, its agronomic requirements, or even the length of time to maturity. The root starch contains bitter-tasting glycerides that must be washed out in a salt solution, and the protein meal left after oil extraction may contain toxic substances that must be removed before it can be used as a feed for livestock or as human food. Research is needed on all aspects of this promising plant.

The guar, or cluster bean (*Cyamopsis tetragonoloba*), is a leguminous herb resembling the soybean. It has been grown for food in India since ancient times, but its great potential lies in the gum in its seeds. Guar gum has five to eight times the thickening power of starch. It is useful as a filter aid in the mining industry; a thickener in cosmetics, hand lotions, and creams; a strengthening ingredient in paper; a stabilizer for salad dressings, bakery products, and ice cream; and in the drilling muds used by the oil industry. Some 25,000 tons of the gum, at a price of $1.50 to $2.50 per kilogram, are produced annually in the United States, and the demand exceeds the supply. Seed yields per hectare from irrigated guar are as high as 1.9 tons, with twenty-two percent being gum, which is worth $625 to $1,050 per hectare at present prices. Improvement through research could make guar a top-ranking agricultural crop in many semiarid tropical and subtropical regions.

THE BOTANICAL WHALE

Few plants can withstand the scorching temperatures, low humidity, and lack of rainfall in the desert. One of those that can is a slate green, twiggy,

Top: Leucaena pods; *Bottom left:* Winged Bean; *Bottom right:* Jojoba

stunted shrub called jojoba (*Simmondsia chinensis*). It grows wild, often in dense stands, scattered over 300,000 square kilometers in the Sonoran Desert of northwestern Mexico, Arizona, and California, where annual rainfall varies from ten to fifty centimeters. Each plant produces many soft-skinned nuts, long used by the Sonoran Desert Indians as food (roasted they smell and taste like roasted coffee beans) and as medicine. Half the weight of an average nut is a yellowish, odorless oil. The meal left after the extraction of the oil contains about thirty percent protein, as well as carbohydrates and fiber. Jojoba oil feels less oily than the usual edible oil. The reason is that it has a radically different chemical structure from any other known vegetable oil. Chemically, it is composed almost entirely of esters of high molecular weight, consisting of straight chain alcohols esterified with long-chain fatty acids. Jojoba oil is a polyunsaturated liquid wax: Both the acid and the alcohol portions have twenty to twenty-two carbon atoms, and each has one unsaturated bond. Waxes of this type are difficult to synthesize commercially, and for decades the only source has been the sperm whale. With growing industrial demands, sperm whales have been hunted ever more ruthlessly, until they have become an endangered species. In 1975 over 20,000 sperm whales were killed, and each whale provided several tons of sperm oil.

Importation of sperm whale oil is now prohibited in the United States, but the real hope for survival of these magnificent mammals is the possibility that jojoba's liquid wax, which is virtually identical with sperm oil, can be produced more economically and in larger quantities than the whalers can supply sperm oil.

The major application of sperm oil has been in lubricants used under extreme pressure in automobile transmissions and other high-speed machinery, and also in machinery operating at both high temperatures and pressures. Jojoba oil has been shown to duplicate sperm oil's lubricating properties; it serves well as a cutting or grinding oil when added to other lubricants; and it may be suitable as a transformer oil or an oil for delicate mechanisms. It has major potential in the cosmetic industry as a component of hair oil, shampoo, soap, face creams and sunscreen compounds, and in pharmaceuticals as a stabilizer of penicillin products and a coating for medicinal preparations. When combined with sulfur chloride it could be used in the manufacture of linoleum, printing ink, varnishes, chewing gum, and adhesives. Its alcohol and acid derivatives can be used in the

preparation of disinfectants, surfactants, detergents, lubricants, driers, emulsifiers, resins, plasticizers, protective coatings, fibers, corrosion inhibitors, and bases for creams and ointments.

When hardened by hydrogenation (the process that produces margarine from vegetable oils), jojoba oil is transformed into a dense solid of sparkling white crystals, called jojoba wax, which resembles spermaceti (also from the sperm whale), carnauba wax, and beeswax. It has a high melting point of seventy degrees centigrade, and a hardness approaching that of carnauba, the "king" of waxes. Jojoba wax has potential uses in polishes for floors, furniture, and automobiles; as a protective coating on fruit, food preparations, and paper containers; in lipsticks and candles; as a sizing for textiles; and as a high-dielectric-constant material for electric insulators.

Yields of up to five kilograms of nuts from an individual jojoba shrub have been recorded; the wild stands of jojoba in Mexico and the United States are estimated to produce 10,000 to 15,000 metric tons of nuts each year. But the most that has ever been collected in the United States was in 1972, when about forty-five metric tons were harvested by the Apache Indians of the San Carlos Reservation in Arizona. The oil obtained from this harvest was distributed by the Universities of California and Arizona for testing by more than a hundred industrial firms across the nation. Only about thirty metric tons were harvested in Arizona and California in 1976, even though the established price of jojoba oil is $11 per kilogram in the United States and about the same in Mexico. The price is high because the nuts must be harvested by hand during July and August—the hottest period of the year—at picking rates of $2.20 to $3.10 per kilogram of nuts. The present world market demand of less than fifty metric tons of oil probably cannot be increased or even sustained unless the costs of the oil can be reduced. At a price for jojoba oil of $2 per kilogram, the estimated demand would be very large, about 127,000 metric tons. Such a price will be attainable only if the jojoba can be successfully domesticated and cultivated on commercial plantations in which the harvesting process is mechanized. This could presumably be accomplished by using machines similar to those employed in harvesting blueberries and grapes, which pick several thousand kilograms per hour. It is estimated that harvesting costs could then be reduced to ten to twenty cents per kilogram of nuts.

Jojoba plants are now being cultivated in Israel, where a plantation

was started about ten years ago, and a small test plantation has been initiated by the University of California, Riverside. Several agencies of the federal government are helping Indians on reservations in Arizona and California to establish jojoba plantations. So far, about forty hectares have been successfully planted, and over a hundred hectares have been cleared for planting. The Indians have allocated more than a thousand hectares of their land for further plantations. To meet the projected world demand, about 100,000 hectares of plantations will be required, at a yield of 2,500 kilograms of nuts per hectare. This could result in a $250 million industry. Under the chairmanship of Parker F. Pratt, the National Research Council's Committee on Jojoba Production Systems Potential, made up of specialists familiar with jojoba in various disciplines from Israel, Mexico, and the United States, including Indian tribal representatives, has prepared a comprehensive report on the feasibility of cultivating jojoba in the Indian reservations of the Sonoran Desert region.

The principal economic difficulty impeding successful development of an Indian agroindustry based on jojoba is the long time required to produce a profitable crop, approximately five to ten years. Although comparable with the time required for profitable harvesting of other high-value crops such as almonds, macadamia nuts, and avocadoes, this long period of investment without return will be very difficult for the desert Indians of Mexico and the United States, with their limited capital resources and extreme poverty. Moreover, the Indian population currently lacks the training and experience necessary to successfully manage, operate, and develop enterprises of the required scale. The NRC committee has recommended establishment of a short- and long-range education and training program for Indian farmers, managers, and researchers, both those involved with jojoba production from the natural shrubs and those concerned with management of future jojoba plantations and processing plants.

Besides Israel and Mexico, research projects on jojoba have been initiated in several other countries, including Japan, Australia, Sudan, and Great Britain. Broadening of this international base of support for jojoba development as a commercial crop is highly desirable. It will encourage research workers in government and private agencies to create higher-yielding jojoba varieties. The international exchange of information on growing jojoba under different environmental and managerial conditions

will be valuable. International cooperation can also be expected to promote production, marketing, and utilization of the nut and its by-products. An international newsletter, *Jojoba Happenings,* is now published by the Office of Arid Land Studies of the University of Arizona. The International Council for Jojoba Development was organized in 1972, and international conferences were held in 1972 and 1976.

GUAYULE—THE FORGOTTEN PLANT

Natural rubber occurs in some 2,000 species of plants. But only two species have ever been used as continuing sources of commercial rubber. One of these, the majestic rubber tree *Hevea brasiliensis,* first discovered in the rain forests of the Amazon and now grown principally in Malaysia and other humid, tropical parts of Southeast Asia, produces nearly a third of the 10 million tons of the total (natural and synthetic) rubber used in the world each year. The other is an inconspicuous shrub, *Parthenium argentatum.* It grows wild in the Chihuahuan desert of Mexico and the trans-Pecos region of Texas, where the rainfall is low and erratic. In pre-Columbian Mexico, the Aztecs made bouncing balls out of its rubber, which they obtained by chewing the stems and spitting out the rubber and vegetable matter separately. The conquering Spaniards corrupted its Indian name to guayule. It is said that half of the rubber used in the United States in 1910 came from guayule.

Both hevea and guayule yield an apparently identical polyisoprene rubber. During World War II, thousands of tons of guayule rubber were produced by the U.S. government in cultivated fields in California, and experimental plantations have been attempted in semiarid regions of many other countries. Yet, today there is no commercial guayule farming anywhere in the world, and the wild guayule plants are being experimentally harvested for their rubber only in Mexico.

Nevertheless, the dramatic rise in the price of petroleum (the raw material for synthetic rubber) during the last few years, and the increasing likelihood that the demand for natural rubber will exceed the capacity of Southeast Asia to produce it, have focused renewed attention on guayule as a potential biological resource for agriculture in semiarid regions. These regions contain some of the world's poorest peoples, not only in Africa, South America, and Asia, but also on the Indian reservations of the southwestern United States.

The history and prospects of guayule are described in *Guayule: An Alternative Source of Natural Rubber,* prepared by a panel chaired by Reed Rollins, sponsored by two boards of the National Research Council, and supported by the U.S. government's Bureau of Indian Affairs and four other federal agencies. The principal reason for the decline of guayule was the government's abrupt abandonment of its Emergency Rubber Project in 1946, when 10,000 tons of rubber in 12,000 hectares of guayule plantations were burned or disked into the ground. Most of the seeds from the genetic improvement program were destroyed, along with millions of seedlings, because it was thought that synthetic "rubber" elastomers would soon completely supercede natural rubber. But during the last three decades, natural rubber has proven superior to the artificial variety for many uses, and the relative costs of natural rubber have been kept low through intensive research. The Rubber Research Institute of Malaysia has achieved a sixfold improvement in the yield of hevea trees and has demonstrated the possibility of a further tripling of annual yields, up to seven and a half tons per hectare. This is in sharp contrast to the best yields for cultivated guayule in irrigated fields at the end of World War II, which were about 0.85 ton per hectare per year. Genetic research and the use of plant growth regulators (such as 2,4,5-trichlorophenoxy acetic acid and 2-chloroethyl phosphonic acid) have revolutionized hevea rubber production. There is good reason to believe that a similar revolution through research could occur in guayule.

The genetic diversity of the guayule plant is immense. Every bush growing in the desert appears to be almost a separate strain. There is a wide variation in the rubber content of the plants, from less than ten to about twenty-six percent, in the rate and size of growth, and in disease resistance, ease of defoliation, ability to compete with weeds, resin content, and cold and drought tolerance. Moreover, guayule can be hybridized with other larger species of *Parthenium,* and it has a unique "bimodal" reproduction system. In one mode, the female flowers do not have to be fertilized to set seeds, and this "apomictic" reproduction ensures that once a good variety is found, it can be multiplied indefinitely without genetic change. One of the greatest research needs is a simple, rapid method for screening plants for rubber content. If such an instrument were portable, the breeder could use it to comb wild stands for the best strains, instead of growing thousands of seeds in a blind groping for desirable types.

For every ton of rubber, the guayule plant contains about half a ton of

resin, including various kinds of terpenes and low-molecular-weight hydrocarbons. In the past it was not easy to separate these liquid tars from the rubber, and almost all the guayule rubber sold was in a tarry form. This resinous rubber gave guayule a bad reputation that still persists in the rubber industry. It has since been found that the resin can easily be removed by use of appropriate solvents. But no deresinated rubber has ever been produced for commercial use. Two major research needs are the development of improved methods for resin separation and for extracting the latex from the shrub without coagulating it to rubber.

It could turn out that research on by-products from guayule will be the key to its successful use. The resin contains volatile and nonvolatile terpenoids, a shellaclike gum, drying oils, and cinnamic acid. In fact, the resin might prove more valuable than the rubber. A ton of guayule leaves also contains about twenty-five kilograms of a hard wax, with one of the highest melting points (seventy-six degrees centigrade) ever recorded. As with jojoba, there is an increasing demand for hard waxes; they also command high prices (about $4 per kilogram).

Guayule has two significant characteristics for potential dry-land agriculture. The plant easily survives long periods of drought by becoming dormant, and it is long-lived. So, while successful guayule production requires an *average* annual water supply of about forty centimeters, the plant can be grown in regions where rainfall is widely variable from year to year. During its long lifetime, the plant does not use or metabolize the rubber it produces, but simply accumulates it, up to periods of at least ten years. When guayule is actively growing, it produces little or no rubber. But when growth slows during periods of cold weather or reduced moisture, the products of photosynthesis are diverted to rubber production, and the rubber content increases. Consequently, the plants could be a living and growing stockpile of rubber and other potentially valuable products, which once established would require little or no maintenance, and could provide farmers with security in bad years. For this reason, guayule could be an excellent crop for stopping erosion, and possibly for grazing, in semiarid wastelands. It might also be a useful intercrop grown between rows of food crops.

Hevea rubber is one of the most labor-intensive crops in the world. If guayule is to compete with it successfully in the United States, not only would annual yields per hectare need to be raised, but production would

need to be mechanized in order to increase yields per worker. In the semiarid lands of less-developed countries, however, guayule cultivation would be basically similar to that of other field crops, and mechanization would not be necessary in rural areas of high unemployment or underemployment. The possibilities in these regions for producing guayule rubber that would be competitive in costs and quality with hevea rubber depend on the development of high-yielding strains and the improvement of processing facilities.

The report *Guayule: An Alternative Source of Natural Rubber* recommends that the U.S. government should initiate a planned, coordinated program of research and development for commercialization of the guayule plant, with special emphasis on agricultural production. Such a program would require the combined skills of plant geneticists, physiologists, pulp and paper technologists, organic chemists, and chemical engineers. It should be undertaken in close collaboration with the government of Mexico, which already has a program for exploiting the estimated 2.6 million tons of wild guayule shrubs (containing over 250,000 tons of rubber) that can be harvested in northern Mexico. The annual budget for the United States' portion of this program could be in the range of $2 to $4 million, but the payoff could be a new agricultural enterprise worth several hundred million dollars.

FAST-GROWING TREES FOR FUEL AND FORAGE

Fuel for cooking and heating water is just as essential as food itself for the poor people of the developing countries. In mountainous and hilly areas, fires must be used if people are to keep warm. In some regions, cattle dung, wheat and rice straw, and corn husks are burned; but these materials have other necessary uses as fertilizer and feed for livestock. Wherever trees are available, firewood is used as fuel. On the average, nearly one ton of firewood per person is consumed each year in vast regions of Asia, Africa, and Latin America. Wood is the "poor man's oil."

With the unprecedented growth of human populations in all the developing countries, more and more wood is being burned each year, and, in many areas, forests are being cut down for both fuel and livestock forage faster than they can be replenished. In the hilly or mountainous headwaters of great rivers, destructive erosion of steep slopes is rapidly increasing; the

resulting sediments choke the rivers and cause more disastrous downstream floods each year. As the supply diminishes, the price of fuelwood continually rises. In Nepal the average family spends about one-fourth as much on fuelwood as it does on food. If the wood is not purchased, one member of the family is often fully occupied in collecting firewood from forest areas at ever-increasing distances from the village. One of the reasons the forests are being denuded is the slow rate of growth of most native trees. The widespread sal tree of India and Nepal, for example, requires eighty years to produce usable timber.

Small plantations of fast-growing trees for fuel and forage could bring great benefits to rural villages. Moreover, with the continuing rise in the cost of fossil fuels, many tropical countries may find it economically desirable to take advantage of their abundant sunshine and year-round growing conditions by establishing large "energy plantations" as a means of capturing solar energy for industry and transportation. Forest trees, with their low nitrogen requirement and their ability to grow on poor, rocky soils and steeply irregular topography, could make an important contribution to meeting future energy needs. The key is high productivity per unit area. For example, with an annual production of twenty-five tons of wood per hectare, which is attainable with several of the trees described below, an area 550 kilometers on a side could provide all of India's present energy requirements. This is about one-fifth of the existing cultivated area in India.

To help in the search for firewood trees suited to the diverse environments of the less-developed countries, Noel Vietmeyer and his colleagues sought the advice of over 300 foresters and botanists throughout the world. Each specialist was asked to nominate those tree species he considered most appropriate for firewood plantations. Out of more than 1,000 species nominated, nearly half were rated as having exceptional promise by one or more persons. For some species, there was general agreement among at least half the specialists that they deserved to be ranked as promising candidates.

Using the results of the questionnaire and other information, an international panel appointed by the Board on Science and Technology for International Development is preparing a manual of promising fuelwood species. This will contain references to institutions and individuals throughout the world who are conducting investigations on each species and a bibliography of published information and recommendations on

desirable national and international action. The panel is chaired by Edward S. Ayensu of the Smithsonian Institution.

Table 2 shows the top species selected by these experts for the five principal environments of the developing countries: tropical highlands, savanna regions, semiarid regions, arid and Mediterranean areas, and wet–dry lowland tropics. About ten to thirty species are shown for each major environment. It will be noted that there is some overlap in the recommendations; eucalyptus and acacia species are highly rated for almost all of the regions, for example.

In considering this list, it must be remembered that in many poor countries trees are used both as a source of fuel and construction materials and as a feed for livestock. The branches are lopped off and carried to the animals, which eat the leaves and tender shoots. Leguminous trees such as acacia provide the most digestible and acceptable nutrients. Hence the trees chosen for village plantations may not be those that can produce the highest caloric value per unit area and time, but those that provide an optimum combination of fuel and forage.

JACK'S BEANSTALK

Heading the list of exceptionally promising trees for the low-lying humid tropics is an evergreen tropical legume, *Leucaena leucocephala,* which is one of the most versatile plants in the world. One of its varieties has traveled from its original home in Mexico and Central America throughout the tropics during the past two and a half centuries. The name Oaxaca (Mexico's fifth largest state and a prominent modern city) is derived from a pre-Columbian word meaning the "place where Leucaena grows." The plant was carried to the Philippines in the Manila galleons, which for 250 years sailed across the Pacific each spring from Acapulco. This "Acapulco" (usually called "Hawaiian") variety, is a short, rugged, bushy tree up to five meters high that makes good firewood and charcoal and is useful as a "nurse tree" to provide shade and nutrients for coffee, cocoa, pepper, vanilla, and other shade-loving crops. It was spread by colonial plantation owners in the nineteenth century to the Netherlands East Indies, Southeast Asia, India, East and West Africa, the islands of the South Seas, and the Caribbean. The Hawaiian variety flowers year round and produces seeds, even when only a few months old. Consequently, it easily becomes a

TABLE 2 Fast-Growing Tree Species for Fuelwood Plantations

A. TROPICAL HIGHLANDS

Casuarina spp.
Eucalyptus globulus
Eucalyptus grandis
Eucalyptus maidenii
Acacia mearnsii
Cupressus lusitanica
Inga spp.
Grevillea robusta
Pinus oocarpa
Pinus caribea
Prosopis chilensis
Quercus spp.
Alnus spp.

B. SAVANNA REGIONS

Gmelina arborea
Anogeissus spp.
Gliricidia sepium
Moringa oleifera
Cassia siamea
Terminalia spp.
Quercus oleoides
Trema spp.
Eucalyptus citriodora

C. SEMIARID REGIONS

Azadirachta indica
Prosopis juliflora
Acacia albida
Acacia decurrens

SEMIARID REGIONS (Cont.)

Acacia nilotica subsp. *indica*
Acacia senegal
Acacia tortilis
Albizzia lebbek
Tamarindus indica
Emblica officionalis
Tamarix spp.

D. ARID AND MEDITERRANEAN AREAS

Acacia albida
Acacia senegal
Acacia raddiana and *Acacia tortilis*
Acacia nilotica and *Acacia arabica*
Acacia seyal
Maerua crassifolia
Tamarix aphylla
Tamarix nilotica
Haloxylon persicum
Haloxylon salicornicum
Colophospermum mopane
Prosopis tamarugo
Retama raetam
Pinus halepensis
Ziziphus spina-christi
Balanites aegyptiaca
Acacia aneura
Acacia cambagei
Acacia brachystachya
Acacia saligna
Azadirachta indica
Cassia siamea

ARID AND MEDITERRANEAN AREAS (Cont.)

Casuarina equisetifolia
Eucalyptus camaldulensis
Eucalyptus microtheca
Eucalyptus gomphocephala
Eucalyptus occidentalis
Parkinsonia aculeata
Pithecellobium dulce
Prosopis africana
Prosopis alba
Prosopis chilensis
Prosopis cineraria

E. WET-DRY LOWLAND TROPICS

Leucaena leucocephala
Syzygium cumini
Acacia auriculiformis
Casuarina equisetifolia
Eucalyptus spp.
Muntingia calabura
Zizyphus mauritiana
Calliandra callothyrsus
Sesbania grandiflora
Guazuma ulmifolia
Terminalia catappa
Gliricidia sepium
Vitex spp. eg. *pubescens*
Prosopis pallida
Mimosa bracaatinga
Pongamia glabra
Trema spp.

noxious weed, forming dense, impenetrable tangles, when it is not regularly harvested for fuel or forage. In East Africa, its low, bushy growth is said to be an ideal breeding ground for the tsetse fly, even though the plant is considered useful for stabilizing eroded slopes. At the same time, the Hawaiian variety produces a highly palatable, digestible, and nutritious food for cattle, water buffalo, and goats. The dry leaves contain twenty-seven to thirty-four percent protein, with a balance of amino acids much

like that in alfalfa and one of the highest pro-vitamin A contents ever recorded in plants.

Within the last two decades two remarkable new varieties of *Leucaena* have been discovered in inland forests of Central and South America. One of these, the Salvador or Hawaiian giant variety, is a tall, virtually branchless tree that can grow to a height of nine meters in two years and twenty meters in six to eight years. In dense plantations, it appears to yield a larger quantity of wood than any known tree, at least in the Philippines. Annual growth increments have been measured from twelve to over fifty tons per hectare. This marvelous tree, with its giant pods packed with shiny dark red seeds, is about as close as a living plant can come to the beanstalk that Jack climbed in the famous fairy tale.

The Peru type, another recently discovered variety of *Leucaena,* produces little trunk but extremely high quantities of foliage—under favorable conditions up to twelve to twenty tons per hectare of edible dry matter containing over twenty percent protein, compared to eight to nine tons per hectare for alfalfa with about the same percentage of protein. The foliage can either be browsed in the field by free-ranging cattle, or harvested and hauled to the cowshed. Alternatively the leaves can be dried, separated by beating, and compressed into pellets for easy transportation to feedlots and dairies.

Unfortunately, *Leucaena* contains an uncommon amino acid, mimosine, which produces goiter in cattle when the diet contains more than thirty to fifty percent dry weight of *Leucaena.* In single-stomached animals—horses, pigs, rabbits, and human beings—mimosine causes hair to fall out. In cattle the bacteria in the rumen transform the mimosine to 3,4-dihydroxypyridine (DHP), which reduces the production of thyroxine by the animal's thyroid gland. This transformation to DHP in the rumen is so complete that the blood, meat, and milk of the animals are quite free of mimosine.

In practice, mimosine toxicity can be avoided by interplanting *Leucaena* with a tropical grass such as Guinea grass and allowing the animals to feed on this mixed pasture. Researchers in Hawaii and Australia have recently produced a low-mimosine *Leucaena* through hybridization with another species of the same genus. In cattle fed on a mixed *Leucaena*-grass pasture, annual weight gains of 900 kilograms per hectare have been obtained in northern Australia; in dairy cattle an annual production of 5,000 to 6,000 liters of milk per hectare was obtained. These yields are about twice those normally expected from tropical grass or legume pastures.

The newly discovered Salvador variety, with its virtual absence of branches, thin bark, and light color, is believed to have much commercial potential as a source of pulp and paper and round-wood poles and posts, and as a medium hardwood for lumber and plywood. As a fuel, used either directly or as charcoal, the wood has uncommonly high density and caloric value for a fast-growing tree. Energy plantations using *Leucaena* could be a continuously renewable source of fuel, because the stumps readily regrow or "coppice," and thus "defy the woodcutter."

Leucaena has a deep, aggressive root system that reaches far below the soil surface for water and nutrients. This enables the plant to withstand long dry seasons and to tolerate a wide array of soil conditions. The root hairs are usually infected with a beneficial mycorrhiza fungus, whose vast network of hyphae helps to obtain phosphorus and other nutrients from the soil. There are also many small lateral roots near the surface. These develop abundant small nodules, housing bright pink rhizobium bacteria that "fix" atmospheric nitrogen by combining it with hydrogen obtained from the carbohydrate produced by the plant. Nitrogen compounds and mineral nutrients are transferred to the leaves, which contain about four percent of nitrogen, 0.4 percent of phosphorus, and up to four percent of potassium under good soil and moisture conditions. Foliage with 500–600 kilograms of nitrogen per hectare, 44 kilograms of phosphorus, and over 200 kilograms of potassium, as well as calcium and micronutrients, can be obtained easily.

Six bags of dried *Leucaena* leaves contain the same nitrogen as one bag of ammonium sulfate. Thus small farmers, for whom commercial fertilizers may be too expensive or even unobtainable, can grow their own fertilizer. The foliage from a *Leucaena* grove can be cut and used to fertilize adjacent farm fields, or *Leucaena* can be interplanted in rows between other crops or under coconut trees. The continually dropping nutrient-rich leaves quickly decay and provide fertilizer for the main crop. In areas of shifting cultivation, where long fallow periods of ten years or more have been traditionally used, the fallow period can be reduced to about two years by reseeding with *Leucaena* after crop plants have depleted the soil.

Because the nutrients are only slowly released from the decaying *Leucaena* leaves, about sixty percent of the nitrogen is lost by the action of denitrifying bacteria, and only about forty percent is effective for enhancing crop growth. Hence *Leucaena* is economically useful as a fertilizer mainly in areas where land can be substituted for other resources. For every hectare of

cultivated land provided with a hundred kilograms of nitrogen usable by crops, an additional half hectare must be allocated to *Leucaena*.

The many actual and potential uses of *Leucaena*, its limitations (it does not grow well in acid soils high in alumina or at elevations above 500 meters), research needed to expand its usefulness, and a scientific bibliography are given in a recently published report, sponsored by AID and prepared by a joint study committee of the Philippine Council for Agriculture and Resources Research and the Advisory Committee on Technology Innovation of the Board on Science and Technology for International Development. The study committee, co-chaired by James L. Brewbaker and Joseph C. Madamba, consisted of forty participants from seven countries: Australia, Malawi, Mexico, Singapore, Taiwan, the Philippines, and the United States.

FLORAL TRAVELS

Great migrations have occurred in the 400 years since the discovery of the New World. Not only human beings migrated: Many species of crop plants and useful trees, hitherto confined to one hemisphere or the other, spread across the world. Out of the sixty-four domesticated crop species whose geographic origin is known, some twenty-two originated in the New World and spread to the old one, and forty successfully made the western voyage across the Atlantic. The species native to the Americas that now provide a major part of the world's food supplies include maize, potato, sweet potato, cassava, tomato, yam, peanut, sunflower seed, and several species of beans. Wheat, rice, barley, grapes, soybeans, sorghum, sugarcane, sugar beets, bananas, oranges, and apples came from the Old World.

Plants often do better when moved to new habitats, because their diseases, parasites, and predators can be left behind. Monterey pines, almost extinguished by disease in their native California, have produced the largest cultivated forests in the world in New Zealand. Because of intractable diseases, the wild rubber trees of Brazil cannot be cultivated successfully in their own country, but their cultivated descendants in Southeast Asia form the basis of a billion dollar industry.

The pressing needs of the people of poor countries, and the great advances in agricultural and basic biological sciences of recent years, could easily result in another wave of plant migration and an extension of the

areas of high-yielding agriculture to vast, previously neglected regions. The work of the National Research Council in identifying promising underexploited species and spreading information about them could make an important contribution to this new enterprise.

SUGGESTED READING*

Firewood Crops: Bush and Tree Species for Energy Production. (in preparation)

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

Leucaena: Promising Forage and Tree Crop for the Tropics. 1977. 118 pp.

Natural Products for Sri Lanka's Future. 1975. 53 pp. Report of a workshop with the National Science Council of Sri Lanka. Identifies neglected and unconventional plant products that can significantly contribute to Sri Lanka's economic development. Published by National Science Council of Sri Lanka.

Products from Jojoba: A Promising New Crop for Arid Lands. 1975. 30 pp. Describes the chemistry of the oil obtained from the North American desert shrub *Simmondsia chinensis.*

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

The Winged Bean: A High Protein Crop for the Tropics. 1975. 43 pp. Describes a neglected tropical legume from Southeast Asia and Papua New Guinea that appears to have promise for combatting malnutrition worldwide.

*With the exception of the report entitled *Products from Jojoba: A Promising New Crop for Arid Lands,* these reports are available at no charge, subject to availability. Write to Noel D. Vietmeyer, Commission on International Relations, 2101 Constitution Avenue, N.W., Washington, D.C. 20418. The jojoba report is available from the National Technical Information Service, Springfield, Va. 22161.

ACTI has published the following studies in addition to those listed on page 200 of Roger Revelle's article. These studies are available from the source indicated.

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

†*Mosquito Control: Some Perspectives for Developing Countries.* 1973. 63 pp. Examines biological control alternatives to conventional pesticides; evaluates state of knowledge and research potential of several approaches. NTIS Accession No. PB 224-749. $6.00.

†*Food Science in Developing Countries: A Selection of Unsolved Problems.* 1974. 81 pp. Describes 42 unsolved technical problems with background information, possible approaches to a solution, and information sources. NTIS Accession No. PB 235-410. $6.00.

†*Roofing in Developing Countries: Research for New Technologies.* 1974. 74 pp. Emphasizes the need for research on low cost roofs, particularly using materials available in developing countries. NTIS Accession No. PB 234-348. $6.00.

**More Water for Arid Lands: Promising Technologies and Research Opportunities.* 1974. 153 pp. Outlines little-known but promising technologies to supply and conserve water in arid areas.

‡*Expansion des ressources en eau dans les zones arides: Techniques prometteuses et possibilites de recherches.* (French language version of *More Water for Arid Lands: Promising Technologies and Research Opportunities.*) 1977. 156 pp.

**Energy for Rural Development: Renewable Resources and Alternative Technologies for Developing Countries.* 1976. 305 pp. Examines energy technologies with power capabilities of 10-100 kilowatts at village or rural level in terms of short- and intermediate-term availability. Identifies specific research and development efforts needed to make intermediate-term applications feasible in areas offering realistic promise.

‡*L'energie et le developpement rural: Ressources renouvelables et options techniques pour les pays en developpement.* (French language version of *Energy for Rural Development: Renewable Resources and Alternative Technologies for Developing Countries.* 1977. 332 pp.

**Methane Generation from Human, Animal, and Agricultural Wastes.* 1977. 131 pp. Discusses means by which natural process of anaerobic fermentation can be controlled by man for his benefit, and how the methane generated can be used as a fuel.

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

Tropical Legumes: A Resource for the Future. (in preparation, 1978).

Underexploited Microbial Processes with Potential Economic Value. (in preparation, 1978).

*Single copies are available for distribution on a courtesy basis to readers in developing countries and the United States who have institutional affiliation with government, education, or research and who have professional interest in the subject areas treated by the reports. Send your request on your organization's letterhead to

Commission on International Relations (JH 215)
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2101 Constitution Avenue, N.W.
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†These reports are available *only* from the National Technical Information Service. To order, send report title, NTIS Accession Number, and amount indicated. (Note. Prices are current for late 1977 and are subject to change without notice.) Pay by NTIS Deposit Account, check, money order, or American Express Card. U.S. orders without prepayment are billed within 15 days; a $5.00 charge is added. Prices for foreign buyers are double the prices indicated, and payment in full must be enclosed. Send order to

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