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AGRICULTURE IN AMAZONIA

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ABSTRACT

21.1 AGRICULTURAL TYPES: PATTERN AND TRENDS

- 21.11 *Terra Firme*: the vast Uplands
- 21.111 Shifting Cultivation
- 21.112 Pioneer Smallholder Annual Crops
- 21.113 Cattle Ranching

- 21.114 Perennial Crops
- 21.115 Mechanized Annuals
- 21.116 Horticulture
- 21.12 *Várzea*: Amazonian Floodplains

- 21.121 Annual Crops of Smallholders
- 21.122 Mechanized Rice
- 21.123 Horticulture
- 21.124 Fiber Crops
- 21.125 Cattle and Water Buffalo

21.2 ALTERNATIVE MANAGEMENT: IMPEDIMENTS AND PROSPECTS

- 21.21 Fertilizers and Continuous Cultivation

- 21.22 Diversity and Sustainable Management

- 21.23 Farm Size and Agricultural Populations

21.3 LIMITS TO AGRICULTURE: HUMAN CARRYING CAPACITY

REFERENCES

ABSTRACT

The varied habitat types of Amazonia, and the varied cultural backgrounds of the region's inhabitants, are associated with a wide range of approaches to agriculture. Agricultural types differ greatly in their yields to humans, their production constraints, and their future prospects. Soils, topography, and other agriculturally important features of the landscape vary tremendously on a microscale, as well as between the two principal zones into which the region is divided: the upland <u>terra firme</u> and the seasonally flooded <u>várzea</u>.

Agricultural patterns are changing rapidly. In terra firme areas the traditional shifting cultivation practiced by indigenous groups has been replaced by other forms as quickly as the groups themselves retreat and disappear. <u>Caboclos</u>, the poor Portuguese-speaking inhabitants born in Brazil's Amazonian interior, practice a form of cultivation similar in many ways to indigenous methods, but also differing in important respects. Far more different is the pioneer agriculture practiced by the waves of recent arrivals to the region, resembling the traditional shifting cultivation only in the initial slash-and-burn method of land preparation. Pioneer planting of annual crops is usually, in one way or another, supplanted by low-yielding cattle pasture. Pioneer farmers often plant pasture themselves, and pasture is planted at an even faster rate by others who buy or take the land from the pioneers. In addition to pioneer farmers who follow annual cropping with pasture, large ranchers are rapidly converting vast expanses of virgin forest directly to pasture. Speculation, even more than generous government incentives, makes pastures highly profitable in spite of low productivity and slight chance of sustainability. Soil degradation and invading weeds reduce pasture yields after a few years. Fertilizers have been put forward as a solution to declining yields, but serious doubts cloud the long term effectiveness of this measure for sustaining pasture productivity.

Much more restricted areas have been planted in perennial crops with the help of government financing. Fungal diseases and world market limitations for the products make it unlikely that a significant part of the region's vast uplands will be planted in cacao, black pepper, rubber and other perennials. Mechanized cultivation of annual crops has also been introduced by a few wealthy newcomers, but long term prospects are poor. Horticulture near large city markets has proved profitable, as high market prices allow the use of expensive inputs.

The Amazon floodplain, or <u>várzea</u>, has the advantage over <u>terra firme</u> of more fertile soils, and far more importantly, the possibility of sustained production since soil fertility is renewed by the silt deposited with each year's flooding. Annual crops planted by small farmers is the traditional use. Mechanized cultivation of irrigated rice has been in one large-scale attempt to apply capital and resource-intensive methods to the <u>várzea</u>.

Other forms of agriculture employed in the *várzea* include horticulture, fiber crops such as jute, and the grazing of cattle and water buffalo.

Researchers have followed a number of approaches in the search for more productive ways of farming in Amazonia. One program hopes to make annual cropping in *terra firme* into a continuous cropping system by applying a delicate balance of chemical fertilizers. Both technical and human obstacles make the system's widespread use unlikely. A number of experimental agricultural systems are attempting to maintain some of the diversity and other characteristics of natural vegetation and traditional cultivation systems. Many of these use different combinations of perennial crops, some combining silviculture and/or perennials with annual cropping. Diverse plantings are appropriate for promoting sustainability, security of yields, and self-sufficiency of farming communities.

Land tenure arrangements have a profound effect on the types and intensities of agriculture employed, and on the effectiveness of agriculture in supporting the human population. The trend to more concentrated land tenure is related to the spread of cattle pastures as the dominant form of agriculture in the region.

Each form of agriculture has limits to its ability to produce yields and support human populations. Some, such as pasture, are very low. Human carrying capacity, the population density that can be supported indefinitely at a given standard of living without environmental degradation (given a variety of assumptions), is limited. Amazonia's twin illusions of infinite size and infinite "agricultural potential" can easily mislead development planners into promoting wasteful and unsustainable land uses. The current rush of immigrants to Amazonia from other can soon be expected to lead to exceeding carrying capacity. Agriculture in Amazonia cannot be expected to solve growing national problems. Sustainable management of agriculture for the region's residents will require a re-orientation of agricultural research efforts and development programs. No single land use choice can ever be recommended for the entire Amazon, but rather a patchwork of different uses to fill different needs and accommodate different constraints. Careful definition of goals is an essential first step in helping agriculture fulfill its primary purpose: continued support of the human population. In addition to sustainable agroecosystems, the long-term wellbeing of Amazonia's inhabitants requires restraints on the concentration of land holdings, limited total consumption, and maintaining the human population below carrying capacity.

21.1 AGRICULTURE TYPES: PATTERN AND TRENDS

21.11 Terra Firme: the vast uplands

21.111 Shifting cultivation

Shifting cultivation or swidden is the traditional method of farming Amazonia's vast unflooded uplands known in Brazil as *terra firme* (Span: *tierra firme*). Indigenous populations have used such "slash-and-burn" agriculture for many centuries as a means of obtaining plant-based foodstuffs from Amazonia's infertile soils, with a minimum of human effort spent on fending off the relentless competition of weeds and crop pests (Carneiro, 1960; Harris, 1971; Gross *et al*., 1979). Large land areas relative to the human populations have allowed employment of long fallow periods, usually several decades, between brief farming periods of 1-2 years. During the fallow period, woody second growth (Port.: *capoeira*, *juquira*, or *quisasa*; Span.: *purma*, *rastrojo*, or *barbecho*) takes over the temporarily "abandoned" fields, accumulating nutrients in the tree biomass, restoring the soil's porosity and other physical structure characters degraded through farming, and increasing the organic matter content of the soil as reduced soil temperatures shift the balance between accumulation and decomposition of soil humus. Soil fauna, greatly depleted during the farming period, returns with consequent resumption of nutrient cycling and other roles in the forest ecosystem.

The *caboclos*, or poor Portuguese-speaking inhabitants of the Amazonian interior, also employ a similar system (Wagley, 1976; Moran, 1974). *Caboclos* generally do not move their residences together with their fields, as indigenous groups often do, but are still able to move their plantings over sufficiently wide areas to have long fallows. Most of the region's river and stream banks now occupied by the *caboclo* population have only been farmed by these racially and culturally mixed residents on the order of one century, in contrast to the much longer history of occupation, very often of the same choice riverside sites, by Amerindian groups. *Caboclos* lack the complex of cultural mechanisms which have been found in many parts of the world to result in long fallows among traditional practitioners of shifting cultivation.

When either primary forest or a second growth stand is cut for farming in Amazonia, it is essential that the downed vegetation be burned. Burning removes the physical obstruction of the dead vegetation, releases needed plant nutrients into the soil (especially phosphorus and cations such as calcium, magnesium and potassium), and of particular importance, raises the soil pH. The extremely acid soils of the region yield only stunted crops if burning is poor. Low soil Ph has a synergistic effect with the low phosphorus levels, reducing the availability to plants of what little phosphorus exists.

During the farmed period, crop yields usually decline as a combined result of exhausted soil fertility and the increased inroads of weeds and pests. The relative importance of the different factors depends on the initial fertility of the soil (Sánchez, 1976). Where soil is extremely infertile, as in the white sand areas of the upper Rio Negro, the end of nutrient supply, especially organic matter from decomposition of the thick mat of forest roots, is believed to be critical (Herrera *et al*., 1978). In rich volcanic soils of Central America the invasion of weeds is credited with at least equal impact on yield declines (Popenoe, 1960). The question of what causes shifting cultivators to "abandon" a given field can easily become a sterile academic debate, as farmers themselves are not concerned with levels of phosphorus, organic matter, or any other soil nutrient, but rather the net result in terms of yield obtained from their labor. Increased labor demands of weeding, combined with declining yields per area, make moving to a new location more and more attractive as farmed period lengthens. The per area yield declines are themselves the combined result of the many individual agricultural setbacks, a kilogram lost to pests being just as unavailable to feed the farmer as a kilogram lost to stunted crop growth.

Yields, and their declines, are exceedingly erratic depending on weather, biological problems, and many other factors. Sometimes yields will be better in the second year than the first, or vice versa, a large sample being needed to draw valid conclusions. Yields of some crops, such as maize, may increase in the second year of cultivation in comparison with the first (Jessup, 1981), although evidence is conflicting. Others report the more traditional view of yields declining steadily from the first year (Penteado, 1967; Watters, 1971: 101, 106; Cowgill, 1962; Sánchez, 1976: 375; UNESCO, 1978: 472-3). One contributing factor to an increase in the second would be the disappearance, as the farmed period progresses, of downed vegetation occupying some of the land area. The soil itself may provide some explanation if allelopathic chemicals released into the soil by the original forest trees have a role in inhibiting crop growth in the first year after clearing. Information on such possible effects is scant and conflicting.

It is important to note that many indigenous groups are believed to move their residences, with consequent "abandonment" of swidden fields, as an adaptation to exploiting game and fish populations over a wide range of territory (e.g. Gross, 1975; Roosevelt, 1980). For many indigenous groups the distinction is often blurred between an actively cultivated garden and an "abandoned" or fallow field, as tree crops planted in the field (or spared the axe during the initial clearing) may be harvested for many years after active cultivation has ceased.

Shifting cultivation is condemned by many agronomists for its inability to provide sufficient surpluses to allow its practitioners entry into the cash economy (e.g. Alvim, 1978), as well as for its leading to deforestation and erosion (United Nations F.A.O., 1957; Watters, 1966, 1971). Advantages of the system include its successful record for supporting human populations during millennia (provided population densities remain low), as well as its self-sufficiency and high productivity per unit of human labor (Leach,1959; Nye and Greenland, 1960; UNESCO, 1978: 467-476; Sánchez, 1973, 1976). It is well to point out that most clearing in Amazonia today is the result of large-scale cattle ranching rather than shifting cultivation, although clearings from both large and small operators have negative effects. Small clearings with short farmed times regenerate far more quickly than large pastures (Uhl, 1982; Uhl *et al*., 1982), but true shifting cultivation with small isolated clearings and long fallows is becoming a rarity in the region. With the present rapid disappearance of indigenous groups (Davis, 1977; Hanbury-Tenison, 1973; Goodland and Irwin, 1975; de Oliveira *et al*., 1979), shifting cultivation can be expected to disappear. Pioneer agriculture by small farmers, both squatters and government-sponsored colonists, resembles shifting cultivation superficially but has profound differences which render it unsustainable.

2.112 Pioneer Smallholder Annual Crops

The thousands of pioneer farmers who have entered the Amazon in recent years from other regions employ agriculture with many essential differences from the traditional long-cycle shifting cultivation of Amerindian and *caboclo* populations. The new migrants come from areas such as drought-prone Northeast Brazil, and from the former coffee and food-crop lands of Paraná and other southern Brazilian states where mechanized soybean and wheat cultivation, along with vast sugar cane plantations for alcohol production, are driving out the former sharecroppers and small land owners. In the case of migration to the Amazonian portions of Bolivia, Peru, Ecuador, Colombia, and Venezuela, newcomers come from Andean areas. The flow of migrants has swollen as a combination of worsening conditions in the source areas and the opportunity to obtain land in Amazonia by taking advantage of the many new highways constructed in the region. Pioneers are settled in government-sponsored colonization areas, as well as both private and public lands where squatters have entered on their own initiative. The new arrivals fell and burn the forest, much as do traditional shifting cultivators in the first step of a swidden cycle, but thereafter the differences in the two classes of systems become more apparent. A few of the pioneers are from *caboclo* backgrounds in other parts of Amazonia; these carefully select the land to be cleared based on indicator tree species present, and plant a diversified array of crop plants (Moran, 1979a). They also are more skillful in timing the felling and burning operations to obtain the best burns, as well as in making the many agricultural decisions from deciding how much to plant of crops like rice (*Oryza sativa*) requiring intensive periods of seasonal labor as compared with more traditional staples like manioc (*Manihot esculenta*) which spread the labor requirements over much the year (Fearnside, 1978, nd-a).

Most of the new arrivals from other ecological regions find adaptation to the new environment difficult. Many of the responses lead them gradually to adopt some of the solutions long practiced by the area's residents (Moran, 1981). The speed and path of the adaptation process varies greatly, however, depending in part on the colonist's background before arrival (Moran, 1979b, 1981; Fearnside, 1980a).

Pioneer farmers do not plant the wide variety of crops employed by traditional shifting cultivators (Smith, 1978, 1981a,b). The more homogeneous and larger fields planted are both more susceptible to pest and disease problems, and represent a more devastating blow when problems do arise. The Transamazon Highway colonists, for example, suffered a severe setback when virtually the entire rice crop failed in 1973, as a result of an untested rice variety distributed by the government colonization agency. Colonists in government-sponsored areas such as the Transamazon Highway expand their planting far beyond what their family's labor supply would permit, through hired hands for felling and harvesting paid by bank financing. The bureaucratic delays and other institutional problems associated with financing can often result in colonist's agricultural efforts failing both agronomically and economically (Wood and Schmink, 1978; Moran, 1981; Bunker, 1980; Fearnside, 1980a, nd-a). Good burn qualities, largely predictable based on meteorological data, and felling and burning dates, are critical to obtaining a good yield (Fearnside, nd-a, nd-b); delayed felling for bureaucratic reasons, or ignorance of the associated risks, can often result in poor burns and failed crops.

The most striking difference between pioneer agriculture and traditional shifting cultivation is lack of the cultural traditions which lead swidden farmers to leave their fields in second growth for long periods before returning for a subsequent crop. Pioneers clear young second growth only one or two years of age with frequency, not a practice that could be expected to continue for long. Colonists have no intention of using a sustainable cycle of shifting cultivation as the basis for their agriculture. Rather, annual crops planted in the early years of settlement are seen as a temporary solution to their immediate needs for cash, while the settler waits for a change to other sources of income such cattle pasture, perennial crops, or selling the land at a good price to someone else who will develop one of these longer-term uses. By far the greatest share of the land area, both in areas of small colonists and in large land holdings, is rapidly being converted to cattle pastures.

Annual cropping by small farmers cannot continue indefinitely in its present pattern, given the unsustainable features of the system. Traditional long-fallow shifting cultivation also becomes impossible when population density increases, as is rapidly occurring in Amazonia.

21.113 Cattle ranching

Cattle ranching, by far the most important agricultural activity in Amazonian rainforest, is growing at such a rate that it can be expected to dominate Amazonian landscapes in all parts of the basin (Fearnside, 1982). Even in areas where intensive government programs promote perennial crops, such as colonization projects in Rondônia, much greater areas are planted to pasture every year.

Ranching is widespread both on the 15 million hectares of "natural" upland grasslands and in the rapidly increasing areas of planted pastures. Beef productivity is low, but, far more importantly, it is unlikely to prove sustainable in the planted pastures (Fearnside, 1979a). The dry weight of pasture grasses produced per hectare per year is small largely due to poor soil, available phosphorus having been found to limit grass yields in several locations on typical OXISOLS and ULTISOLS (Serrão *et al*., 1971; Koster *et al*., 1977; Serrão *et al*., 1979). Pastures are quickly invaded by inedible weeds, better adapted than the grasses to the poor soil, in addition to being spared the grazing pressure of the cattle (Serrão *et al*., 1971: 19; Simão Neto *et al*., 1973; Fearnside, 1979a). Of 2.5 million hectares of planted pastures in the Brazilian Amazon by 1978, 20% were considered "degraded", or invaded by second growth (Serrão *et al*., 1979: 202).

The question of how soils change under Amazonian pastures is one of more than academic importance in Brazil. Massive governmental programs subsidizing pasture in the region have received impetus from claims that pasture improves the soil, and, by implication, is sustainable indefinitely. In 1974 the head of the principal government agricultural research institute in the Brazilian Amazon announced that comparisons of soils under virgin forest with soils under pastures of various ages both on the Belém-Brasília Highway at Paragominas and in ranching areas of northern Mato Grosso had shown that:

> Immediately after burning (of forest) the acidity is neutralized, with a change in pH from 4 to over 6 and aluminum disappearing. This situation persists in the various ages of pasture, with oldest pasture being 15 years old, located in Paragominas. Nutrients such as calcium, magnesium, and potassium rise in chemical composition of the soil, and remain stable through years. Nitrogen falls immediately after the burn but in a few years returns to a level similar to that existing under primitive forest. (Falesi, 1974: 2.14; my transl.)

The soil changes led to the conclusion that:

> The formation of pastures on latosols and podzolics of low fertility is a rational and economic manner in which to occupy and increase the value of these extensive areas.

(Falesi,1974: 2.15, my transl.)

The data on which these conclusions were based (Falesi, 1976), when examined more closely, reveal that soil does not improve from the point of view of pasture growth. Available phosphorus, the element limiting pasture growth in these areas, decreases over the period (Fearnside, 1980b). A more detailed study of soil change in the Paragominas ranching area also confirms that the soil degrades, rather than improves, from the point of view of pasture growth (Hecht, 1981, 1982b). Brazilian government agencies concluded in 1977 that the soil improvements they had noted were not sufficient to maintain pasture productivity without the addition of phosphate fertilizers but that adding 50 kg/ha of P_2O_5 (about 300 kg/ha of superphosphate) would solve the problem of nutrient deficient growth limitation (Serrão et al., 1979; Serrão and Falesi, 1977; Toledo and Serrão, 1982).

Adding phosphorus is not in itself sufficient to render pasture sustainable, as other soil characters continue to deteriorate until they limit production. Soil compaction is a major problem. Exposure of the soil to sun and the trampling of cattle in pastures quickly results in the soil becoming hard and dense, with reduced pore volume and water infiltration capacity (Schubart et al., 1976; Dantas, 1979). Success has often not been great in fertilized pastures in other tropical areas. In Peru researchers found that "with time, these mixed pastures lose productivity because of soil compaction by animal hooves, disease in legumes and probably deficiencies of nutrients not provided by single superphosphate. The proposed management alternative considered is to revert back to crops, fertilize heavily and start the cycle over again" (Sánchez, 1977 citing results of Peru, IVITA, 1976). Pasture growth is reduced as the compacted soil restrains the plants' roots, and soil erosion increases as rain water runs rather than sinking into the soil. Vital to the phosphorus fertilization program has been heavy subsidization of its cost by the government, through attractive loans with long grace periods and negative interest rates in real terms.

Brazilian government recommendations regarding cattle ranching have changed several times as additional problems have come to be known. After the 1974 theory of self-improving pastures was changed to one of pastures sustainable with limited phosphorus inputs, the drawbacks of Guinea grass (Panicum maximum), the recommended species occupying 85% of the planted pasture area in the Legal Amazon by 1977 (Serrão and Falesi, 1977) became evident. The grass's disappointing performance on the poorest soils, inability to reseed itself under many conditions, and bunchy habit facilitating invasion of second growth (as well as erosion), led to the official change to promoting creeping signal grass (Brachiaria humidicola) in about 1979. Brachiaria humidicola has the advantage of forming a low dense cover, but has low yields and is not, as was at first believed, immune to the attacks of the homopteran bug known as cigarrinha (Deois incompleta, Cercopidae) that destroyed many pastures planted with the congeneric species signal grass (*Brachiaria decumbens*) along the Belém-Brasília Highway in the early 1970's (de Brito Silva and Magalhães, 1980; Hecht, 1982b).

Would phosphate fertilization, as recommended by the Brazilian government (Serrão and Falesi, 1977), make cattle ranching a sustainable undertaking in Amazonian *terra firme*? The question is a vital one given the continued rush to convert forest to pasture. If fertilized pasture is unsustainable, or is sustainable only with the present government subsidies of fertilizer purchase and application, then the possibility of fertilizing may prove to be little more than an illusion. Planners may be led to advocate continuation of the rush to pasture on the assumption that areas can always be made productive at a later date. Phosphate applications produce immediate and dramatic improvement in degraded pasture but it is well to remember that the number and magnitude of nutrient deficiencies to be supplied, as well as the cost of steps needed to counter the deterioration of soil physical structure, will increase as pasture use is prolonged. Ultimately, the cost and availability of the inputs needed to maintain a significant portion of Amazonia as fertilized pasture may restrain reliance on fertilizers. Even with generous subsidies available for pasture fertilization, most ranchers presently prefer to concentrate their resources on clearing larger areas rather than improving their pastures. A survey done in 1977 of 92 ranches in northeastern Pará found only one ranch (1.08% of the sample) using any kind of fertilizer on pasture (Homma *et al*., 1978: 18).

Pasture is attractive to landowners for a number of social and institutional reasons, production of beef often being a minor consideration. A major factor is pasture's capacity to occupy a large land area quickly with a minimum labor and capital expenditure. Amazonia's land tenure system is based almost entirely on physical possession of the land. Formal documentation of land titles normally occurs only after the "owner", or his representatives, have occupied the claimed area. Violence and fraud are commonplace in eliminating less powerful competitors for claims, especially small farmers or Amerindians (Mueller, 1980, 1982; Martins, 1980; Davis, 1977; and many others).

Clearing land is considered a "betterment" (*benfeitoria*), and pasture is the easiest means of keeping land from reverting to secondary forest once cleared. Land has a tremendous value as a speculation, which accrues both to large land holders drawn to the region by potential capital gains and to smaller farmers who come with the intention of making a living through agricultural production. Pastureland prices in northern Mato Grosso increased at a rate of 38% annually during the 1970-75 period, after discounting inflation (Mahar, 1979: 124). No agricultural production system can match these rates of return. Even small farmers who do not view themselves as speculators are tempted to sell their holdings to receive the financial reward obtainable for having occupied a site--a reward which is usually much more than they have ever made through their farming efforts. The lure of speculative profits hinders agricultural development by raising land prices to a point where more productive small farmers are excluded, and by channeling land use decisions toward unproductive pasture rather than intensive management of smaller areas. Ironically, it is the lower price of land (relative to other inputs) which leads to extensive use patterns and little concern for sustainability. Land prices rise to levels far higher than would be justified by the value of land as an input for production (cf. Found, 1971). The skyrocketing prices are partly due to the land's function as a store of value, providing protection from Brazil's triple digit inflation. Expectation of future price increases is an immediate motivation for many purchases; the anticipation of uninterrupted expansion and improvement of road access, as well as the continued influx of new arrivals in the region, underlie these hopes. In the case of pasture developed with governmental incentives, the value of land as a key giving access to this rich trove of tax exemptions and concessionary financing adds greatly to its value.

Incentives for pasture projects approved by Brazil's Superintendency for Development of the Amazon (SUDAM) are a major contributing factor to deforestation for ranching (Mahar, 1979; Fearnside, 1979b). Approved projects allow their owners to invest up to 50% of the income tax these individuals or firms would have otherwise had to pay to the government. The decision to invest is logical for tax reasons alone for anyone with significant income from other sources in the developed southern part of the country, even if the pasture schemes are economic failures when viewed separately. In addition, an approved project allows borrowing from the government-supported Bank of Amazonia, Anonymous Society (BASA) with no interest, although principal is adjusted yearly to compensate for inflation (usually by a percentage below real inflation). No payments need be made during a grace period of five years; formerly the grace period extended for seven years. Moreover, inspection of the remote ranching projects is lax, allowing many to invest substantial parts of the subsidized financing in more profitable ventures elsewhere.

The generous terms of incentive arrangements not only offer a pull to attract investors to Amazonian lands but are themselves a contributor to the inflation that pushes investors to seek shelter in real estate. Brazil's agricultural incentives are viewed by economists as one of the major factors in the country's notorious inflation, according to former Brazilian finance minister O.G. de Bulhões (Gall, 1980). Inflation occurs any time large amounts of money are spent on unproductive endeavors, thereby putting money in the pockets of consumers without contributing a corresponding flow of products to the economy to satisfy resulting demand.

A change of policy in 1979 has restricted new incentivated ranching projects to parts of Legal Amazonia outside the area defined as "high forest". Contrary to popular belief, the change in SUDAM policy has not halted the subsidized expansion of ranching. The hundreds of SUDAM projects already approved for the "high forest" area continue to receive their full incentives, and most of these have hardly begun to clear their forested area. At the same time, new projects are approved for the large areas classified as "transition forest" along the southern fringe of Amazonia, already the focus of the most intensive ranching activity.

Many forces leading towards the rapid spread of ranching suggest that this land use, of dubious sustainability, will continue to predominate in the expanding clearings in Amazonia.

21.114 Perennial Crops

Perennial crops, such as cacao (Theobroma cacao), coffee (Coffea arabica), rubber (Hevea brasiliensis), and black pepper (Piper nigrum), are seen by many planners as holding great promise for producing sustainable yields in Amazonia (e.g. Alvim, 1978, 1981). Other perennial crops in earlier phases of expansion as commercial planting include African oil palm (Elaeis guineensis), various native and introduced fruit trees, and guarana (Paullinia cupana), the Sapindaceous woody climber used in a Brazilian soft drink and as a sex stimulant. Sugar cane (Saccharum spp.) is also officially classed as a perennial crop due to its ability to sprout back for subsequent croppings after harvest, although its herbaceous nature and need to be re-planted after every 2-3 crops in order to maintain full productivity make it more like an annual crop in ecological terms, while its highly seasonal labor requirements make it more like many annual crops in social terms.

Principal reasons for hopes that perennials will prove sustainable are that (1) the products' value, in contrast to annual crops such as rice and maize, justifies the cost of supplying nutrient requirements through fertilizers, rather than relying on the small and quickly exhausted stocks in the soil (Alvim, 1973), (2) plant nutrient losses are minimized as compared with annual crops, due to better recycling within the agroecosystems, since leaves fall to the ground to contribute to soil fertility in plant root zones, and (3) the soil is protected from direct impact of sun and rain in the case of tree crops such as cacao and rubber. In the case of black pepper, a vine crop grown on posts in the open sun, erosion and other effects are much more akin to annual crops than is case with arborescent crops like cacao (Fearnside, 1980c).

Perennial crops are affected by a variety of diseases, raising serious doubt about some of the plans for large plantations of these crops. "Permanent crops," as perennials are euphemistically designated in Brazil, are often anything but permanent. Rubber is the best known example. This native Amazonian tree grows wild as scattered individuals. Wild trees dispersed throughout the rainforest are susceptible to the fungus Microcyclus (formerly Dothidella) ulei, causing South American leaf blight, or "SLAB," but the impediment of many trees of other species separating each individual rubber tree from others of its own species prevents the disease from ever reaching epidemic proportions. Susceptibility to pest and disease attacks of monospecific stands in comparison with scattered individuals in a diverse forest has been hypothesized as a selective pressure leading to the evolution of rainforest tree species equipped to reproduce and disperse themselves while present in such sparsely distributed patterns (Janzen, 1970a). When rubber is planted in monocultural plantations, the fungus passes easily from tree to tree, resulting in death or low productivity of susceptible plantations in regions favorable to the fungus. Fordlandia, the Ford Motor Company's plantation begun on the Tapajós River in 1926, was attacked by Microcyclus: it became uneconomic in the mid-1930's, was carried on a few years due to Henry Ford's persistence plus the advent of World War II when rubber was produced at all costs to compensate for supplies unavailable from Southeast Asian plantations. After World War II the Fordlandia plantation was abandoned, and the second Ford plantation at Belterra 100 km downstream, begun in 1934 in an attempt to avoid the fungus, was turned over to the Brazilian government as a money-losing proposition (Sioli, 1973). Although attacked by Microcyclus, Belterra still functions today, with continual government subsidy and a constant battle of grafting and spraying to combat losses to the fungus. The best solution to the fungus problem has been found to be locating plantations in areas where a sufficiently harsh dry season causes the trees to lose their leaves once a year, combined with the expensive process of grafting resistant tops to high yielding root stock, and a battery of fungicides to control the disease. Brazil, once the world's principal source of rubber, is forced to import two-thirds of its natural rubber needs from Southeast Asia, despite a sustained program of research, extension, and government subsidies to encourage production in the Amazon region.

Black pepper, introduced to Amazonia by Japanese immigrants in 1933 (Loureiro, 1978: 282-84), produced large and valuable harvests in areas of Japanese settlement in the 1950's and 1960's. The fungus Fusarium solani f. piperi first appeared in 1960 at Tomé-Açú (de Albuquerque and Duarte, 1972), later spreading to other pepper-growing locations in the Brazilian Amazon. The result has been devastation of the crop at one location after another, now affecting the most recent plantations on the Transamazon Highway (Fearnside, 1980d). As long as pepper prices remained high, re-planting or moving to new locations was a practical means of dealing with the disease. No resistant varieties have yet been found, and spraying has proved unsatisfactory as a means of control. Falling world market prices for pepper have contributed to making pepper less attractive, although many government financed pepper plantings exist.

Cacao, a native Amazonian plant, is also susceptible to local fungal diseases. Witches' broom disease (Crinipellis perniciosa, formerly Marasmius perniciosus), attacks plantations, even those of relatively resistant seed varieties produced by government breeding programs in the State of Bahia, the traditional cacao producing region of Brazil located outside of Amazonia and away from the native range of the *Crinipellis* fungus. Breeding programs for resistance to fungal disease suffer from the disadvantage of such programs for any tree crop, in that the much shorter generation time of the fungus in relation to the tree allows the disease organisms to evolve ways of breaking the resistance faster than trees can evolve new means of resisting attack, even with the help of plant breeders (Janzen, 1973). Witches' broom was a major factor in the demise of cacao production in the State of Pará at the end the nineteenth century (Pará, SAGRI, 1971 cited by Morais, 1974). The recent government financing and extension programs for cacao on the Transamazon Highway and in Rondônia have resulted in marked increases in planted areas. Witches' broom attacks have led to some farmers abandoning their plantations, to some following government advice to spray and remove affected branches and fruits, and to many others to taking an attitude of waiting to see how the disease will progress.

Disease will undoubtedly be a major factor affecting the extent to which cacao and other perennial crops spread in Amazonia. Disease attack can be expected to have a synergistic effect with falling market prices to restrict the spread of cacao. The world price of cacao has been falling since the peak reached in 1977. World Bank estimates of the future course the decline indicated FOB cacao prices dropping, in constant 1980 US dollars, from the observed $3,489/metric ton in 1979 to a projected $2,837 in 1984 and $2,037 in 1989 (International Bank for Reconstruction and Development, 1981: 100). Increased world cacao production, partly from expanding plantations in Amazonia, is one factor contributing to the expected decline (Skillings and Tcheyan, 1979), as is anticipated progress in producing substitutes for cacao in chocolate (International Bank for Reconstruction and Development, 1981: 79). Since controlling witches' broom is expensive, requiring both a large amount of labor to remove affected branches by hand and costly copper-containing fungicide sprays, growers can be expected to have less motivation to incur these expenses as cacao prices fall. Once disease foci become well established in neglected plantations, losses and control costs can be expected to increase in surrounding areas, further weakening motivation to control the disease. Disease and pest problems can also be expected to increase as the size of monocultures of perennial crops increases.

Irrespective of the biological problems of perennial crops, economic limits are sure to prevent these land uses from occupying a significant portion of the vast area of Amazonia, although the relatively small area that could be planted to these crops without saturating world markets could provide a significant income for the region.

21.115 Mechanized Annuals

Mechanized cultivation of annual crops in *terra firme* has been increasing in recent years but still represents only a tiny fraction of the total planted to such crops as rice and beans. Wealthier newcomers to the region arriving from areas in southern Brazil where tractors and other machinery are commonplace have increasingly brought with them the cultural orientation and knowledge, as well as the machinery and financial resources, needed to employ this form of technology. Mechanization avoids the headache of obtaining hired hands to do manual labor at the seasons of peak labor demand. Since most people come to the area with the intention of staking out their own claim rather than working for others, the relatively few workers available for hire find a sellers' market for their labor. Mechanization has disadvantages as well. The isolated settlers find much higher costs for obtaining spare parts and skilled maintenance for the equipment than they had experienced in the highly developed South. At the same time, farm gate prices of cereal crops are lower, since the cost of transportation to distant markets is far greater. Use of tractors is also difficult in much of the Amazon where land is dissected into steep slopes, contrary to the popular illusion that the area is as flat as it appears from the air. Removing rainforest tree stumps and partially burned trunks is a costly prerequisite for using tractors in agricultural operations. Destumping almost always requires bulldozing the land, thus removing the most fertile upper layer of soil, as well as contributing to soil compaction (Van der Weert, 1974; Seubert *et al*., 1977; Uhl *et al*., 1982b). Plowing the fields has the disadvantage of bringing less fertile lower layers to the soil surface, in contrast to many temperate zone farming systems where topsoil is deep and lower layers consist of relatively unweathered material rich in plant nutrients.

The influx of southern Brazilians to the Amazon can be expected to increase the number of these new arrivals wanting to apply their capital to mechanization. Improved transportation and urban infrastructure, as with the paving of the Cuiabá-Porto Velho in 1983, will make today's frontier areas increasingly more attractive to these wealthy farmers. Better transportation will make the products more marketable, as will the progressive disappearance of staple food crops from Brazil's South, where these land uses are now being quickly replaced by export crops such as soybeans. At the same time, rising land values will make investing capital in equipment more attractive than in land clearing as currently occurs. Forces that can be expected to hold any explosion of mechanization in check include continued migration of manual laborers to the region, presumably to lead in a drop in wages from present levels which are far above those in other rural areas of Brazil. Increasing fuel costs as fossil fuel supplies dwindle will also slow mechanization, as will the disadvantages of soil and topography already mentioned. The tremendous amount of capital that would be required to convert any significant portion or Amazonia to mechanized agriculture insures that cheap, quickly installed land uses like pasture will dominate for the foreseeable future.

21.116 Horticulture

Growing vegetables has become a profitable venture for enterprising farmers located near large cities in the Amazon. Market prices for such commodities as tomatoes are as much as seven times higher in Manaus than in São Paulo, and much of the produce sold is actually flown in from São Paulo, over 2600 km away. Around major cities such as Belém and Manaus, as well as many smaller towns such as Altamira on the Transamazon Highway, farmers specialized in horticulture are often of Japanese origin. These farmers have a cultural tradition of intensively cultivating small areas, together with liberal use of fertilizers, pesticides, and other costly inputs, practices foreign to most of Amazonia's other inhabitants. The high price of inputs has been compensated by high value products, and the ventures have often proved economic successes.

Horticulture is much more difficult in the tropics than in other regions, due to greater losses to diseases and pests. Rural residents grow what few green vegetables they include in their diet in raised windowbox-like structures called _hortas_. The legs of the _hortas_ are protected against rats (_Rattus rattus_), and sometimes against leaf-cutter ants (_Atta_ spp.) as well. Soil in the box is fortified with ash, black "Indian earth" (_terra preta do índio_), or other nutrient-rich supplements. Production of green onions (_Allium cepa_), collard greens (_Brassica oleracea_ var. _acephala_), and other vegetables is meager, but supplies an important addition to the usual meal of manioc flour, rice and, when available, beans.

Commercial horticulture must combat plagues of insects, slugs, rats, and other pests, as well as disease-causing fungi, bacteria, and viruses. One successful system for growing tomatoes is employed commercially by a Seventh Day Adventist agricultural school 92 km from Manaus. Open-sided greenhouses with polyethylene roofs shield the crop from rain, thus avoiding removal of heavy doses of pesticides and fungicides from the leaves and fruits. The greenhouses also buffer the crop from rapid changes in temperature and humidity, believed to be the cause of tomatoes grown in the open having a tendency to split before ripening. Soil in wooden troughs containing the plants is sterilized prior to planting, and irrigation is done by periodic flooding of small ditches in the soil in each trough, to prevent loss of protective chemicals and to avoid creating disease-favoring humid conditions for the aerial portion of the plant. Division of the plantation into separate greenhouses also helps prevent the spread of diseases, as do elaborate procedures for disinfecting and controlling use of garden tools. Large quantities of reasonably well-qualified but low-paid labor from students is required.

Another commercial scale horticultural enterprise near Manaus is run by the municipal government. Settlers have been assigned individual small plots in Iranduba, on land fertilized with processed garbage from the city of Manaus. The scheme provides for irrigation, transportation, supply of chemical inputs, agronomic advice, marketing arrangements, and housing in a planned village. Tomatoes (*Lycopersicon esculentum*), cabbage (*Brassica oleracea* var. *capitata*), green peppers (*Capsicum annum*), and other vegetables are grown for marketing at a cycle of weekly markets in different parts of the city of Manaus. Yields and product quality are somewhat lower than under the Seventh Day Adventist system, but the product forms an important addition to the city's food supply.

The many Japanese immigrants engaged in raising vegetables near Amazonian cities do so with intensive application of fertilizers and manure, especially chicken manure often obtained from poultry raising ventures on the same farms. Chickens are raised on a diet of pre-mixed food grains imported from southern Brazil. Land is often tilled with micro-tractors or hand-pushed motorized tillers. Pesticide use is extremely heavy. Japanese embassy staff offer technical support, conducting surveys and giving farmers Japanese language computer outputs with individualized reports and advice. More important to the success of these farmers is the close-knit network of information exchange and mutual assistance offered by the Japanese immigrant community itself. Cultural emphasis on thrift, sober planning, and hard work have also been essential to the accumulation of capital and information needed to pursue this form of agriculture.

21.12 *Várzea*: Amazonian Floodplains

21.121 Annual Crops of Smallholders

In the past, Amazonian indigenous populations made extensive use of the Amazon's *várzea*, or floodplain, during the period of each year when river water level is low (Lathrap, 1970; Meggers, 1971; Denevan, 1966; Gross, 1975; Roosevelt, 1980). Várzeas have been used to a far lesser extent by *caboclos* occupying these areas since most riverside Amerindian populations disappeared in the years immediately following European contact. *Várzea* soils are more fertile than almost all *terra firme* soils, but the most important difference is not that *várzea* yields are higher when a crop is harvested. Far more significant is the possibility *várzea* offers for a sustainable yield without the lengthy fallows (or heavy fertilization) required to make annual crops produce for more than one or two years on *terra firme*. Annual flooding in the *várzea* deposits a fresh layer of fertile silt and leaves the land virtually free of weeds and pests at least once per year, at the moment when the water recedes: "the river is the plow."

Várzea areas can be subdivided into horizontal zones such as mud bars, levees, backswamps, and beaches (Denevan, 1982). Only the levees are unflooded year round. Soils, crops, and timing of agricultural activities differ for each zone. Bergman (1980) describes a typical crop zonation from a Shipibo village on the

Ucayali River in Peru: rice and beans on the beaches; maize, sugar cane, and jute on the levee foreslope; bananas, manioc, and fruit trees on the levee tops; jute and sugar cane on the levee back slopes; and beans and pasture in the backswamps farthest from the river. *Caboclo* exploitation of *várzea* in the Guamá River near Belém has a similar zonation of crops; the addition of on associated zone with supplementary plantings of perennial crops on nearby *terra firme* has been suggested as making the pattern a model for Amazonian settlements (Camargo, 1958).

The timing of the rise and fall of water levels dominates every aspect of *várzea* agriculture. Years when the water level begins to rise earlier than normal, or rises to higher than normal flood levels, can be disastrous to *várzea* cultivators. These uncertainties have been hypothesized to explain a wide array of cultural adaptations of indigenous *várzea* groups, as well as limits to *várzea* as a base for "cultural development" (Meggers, 1971: 149), although not all anthropologists agree with this interpretation (Roosevelt, 1980: 23).

The continuing deforestation of Amazonia can be expected to result in higher and less regular flooding. Indeed, some evidence exists that such changes may have already begun in the upper Amazon (Gentry and Lopez-Parodi, 1980, but see Nordin and Meade, 1982; Gentry and Lopez-Parodi, 1982). Among many negative effects, these changes will make cultivation of annual crops in the Amazonian *várzea* increasingly more difficult.

21.122 Mechanized Rice

Mechanized cultivation of irrigated rice is being pursued commercially in one location in *várzea* of the lower Amazon as a part of the Jari project (Fearnside and Rankin, 1980, 1982, 1985). The potential, or lack of potential, of this form of capital intensive high yield agriculture is a question with importance far greater than the relatively insignificant area of the present 3062 ha under cultivation, or the 14,165 ha to which the plantation is eventually expected to expand if probable ownership changes do not alter the previous planning. The rice project is not included in U.S. shipping magnate D.K. Ludwig's sale of silvicultural and mining operations at Jari to a group of Brazilian firms (*Veja*, 27 January 1982: 92).

Rice is currently grown on a rolling schedule, with different fields being planted and harvested at different times. Any given field produces two crops per year, although experiments underway may eventually permit about 30% of a full crop's yield to be harvested from a ratoon or stubble crop during the interval between the two crops planted from seed. Yields in most years have been on the order of eight tons of rice (with husks) per hectare per year. A drop to around seven tons/ha/year in 1979 caused great concern among the technical staff and company officials.

Several drops in yield have occurred and for the most part been countered by management changes. A sulfur deficiency was discovered (Wang *et al*., 1976) and corrected by changing the nitrogen fertilizer used from urea to ammonium sulfate. Iron toxicity contributed to a sharp fall in yields in 1979 to about seven tons/ha/year. Various insect pests, especially army worms (*Spodoptera frugiperda*) and stink bugs (*Oebalus poecilus*), are also believed to have contributed to the drop. When completed, an improved canal system and regrading of fields are expected to allow the fine-water management needed to minimize these problems. Rice variety changes, increased pesticide use, and greater attention to a host of management details are hoped to reverse the decline. In the future, yields are expected to improve with the construction of a canal to allow changing the irrigation source from the Araiolôs River to the less acid and more nutrient-rich Amazon. A variety of insect pests, mites (Acari), nematodes, weeds, and fungal diseases extract some toll on rice production. Perhaps more important are the diseases, weeds, and pests that have not yet arrived at Jari's rice project in São Raimundo. The rice plantation has been enjoying the honeymoon from coevolved pest and disease organisms that has been a repeating pattern for newly introduced species throughout the world (see Janzen, 1973; Elton, 1958). Neighboring countries have biological problems in irrigated rice which can eventually be expected to reach Jari, such as "hoja blanca" virus in Venezuela and two major graminaceous weeds in Surinam (*Leptochloa scabea* and *Ischaemun rugosum*). Jari was able to use the IR-22 rice variety as its mainstay for six years, even though this high-yielding variety is highly susceptible to rice blast (*Piricularia oryzae*). When the fungus arrived, IR-22 was already being phased out in favor of more resistent varieties. The most effective response to disease problems is generally a switch to more resistant varieties, chemical treatments representing only a temporary measure. Managing large monocultures is a constant race, pitting human efforts to breed, identify and propagate appropriate varieties against the ever-changing array of biological problems. The outcome of this contest is never guaranteed.

Irrigated rice of the type planted at Jari fails to take advantage of the Amazon *várzea's* major advantage: the annual renewal of soil fertility by flooding and siltation. Instead, the fields are isolated from the river's water level fluctuations by polder--a dike surrounding the fields, into which water must be pumped both in and out. The soil enclosed in the polder has essentially been being mined for nutrients in these early years since many nutrients have been removed in the crop without being fully replaced through fertilization, in the same way that the mining of ore deposits removes the resource without replacement. Compensating increases in fertilizer-supplied inputs can restore the balance, but at an increased cost.

The dependence of mechanized agriculture on nonrenewable resources may prove to be a long-term problem making it less attractive in the future.

21.123 Horticulture

Várzea areas near urban markets are increasingly being cultivated for vegetable production. The farmers are usually from *caboclo* backgrounds, with many changes in their agricultural methods in comparison with the traditional largely subsistence agriculture of the scattered *caboclo* residents of more remote areas. Many have come to these areas from other parts of the region. Government extension agencies provide advice to producers within ready boating distance of the agents' posts. The agencies also help in obtaining seeds, insecticides, sprayers, and other necessities. Impact of extension agencies appears to be much greater with introduction of this novel and demonstrably profitable technology than are similar efforts with subsistence crops more familiar to the farmers. Horticulture among these well-located *várzea* residents is generally profitable and is expanding, although many failed attempts at individual plantings can also be seen. Defending these crops against diseases and pests requires a large store of knowledge to be able to recognize and treat a given problem as soon as it arises, as well as stocks of chemical remedies readily at hand.

21.124 Fiber Crops

Jute (*Corchorus* spp.) and malva (*Malva rotundifolia*) are common *várzea* crops among small farmers. Jute was first introduced to the region in 1934 by Japanese immigrants (Soares and Libonati, 1966), although most jute farmers today are not of Japanese origin. Jute is most prominent in the várzeas of the middle Amazon, while malva is most common in the tidally influenced várzeas in the Zona Bragantina of Pará, as well as in the floodplains in the lower portions of the Solimões (Upper Amazon) River. Malva is sometimes also planted on *terra firme*, but it exhausts the soil quickly and does better in the fertile floodplain. Jute and malva can be processed into bales of saleable fibers by hand labor, can be stored and transported without spoilage, and can be sold for cash.

21.125 Cattle and Water Buffalo

Zebu cattle (*Bos indicus*) are grazed on natural *várzea* grasslands in many parts of the Brazilian Amazon, especially in the lower part of the Rio Solimões (Upper Amazon) and in the várzeas near the Amazon's mouth. Productivity is quite low in part due to poor quality fodder, but more importantly due to stress in months when water level is high and grazing land nonexistent. During this critical period the cattle are herded together either on isolated hilltops still above water, on raised wooden platforms (*marombas*), or on floating barges. The cattle tenders bring as much fodder as possible, carrying by boat or towing loads of macrophytes cut from the river's "floating meadows," from semisubmerged grasses along the river margins, or from *terra firme*. Cattle become emaciated and frequently die during the flood period. Cattle tenders try to sell as many animals as is practical as the water level rises in order to keep their herds at a manageable size during the flooded period. When water levels fall again, there is a superabundance of pasture area.

Water buffalo (_Bubalus bubalis_) were first introduced to Brazil from Asia in 1895, and since the early 1960s the population of these animals has been exploding at an estimated 10% per year (do Nascimento, 1979). The _várzeas_ of the enormous Ilha do Marajo at the mouth of the Amazon have been the focus of most water buffalo ranching. Water buffalos are better adapted than Zebu cattle to the wet conditions of the _várzea_, being well equipped for swimming and wading during the flood season. Much of the Marajo herd is raised for meat, but Brazilian government agricultural research efforts both in Pará and Amazonas states are most enthusiastic about water buffalo as a source of dairy products such as milk, butter, and cheese. Water buffalo milk is richer and produced in larger quantities per animal than is cows' milk, and each liter yields 50% more cheese or 43% more butter (do Nascimento, 1979). It is well to note, however, that water buffalo in commercial operations, such as those in much of the Jari Project's _várzea_ area, are noticeably less fat and healthy than are those in government experiments. Nevertheless, replacing the Zebu cattle presently grazed on _várzea_ grasslands with the clearly superior water buffalo could significantly increase the production of dairy products in the region.

21.2 ALTERNATIVE MANAGEMENT: IMPEDIMENTS AND PROSPECTS

21.21 _Fertilizers and Continuous Cultivation_

Agronomists working at Yurimaguas, near Pucalpa in Amazonian Peru, have directed their efforts towards devising a system that would permit continuous cultivation of annual crops by small farmers in _terra firme_ (North Carolina State University Soil Science Department, 1975, 1976, 1978, 1980). The system developed has produced two crops per year from the same field over a ten year period using a rotation of upland rice, maize, and soybeans (Nicholaides _et al_., 1982).

Although the Yurimaguas experimenters are enthusiastic about the system's potential for implementation by small farmers over vast expanses of _terra firme_ (Sánchez, 1977; Nicholaides _et al_., 1982; Sánchez _et al_., 1982; Valverde and Bandy, 1982), several drawbacks may make any such expansion more difficult and less rewarding than imagined. The system requires continuous inputs of fertilizers. Although present prices for these inputs in Peru are apparently low enough to be justified by the yields so far, the long-term costs and availabilities of these are a major cloud on the horizon for fertilizer-based agriculture worldwide. Projections of global trends from 1976 indicate potash being exhausted by the year 2062 and minable phosphate rock by the year 2027 (United States, Council on Environmental Quality and

Department of State, 1980; see also Institute of Ecology, 1972). Although the trends of the recent past cannot continue through all of this period due to other restraints on population and cultivated area (Wells, 1976), unprecedented price increases can be expected as supplies of these resources, non-renewable on a human time scale, dwindle. Nitrogen, generally the major nutrient deficiency for tropical agriculture (Webster and Wilson, 1980: 220), is an element whose supply depends heavily on the world's vanishing reserves of fossil fuels if plant requirements are to be met through fertilization.

A major practical problem in implementing the "Yurimaguas Technology" on a wide scale in Amazonia is the need for a continuous input of technical information. As soil nutrients are exhausted in any given field, the balance of nutrients added must be continuously changed. After eight years, the experimental plantings require supply of all essential elements with the exception of iron and chloride (Nicholaides et al., 1982). Soil samples must be taken every year from every field, chemical analyses performed, and the results interpreted and explained to the farmer in terms of fertilizer requirements. Even the staff of qualified agronomists at Yurimaguas have experienced sharp yield declines in years when nutrient balances were not spotted and remedied in time. The prospect is slight of semiliterate farmers doing as well when dependent on a frail chain of poorly qualified extension agents as their link to information sources on constantly changing input requirements. The present infrastructure of soil analysis laboratories in the Amazon has difficulties in processing a few thousand samples for research purposes; the barriers to expanding this infrastructure sufficiently to cope with the millions of samples needed to apply the Yurimaguas system to a significant portion of Amazonia would be tremendous in the foreseeable future.

In the long term, agronomic problems other the nutrient deficiencies encountered in the present scheme are likely to become increasingly difficult to solve. Soil compaction is one such problem (Cunningham, 1963; Baena and Dutra, 1979), as is the decline in organic matter indicated in the Yurimaguas data (Nicholaides et al., 1982). Erosion, apparently not a significant problem on the "flat Ultisol" of the Yurimaguas station, is likely to be a major problem if extended to much of Amazonia where many areas of intensive settlement are far from flat. The experimenters point out that the system has "low erosion hazard except during periods of intense rainfall" (Nicholaides et al., 1982), but just such periods of intense rainfall are characteristic of Amazonia.

Profitability of the system, even in the short term, may well be less than the Yurimaguas results would indicate. The substantial costs of supplying the technical information required to maintain the system, including performing soil analyses and communicating their results and significance, are not included in calculations of the system's profitability. Also, both the experiment station staff and the 11 farmers described as "respected farm leaders" who have tried the system can be expected to obtain better results than the masses of less well qualified farmers that would use the system if expanded on a large scale.

The problem of devising annual cropping systems for *terra firme* is an important one deserving intense research. It is essential to remember that a practical and sustainable system of this type has yet to be devised. One should be wary of placing faith in the future development of such technology to save tropical peoples from the consequences of unwise forest clearing and land use decisions being made today.

21.22 Diversity and Sustainable Management

Most of the history of human agricultural development has been one of finding ways to reverse or arrest the process of ecological succession (E.P. Odum, 1971). "Climax" communities, usually diverse forest, are replaced with earlier successional stages such as low-diversity stands of herbaceous crop plants or pasture grasses. Earlier successional stages offer the advantages of quicker yields, of higher net primary productivity, and of a greater share of the plant's energy budget being allocated to producing the seeds and fruits that humans are interested in harvesting. An additional advantage of the simplified crop stands is the ease of applying energy supplements, such as fossil fuel inputs for mechanization. This strategy can prove a cruel illusion. In Howard Odum's (1971: 115-16) classic statement: "A whole generation of citizens thought that the carrying capacity of the earth was proportional to the amount of land under cultivation and that higher efficiencies in using the energy of the sun had arrived. This is a sad hoax, for industrial man no longer eats potatoes made from solar energy; now he eats potatoes made partly of oil."

Such simplification has many other disadvantages (see Dickenson, 1972; Janzen, 1970b, 1973; Fearnside, 1983b). The direct contribution of the farmer's production to his own diet is reduced, obligating him to rely on expensive, uncertain, and often lower quality products purchased through middlemen from other distant monocultures. The single stratum of the monoculture has less complete utilization of the space and incoming sunlight, as bare earth is often unoccupied by photosynthetic material. Land is also left bare between crops. The unshaded soil leads to greater weed competition and labor (or fossil fuel) requirements to achieve control, as well as to soil erosion. Open nutrient cycles allow greater losses of soil nutrients, in contrast to the relative effectiveness in minimizing leaching afforded by the deep roots and well-developed cycling of trees and their litter communities. Concentration on a single crop exposes farmers to international market fluctuations beyond their control, whereas having a variety of agricultural products gives them the insurance of income from the other crop species should the market plummet for any particular species. The same disadvantage applies to the farmer's hardship when faced with crop losses from bad weather, pests, or diseases. The chance of pest and disease outbreaks is itself increased by removal of both natural chemical defenses and the protection afforded by spatial heterogeneity. Labor requirements for maintaining monocultures are usually far more seasonal than those for diversified plantings, thus making less use of family labor and fostering less socially attractive systems of migrant labor. The concentration of management and marketing decisions in distant elites can also prove a profound social disadvantage, as sugar cane growers on the Transamazon Highway have discovered during a decade of worsening relations with a series of three successive mill management concerns. Frequent disagreements over acceptability, price, and payment schedules for cane, usually settled to the disadvantage of the producers, have led to a climate of mistrust and violence in the cane-producing area.

Although as yet only in its infancy as a field of research, attempts are being made to develop sustainable and diverse crop associations for tropical areas (e.g. Bishop, 1978, 1979, 1982 in Ecuador; Gleissman _et al_., 1978, 1981; Gleissman, 1979 and Alarcón, 1979 in Mexico; May and Momal, 1981 in Indonesia). In the Brazil Amazon, systems are under development by the Brazilian Enterprise for Research in Agriculture and Cattle Ranching: EMBRAPA (de Andrade, 1979), the Commission for Promotion of Cacao Growing: CEPLAC (Bazán _et al_., 1973), and the National Institute for Research in the Amazon: INPA (Arkcoll, 1979). Many are based on the modification of traditional systems which have had the benefit of centuries of trial and error by indigenous populations (see Clarke, 1976, 1978). Better designs of polycultural systems are needed (Kass, 1978), especially including effects which reduce insect attacks through increased diversity (Root and Tahvanainen, 1972; Risch, 1980). Theoretical approaches can help save time and resources needed for trial-and-error testing of possible intercropping combinations (Vandermeer, 1981). Increased agricultural intensity and decreased diversity (Pool, 1972) and decreased interfield spacing (Janzen, 1972) also increase vulnerability to insect attack. The presence (Popenoe, 1964; Janzen, 1972: 5) or absence (Price, 1976 cited by Gliessman, 1979; Janzen, 1974) of nearby woody vegetation can increase agricultural pest problems depending on their role as reservoirs for populations of insect pests or biological control agents.

Some attempts have been made at modifying shifting cultivation to produce higher returns. Suggestions include eliminating some of the fallow period (Guillemin, 1956; Andreae, 1974; Ahn, 1979). The "corridor system", begun by Belgian administrators in Zaire before independence (Martin, 1956; Ruthenberg, 1971) has not been tried elsewhere or continued after the end of Belgian rule in its original site. Unfortunate rigidity in the planning of the scheme brought on many problems avoided by the flexibility in locating and timing cropping that is the hallmark of traditional systems. Social pressures also led to overly shortened fallow periods, the Achilles' heel of shifting cultivation in many locations (e.g. Vermeer, 1970 in Nigeria; Freeman, 1955 in Sarawak, see also Nye and Greenland, 1960; Watters, 1971; UNESCO, 1978). Adding carefully chosen "modern" inputs, such as herbicides, has also been suggested as a way of "bringing the green revolution to the shifting cultivator" (Greenland, 1975).

Interest has been high in variations of the taungya system, or agri-silviculture (King, 1968; Mongi and Huxley, 1979; Hecht, 1982a; Dubois, 1979). Taungya, a system with a long history of application in Southeast Asia, involves planting annual crops together with silvicultural tree species such as teak (*Tectonia grandis*). The trees take the place of growth in the shifting cultivation cycle, giving a valuable yield at the end of each cycle although they do not supply the ash of burned secondary vagetation as in unmodified shifting cultivation. The necessity of clearing forest for taungya has environmental costs which limit the extent to which this or other systems requiring clearcutting should be promoted, but advantages exist for employing agri-silvicultural systems on land already cleared for low productivity uses such as pasture (see Fearnside, 1983). Taungya and systems like it are far from ideal: serious erosion can easily result over the long term (UNESCO; 1978: 464; see Bell, 1973 on erosion under teak plantations in Trinidad). One of the important features of taungya for supporting human populations is its appropriateness for use by small farmers. Farm size is itself one of the major determinants of land use choices, and the ability of agriculture to support human populations.

21.2.3 *Farm Size and Agricultural Populations*

The question of land tenure distribution lies at the root of any discussion of agricultural land use and production in Amazonia. Land tenure in Brazil has traditionally been extremely skewed, with most of the land in a small number of large properties or *latifundios*. In 1975, 0.8% of Brazil's "rural establishments" were over 1000 ha in area and represented 43% of the land, while 52% were under 10 ha representing only 3% of the land (Brazil, IBGE, 1980: 314-16). Regional differences in land quality make the concentration even greater in terms of its ability to support agriculture: the National Institute for Colonization and Agrarian Reform (INCRA) cadastre for 1972 revealed that 72% of all farms were *minifundios*, or establishments with less than one "rural module" of land, a unit unique to each region, officially defined as the size required to absorb the year-round labor of the farmer and his family, while large enough to permit "social and economic progress of the domestic unit" (with supplementary hired labor) (da Silva, 1978, cited by Wood and Wilson, 1982). The degree of land concentration varies between the regions of Brazil, being highest in the Northeast and in Amazonia. Within Amazonia great variation exists: properties over 1000 ha in area account for 85% of the total farm area of Mato Grosso, but only 33% in Rondônia (Mahar, 1982). Within Rondônia, the state where the most government colonization projects have been located, land concentration varies from areas of 100 ha colonist lots in the older settlement projects (50 ha in the ones now being implemented), to areas where 3000 ha ranches area auctioned from public lands, to areas of much larger holdings. The Gini coefficient, an index of land tenure concentration, has been increasing in Brazil, rising from 0.842 in the 1950 - 1960 period to 0.844 in 1970 and 0.855 in 1975 (Wood and Wilson, 1982). High indices, of around 0.86, dominate in ranching areas in the Amazonian parts of Goiás and Maranhão, while low indices of around 0.28 are typical of old areas of small farmer settlement in the Zona Bragantina near Belém (Hébette, and Acevedo, 1979: 117-21). Forms of agriculture employed vary with the size of the holdings. Large land owners are more likely to engage in ranching, while smallholders are more likely to plant annual crops.

As a general rule, small properties do not produce consistently more or less per cultivated hectare than large properties on land of the same quality planted with the same type of crop, but produce far more per unit of total area, according to a World Bank study of six tropical countries including Brazil (Berry and Cline, 1976, cited by Eckholm, 1979: 17-18). The smaller units produce more because of cultivating a greater fraction of the land area, as well as by more intensive techniques such as double cropping in some areas. In northeast Brazil, where land tenure concentration is notorious, the World Bank study argues that redistribution of the land small holdings would give an 80% increase in agricultural production. A similar situation appears to be developing in Amazonia, where "replication" of northeast Brazilian land tenure arrangements has been noted by many social scientists (e.g. Ianni, 1979a,b). The process is only one of several in changing land tenure patterns in Amazonia, others including the breakup of large claims of rubber "barons" (see Cardoso and Muller 1978: 74-76), a statistic largely an artifact of boundary readjustments and the subdivision of farmers' small plots into ever smaller *minifúndios* as the land is divided through inheritance (Hébette and Acevedo, 1979; Martine, 1980). Unevenness of land tenure can be expected to increase in much of the region once the first wave of pioneers has passed. Land tenure concentration occurs through the takeover of squatters' claims by large ranches, as occurred along the Belém-Brasília Highway (Valverde and Dias, 1967; Mahar, 1979: 78), or through a process that does not appear in government statistics: the purchase in the names of wives, children, or other relatives of a number of adjoining or nearby properties by wealthier newcomers as in colonization areas like those on the Transamazon Highway. Concentrated land tenure results in both lower overall production and the favoring of crops not eaten locally, in addition to a greatly reduced contribution of what is produced to supporting the human population (Durham, 1979 for an excellent example from Central America).

21.3 LIMITS TO AGRICULTURE: HUMAN CARRYING CAPACITY

Human carrying capacity refers to the density of a people that can be supported indefinitely in an area at an adequate standard of living without environmental degradation, given appropriate assumptions concerning productive technology, consumptive habits, and criteria for defining an adequate standard of living and acceptable environmental degradation. Criteria can include adequate security of a given family meeting the standards in any year. Since exceeding carrying capacity leads to failure to maintain adequate levels of consumption and environmental quality, achieving a balance at a density below carrying capacity is of supreme importance for the long-term future of the region's inhabitants. Intense flows of migrants are currently entering the Amazon region especially in Rondônia. The population of Rondônia rocketed by 331% from 116,620 in 1970 to 503,125 at the 1980 census (Brazil, IBGE, 1981: 5). The northern region (Rondônia, Acre, Amazonas, Roraima, Pará, and Amapá) grew by 65% while the country as a whole grew by 28% during the same period. The rapid increase in population in areas like Rondônia, combined with the exclusion of settlers from much of the land area by owners and other claimants already there, mean that population densities can be expected to quickly exceed carrying capacity in settled areas.

The individual agricultural systems discussed in previous sections of this chapter all have finite limits, as does agriculture everywhere. That the limits are often lower than recent arrivals to the region or overly enthusiastic government planners envision is far less important than the fact that limits exist. Amazonia is a land of many illusions, both of infinite area and of infinite agricultural "potential." These illusions lead governments to propose, and the public to accept, roadbuilding and agricultural colonization as solutions to such national problems as poverty and social unrest due to overpopulation, highly unequal land tenure distribution, and rural unemployment precipitated by coffee-killing frosts and changes in agricultural patterns to mechanized agribusinesses.

The combination of overpopulation and skewed land tenure had been noted as a prime motive for the migrations to colonization areas in the Amazonian portions of Bolivia (Nelson, 1973), Peru (Aramburu, 1982), Ecuador (Uquillas, 1982), and Colombia (Carrizosa U., 1982), in addition to alleviating social tensions in Northeast Brazil in prompting Brazil's National Integration Program for establishing the Transamazon Highway colonization schemes (Kleinpenning, 1975, 1979; Ianni, 1979). Despite the fanfare often accompanying the launching of colonization initiatives, their role in absorbing displaced populations has been minimal, being dwarfed by migration to urban slums. In Brazil, the National Integration Program absorbed only 7,839 families, or 0.3% of the rural exodus during the 1970s (assuming that the virtually paralyzed program absorbed no more net immigration after 1977), while the 24,242 families settled in the entire Northern Region during the decade represent less than one percent of the rural exodus during the period (Wood and Wilson, 1982).

The notion that agricultural development in Amazonia is capable of providing long-term solutions, the "Solution for 2001" as the Transamazon Highway was enthusiastically christened (Tamer, 1970), has been doomed from the start. If one were to make the improbable assumption that all of Brazil's Legal Amazonia were distributed as 100 ha (1 km^2) lots in the manner done in colonization areas along the Transamazon Highway, only five million families, or about 25 million people, would fill the entire region. This represents less than eight years of growth for Brazil's 119 million 1980 population increasing at the current 2.4% per year.

In discussing the merits of different forms of agricultural development, one must be very clear about what the objectives of development are. Conflicting objectives is the most common cause of divergent views on what forms agriculture are most appropriate. Many proposals for Amazonia are directed at solving problems outside the Amazon Region, such as alleviating rural poverty in migrant source areas, urban squalor aggravated by the flow of new arrivals in cities like São Paulo, providing products for markets in other parts of the country, producing export earnings to lessen national debts, and providing investment opportunities for speculators and businessmen from more capital-rich regions. Farming the Amazon is a difficult and poorly-understood challenge, and supplying the needs of the Amazon's residents alone is not an easy task if it is to be done on a sustainable basis. The suggestion has been made that Brazil's development effort be directed to other regions, such as the central Brazilian scrubland or _cerrado_ (Goodland _et al_., 1978; Goodland, 1980). At the least, I would suggest, the portion of the agricultural development effort in Amazonia motivated by problems outside the region should be applied instead to addressing the problems directly in those regions.

Exponentially growing national problems cannot be solved for long by exploiting a finite resource such as Amazonia. Even problems which do not grow can only be solved if the agricultural systems employed are sustainable. Recognizing the limits of agriculture is the first and most essential step in redirecting development policies as a whole such that the human population can be maintained at an adequate standard of living on a sustainable basis. Estimating human carrying capacity is an essential element in any such redirection (Fearnside, 1979c, 1983d). Devising sustainable agroecosystems is also essential, and is a task which will require a sharp reorientation of the present emphasis in agronomic research priorities. Presently, agricultural research usually aims at obtaining higher and higher crop yields, or, more accurately, at producing higher monetary returns on money invested in agriculture. Producing the greatest profits is not necessarily consistent with sustaining production (Clark, 1973, 1976; Fearnside, 1979b). Researchers should strive to produce sustainable systems, even if yields and profits are lower. Agroecosystems also need to serve the needs of family consumption, producing the diverse array of products required for local consumption, and doing so with a premium on the security of obtaining an adequate harvest. Technologies that increase yields at the cost of security may make sense to government planners who see only aggregate statistics, or to wealthy investors who can afford to gamble on risky ventures to maximize "expected monetary value" (see Raiffa, 1970), but such risky agricultural choices are far less wise for the small farmer who depends on the yield to feed his family from year to year. When a crop fails on an agricultural experiment station, the agronomists in charge receive their salaries at the end of the month as usual, but when a small farmer's crop fails his family goes hungry. The difference in perspective needs to be incorporated into decisions about research priorities and the promotion of new technologies.

The available development choices for Amazonia, both agricultural and non-agricultural, have widely differing prospects in terms of agronomic and social sustainability, competitiveness without subsidies, self-sufficiency, fulfillment of social goals, retention of development options, effects on other resources, and macro-ecological effects (Fearnside, 1983b). What is needed is a patchwork of areas in different land uses, fulfilling different needs and restricted by different standards for environmental quality (cf. Margalef, 1968; E.P. Odum, 1969; Eden, 1978; Fearnside, 1979b). Agricultural development must be pursued in the context of an interlocking system of components, no one of which can be changed without affecting the others, and no one of which alone can be expected to achieve goals such as sustaining an adequate standard of living for the region's population. Agro-ecosystems must be sustainable, concentration of land holdings must be limited, total consumption must be limited, and the population must be maintained below carrying capacity.

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