Chapter XII

The Gene Revolution: Maximizing Yields in the Tropical Moist Forest Biome

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It is the skills of plant geneticists, rather than large amounts of artificial additives such as pesticides and fertilizers, that have led to one record after another in crop yields in , . . both temperate and tropical zones (Norman Meyers, The Sinking Art, 1980).

ABSTRACT

Should there be a Gene Revolution, based on low-input multiuse extensive agroecosystems, to supplant the Green Revolution, based on high input intensive agriculture? Genes best adapted to the marginal environments found in the humid tropics should be pooled, combined, and recombined to produce moderate-yielding, well-adapted, multipurpose species. These gene combinations and recombination should be tested, not for their yields in monocultural situations, but in well-planned, multitiered intercropped agroecosystems.

The search for appropriate genes can be scientifically directed by a computerized catalog of the varieties, cultivars, and species of potentially economic native and introduced species. Technologies that would be part of such a multiple-use agroecosystem would include small-scale biomass- and alcohol-fueled and solar plant-extraction equipment, as well as fermentation and distilling apparatus, designed to run on some of the products of the agroecosystem. In summary, the Gene Revolution should be directed toward a multitiered, multiuse, polygenic, low-input agroecosystem, fueled and fertilized from within. The Gene Revolution should pull together the five major ingredients important in marginal environments: 1) tolerant germplasm, 2) multiple and intercropping scenarios, 3) organic gardening (recycling animal and plant residues), 4) biological control of pests (including allelopathy), and 5) whole plant fractionation and utilization for such integrated agroecosystems. Such systems should be developed from existing farms, not from the forests.

INTRODUCTION

... Plant germplasm can be selected and superior cultivars developed on the basis of their adaptation to problem soils. Although we have moved slowly to capitalize on this information, it offers great promise in reducing energy inputs and improving the reliability of crop yields in both developed and developing countries (A. A. Hanson, 1976).

The highly weathered soils of the humid tropics will rarely support conventional crops for long periods without a high level of inputs. But such inputs are rarely affordable to developing tropical countries. If these countries cannot afford the inputs required for high-level production of conventional food crops, perhaps they should aim instead for a moderate production of nonconventional crops with moderate inputs. The Green Revolution, which called for maximum inputs, has pretty well run its course, maximizing productivity where high inputs are possible. It is time for the Gene Revolution, to tailor existing plant types to maximize output with minimal input. The genes exist in nature, but they are disappearing fast. It is up to the Gene Revolutionists to get the genes together in the most meaningful manner, to maximize productivity under various low input scenarios.

With the end of the cheap energy era, developed and developing countries must reassess their imports and exports, their agricultural inputs and outputs, and their needs, often with a view toward substituting botanochemical fibers, fuels, and pharmaceuticals for those derived from petrochemicals.

Energy-hungry developing countries should closely watch developments at the Northern Regional Research Laboratory in Peoria, Illinois. If the botanochemical approach is practical today or tomorrow in an energy-rich country like the United States, then it will be all the more practical in the energy-poor countries of the humid tropics because:

1. Natural (and agricultural) productivity per unit area is higher in tropical than temperate zones, other things being equal. Hence, there should be much more biomass for a total-utilization scheme. The Gene Revolutionist is charged with finding the best genes and combining them in the best plants for maximizing output in the marginal low-input farm scenario.
2. The diversity of useful species on which to draw for our total-utilization concept is perhaps 10 times as high in the Tropics as in the temperate zone. Hence, the array of combinations for the recommended intercropping approach is staggeringly complex. The multitiered, intercropping agroecosystem being studied seems to be one of the most highly productive terrestrial agroecosystems, competing with the highly productive aquatic ecosystems of the Tropics. Yields of either of these systems can be improved vastly by the addition of ameliorated sewage sludge or other natural fertilizers in lieu of artificial fertilizer inputs. However, sewage sludge is recommended for biomass and chemurgic crops, *not* food crops.

In this talk, I will try to respond to the central issue: the highly weathered soils of the hot, wet tropics. These soils are rich in aluminum, silica, and iron, and poor in the common plant nutrients. What could USDA's Economic Botany Laboratory (EBL) do to improve "biological productivity of such soils without using much or any chemical fertilizer?" That is the charge put to me by the Office of Technology Assessment. Let's analyze that a bit before proceeding. Is it rare that we can improve natural biological productivity? Nature does a good job maximizing biological productivity under nature's constraints. If I compared productivity, I would only be comparing usable with total productivity. And if we are talking about the maximum Usability Concept, then we are not talking conventional agriculture at all.

Before laying out my plans for any country, I would analyze their import tables, especially the energy columns. Then I would plan a multitiered agroecosystem that would maximize benefits to the countries, import-export situation, seeking the best genes to maximize output for a modicum of inputs, under the ecological conditions prevailing. Geneticists could maximize the yields while American technology could maximize the extraction of useful products from the total yield.

Humid tropics has been variously defined. Most of my examples relate to what is called the Tropical Moist Forest (TMF), where annual biotemperatures are greater than 24° C and annual rainfall is between 2,000 and 4,000 mm. I have spent years in the Tropical Moist Forests of Latin America, and am still awed by the diversity of economic products endemic to the area. There are even more exogenous economic species from similar ecological zones outside Latin America. Unlike others in this workshop, I do not stress using native species, but I share the belief that we should not introduce exotics that are ill-adapted to an area. EBL's computer system helps find the right germplasm for a given tropical ecosystem.

Drawing on these tropical gene pools, the Gene Revolutionist has perhaps more than 75 percent of the world's species to consider, perhaps 250,000 species. Each is a unique chemical factory, manufacturing biomass that we may need to draw upon as a source of energy. As the preface of the National Research Council's book, Conversion of Tropical Moist Forests, begins: "The tropical moist forest biome is biologically the richest, and least well known portion of the earth's surface."

Unfortunately, much of TMF is underlain by *femalsols* (strongly weathered soils of tropical regions, consisting mainly of kaolinite, quartz, and hydrated oxides, and having a low base exchange capacity). Dudal (6) summarizes the mineral stress phenomena in such soils:

1. Deficiency in bases (Ca, Mg, K) and incapability to retain bases applied as fertilizers or amendments.
2. Presence (pH < 5.2) of exchangeable Al, toxic to many species and active in binding phosphates.
3. Presence (acid soils) of free Mn, also toxic.
4. Fixation of phosphate
5. Deficiency of molybdenum, especially for legumes.
6. Fe and Mn toxicity shown by paddy rice.

Such soils are said to occupy more than a billion hectares, more than 8 percent of the world's soil.

There are those who say that conversion of TMF to agriculture will lead only to the so-called "red desert. " Ewel (8) says, however:

> The red desert view of mature tropical ecosystem destruction is incorrect. Nature abhors a vacuum, so sites laid bare by human activity are quickly covered by some kind of community, although not usually the original one. We must face the fact that successional communities are going to be the dominant tropical ecosystems of the future.

ECONOMIC BOTANY LABORATORY

I am still awed by the diversity of the Tropical Moist Forest. Working at the Economic Botany Laboratory, I have begun to try to organize the information pertinent to the Tropical Moist Forest. There is already so much information that we depend on computers to assimilate the information. We are primarily concerned with the medicinal plants of the world, especially those with anticancer activity. secondly, we are concerned with cataloging agronomic, ecological, geographical, and utilitarian information on economic plants of any description. From his studies alone, Schultes (23) compiled a list of more than 1,300 species employed by natives of the northwest Amazon as medicines, poisons, or narcotics. Our computer files already contain entries on more than 4,000 folk medicinal species, some of which double as food plants, fiber plants, dye plants, etc. We have yield data on some of these, under various ecological regimes in the Tropical Moist Forest.

With careful expansion, such a data base could catalog information on ecology, utility, and yields of all economic plants, and guide the Gene Revolutionists in their search for the right genes or germplasm. Details of some strategies that should be employed in the quest of tolerant germplasm are explored in Duke (7). Ecological data on more than 500 species suitable for exploitation in the Tropical Moist Forest are tabulated. I will not relate all those data here, but will present a few examples.

We know the conventional yield figures for only a fraction of tropical crops. Biomass or residue figures are even rarer, although such numbers are necessary for systems analysis of the yield potential of a multiuse agroecosystern. According to Westlake (29), conversion factors range from 1.3 to 4.0 for estimating aerial biomass from conventional yield units. I called all the experts I could find, in vain, in my search for the biomass figures for the temperate lentil. Who would I call for such figures on the myriads of tropical products? The numbers do not exist. “The accuracy of productivity measurements is the lowest for tropical areas. The key to future refinement of our understanding the global productivity capacity lies, therefore, in the study of tropical primary productivity” (16). If biomass is a viable competitor in the energy field, it is time pertinent numbers were generated by baseline research program.

If I were Secretary of State, determining what strings were tied to AID funds overseas, I would see to it that funds went to carefully distributed research plots in developing countries. These plots would be funded to generate the numbers needed to support Maximum Utilization Concepts. How much biomass can we grow and harvest under various scenarios? Which scenario gives us the greatest net usable returns? I would fund no studies that did not give biomass yields related to climatic and edaphic data, and I would fund no country that did not make a commitment to preserve their current forests, and concentrate on increasing the productivity of current croplands.

Why should the remaining forests not be converted into agroecosystems? If they are lost, thousands of undescribed species will disappear forever before they have been named. Thousands of others will disappear with no studies of their economic potential. It is difficult to put a price on their heads. One in ten species studied shows anticancer activity; but only about 15 of the first 30,000 species studied in our anticancer program are of sufficient interest to have reached preclinical testing. Only one of those has resulted in thousands of remissions in cancer. This superstar, *Catharanthus roseus,* the Madagascar periwinkle, is a pantropical ornamental and folk medicine in Tropical Moist and Dry Forests. There are probably nine more superstars awaiting discovery (if they do not fall victim to the tropical axe). Can we afford to extinguish them?

THE QUEST FOR TOLERANT GERMPLASM

Elsewhere, I have advocated and outlined measures for seeking out the genes we need for marginal environments in the Tropics (7). Other research backs this idea:

> The correction of Al and Mn toxicities by liming is not always economically feasible, especially Al toxicity in strongly acid subsoils. However, plant species and varieties with species differ widely in their tolerance to both factors, and some of these differences are genetically controlled (10,25).

It is such differences we hope to capitalize on in the EBL Quest for Tolerant Germplasm. It is cheaper to increase yields by finding a cultivar that will tolerate the acidity, and its complications, than to increase the yields by importing 6 tons of lime per acre. This is just the first step in the Gene Revolution. Incorporating the appropriate genetically tailored species, varieties, races, and cultivars in a multitiered, multiple cropping system requires even further genetic selection, manipulation, and experimentation.

INTERCROPPING

Work on multitiered agroecosystems is proceeding most rapidly in Asia, but temperate systems are familiar to us all. Two-tiered systems, with hay, legume, or cereal crops alternating or intercropped with rows of fruit or nut trees, are common. Thousands of combinations are possible in a tropical three-tiered system. In one, pineapple was planted as the ground crop, cocoa as the first story, and pepper as the second story. Total harvestable crops and residues from such systems usually exceed significantly the expected crops of the individual species, had they been planted in monoculture. Advocating agroecosystems that simulate the natural ecosystem it replaces Hart (12) says:

> The replacement of weeds by analogous crops and an increase in crop diversity will usually reduce the amount of energy used by weeds and pests.

Those systems of tropical forestry and agriculture that have been successfully employed for the longest periods are those that favor the maintenance of large mycorrhizal fungus population. Traditional shifting agriculture in small forest-enclosed plots probably attains mycorrhizal homeostasis. Mycorrhizae seem to minimize the expense to the host of seeking-out minerals. Cultivation of annual crops may lead to increased prominence of nonmycorrhizal species and grasses in weed communities. Soil sterilization can eliminate mycorrhizal fungi, and fungicides used against pathogens may adversely affect mycorrhizal fungi as well. Monoculture of crops that are probably nonmycorrhizal, such as grain amaranths and chenopods, might markedly lower mycorrhizal fungus populations and jeopardize subsequent mycotrophic crops (14).

LEGUMES

Even the nitrogen fixed by legumes is not free. Under conventional farming, there is a price to pay for the nitrogen contribution of the legume. In an unpublished paper, I pulled, at random, biomass yields for pure stands of C-4 grasses, C-3 grasses, and legumes. Though relatively higher in nitrogen and protein, the legumes yielded only half as much total biomass as the C-3 grasses, which in turn yielded only about half as much total biomass as the C-4 grasses. These are the biological costs *(1)* for nitrogen fixation and (2) excessive photorespiration. Although no one seems to have accepted my simple *1:2:4* ratio, I believe it. So called super-yield targets in the United States are 100 bushels of soybeans; the target for corn is 400 bushels.

Appropriate combinations of legumes and grasses seem to give the best yields for forage or hay, and probably for maximum utilizable biomass under renewable situations where water is not the limiting factor. The C-4 grass might give highest yields for a while, but it seems doubtful that such yields would be sustainable without the help of added N, be it from legume, crop residues, manure (green or brown), or sewage sludge. For high-quality leaf protein, the legume seems indispensable for most scenarios (without the sewage increment) whether the protein is for animal food, human food, or chemurgic use.

The amount of N fixed by legumes varies of course, but some of our economic legumes play a larger role than making beans and fixing nitrogen. According to Nigmator, et al. (1978), the cultivation of the legume licorice (Glycyr*rhiza glabra)* showed a marked ameliorative effect on saline soil in Uzbekistan, Russia. The licorice, in pure stands, did not form a complete soil cover during the first 1 to 2 years, but this was achieved by sowing it in mixture with sudan grass, cowpea, and lablab. The mixture decreased the evaporation and the rise of salts to the upper soil layers. Haines, et al. (11), reported that undersowing sycamore *(Platanus occidentals)* with clovers and vetch in a discultivated, z-year-old plantation suppressed weed growth to the point where height and volume increments of the young trees were increased significantly.

According to Felker (9):

> Leguminous trees have a unique advantage over annual legumes in dealing with the inhibitory effect of drought stress on nitrogen fixation because the deep-rooted leguminous trees may reach moisture, and thus relieve the plant of water stress for a longer time in the year than is possible with annuals.

An illustration of the ability of leguminous trees in semiarid climates to increase soil fertility more than annual legumes can be found in West Africa, where yields of peanuts are increased if grown beneath Acacia albida trees.

The work on "teaching the grasses to fix nitrogen" goes on, but does not generate as many headlines as in the past. Nitrogen-fixation is being reported in more and more nonlegumes. Just this month, I noted an abstract dealing with nitrogen fixation in blackberries. Becking (z) assayed nitrogenase activity by acetylene reduction in detached *Rubus ellipticus* root nodules. It was similar to that in several nonlegume N_2 fixing nodules. The endophyte was an actinomycete.

AZOLLA AS FERTILIZER

While legumes are one source of fertilizer for our multitiered agroforestry units, tropical azollas might be another. Azolla, an aquatic fern, is a source of nitrogen. Clark (5), reviewing Azolla use in China, notes that Azolla "seed" are started in nurseries, then the seed ferns are introduced directly into rice paddies. In some areas, two rows of rice are planted with the Azolla growing in larger rows on either side of the double rice rows. Yields of 15 MT/ha of rice and 150 MT of Azolla have been reported for this simultaneous cultivation method. Rice grown with conventional fertilizers averages only 10 MT/ha (5). No mention is made of fish biomass harvested from such ecosystems. Could they also harvest 15 MT/ha catfish as have been reported from well-aerated Louisiana fishponds (21)? Grass carp *(Ctenopharyngodon idella)* and *Tilapia mossambica* are said to relish azolla, which has also been fed to cattle, chickens, ducks, and even has been suggested for human consumption. Typically, yields of grass carp are 10 times higher in the Tropics (l,500 kg/ha) than in the temperate zone (164 kg/ha).

Unfortunately, we do not know that Clark's 150 MT of Azolla is dry weight or wet weight; if dry weight, we have our fertilizer factory producing biomass equivalent to some of the highest reported, while increasing the yields of the rice crop, almost incredible. Here let me point out serious conflicts facing USDA officials: there are potent advocates and opponents of the introduction of many of the biomass wonders of the world (Acacia, Azolla, Leucaena, Prosopis, etc.) and the opponents hope that the advocates are willing to foot the bill should these wonders become the major weed of the 21st century.

I mention Azolla first because it is being championed as a free fertilizer, one producing 150 MT of biomass, while increasing the yield of rice by I% times. These are the "facts" hailed by the advocates. Azolla pinnata can double its biomass in 3 to 5 days, maybe 5 to 10 days in the field. Some claim that Azolla will suppress other weeds in rice, if not the rice itself. Other reports indicate the Azolla can either prevent mosquitoes from laying their eggs of their larvae from surfacing. Some say it releases nitrogen while alive, others only after death. Vietnam reports 1 MT/ha N fixed per year; China 0.7 to 1.8 MT N (13).

But there is a weed potential lurking there. Weeds cost the United States about $16 billion in 1979. Would Azolla introduce increase yields or would it clutter up more ponds than it helps. Responsible weed scientists as loudly and justly proclaim their fears as responsible forward-lookers champion this "free" fertilizer. There is no cut and dry answer.

On the negative side of the Azolla equation:

- In Japan, there have been complaints about Azolla covering the rice seedlings.
- In the Philippines, Azolla is called a weed in rice.
- In New Jersey, it has clogged up water channels to boat traffic.
- In South Africa, farmers claim it killed fish, prevented cattle from drinking the water, and clogged pipes.

MEAT OR MEAT

The Tropics may not face the heat or meat decision that temperate countries will face if there are no energy breakthroughs soon. According to some estimates, more than 90 percent of U.S. cereals and legumes are destined for animal food. If Americans went vegetarian tomorrow, and quit exporting grain, more than 95 percent of our agricultural biomass could go into ethanol production here. Some of us would rather be warm and do without meat, than be cold and eat meat regularly; others would say an emphatic "no." According to Meyers (19), much TMF biomass goes into cheap hamburger for the United States. Would it be better converted to fuel for the people of the TMF?

I have been a human guinea pig on three human nutrition studies at USDA, all involving high fiber and/or vegetarian diets. In one, 20 male subjects, none vegetarian or particularly sympathetic with vegetarianism, were fed soy protein in lieu of meat protein. None suffered from the soy as opposed to meat. On the contrary, there were no significant changes in the health of the subjects, at least by the standards investigated. From 40 to 50 percent of the human subjects preferred each soy analog to its meat counterpart.

Thanks to coal, America need not face the heat or meat crisis immediately. Thanks to the temperature of the humid tropics, the TMF might not face that choice either. But they might need to decide whether their biomass residues go into animal production or fuels for their machinery.

WOOD

Even today in the United States, wood is said to provide more energy than hydroelectric or nuclear power. Wood is a valuable byproduct of the multitiered agroecosystem, and the Gene Revolutionist should remember that in tailoring species for TMF.

> The growth rate of tropical weed trees characteristic of the humid lowlands are quite remarkable. I have measured naturally regenerated *Trema micrantha* in Costa Rica's OSA Peninsula, which were 9 m tall at one year, and more than 30 m tall at 8 years. It is these fast-growing, low-density trees which will constitute the wood resource of the future as mature tropical forests are felled and regenerate (8).

Ewel's figures for 13-month-old regrowth in various life zones are TWF, 12 MT/ha; TDF, 10 MT/ha; SWF, 6 MT/ha; SDFA, 5 MT/ha; and Tropical Montane Rain Forest, 1 MT/ha.

I do not advocate replacement of wood as a source of energy for cooking and heat in the TMF. I do advocate the production of cheap wood-burning devices for distribution to the poor. Most of the timbers of the Tropics go up in smoke, much of it wasted. With energy-conserving wood stoves, there would be more biomass available for the production and distillation of alcohol and other uses.

Liquid fuels for use in cars, trucks, and vehicles should be produced by all but the smallest farms in cheap mass-produced stills provided by the technologically well-off,

SEWAGE

There is justifiable concern that maximum use will strip the soils of organic matter. If we only use the above-ground biomass, we leave the below-ground biomass. According to Van Dyne, et al. *(28):*

> Below-ground production is more than twice above-ground in annual grasslands, but standing crops of biomass below-ground maybe five to ten times as much as above--ground standing crops.

The humid tropics do not lack water like the arid tropics, but they do need organic fertilizers, especially if continuously harvested. Here I take the opportunity to introduce into the tropical scenario an idea that I think should be exploited in the United States: piping sewage sludge out of the cities of the world and into energy farm areas. The pipeline routes could parallel proposed coal-slurry lines, natural gaslines, or petroleum pipelines. Oil shale mines, strip mines, any type of old mine site could be partially or totally reclaimed or improved with sludge-planted areas. The highest biomass yield reports I find are from The wealth of India, where such yields as 160 MT/ ha for Pennisetum *purpureum* are reported for fields irrigated with sewage. Westlake *(29)* reports unusually high yields even in the temperate zone. With sewage irrigation and intercropping, he reported DM yields of mixed alfalfa-orchardgrass at *26* to 39 MT/ha, at least five times greater than the expected yield of alfalfa alone, without sewage irrigation. This compares with 40 MT for *Phragmites australis,* which Westlake describes as the most productive temperate community.

City planners should adopt the Design With Nature Concept, building above the productive alluvial plains, clearly the most productive lands in any biome, with nothing but natural inputs. Alluvial plains and energy sumps should occupy the fertile lowlands, while no more building on the floodplains should be permitted. These most fertile lands are being gobbled-up by suburban creep, here and elsewhere.

I decry the cancellation of plans to barge sludge to Haiti, because I believe sewage sludge could play a big role in the greening of Haiti or the Sonoran or Negev deserts for that matter. We could concomitantly alleviate the shortage of water and organic matter in the desert, with its low real-estate values, while alleviating the waste disposal problem in the cities, with their high real-estate values.

Water-borne sludge could prove a boon to the humid tropics. If sewage sludge can double yields in the humid tropics, the reverse pipeline could be shipping ethanol out, still leaving a positive balance in organic matter in the humid tropics. Once the pipelines were established, the sludge could be a free input, doubling outputs. Hence, I see this untried concept as one way to double the productivity of the humid tropics, or treble the productivity of the arid tropics, with a free input. The excess yields could be devoted to production of alcohol, for internal or external energy use.

Such an area might appropriately be called an energy sump, and would not be an attractive place to live, but the products of the energy sump could make jobs there, and a higher standard of living elsewhere.

Here, as much as anywhere, the talents of the Gene Revolutionists will be called into play. The genes for maximizing productivity in the energy sump will be very different from those for maximizing productivity in the unaltered humid tropics. Planting, cultivating, weeding, and harvesting technologies, even the recommended varieties, if not species, will be different for the two scenarios.

OIL SEEDS

Back in April 1977, I suggested that palm oil might someday be competitive with petroleum. Today, foreign palm oil in New York is still higher than domestic petroleum at the pump, but at the rate the gap has closed since my paper. Palm oil will be as cheap as petroleum by the year 2000.

Oil palm is one of many species with varieties tolerant of the allic soils of the humid tropics. Oil palm is currently growing in countries that show deficits in both edible oils and energy. It has already been shown that simply growing legumes between the oils palms can increase oil yields by 2 MT/ha/yr (3) or the equivalent of 6 barrels of oil per hectare, simply by the selection of proper legume for intercropping. These legumes (Centrosema *pubescens, Pueraria phaseoloides),* in addition to increasing our energy budget, at little or no cost following planting, can provide food, conventional or unconventional. I am sure, based on temperate figures, that more protein per hectare will be produced if the whole aerial biomass of the legume is harvested, thrown into our energy vat, the leaf protein extracted for human consumption, the carbohydrates for ethanol production, the residues for return to the soil.

We have spoken only of the oil yields of the oil palm, There is still a lot of unused biomass, which could go, depending on the outcomes of our systems analysis, into ethanol production, internal or external combustion devices and/or soil amendments.

Not all, but most palms, survive or thrive in the humid tropics. Like the oil palm, they are multiple-use plants, prime candidates for the upper or intermediate stories in the multitiered agroecosystem for the humid tropics. Could we not multiply the yields of these unstudied palms by 10 as we have done with the Hevea rubber plant. Let’s look briefly at one mentioned by Amazonian expert R. E. Shultes (23):

> *Orbignya martiana:* One palm may produce a ton of nuts a year, 198 pounds of which is kernel . . . with up to 72 percent of an almost colorless oil very similar in composition to coconut oil. The seed cake remaining, containing 27 percent protein, is an excellent animal feed. I read this as a ton of biomass per year, more than 100 pounds of which is oil. I don’t know that these figures are more or less reliable than those with which Calvin derived 50 barrels of diesel per acre. Conservatively, it would take four of these productive palms to produce one barrel of oil per year, or 200 trees to produce 50 barrels, From my experience in Latin America, I would pin my 50 barrels/acre hope on the palm before I would Calvin’s Diesel Tree. Calvin figured at least 100 trees per acre, but his trees were 1 m in diameter. I don’t know any palms that big. Thin canopied palms would permit intercropping of food crops, which I speculate would be impossible in the shade of “diesel trees.”

Note that with our hypothetical *Orbignya,* with no genetic research, we are getting 50 barrels of palm oil per acre, with a residue of 1,900 pounds per tree. We have assumed a tree producing 2,000 pounds of fruit, 100 pounds of which is oil (3,300 pounds are reported, with an oil yield in excess of 200 pounds oil per tree). Assume 300 to 350 pounds per barrel of oil. We can further assume after the extraction of our 100 pounds of oil, we have 1,900 pounds of biomass in the pot, 900 pounds of which might, conservatively, be water. Of the remaining 1,000 pounds, perhaps there is another 100 pounds of protein, per tree, and 900 pounds of carbohydrates, etc., 400 pounds of which might give us another barrel of ethanol per hectare. So, hypothetically we have 100 pounds of protein and 2 barrels of ethanol as byproduct from our 1 barrel of palm oil.

The technology needed for this oil palm scenario:

1. oil extraction (available for oil palm);
2. carbohydrate fermentation and distillation; and
3. protein purification and sanitation, for human or animal production.

There are palms for the arid tropics, for the humid tropics, for brackish swamps, for freshwater swamp situations, and for our sewage sump, all potentially intercroppable with other food/energy/chemurgic crops. But the Gene Revolutionist has not started to tailor these species to specific environments and to increase their yields. And we have not even talked about the waxes, steroids, leaf-proteins, and ethanol that could be produced by the leaves. Some palms will disappear before we have studied their potential.

Production of conventional palm oil (from Elaeis) was expected to total 4.3 million MT in 1979-80, compared to 3.9 million MT in 1978-79 [1). Whether or not these are viewed as petroleum alternatives, many oilseeds are handled in the U.S. market. Residues could be used for alcohol or methane generation, or as a soil amendment.

Some prices quoted in the Chemical Marketing Reporter for various tropical oilseeds during 1979 are avocado ($ S. IS/lb), castor oil ($0.40/lb), coconut ($0.57/lb), corn ($0.50/lb), cottonseed ($0.18/lb), oiticica ($0.60/lb), palm ($0.33/ lb), palm kernel ($0.42 /lb), and soybean ($0.48/lb). The newly generated market for jojoba "oil" has a cult of followers, but this so-called oil is a liquid wax, unique to the jojoba among plants. Soy oil, peanut oil, and sunflower oil have been used as diesel substitutes.

ALLELOPATHY

Allelopathy has not yet been developed to be an alternative to herbicides. But if different chemurgic species are selectively herbicidal, as one gathers from reading the allelopathic literature, then all these herbicidal activities should be cataloged. Residues of the allelopathic species might then be returned to the intercropped agroecosystem where its herbicidal effects will do the most good and least harm. One can even suggest how coumarin-containing residues (Melilotus, Trigonella, etc.) can be used to stimulate rooting in the softwood cuttings used for propagation in our tropical agroecosystem (17). Steenhagen and Zimdahl (26) show that the hydrocarbon-producing *Euphorbia esula* reduces the frequency of quackgrass and ragweed, but also reduces the growth of tomato seedlings. Dry leaves of the medicinal species, *Parthenium hysterophorus,* inhibit growth and modulation in legumes, branching in tomato and plant height in ragi *(Eleusine coracana)* and reduce the yield of bean, tomato, and ragi. On the other hand, the leaves stimulate the growth of *Pennisetum americanum (15).* Such data are being generated rapidly, but there seems to be no computerized catalog to enable us to evaluate and use these data effectively in planning multiuse agroecosystems.

DRUG CROPS

The Economic Botany Laboratory specializes in medicinal plants. We have found that there are often huge residues of biomass following drug extraction. It takes 1 1/2 MT of dry stem and bark of Maytenus to yield a gram of maytansine, one of the anticancer superstars of the last decade.

Bruceine, cassia, caffeine, cocaine, heliotropic, ipecac, papain, pilocarpine, quinine, quinidine, reserpine, rutin, steroids, and theophylline: these are a few drugs that can be harvested in the humid tropics. Many of these are million dollar items that could be extracted on-site as income producers, leaving behind 99 percent of the biomass for food and/or fuel production. Some drugs might be byproducts from conventional foods, e.g., caffeine from coffee and tea, theophylline from tea, steroids from legumes, rutin from buckwheats. The steroids once derived from tropical dioscoreas ("barbasco") are now largely derived as byproducts of legumes and agaves.

ESSENTIAL OIL

The United States imports nearly 10,000 MT of essential oils at close to $100 million per year. This probably represents the distillation of about one million MT of biomass, 99 percent of which could have been funnelled into food and fuel production as byproducts. By no means all of these essential oils are humid tropical species, but I list a few that are from the humid tropics:

- Trees: bay, bergamot, camphor, cassia, cinnamon, clove, copaiba, grapefruit, guaiac, lemon, lime, linaloe, nutmeg, petitgrain, ylang-ylang
- *Forbs:* cardamon, citronella, ginger, lemongrass, palmarosa, patchouli, vetiver.

The trees might be considered as alternating trees or strata with other trees, like palms, in the upper strata of our multitiered agroecosystem. The forbs might be considered for the ground layer. Our Gene Revolutionists should already be looking for tolerance to shade and root competition in our lower tier, and tolerance to root competition in candidates for the upper tier.

FIBER CROPS

On the last day of October 1980, an official called from the Strategic Materials Department to ask where in our 50 States we could grow several strategic materials. Among them were two tropical fibers, abaca and sisal, the former adapted more to the humid tropics, the latter more to the arid tropics. With sisal, fiber yields are only 3 percent of the leaves. From the remaining 97 percent biomass, I am certain that steriods, waxes, leaf protein and alcohol, even tequila, could be produced. Many natural fibers can be produced in the humid tropics, among them abaca, baobob, coir, cotton, ensete, hemp, henequen, jute, kenaf, remaie, roselle, sisal, snakeplant, sunn hemp, etc. As the cost of petrochemicals rise, some economists predict a return to natural fibers instead of synthetics.

GUMS, RESINS, AND BALMS

Some chemicals in this group approach the classical petrochemical or “neoclassical” botanochemicals. Swedish and Finnish firms are reported to have developed an efficient turpentine car engine that runs on turpentine produced from the oleoresin of scotch pine. High road mileage is claimed for turpentine (20). Presumably, yields of tropical pines may be higher than the temperate pines. The Gene Revolutionist would be charged with increasing both the nut (pinyon) and turpentine for specified intercropping stratagems under specified ecological conditions.

Copaiba oil, traded at over $2.00 per kilo, may or may not be the same as the oil from Melvin Calvin’s tropical “diesel tree” *Copaifera langsdorfii.* According to Dr. Calvin, (4) 1 1/2 inch holes drilled halfway through large trees about 2 feet above the ground yield about 20 liters of “diesel” (mostly 2 or 3 main C-15 sesquiterpenes and 30 or 40 minor C-15 sesquiterpenes) in two hours. The holes are bunged and retapped again in about 6 months, and said to yield another 20 liters of diesel, or 40 liters of diesel per year per tree. This is exactly the same yield reported in Grieve’s *Modern Herbal, 1931.* Dr. Calvin, perhaps optimistically, calculates that we can get 25 barrels of diesel per acre per year on a sustainable basis from the copaiba tree (18). Unfortunately, the tree seems to be intolerant of frost. I will be getting resin from an equally productive timber species of *Copaifera* during my next trip to Panama.

Gum arabic, guar, karaya, locust, myrrh, olibanum, and tragacanth are among some of the vegetable gums now traded. With problems in Iran, a major producer of tragacanth, prices of tragacanth have risen considerably. In April 1979, 56,900 pounds of tragacanth were imported with a value of $608,346. More than 23 million pounds of guar gum were imported in that same month. Acacia, Tamarinds, and Sterculia are major tropical sources of gums that can provide renewable harvests in intercropping strategies.

RUBBER

The first *Hevea* plantation set out in the Far East yielded about 450 pounds dry rubber per acre, while currently available clones yield about 3,000 lbs/acre (<10 barrels). New chemical treatments applicable during tapping can increase the figure to 6,000 lbs an improvement of 13.3 times. These yields are available while leaving the biomass intact. Other options might be to grow whole plants for rubber extraction between our upper story palms in the humid tropics. The Petroleum Plant from which Calvin once projected 50 barrels per acre could be grown in the humid tropics as well as the arid tropics. Detractors from Calvin say yields would be closer to two barrels than 50 barrels from the "Petroleum Plant."

Calvin's plant has received other headlines under the name of gopherweed *(Euphorbia lathyris):*

> Melvin Calvin, Nobel Laureate in Chemistry, believes that the U.S. could produce more than 2 million barrels a day of gopheroil by 1995, The Department of Energy has granted Calvin $250,000 to continue his research. Marvin Bagby, head of the Agriculture Departments hydrocarbon-plant research project, thinks that gopherweed is the leader among 45 hydrocarbon-bearing plants that have commercial promise (l).

Other species of Euphorbiaceae are better adapted to and more productive in TMF than the headliners Calvin promoted. The latex of milkweeds could more appropriately be funnelled into rubber production. Be it spurge or milkweed as hydrocarbon sources, the whole plant would be thrown into the extraction vat, with waxes, drugs, rubber, leaf-protein and ethanol as feasible byproducts, all grown between our upper-story palm trees. Whether Calvin gets 2, 10, 25, or 50 barrels/acre of petroleum or rubber from the "petroleum plant," gopherweed," or "diesel plants," I maintain that the ethanol potential from the residues has more energy content than what he obtains.

WAX CROPS

Waxes tend to be more frequently derived from arid land plants than humid tropical species. But if the wax can be taken as byproduct, like ethanol, following extraction of edible leaf protein, humid tropical waxes might become export money-makers. In the Chemical Marketing Report, one finds such waxes as the temperate bayberry wax ($3.00/kg), the arid lands candelilla wax ($3.()()/kg), and the subtropical carnauba wax ($4.00/kg). Yields rarely exceed 1 percent of the plant, leaving 99 percent of the biomass *as* waste, or better as leaf-protein or energy stock. One second-growth "weed," *Calathea lutea,* of the humid tropics, could serve as source for food, wax, and biomass, as could members of the banana family. The Calathea is easily propagated with as many as 30,000 plants per hectare, yielding up to 70 pounds of wax per acre (23). I project that would leave at least 29,700 pounds dry weight of biomass in the vat for leaf protein and ethanol production. This leaves the underground roots untapped. Aerial biomass yields of 18 MT/ha might complement the ediblerooted *Calthea allouia* (12 MT root / ha). Here we must remember that increases in the below-ground yields will usually be compensated for by losses in above-ground yields. Calathea and other tropical plants, now all but unexploited, can yield food, fiber, fuel, and residue for the energy farm of the humid tropics.

WEEDS

Neither the Weed Science Society of America (WSSA) nor the oil companies have loudly advocated the use of biomass as an energy alternative in the past. I find it interesting that there were five items in the October 1980 Newsletter of the WSSA hinting at plants as a source of energy. Not necessarily believing the figures myself, I summarize the estimates from that WSSA newsletter:

- *Euphorbia: 50-125* bbls / ha,
- *Salsola:* Arizona grant to make fuel from the Russian thistle, a serious weed.
- *Asclepias:* Improved variety of milkweed could be source of biomass for synthetic fuels and chemical feedstocks and a source of fat, protein, oil and fiber. Lab estimate of 60 bbls / ha crude oil.
- *Parthenium:* Guayule provides a latex that can be used for fuel, petrochemicals, and rubbers.
- *Simmondsia:* Speculation holds that mature jojobas might produce the equivalent of 50 bbls / ha.

It might be added that these optimistic estimates are based on marginal weed species in areas of marginal inputs. But these are gross energy outputs. Whether it would take 100 to 250 bbls / ha input to obtain the 50 to 125 bbls / ha output is speculative. No one has analyzed the energy inputs required to obtain these optimistic outputs. Research should provide these numbers.

A more pessimistic note comes from Shell's "Ecolibrium" 9(4):1980:

> According to the Gold Kist plant officials, a good peanut crop can reap 142 gallons an acre. And, unlike alcohol from grain, you don't have to distill peanuts to get oil, you just squeeze them. The peanut oil costs about $3.00 a gallon.

The 142 gallons an acre is equivalent to less than 10 barrels per hectare.

This shows the wide disparity in figures used by optimists and pessimists. Scientific research should rectify this disparity.

It seems doubtful that the herbicide industry would encourage hand harvesting of weeds and their conversion into alcohol and / or protein. I advocate just that in TMF countries with unemployed hungry people. Almost all studies show that hand weeding, though using human labor, results in better yields than herbicide controls. In some cultivated communities, weeds constitute 8 to 27 percent of the shoot biomass. This 25 percent might represent 2.5 MT on a tropical hectare, which could be harvested and converted to fuel, at the same time increasing the yield of the crops the weeds were competing with.

TROPICAL MOIST FOREST BIOMASS

Do energy farms produce more biomass than the pristine moist forest produces? Those who speak of highly productive TMF mention great quantities of biomass. The climax forest is in equilibrium, metabolizing as much as it synthesizes, so that although gross production may be extremely high, metabolism erases the profit, leaving no net biomass increase. Do agroecosystems produce more total biomass than native forest ecosystems? I cannot say categorically. The optimist figures on arid land weeds yielding 50 to 125 barrels of oil per hectare; the pessimist peanut prospectus lies at less than 10 barrels per hectare. And we see estimates of up to 150 MT dry weight from some tropical grasses under sewage irrigation. These figures suggest to net that agroforestry is more productive of biomass than the climax forest. Estimates of the net primary production of tropical forests (table 1) presented by UNESCO (27) range from 9 to 32.

For comparison, I list in tables 2 through 4 some examples of yields of tropical crops that can be grown in the lands occupied by the forests mentioned in table 1. These data, gathered from a variety of sources, do not consistently represent maximums, minimums, or means, nor are such data available. Hence, these numbers cannot be compared.

Today the biomass data bank at the Economic Botany Laboratory has close to a thousand entries in it. EBL is probably the best equipped lab in the USDA to compare biomass potential of different monocultural, polycultural, and natural ecosystems. Consequently, I have brought my computer to this workshop so you can check it out on the spot. Incidentally, EBL is probably the best equipped lab in the USDA to give you the ecological amplitudes, nutritional analyses, and folk-medicinal attributes of the little known economic plants of TMF, some of which now extant, may soon be extinct.

Table 2.—Tropical Root Crops (yields in MT/ha)

Arrowroot	37
Canna	85
Cassava	56
Gallan	120
Ginger	30
Groundnut (bambarra)	4
Leren	12
Lotus	5
Peanut	5
Sweet Potato	36
Taro	128
Turmeric	35
Yambean	90
Yautia	32

Table 3.—Tropical Vegetables (yields in MT/ha)

Banana	**18 M**T
Cantaloupe	**14 M**T
Eggplant	**24 M**T
Garlic.	**10 M**T
Okra	**23M**T
Onion	**29M**T
Pepper	14MT
Pigeonpea	13MT
Plantain	45MT
Pumpkin	23MT
Squash	23MT
Tomato	22MT
Tomatillo	36MT
Yardlona bean	10 MT
Watermelon	20MT

Table 1.—Estimates of Net Primary Production (MT/ha/yr) in Tropical Forests (UNESCO,1978)

Forest type	Location	Net production
Equatorial	Yangambi, Zaire	32
Equatorial	Khao Chong, Thailand	29
Secondary forest 40 years old	Kade, Chana	24
Lowland dipterocarp	Pasoh, Malaysia	22
Bamboo in monsoon forest	Burma	20[a]
Subequatorial (Banco plateau)	Ivory Coast	17
Bamboo in rain forest	Burma	16[a]
Dry deciduous	Varanasi India	16
Lower montane	El Verde, Puerto Rico	16
Subequatorial (Yapo plateau)	Ivory Coast	15
Seasonal rain	Anguededou, coastal Ivory Coast	13
Mangrove	Puerto Rico	9

aEstlrnate does not include roots.

Table 4.—Tropical Spices

Trees:		
Allspice	Pimenta dioica	
Bayrum tree	Pimenta racemosa	
Camphor	Cinnamomum camphora	
Cassia	Cinnamonmum aromaticum	
Cinnamon	Cinnamomum verum	
Mace	Myristica fragrans	
Herbs and vines:		
Lemon grass:	Cymbopogon citratus	95 MT WM
Patchouli	Pogostemon cablin	36 MT WM
Pepper, black	Piper nigrum	6 MT (fr)
Vanilla	Vanilla fragrans	1 MT (sol)
Vetiver	Vetiveria zizaniodes	2.5 MT (rt)

Table 5 presents estimates of standing phytomass and net primary productivity for some of the various vegetation types that might be expected in a tropical country. I believe, but cannot prove, that intensively managed agroecosystems used in places formerly occupied by these forest types could produce two to five times as much (except for the alluvial swamp forests). I do not advocate replacement of forest with agroecosystem, but better management of existing agroecosystems.

Table 5.—Net Primary Productivity

	Republic of Panama Phytomass MT/ha	NPP MT/ha
Tropical:	240	18
Humid tropics:	440	29
Bright Ferrallitic Evergreen	650	27
Swamp Forest	500	25
Bogs	300	150
Monsoon Forest (Savanna) Red	200	16
Monsoon (Dark Soil)	80	15
Alluvial Forests	250	70
Mangrove	130	10
Submontane Evergreen	700	35
Submontane Monsoon	450	29
Semiarid tropics:	***107***	***14***
Xerophytic Forest (Ferrallitic)	250	17
Grass Shrub Savanna (Redbrown)	40	12
Grass Shrub Savanna (Black)	30	11
Grass Shrub Savanna (Solonets)	20	7
Swamp Savanna	60	14
Alluvial Gallery	200	60
Sub montane Xerophytic Forest	200	15
Sub montane Savanna	40	12
Arid tropics:	***7***	***2***
Savanna (red-brown soils)	15	4
Alluvial Gallery	150	40
Tropical Desert	1.5	1
Psammonphyte on sand	1.0	0.1
Desert (Coalessed soil)	1.0	0.2
Halophytes (solanchaks)	1.0	0.1
Submontane Desert	7.0	2.0
Subtropical:	***133***	14
Humid subtropical:	***366***	***25***
Bright ferrallitic Evergreen	450	20
Rendaina Evergreen	380	16
Prairie	30	13
Swamp Forest	400	22
Meadow Bog	200	130
Gallery Forest	250	40
Submontane Forest	410	18
Semiarid subtropics:	***99***	***14***
Xerophytic Forests	170	16
Shrub-steppe (Gray-Brown soil)	35	10
Shrub-steppe (Soloneta)	20	6
Shrub-steppe (Chernoaenoid)	25	8
Psammophyte on sand.	20	5
Halophytes on Glanchak	1.5	0.5
Gallery Forest	250	40
Submontane Forest	120	13
Submontane Shrub-steppe	99	14
Arid Subtropics:	***14***	***7***
Steppe desert (Serozem)	12	10
Desert (sub-desert soil)	2	1
Psammonphytes on sand	3	0.1
Desert on takyrs	1	0.5
Halophyte on solonchak	1	0.2
Gallery Forest	200	90
Submontane Desert (Serozem)	15	12
Submontane Desert (Desert soil)	3	1

SOURCE Rodln and Brazil in Lieth. 1978

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