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AGROFORESTRY IN THE AMAZON BASIN: PRACTICE, THEORY AND LIMITS OF A PROMISING LAND USE

Susanna Hecht
(Universidade de California)

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AGROFORESTRY IN THE AMAZON BASIN:

Practice, Theory and Limits of a Promising Land Use

S.B. HECHT

General Introduction

This paper explores the potentials for agroforestry in the Amazon Basin. Agroforestry systems are "sustainable land management systems that combine the production of crops (including tree crops) and forest plants simultaneously or sequentially on the same unit of land, applying management practices that are compatible with the cultural practices of the local population" (King and Chandler 1978). Crops here can denote animals as well as vegetal products of all types. "Agroforestry" is a term that covers an enormous range of land uses at all scales of tenure and investment, ranging from subsistence to plantation farming, and from dozens of species (Conklin 1954) to only two or three. Agroforestry usually involves multiple canopies, either in space or time, and more than one harvestable stratum.

Agroforestry has received a great deal of attention in recent years. In 1979, three major conferences dealing exclusively with agroforestry were held, one sponsored by CATIE in Costa Rica (de las Salas, 1979), one by ICRAF in Kenya (Mongi and Huxley, 1979), and another by ICRAF and DSE, ~~also~~ in Nigeria (Chandler and Spurgeon, 1979). Many national agricultural research programs are beginning to include agroforestry experiments as indicated by the country as well as research reports in this volume. Although this level of interest is new, the farming systems themselves are not. Agroforestry, particularly as related to shifting cultivation, is the foundation of agriculture throughout the lowland tropics, and has been the basis of several market and cash crops industries, including that of Nigerian oil palm (Obi and Tuley 1973), and the Asian cash crops cited in Kundstater et al (1978). King (1979a,b) also points out that some of the world's most valuable tropical hardwood plantations were developed using shifting cultivation and agroforestry techniques. While not all shifting cultivation is agroforestry, many shifting agriculturalists purposely plant or protect woody perennials for subsequent harvests. Species commonly used in Amazonia include Inga (*Inga edulis*) used for fruit and fire wood, Papaya (*Carica papaya*), genipa (*Genipapo americana*), and peach palm (*Guilielma gasipaes*) ( ). These types of shifting cultivation systems have served as the prototype for many agroforestry systems that incorporate successional features (Hart 1980, Dubois, 1979 Bishop 1978). The presence of shifting agriculture throughout the tropics suggests that many attributes of such systems can be modified and intregrated into commercial agricultures.

Forests and Agroforestry

In the rush to colonize the Amazon, the importance of forest resources (including forest-mediated benefits such as flood control: Gentry and Parodi 1980) to Amazonian economies has often been overlooked, both in terms of value and labor absorption (Godfrey 1979, Guess 1979). For example, the Banco do Brasil reported that in 1979 the State of Para exports were valued at 234 million dollars. Wood products generated some $70 million. Black pepper accounted for $43 million. Brazil nuts generated $32 million, while palm hearts provided some 15 million dollars

(Banco do Brasil, reported in O Liberal, July 28, 1980). Over half of Para's export dollars were gained from three strictly extractive products: wood, nuts and palm hearts. Table 1 gives an idea of the production and values of forest products. Table 2 indicates numerous latexes, oils, resins and medicinals, many native to the Amazon, that could be introduced into agro-forestry systems.

Estimates of the potentially exploitable wood volume in Amazonia range from 60 to 120 cubic meters/ha on the uplands (terre firme) and from 30 to 90 cubic meters/ha on the floodplains (Pandolfo, 1978). While eight species comprise most of the timber trade (Palmer, 1977), over two hundred Amazon species have been studied in various Brasilian, British and American laboratories, and the properties of a wide variety of woods are relatively well known (Caravajal, 1978). The silvics of several species are being studied (SUDAM, 1979), including many for which there already exist comparative data from other tropical Latin American sites (e.g. Cedrela odorata, Cordia alliodora).

In spite of the large forestry potential, at the moment only three woods dominate the trade: "Ucuuba" (various Virola species), mahogany (Swietenia-macrophylla), and "Andiroba" (assorted Carapa species). These species are often found in relatively uniform stands, and probably could be managed for sustained yield. Unfortunately, harvesting has not been sufficiently monitored or controlled, allowing the Swietenia and Virola stocks to be over-exploited (Fox, 1976; Rodriguez, 1976; Godfrey, 1979). Amazon forestry has been described by Fox (1978) as a "huge controlled mess." Detailed analyses of the area's forestry industry are beyond the scope of this paper, but are discussed in Muthoo et al, 1977; MA/INDF/COPLAN (1977); FAO 1976; Bruce 1976, Glerum and Smit, 1960, 1962; PRODEPEF, 1975; Pandolfo, 1978, Palmer, 1977. One possible means for rationalizing forest management could be the integration of forest plantations with subsistence agriculture, one of the oldest and most developed techniques of agroforestry.

Deforestation

International concern about tropical deforestation has sparked polemics on both sides of the issue, prompting the US National Academy of Sciences to commission a report (Myers, 1980). This document was subsequently critiqued by Lugo and Brown (1981) who argued that its conclusions overstated the rate and degree of tropical forest alteration. There is no consensus yet on this question, but various estimates of the rates and magnitudes of deforestation in the Amazon countries are given in Table 3. While many of these figures are approximate, it is not unlikely that over 15 million ha. of the Amazon Basin have been cleared within the last decade. Detailed information is available for the Brasilian Amazon based on ERTS satellite data and presented in Table 4. Between 1976 and 1978 some 2 million ha. of forest were cleared in the Brazilian Amazon alone. If current clearing rates are extrapolated (ignoring the tendency of the rates to increase in many of the areas) one may estimate that over 11 million ha. of the Brazilian Amazon have been cleared, most of it within the last ten years. In zones where cutting has been particularly pronounced, Tardin et al (1979) showed that almost one third of the forests have been replaced by other land uses, particularly ranching.

The debate over the magnitude of clearing has been colored by several allied concerns. First, much of the wood cut was simply burned. Though infrastructure and sufficient price incentives for forest use were lacking, the waste of millions of cubic meters of timber by burning cannot be simply dismissed, especially since many very valuable forests have often been replaced by unstable land uses. This has occurred in the state of Acre where natural rubber forests were cleared for pasture and in Para, where grasslands supplanted mahogany and Brasil nut forests (Godfrey, 1979; Bunker, 1980). The collapse of some agricultural systems and the subsequent land abandonment after forest removal, as well as the speculative nature of much of the land development process, argues for a re-examination of clearing, and the land uses that supercede forests. It is environmentally destructive land use, rather than deforestation per se, that is at issue.

Agroforestry is no panacea, but it is widely and successfully practiced throughout the Basin and has many features that moderate some of the environmental stress placed on agricultural systems in the Amazon. Agroforestry systems can maintain forest resources while increasing food production, making the expansion of agriculture into forest economies an integrative rather than a substitive process.

AGROFORESTRY SYSTEMS IN THE AMAZON

Introduction

Amazonian land uses are outlined in Figure 1. The forests are the foundation of virtually all the production systems, providing extractive products, fallows, and ash. Land uses divide into those that supply industrial raw materials and those that supply foods. As enterprises become more capitalized, plant species diversity tends to be reduced. The size of land holdings tends increases where cash crops predominate.(IBGE 1975) Recently implanted cattle operations are essentially a corporate form, and occupy large land areas, hence they are included in the more capitalized "plantation" end of the spectrum.

As Okigbo and Greenland (1976) indicate, mechanization and the use of agricultural chemicals of various kinds have been essential to the replacement of multicrop agricultural systems by monocultures, but high energy and chemical additions are often uneconomic in the Amazon. When agricultural inputs of various kinds are lacking or erratically available and expensive, and where labor (in commercial ventures) becomes economically prohibitive, multispecies cropping becomes prevalent. For example, high weeding costs have influenced the shift to agroforestry at the highly capitalized Jari pine and Pirelli rubber plantations in the state of Para.

Definitions of Agroforestry Systems

The broad definition of Agroforestry cited earlier refers to a "sustained land management system that combines the production of crops including tree crops, forest plants, and/or animals simultaneously or sequentially on the same piece of land" (King and Chandler, 1978). This generic term is divided into numerous sub-categories that refer to distinct agricultural systems.

> "Agrosilviculture" is the concurrent production of agricultural crops (including tree crops) and forest crops.
>
> "Silvo pastoral" systems integrate tree production and livestock production.
>
> "Agrosilvopastoral" systems include animal, tree, crop, or forest products production.
>
> "Multipurpose forest tree production", often cited as a separate category (King, 1979a), involves managing trees not just for timber production, but also for site amelioration, fodder, fruits, and firewood.

Multipurpose species are common in agroforestry agriculture and in this article are considered in the context of specific production systems. Each of these agroforestry systems encompasses agricultures of very different structures.

Agrosilvicultural systems

The subclassifications of agrosilviculture are best determined by whether the systems include a sucessional phase or not. Clearly, a _Cacau_ x _Cordia_ agrosilvic system differs profoundly from a "Taungya" (subsistence crops, planted commercial timber species and fallow) production system in several basic ways. For convenience, we discuss successional and simple cash crop agrosilvic systems separately.

Sucessional Agrosilvicultural Systems: Natural System Analog, Taungya, Shifting Cultivation.

Successional agrosilvic systems include several forms, depending on the purpose and degree of utilization of the "fallow". Characteristically, successional systems are harvested for wood or fruits after the first few years of annual cropping. These may be continuously harvested (as in shifting cultivation, and natural system analogs) or essentially 'abandoned' until timber harvest at the beginning of a shifting cultivation cycle (Taungya).

Natural System Analog.

When plants are purposely introduced into the fallow, the succession is manipulated and is the prototype for what Hart (1980) terms the "natural system analog". Hart further emphasizes that this system is not just a simple chronological sequence of crops, but one where each successional stage contributes to the physical requirements of the next crop. Instead of planting perennials and continuously removing weeds until the crops reach maturity, annual crops and short lived perennials are substituted in the understory. Planting systems of this type are shown elsewhere in this volume (see Bishop, Valencia). They have also been developed by Dubois (1979) for specific Amazon situations.

Taungya

Taungya is the best documented of commercial successional agroforesty systems. Practiced in South America mainly in Surinam, and experimentally in Columbia and Peru, it focuses on harvesting of timber species with annual cropping. Forest is cleared, burned and planted with the annual food crop. Then, commercial timber species are planted into the swidden plot. After harvesting the annuals, the system proceeds through succession. At the end of the rotation period, the commercial trees are harvested and the land cleared, and put into crops and timber seedlings once again. Many of the teak and mahogony plantations in Africa and Asia have been developed using this technique.

Shifting Cultivation

Small scale agroforestry agricultures are some of the most successful continuous farming systems in the tropics in spite of the frequent criticism leveled against shifting cultivators, blaming their demographic increase for land degradation (Galvao 1979, Myers 1980).

Shifting cultivation systems have been misperceived by many observers of the Latin American tropics. Most of the discussion and description of shifting agriculture in South America has occurred within the last 20 years (Watters, 1970; Sanchez, 1973), a period when vast population dislocations have taken place. These have been associated with changes in access to land (such as the relative decline of tenant farming (Sawyer, 1978), tenure laws and jurisdiction (Bunker, 1979, 1980a; Sawyer, 1978; Pompermeyer, 1979) and colonization projects (Nelson, 1975; Mahar, 1979; Bunker, 1978). Populations unfamiliar with lowland tropical environments, like the migrants from the Andean Sierra, or the Brasilian Northeast, were thrust into rainforest areas at the same time that federally subsidized corporate groups, and land speculators were becoming active in the same regions. While the Amazon area was perceived as "empty", in fact many of the lands were often occupied, and legitimately claimed (Ianni, 1978; Durham, 1977). The extremely migratory and ephemeral nature of much of the shifting cultivation easily observed in Amazonia (along roads) has its roots not in intentional land mismanagement or lack of understanding of effective fallow lengths, but in the land conflicts, speculation, human displacement and power dynamics at the frontier (Pompermeyer, 1979; Godfrey, 1979; Schmink, 1977; Nelson, 1975; Ianni, 1978).

While shifting cultivation systems frequently are understood as ecologically rational at low population densities (Sanchez, 1974; 1976), they are described as destructive when demographic increases reduce the land area per family/or individual and fallow times are shortened, resulting in land degradation. Such an analysis, focusing on only a small part of the picture, ignores the context in which most shifting cultivators must operate. The person/land ratios are extremely low in Amazon areas for all the countries discussed in this volume (see Annex and Country reports). Before "blaming the victim" it is worthwhile to examine tenure arrangements. In the state of Amazonas, Brasil, for example, 96% of the agricultural establishments had holdings of less than 100 ha, but controled merely 15% of the land. Meanwhile, of the area in private domain maintained as forest or classified as non-utilized productive land, 77% was held by only 28 of a total of 92,741 agricultural establishments surveyed (IBGE 1979). While reduced fallow times will clearly affect the productive capacity of land, the underlying problem for shifting cultivation often is not technical or demographic but related to land distribution and control.

Successional agroforestry systems are low input, species diverse systems. They are oriented toward small agriculturalists, and focus on supplying food crops as well as some timber and cash crops. Such systems have been successful in developing cash crop industries in many areas of the tropics (e.g. Obi and Tuley 1973, Kundstater et al 1978, Okigbo and Greenland 1979). Further, existing fallow systems can be made more economically interesting by incorporating commercial species into the subsistence crop complex.

Cash Crops Agrisilviculture

Cash crop systems using agroforestry techniques have a long history in tropical agriculture. In the Amazon, however, incentive programs for cash crops (with the exception of cacao) do not i clude funds for silvicultural components, in spite of the prevalence of agroforestry systems throughout the Amazon Basin. Many fruits and truck crops are already grown in mixed plot cultivation such as papaya intercropped with vines of passion fruit. These systems, though important for the local food supply, are inconsequential when compared in area and revenue with the major plantation crops, black pepper (Piper nigrum), Cacao (Theobroma cacao) and rubber (Hevea brasiliensis).

Pepper. The cultivation of black pepper in the Amazon has been plagued by the attack of Fusarium nigrum and F. solani that limits the productive life of pepper plants to 5-7 years. When heavy infestation of Fusarium occurs in a field, the agriculturalist generally switches into cacau, and in this manner profits from the residual nutrients from pepper fertilization. Peck (1979) points out that this substitution process of cacao for pepper is flexible and is generally accompanied by the introduction of leguminous trees (usually Erythrina sp.) to provide shade for the young cacao plants. In a system such as this where replacement of one cash crop by another occurs sequentially the possibilities for the introduction of forestry species is excellent. Further, pepper plants are more shade tolerant than was initially realized. Research at INATA (Tome-Açu, Pará, cited by Peck 1979) indicates that pepper can tolerate 20% shading without a decrease in production. It is then feasible to introduce in pepper fields some interesting economic species with light canopies. Leguminous species such as *Erythrina* and *Glircidia*, that tolerate pruning and thus allow the cultivator to control the degree of shading (Budowski 1978, Urquinart 1965) have been especially effective. Another alternative might be the selection of legumes of moderate height that do not require pruning, such as some *Inga* and *Pithecellobium* species, as well as commercial species. like *Cordia alliodora*

Cacao. Latin American cacau cultivation has traditionally developed with the "cabroca" technique whereby the forest understory is cleared and cacao is planted underneath canopy trees. The use of commercial timber species in conjunction with cacau is better developed than with almost any other cash crop.

Cacau production is higher in certain climatic regimes and with heavy fertilizer applications when grown without shading. However, in many Amazonian environments where dessicating winds and a strong dry season predominate, the microclimatic buffering produced by shade trees may be highly desirable.

During the first three years, shading and planting density are critical for the cacao plant (Entwhistle 1972, Mabey 1967).

Shade at this stage affects the height at which the plant bifurcates. In full sun, this bifurcation occurs at a low height causing subsequent management problems, Murray (1957) believes that the optimal bifurcation occurs with 50% shading. Beyond the physiological influences on cacao development, shade can reduce damage caused by insects by reducing physiological stress, as well as creating habitat for pest predators, and can diminish the weed populations (Cunningham and Burridge, 1960). Cacau is a rather nutrient demanding species, and requires heavy nitrogen additions. Some of the nitrogen requirements can be met by interplanting cacau with legumes such as *Erythrina*.

Species selected for interplanting with cacao should reach commercial dimensions within 25 years. In humid tropical conditions it is possible, with species such as *Cordia alliodora* to achieve wood volumes on the order of 200 cubic meters per ha per rotation. This represents a substanial economic gain if one considers that the value of this commercial timber is on the order of $10-20 US per cubic meter. This kind of financial return helps promote renovation of cacau plantations, because the wood becomes harvestable at the point where cacao production is declining (Peck 1979).

Coffee. Amazonian coffee production is still essentially a largely montane crop, but is increasingly being planted in Rondonia. This crop is traditionally grown with shade trees such as *Erythrina* and *Gliricidia*. Promising native species for interplanting include *Cordia goeldiana*, *Schizolobium amazonicum* and *Pithecolobium saman*. (Peck 1979)

The characteristics of desirable species for intercropping agrisilvic systems depends on the goals of the agriculturalist, and the needs of the farm and the agro-ecosystem. N fixation, supplemental animal feed, firewood, fruits, soil protection, economic return, wind breaks are all legitimate consideration for species selection. In general, species for use in multi-strata cropping systems should have these attributes (Peck 1979):

1) Apical dominance and good form, and relative tolerance to pruning when established at low densities

2) Rapid growth, with a rotation period appropriate to the renovation of the other interplanted species

3) Good quality wood with an established market

4) Canopy characteristics that permit the passage of light

5) A root system that is relatively deep, and that allows the tree to resist wind and that does not result in intense competition with the associated tree crops

6) Deciduous species are preferable because of the reduced transpiration and organic matter addition during the dry season.

Cattle Ranching and Agroforestry Systems

Of all the agricultural land uses in the Amazon, cattle ranching dominates in both area and investment. Livestock production has rapidly expanded throughout the Latin American lowland tropics (Parsons, 1970; 1976), but the success of this land use in converted forested areas of the Amazon remains variable (Koster et al., 1977; Fearnside, 1978; Serrao et al., 1979; Hecht, 1981). Productivity declines due to losses of soil fertility (Falesi, 1976; Koster et al., 1977; Serrao et al., 1979; Hecht, 1981) and weed invasion (Hecht, 1979; Dantes, 1980) are frequent. Serrao estimated that the area of degraded pasture was close to 500,000 ha. Hecht (1979) suggested that close to

50% of Amazonian pastures are seriously damaged, an estimate corroborated by Tardin, et al (1979) Landsat and ground truth study of the Barra de Garcas region, one of the major cattle development areas in the Amazon, and often considered the most successful. Pasture is defined as "seriously damaged" if weed invasion covers more than 50% of the basal area, when P levels drop below 1 ppm, and soil bulk densities are 30% higher than forest. Livestock production in plantation systems in the Amazon and elsewhere, however, has proved quite successful (Thomas, 1977; Bene, 1978; Apolo, 1979; Rios, 1979), suggesting that livestock systems are less ecologically damaging and more economic when they are developed as part of an agroforestry complex. Toledo and Serrao (elsewhere in this volume) argue, however, that the use of inappropriate technologies, rather than the ecological structure of pastures, is responsible for the collapse of many pastures converted from forest.

Definitions

Pastures that incorporate trees fall under the heading of "agrosilvo-pastoral" systems, an unfortunately ponderous generic term. Included under this rubric are "integrated farming systems" such as those described by Bishop, elsewhere in this volume. These include animals, crops and useful tree species. Forest grazing, or "silvo-pastoral systems" describes a situation where animals graze a ground cover crop grown under plantation trees. "Agropastoral" systems are those that encompass livestock as well as trees grown for food (human or animal), or site protection including firebreaks, windbreaks, living fences, soil nutrient ameliorators, watershed management, shade or any combination of the above (Budowski and Coombs, 1979). In the Amazon, forest grazing schemes are the most developed in area and management, and seem to be reasonably economic. Agrosilvopastoral systems are, however, still relatively rare in spite of their potential in maintaining already developed sites, and recuperating degraded areas.

Existing Silvopastoral Systems in the Amazon

The best known forest grazing scheme in the Amazon is Jari's *Pinus caribea x Panicum maximum* system. Over 20,000 ha of Pine plantation have been overseeded with grass mainly to lower the exorbitant cost of weed control. Extensive grazing in the plantations produced about 50 kg/ha/yr of meat and has substantially diminished weed management costs. While beef cattle reduce the pine growth by some 5%, the savings in brush control costs after two years is sufficient to pay for seeding and fencing (Toenniessen, 1980).

At the Pirelli rubber plantation in Marituba, Para, cattle graze a cover crop of kudzu (*Pueraria phaseoloides*) as well as a shade tolerant native herb in an intensively managed rotation. The cattle gain some 75 kg/ha/yr, a figure competitive with conventional grazing in pastures converted from forest. Costs of controlling kudzu and weeds have been greatly reduced (Castagnola, 1978, personal communication). Plantation operators find that the productive ground cover as well as shading, diminishes weed establishment and invasion. The increased expense in animal management and infrastructure is offset by the reduced labor costs of weeding, and the return on the calves and meat.

Forest grazing in the Amazon is in its infancy due to the rarity of plantation agriculture, but has the potential to be integrated into current programs expanding or developing new plantations, such as PROBOR program for rubber (described by Dr. Rocha-Maia elsewhere in this volume). Agroforestry techniques for palm oil plantations are well developed in Asia and Costa Rica, and could be integrated into oil palm, and possibly peach palm plantations (Thomas, 1978) where cover crops such as kudzu or Desmodium ovalifolium can be effectively grazed. Many forestry plantation species have been successfully grown with forage crops. These include species such as Cordia aliodora, Cedrela odorata, Eucalyptus deglupta, Leucaena leucocephala, Sesbania grandifoilia, Acacia mangioa, Schizolobium amazonica, Tabebuia spp, Octea spp, Caryocar spp, and Parkia spp. These are species with well developed national and international markets. Further, the silvics of these species is relatively better known compared to that of most Amazonian species. The potential for mixed plantations of native trees with cover crops grown underneath, is an unexplored, but interesting possibility in the Amazon. Plantations of diverse species are emphasized because

> "The adoption of monocultural systems has led directly to an increase in the number and severity of pests and diseases on forest crops ... There seems to be evidence that much of this is due to the uniform and crowded conditions that plantations provide, and that cultural operations in plantations have often accentuated." (Gibson and Jones, 1977)

A partial list of tree species that occur naturally in Amazon pastures and that are also used in the Amazon timber industry is presented in Table 5.

Agropastoral systems

The practice of grazing cattle in orchards is a common one in much of the Amazon. The orchards are not generally commercial, however, and are used to supply fruits for family, relatives, friends and workers on a ranch. Species that have commercial potential and that can be easily introduced into pastures include cashew (Anacardium occidentale), mangoes (Mangifera indica), jambo (Eugenia jambos), avocado (Persea americana), Annonas of various kinds as well as some Brasil nut (Bertholletia excelsa) cultivars. These orchard products are highly prized in national markets, and with some processing can be introduced into international ones. Brazil nuts and cashews already have a large market in North America and Europe.

Forage Trees

Trees are widely used as forage resources in the arid, semi-arid and subtropical world (Piot, 1969; Gray 1970; McKell, Blaisdell and Goodwin, 1972; Whyte, 1974; Baker, 1978), and their use has always been essential to livestock production in tropical Africa, the Brazilian Northeast, and Asia. Ranching development in Amazonia has generally overlooked arboreal sources of calories and protein for animals in spite of the importance of shrubs to animal diets (up to 64% of the protein in the dry season) in natural grasslands such as the Cerrado (Simão Neto et. al. 1977). The tendency of livestock development research organizations in South America to work mainly with improved herbaceous legumes and only the odd shrub such as Leuceana and Cajanus, has neglected trees as a potentially major fodder resource. There are a wide variety of native species within the Amazon that are browsed (Hecht, 1979); numerous fodder species are known for Africa and Asia (NAS 1980), and the cerrado could potentially supply species for use on degraded sites.

In most of the Amazon, seeds of 'Leuceana' (Leucaeana leucocephala) and Cajanus cajun ('Guandu' or pigeon pea) are the only forage shrubs that are commercially available. In unfertilized sites Leucaena is difficult to establish, and must be planted as seedlings. What few treelets survive are usually obliterated by zealous grazing in the usual extensive system found in the Amazon. Guandu, while not as palatable as Leucaena, can be easily established by mixing in the legume with grass seed when establishing a pasture. Guandu is not particularly fire tolerant, but is rarely eliminated with burning. Schaafhausen (1965) has shown for Sao Paulo that in 90 days with no rain, young Nellore steers fed on guandu had weight gains of .57 kilos per day for a total dry season weight increase of almost 46 Kg. Amazonian cattle generally lose weight in the dry periods, on the terra firme. Browsing of many native shrubs that invade pastures is well documented (Dantes and Rodrigues, 1980; Hecht, 1979; Serrao et al, 1979), but the use of shrubs for forage in most of the Amazon occurs not by intention, but desperation. In many of the weedy and degraded pastures where improved grasses and herbaceous legumes have been outcompeted by the regenerating vegetation, shrubs are often the only source of food for cattle.

The use of arboreal forest species with ranching is quite well developed in Central America, and their use in agropastoral systems in the Amazon is a research area of great importance. The quality and quantity of grass is not uniform throughout the year in Amazonia, especially in the semievergreen areas of the Amazon (Cochraine and Sanchez, this volume), and feed shortages and overgrazing are common. The uses of arboreal forage sources could make a major contribution to animal diets. Fodder in the Amazon has usually meant foliar sources of protein and carbohydrates, but this ignores the possibility of using edible fruits produced by trees. Some species such as Prosopsis juliflora, Pseudocassia spectabilis, Parmentiera cereifera and Cassia grandis demonstrated reasonable protein levels in fruits (Peck 1979). Table 6 lists a number of species that provide edible foliage or seeds and that have been used in pasture systems in South and Central America and might, with testing, be extended to Amazonian pastures. Arboreal forage species can provide ancillary benefits such as shading, wind breaks, and can potentially intercept raindrops, reducing the erosive impact of rains.

Site Amelioration

The use of trees for site amelioration is an agroforestry technique according to the definitions of Combs and Bubowski (1979). Site amelioration can include fire and wind breaks, living fences, shade trees and species that improved soil properties.

Wind and Fire Breaks Wind and fire breaks are rare in most of the Amazon, in spite of the dessicating winds that scour many regions in the dry season. When the native vegetation is cleared for pastures, maintenance of a 200-500 meter strip of forest at the perimeter of 1,000 ha of pastures provides relatively good wind and fire control. Wind breaks using fast growing species such as *Gmelina*, and some *Acacias* have been planted in southern Para. Wind breaks composed of species of *Sesbania*, *Leucaena*, *Inga*, *Gliricidia*, *Cassia*, and *Albizia* can be used for a variety of purposes such as fodder, fire wood, and food, are an interesting possibility for Amazon pasture areas.

Grassland burning is one of the few management techniques that ranchers use to control pests, especially in the semievergreen areas of the Basin. Burning at the end of the dry season (both intentional and accidental) is widespread and often uncontroled. Some ranches in the Amazon leave swaths of natural forest as fire breaks (ranging 200-500 meters) and this has proved to be reasonably successful.

Living fences Living fences, widespread in Central America, are an interesting and neglected possibility in the Amazon region. In most Amazonian environments, fences must be replaced in four to eight years, even when fence posts are treated to retard decay. Most species used as living fences are quickly established and also provide a number of auxiliary benefits such as shade, fodder, small scale wind breaks, and wildlife habitat. Sauer (1979) has documented 57 species that are regularly planted as living fences in Costa Rica. *Gliricidia sepium*, *Erythrina poepegiana*, *Sesbania* spp, *Colubrina* spp, *Jatropha* spp, and some

Bursera are among species that suggest themselves as living fence material in the Amazon.

Soil Amelioration In Amazonia, where forest clearing results in rapid nutrient decline of most elements within a year after clearing, plants that accumulate or fix nutrient elements are of great significance. Restoration and maintenance of soil fertility in tropical environments should be a priority in the design of agricultural systems for these zones. While the use of herbaceous legumes is (only) widespread, and the bulk of research is oriented to them, leguminous trees may be a better choice for many reasons. First, as Jones (1972) has indicated, many herbaceous tropical legumes are not very tolerant of grazing. Secondly, with the tendency to use aggressive grasses such as Brachiaria humiicola, establishment and persistence of herbaceous legumes is problematic. The problem of persistence is a general one of scandent tropical legumes (except kudzu) even with relatively non-aggressive grass species such as Panicum maximum (Halliday, 1979).

The use of soil-ameliorating trees is widely observed throughout the tropics (see, for example, NAS 1978; Mongi and Huxley, 1979; de las Salas, 1979) but hard data such as the amount of N fixed, is lacking. Trees are generally grown for the other benefits that they may provide, and the fixing of nitrogen or the accumulation of P or K is usually seen as an incidental side effect. Species that are valued as possible nutrient accumulators are intentionally planted in Africa and include such species as Acioa barteri, Alchornia cordifolia, Anthonotha *macrophylla*, *Albizia sp*, to mention a few (Okigbo and Lal, 1979). Use of soil-improving species in Central and South America is not well documented, but certainly exists (Chacon and Gleissman--in press.) Deccarrett (1966) has studied some of the more widely used shade trees that are also nitrogen fixers. His data are presented in Table 7 and suggest improved soil and forage nitrogen contents with pasture tree legumes.

Numerous native leguminous species will nodulate in agricultural conditions. In fact, the improved pH after burning probably favors rhizobia. Numerous *Ingas*, *Cassias*, *Tephrosia*, have been observed by this author to nodulate in pastures after burning. This is a research area that deserves a great deal more attention, as a means of countervailing the tendency for N diminution in pastures.

Agroforestry systems exist in almost every kind of Amazonian agriculture, but the question remains 'Why do they work?' In the next section, some of the possible mechanisms are discussed.

ECOLOGICAL ASPECTS OF AGROFORESTRY

Introduction

In the Amazon, monocropping practices frequenty have been associated with declines in production and agricultural collapse for virtually every kind of agicultural activity. The devastating economic influence of pests and soil deficiencies or toxicities is documented for almost every agriculture practiced in the basin, as the reports in this book can attest. Conventional monocrop agriculture deflects virtually all ecosystem energy, nutrients, and cultural practices toward short term enhancement of yields. This is usually achieved by energy and nutrient supplements, as well as biocides of various kinds.

When technical skill and agronomic inputs are cheap and available, this agricultural model has been successful throughout the world, even though its rationality in the face of high energy costs has been questioned even for the US (Pimentel et al 1973). These kinds of managerial and material inputs are expensive in the Amazon, and are neither unformly effective nor available. The environmental stresses placed on agricultural systems in the Amazon may require that agricultures incorporate more structural complexity. More ecosystem energy may need to flow into protective functions that improve nutrient cycling or reduce herbivory.

Amazon Ecosystems and Pest Dynamics

85% of the Basin is covered by high biomass, extremely species-rich forests (Prance, 1978) that are characterized by a plethora of subtypes (Pires, 1973, 1978, Heinsdijck 1962, RADAM 1974, Salati and Schubart, this volume). Forests of the Amazon are more usefully perceived as mosaics of relatively analogous structure, rather than a species-diverse, but essentially uniform formation. The variety of forest types has several implications for pest problems in the Amazon. Many planners do not realize that pest communities of most Amazonian agricultural systems are not only extremely heterogeneous, but also differ dramatically from region to region. Strong (1974, 1978), surveying pests of cacao and sugarcane, showed that most insect pests are recruited quickly and independently from the native biota with pest numbers rising asymptotically. In his cacao study (1974) only 1.5% of the pests were classified as widespread. He also found that the size of the area in cultivation was the best predictor of the number of pest species of a particular crop. Kellman (1980) points out that pest communities in tropical areas change rapidly with time and with cultivation techniques.

Weed communities in the Amazon seem to follow the pattern of invasion by endemic pests. While weed surveys are in their infancy, sufficient data exist for a preliminary analysis. In Brazil, Dantes and Rodrigues (1980) surveyed pasture weeds in three experimental stations. One was located at a varzea site near Manaus, and the others in the major upland cattle areas of Para: Paragominas, and the Araguaia region.

The Itacoatiara site reflects the overall lower species diversity of varzea ~~(flooded forest)~~. There were only 43 species recorded compared to 106 to the South of Para, and 176 for Paragominas. Of all the weed species Dantes and Rodrigues recorded, only 20% were shared by more than one of the three sites. Species overlap between any two sites was less than 10%. Of the total of 266 species they recorded, only 10 were documented for all three localities and these are cosmopolitan species such as Emilia sonchifolia, Euphorbia hirta, Panicum bolivense, Sida micanthra, Physalis capsifolia, and Stachytarpheta cavanensis.

Such empirical studies suggest several principles important for pest management in Amazonian agriculture:

1. The diversity of pest organisms affecting a crop is probably greater than in the montane, seasonal, or drier tropics.

2. The pest diversity or intensity may correlate with the diversity of forest sites cleared for agriculture.

3. Organisms invading Amazon agricultural sites are largely endemic. This implies that:

   a) pest organisms and outbreaks are not easily predictable;

   b) many species in the basin can perform similar functions;

   c) control techniques devised in one area may be difficult to extrapolate to another.

Given the extraordinary heterogeneity of Amazonian ecosystems, and the difficulty of predicting and controlling pest outbreaks in many Basin agricultures, a cultivation system that incorporates means of reducing the numbers or economic effect of pests is highly desirable.

Agroforestry and Pest Dynamics

Heterogeneous crop mixtures can function in a variety of ways to buffer pest populations either by environmental alteration or through the ecological dynamics within the field. Environmental changes initiated by multi-species cropping modify the agricultural crop system so that: (1) it becomes difficult for a pest to enter, and (2) it becomes undesirable for a pest species. Multiple crop systems have been shown in many cases to reduce the attractiveness of a crop to its pests by reducing visual or olfactory stimuli (Norton and Conway, 1977; Pimentel, 1961, a, b) and by diverting the pest away from the target crop or physically interfering with colonization. The increased ground cover and shading provided in multicrop agroforestry systems can reduce the ability of many weeds to establish themselves, or to compete effectively after establishment. It has also been suggested that polycultural cropping systems are less susceptible to pest and disease outbreaks because the noxious organisms spread less rapidly in mixed agriculture (Apple, 1972; Evans, 1960; Ruthenberg, 1971).

Species Diversity

The spatial heterogeneity of multicrop systems, as well as varied microclimates, provide habitats for pest predators and parasites that can control outbreaks. Further, the multiplicity of species can provide food during the non-entomophagous parts of a pest predators' life cycle, as well as alternate prey for the entomophagous stages when the pest density is low. While heterogeneous cropping theoretically might exacerbate pest problems by providing an important habitat requirement for the pest, or by diverting a pest predator onto another food item in the field (Way, 1975), the prevalence of agroforestry systems suggests that this is not a common occurrence (Wood, 1979).

In monocanopy, single crop ecosystems, the environment is structurally quite homogeneous, nutrient enriched and occupied by genetically uniform, same age organisms designed for high yields. In most tropical arable crops, reinvasion and pest buildup occur each subsequent season. Once classic "pest" species that are highly invasive with high reproductive rates enter a monoculture, particularly of field crops, appeals to the stability of the natural ecosystem are foredoomed to failure, since there are not enough natural ecosystem components to control outbreaks (Southwood, 1977). Rather quickly, pest organisms swamp the agricultural crop in question. Hence the poor track record (over the long run) of most Amazon monocultures, particularly those of annual crops. Chemical additions become necessary to maintain the agriculture. When these become too expensive or unavailable, or the crop price too low, these agricultures collapse. Tingo Maria, the Trans Am and the Paragominas cattle region are all examples of this process.

Agroforestry systems incorporate many features that can serve as a basis for pest management by manipulating processes that affect economic injury levels. The widespread use of agroforestry techniques at all scales of capitalization in Amazonian agriculture suggests that while it may not be known yet exactly how agroforestry systems work in pest management, they often do. Clearly, the pest dynamics of agroforestry systems are a critical research area.

Soil Conservation and Agroforestry

The role of vegetation in nutrient storage is important for most Amazonian ecosystems. (See Salati and Schubart, Sanchez and Cochrane, this volume). When forests on poor soils are cleared and nutrient cycling mechanisms are destroyed or interrupted, most of the nutrients in the vegetation are shunted to soil storage, where they are vulnerable to loss by erosion and leaching.

Table 5 comparing forest, regrowth and old pasture for phytomass illustrates the dramatic reduction in biomass storage with continuous cultivation. Soil nutrient declines for all elements but Ca and Mg have been documented under pasture after forest clearing (Falesi, 1976; Serrao et al, 1979; Toledo and Morales, 1979; Hecht, 1981). Although the ecosystems presented in Table 5 are not strictly comparable they suggest the dimensions of the problem.

Effective nutrient conservation may require that nutrient cycling components and mechanisms be introduced into agricultural systems. Systems without biogeochemical conserving management, such as fallows, heterogenous crop mixtures, sequential cropping, or complex structure will require large nutrient, energy, and biocide inputs.

Agroforestry systems are potentially far more nutrient conserving than monocanopy herbaceous field crops (Okigbo and Greenland, 1978; Dubois, 1979; Bene et al, 1977; Wilkin, 1977) especially at low input levels. The structural complexity and different nutrient requirements of multi-species agricultural systems incorporate many soil conserving features.

Soil Physical Properties of Soils in Agroforestry: Erosion Control

Latin American pedologists have justifiably focused on the chemical aspects of soil fertility. Much of the current data on the effects of soil physical parameters on cultivation is derived from African and Asian researchers (Lal, 1979; Aina et al, 1979, Aina 1979). In this section we focus largely upon erosion, but readers interested in soil moisture or temperature dynamics are referred to Lal (1975, 1979), Cummings and Lal (1979), Wood (1977), and Wolf and Drosdorf (1976).

High intensity storms, large drop size and high energy load are characteristic of tropical rains (Lal, 1979) and result in a potentially high erosive and compactive rainfall (Okigbo and Lal, 1979). Under continuous cultivation the deleterious effects on soil structure, and the problems of nutrient decline due to soil erosion are intensified. Sanchez and Cochrane (1979) indicate that 29% of tropical South America should not be used for agriculture due to erosion hazards. While serious erosion potential is usually confined to mountane zones, Table 8 demonstrates that even on moderate slopes, erosion can be severe.

Continuous cultivation with poor soil protection can reduce the productive capacity of a site when progressive deterioration of soil structure results in compaction, reduction in infiltration and soil erosion (Wood, 1977; Lal, 1978; Sanchez and Cochrane, this volume). Sanchez (1979) has pointed out that the bulk of the gully erosion in the Amazon is associated with road building and construction. Sheet erosion is common in the Amazon and will be particularly pronounced after burning and at the onset of the first rains (Smith, 1976; Fearnside, 1978; Scott, 1978; MacGregor, 1980), before the canopy has leafed out sufficiently. Table 8 gives some erosion data for several Amazonian sites. Scott (1978) has documented the reduction of sediments in streams by over 60% after vegetation covered swidden plots and by 85% once the canopy of Chac-Chac (a _Pteridium aquilinum_ dominated deflected succession in the premontane Peruvian Amazon) recovered from burning. The manner of cultivation and amount of weeding also affect sediment loss.

Pasture, even on steep slopes, is very effective in erosion control, but it is important to remember that the pasture experimental plots do not include the grazing animal, and caution should be used in extrapolating pasture erosion results.

Several beneficial effects of a closed vegetation cover (especially if it involves multiple canopies) are possible in agroforestry systems. Canopies break the impact of raindrops. Rooting habits of plants differ and are important in manintaining soil porosity. The constant organic matter additions onto the soil surface buffer raindrop impact and improve soil structure.

Soil organic matter levels increase and equilibrate rapidly under forest fallow (Cochrane and Sanchez, this volume). Rapid biomass accumulation (Snedaker, 1980) during early succession, as well as the relatively greater proportion of leafy components in the biomass in the first years of fallow (compared with mature forest), are probably responsible for the rapid rise in soil organic matter. Organic matter accumulation in agroforestry systems is likely to be similar to successional systems, but this question still requires research.

Organic matter additions to soils are of interest for maintaining soil structure and tilth. Litter is also an important cycling locus for the vegetation (Stark and Jordan, 1978; Medina and Herrera, 1979). Agroforestry systems, whether in sequential cultivation (with a fallow or modified fallow) or in continuous cultivation with a well developed tree component, are more likely to conserve soil structure and reduce erosion than conventional production systems where the soil surface is periodically exposed by harvesting and/or burning.

Soil Nutrient Dynamics

Certain agroforestry systems have the potential to maintain higher levels of ecosystem nutrients, and to recuperate nutrient losses after cultivation. Lal (1979) reports that in Nigeria no herbaceous cover was as efficient in regenerating overall soil fertility as woody vegetation. There are a number of reasons for this. A diversity of plant species will have somewhat varying requirements and differential rates of nutrient uptake. Mechanisms of nutrient accumulation probably similar to rainforests may occur through a variety of pathways including capture of nutrients in rainfall (Jordon et al and Bernhard Reversat, 1975, 1980), enhanced absorption through physiological mechanisms (Odum, 1970), structural features (Klinge and Fittkan, 1972), and symbiont associations, both microbial and fungal (Stark and Jordon, 1978). The structural complexity of rooting systems in a diverse agroforestry plot implies absorption of nutrients at varible depths. Nutrient retention is accomplished through increased evapotranspiration that reduces leaching (Likens and Borman, 1930; Bartholomew, 1953; Harcombe, 1977) ~~as well as~~ and promotes ~~promoting~~ nutrient cycling. Kellman (1970) has suggested that secondary species may cycle nutrients at higher rates than climax species. Because many components of agroforestry systems are members of early to intermediate successional communities (Cordia, Mahogany, etc.), rapid cycling could occur.

After clearing and burning forest, values for most elements except N and C are initially increased in the soil (Nye and Greenland, 1960; Zinke et al, 1978; Seubert et al, 1977; Falesi, 1976; Serrao et al, 1979; Hecht, 1981). Higher soil P levels are due to additions from the burned biomass, and occasionally enhanced availability through pH modification. K is also released from the burned vegetation. These impressive soil modifications reverse themselves after the first few years of cropping (Nasciamento and Brinkman, 1973; Falesi, 1976; Serrao et al, 1979; Sanchez and Cochrane, this volume). When most of the nutrients in the ecosystem are held in soil organic matter and forest biomass, the elimination of the forest destroys a critical storage site, and transfers these nutrients to the soil where they are more vulnerable to leaching and erosion. Analyses of only soil nutrients obscures the fact that total ecosystem nutrient stocks have changed. Figure 2 shows nutrient storage for soil, vegetation, litter and roots in primary forest, successional vegetations and grasslands. Ecosystems with a woody component (tropical forest and successional forest) accumulate larger amounts of N, K, P.

Uptake patterns encountered in various successional species are quite diverse as one can see in Table 9. Selection and protection of nutrient accumulators in fallows is easy to effect and an important research area (see Bishop, this volume; Tergas and Popenoe, 1970; Hecht, 1979; Lal, 1979). A great deal of research remains to be done on the soil dynamics in agroforestry systems in the Amazon, but results from African and successional systems suggest that more efficient nutrient cycling and storage could occur in agroforestry systems.

FACTORS AFFECTING AGROFORESTRY EXPANSION

The expansion of agroforestry in Amazonia is limited in part by lack of technical experience with these systems, and a view that species-diverse agricultural fields are somewhat less "developed" than monocultures. More critical, however, are the contradictory processes that characterize Amazonian occupation.

A variety of development goals in the Amazonian countries has accelerated clearing and agricultural colonization by both corporate entities and individuals (Nelson, 1975; Mahar, 1979; Durham, 1977; Goodland and Irwin, 1975; Pompermeyer, 1979; Ianni, 1978). Since the early 1960's, several trends have accompanied deforestation; one is that land itself rather than its production has become a highly negotiable commodity. Land values have soared above inflation rates even where the productive capacity of the land is declining (Mahar, 1979). When land is treated strictly as a commodity, careful management often becomes of secondary importance. Further, development decisions (at least in the Brazilian Amazon) are frequently made by economic groups outside of Amazonia. As many as 90% of the land titles in the state of Amazonas, Brasil, are held by individuals or corporations outside the region (Pires and Prance, 1977). These groups, generally lacking in tropical experience and with interests dominated by speculative motives, can devise land development techniques that can be quite damaging. For example, the widespread use of mechanical forest clearing methods commonly used by corporate ranches in the southern Amazon, can severely reduce soil productive capacity (Seubert et al, 1977; Serrao and Toledo, this volume).

Land ownership in much of Amazonia has been confused by contradictory land statutes, byzantine titling procedures, multiple agency jurisdiction over land, fraud and corruption

(Ianni, 1978; Pompermeyer, 1979; Sawyer, 1979; Bunker, 1978; Rodrigues and da Silva, 1977). The virulence of land conflicts throughout the Amazon suggests serious problems of speculation and land tenure, and these often interfere with rational resource use, leading to short term, and often destructive exploitation.

Agroforestry is a land use that does not reach fruition quickly, and in a speculative economy there is little incentive to implant and maintain such an agriculture. There is also an attitudinal constraint that views dramatic physical alteration of a landscape as proof of progress. Ultimately planners must come to view forests not as obstacles to development, but as one of its end products.

Conclusions:

While agroforestry is widely practised in the Amazon, it is the least studied of all tropical agricultures. Research in agroforestry will require an interdisciplinary ecological approach to agricultural systems that must include agronomists of all kinds, anthropologists, geographers, rural sociologists as well as economists. It also implies a perceptual change; for a sustained yield agriculture necessitates an integrative rather than substitutive orientation.

Several basic research areas need to be addressed if agroforestry systems are to receive the emphasis in development programs that they deserve. These include:

1) Large scale, comprehensive surveys of indigenous agricultural systems addressing when, how, why, and which species are used, and what role these can play in different agricultural

systems..

2) Basic research on the agricultural ecology of pests in tropical crops.

3) Nutrient cycling and dynamics in tropical agroforestry systems.

4) Research on components for agroforestry systems (i.e. Inga, commercial wood species, food producing trees) and their interactions with food crops and pastures.

5) Research on the social relations of production systems is also necesary, since different agricultural paths can exacerbate or ameliorate the economic and social inequalities that exist within the Amazonian countries.

In closing, it seems appropriate to cite one of the first Western thinkers who addressed problems of deforestation and agricultural development, as a cautionary note for today's Amazon developers:

> The very signs from which we form our judgements are often very deceptive; a soil that is adorned with tall and graceful trees is not always a favorable one, except of course, for those trees.
> (Pliny, Natural History, Book 17, Chapter 3)

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The section on cash crops agroforestry is based largely on the 1979 work by, and discussions with, Robert Peck.

1. Brazilian

Table IX. Amazon Forestry and Forest Products: Production and Value 1974-1976

Commodity	Production in tons 1974	1975	1976	Value in 1,000 cruzeiros 1974	1975	1976
Acai fruits[1]	n.d.	17,474	18, 743	n.d.	16,694	22,098
Andiroba[2]	325	252	302	84	175	116
Babacu nuts[3]	1,354	1,227	1,784	1,266	1,785	1,305
Balata[4]	274	283	512	1,033	1,510	5.424
Caucho[5]	162	327	319	811	2788	2,814
Copaiba[6]	160	23	26	2,341	162	204
Cumaru[7]	24	13	13	130	119	180
Hevea[8] latex	19,086	13,060	14,678	124,789	99,871	154.589
Hevea liquid	1027	887	1,016	2,951	3,538	5,380
Jatoba[9]	32	33	21	59	107	53
Macaranduba[10]	526	496	541	1,540	1,900	2,464
Murumuru[11]	107	44	41	35	19	22
Palmito[12]	24,342	192,182	197,671	4,486	74,818	121,783
Sorva[13]	3,787	3,294	6,197	9,083	9,878	20,047
Timbo[14]	19	6	15	34	8	25
Ucuuba[15]	111	110	109	81	78	95
Brasil Nuts[16]	35,776	51,719	61,043	53,302	100,953	171,006
~~TOTAL~~				~~203,025~~	~~314,403~~	[illegible]

Wood Production *	Production 1975	Production 1976	Value 1975	Value 1976
Logs	7,684,359	8,770,955	1,101,407	6,726,099
Charcoal	33,789 m^3	36,497 m^3	29,913	40,310
Firewood	16,333,375	16,620,382	294,440	366,463
TOTAL			[illegible]	[illegible] 7,132,872

Source: Annuario Estatistico do Brasil, 1977, 1978.
1) Euterpe oleraceae 2) Carapa guianensis 3) Orbynea speciosa 4) Manilkara bidenta ~~[illegible]~~ 5) Castilloa ulei 6) Copaifera multijuga 7) Dipteryx oderata 8) Hevea brasiliensis 9) Hymenea coubaril 10) Manilkara huberi 11) Astrocaryum murumuru 12) Euterpe edulis 13) Couma utilis 14) various Vines 15) Virola sp. 16) Bertolettia excelsa

* Wood values also include parts of Mato Grosso and Goiás. During this statistical period, forest clearing in the Central West was concentrated in ~~these two states~~, the Amazon areas of these two states.

Table K2. Amazon Species as sources of Latex, Oils, resins and Medicinals with existing markets

Genus and Species	Family	Use
Latex		
Hevea brasiliense	Euphorbiaceae	Rubber
Hevea genera	"	"
Castilloa ulei	Moraceae	"
Sapium sp.	Euphorbiaceae	"
Manilkara bidentata	Sapotaceae	Isomers of rubber but not elastic. Natural plastic of industrial interest
Pouteria gutta	"	"
Landolphia elata	Apocynaceae	"
Ecclinusa balata	Sapotaceae	"
Actras sapota	"	Chicle
Oils		
Acromia sclerocarpa	Palmae	Edible and soap oil
Orbynea martiana	"	Kernals contain 60% oil
Oenocarpus sp	"	Edible oil
Carapa guianensis	Meliaceae	Analgesic and soap oil highly productive (200 kg/
Caryocar Brasiliensis	Caryocaraceae	Soap, insudrial oil
Licania rigida	Rosaceae	Industrial uses
Resins		
Hymenea coubaril	Leguminoseae (~~Caesalpin.~~)	varnishes
Eperua sp	"	Laquers and varishes
Dye Plants		
Bixa orrelleana	Bixaceae	edible red dye
Aromatics		
Dipteryx oderata	Leguminoseae (~~Caesalp~~)	Source of Coumarin, ~~and aromatic~~, and dicoumeral ~~and~~ anti-coagulants)
Croton	Euphorbiaceae	Linalool (rose aromatic)
Medicinals		
Chondodendron	Menispermaceae	Curare
Abuta	"	"
Telitoxica	"	"
Strychnos	Loganaceae	"
Rauwolfia (12 sp)	Apocynaceae	Reserpine
Croton sellowii	Euphorbiaceae	Antibiotics
Capraria biflora	Scrophulariaceae	"
Thevetia peruviana	Apocynaceae	Cardiac glycosides (digital
Asclepias currassavica	Asclepidaceae	"
Chenopodium ambrosoides	Chenopodiaceae	ascaridole (vermifuge
Stevia rebaudiana	Compositae	Stevioside (sweetner 300x as powerful as sucrose)
Dimorphandra mollis	Leguminosae	Source of Rutin

Source: Mors and Rizzinni (   ).

Table 3. Tropical lowland forests of the Amazon Basin: Approximate area of forest clearing rate and dominant replacement land use.

Country	Amazon Forest Area (ha)	Current clearing rates (ha/yr)	Dominant Land Use
Brasil	280,000,000	2,000,000[1]	95%+ cattle ranching
Colombia	30,900,000	150-200,000	cattle, rice
Ecuador	87,000,000	n.a.	81% cattle [3]
Peru	65,000,000	n.d. on rates, but 10% thought to be cleared[4]	15% cattle, cash crop but mostly subsistence
Venezuela	13,352,000	n.a. ~~although~~ 30% of all Venezuelas forests cleared 1950-1975[5]	Cattle
Bolivia	16,200,000	3,000 [4]	Cattle, citrus, cacao, coffee
Surinam	13,352,000	3,000[4]	Subsistence, Forestr
French Guiana	8,646,000	Negligible[4]	Subsistence
Guyana	13, 400,000	10,000[4]	Subsistence

Sources: 1) INPE (1980) 2) CONIF (1978), Myers (1980) 3. Myers (1980) Gentry (1978) 4). Myers (1980) 5) Hamilton (1977).

Clearing here implies total replacement for an alternate land use. Selective logging etc is not included. These are approximate figures.

Table 4. Deforestation in the Brasilian Amazon

State	Area cleared in 1975 (A)	Area cleared in 1976-1978 (B)	% increment in (B/A)	Total 1978	Estimated clearing 1980*
Amapa	15,250	1,800	11.8%	17,050	20,119
Para	865,400	1,379,125	159.0%	2,244,524	3,575, 528
Roraima	5,500	8,875	161.0%	14,375	23,000
Maranhao	294,075	439,325	149.0%	733,400	1,092,766
Acre	116,550	129,900	111.4%	246,450	273,559
Rondonia	121,650	296,800	243.9%	418,450	1,016,833
Mato Grosso	1,012,425	1,823,075	180	2,825,500	5,085,900
Amazonas	77,950	100,625	129.0%	178,575	230,361
TOTAL	2,859,525	4,857,650		7,717,175	11,318,060

Source: INPE, IBDF. (1980)
* Calculated by multiplying the increment number with the deforested totals of 1978.

Table 5.

Amazon Timber species Tolerant of Pasture conditions.

Scientific name	Family	Common name (Dantes Rodrigues)
Bagassa guinensis	Moraceae	Tatjuba
Psidium Guianensis	Myrtaceae	
Siparuna ~~guinenensis~~ foetida	Monimiaceae	
Inga sp	Leguminosae	Inga
Cordia goeldiana	Moraceae	Frejo
Enterolobiumschombergii	Leguminosae	Tamboril
Hymenea coubaril	Leguminosae	Jatoba
Hymenolobium sp.	Leguminosae	Angelim de mata
Pithecolobium racemosum	Leguminosae	Angelim rajado
Stryphnodendron pulcherimum	Leguminosae	Angelim
Goupia glabra	Celastraceae	Cupiuba
Didimopanax mororoti	Araliaceae	Mororoto
Protium sp	Burseraceae	Breu
Octea sp.	Lauraceae	Lauro/ Arapira
Bertholetia excelsa	Lethycidacea	Castanha
Cedrelinga catenaeformia	Leguminosae (Mimosoid.)	Cedronan
Brosimum sp.	Moraceae	Garotte
Vismia Guianensis	Guttiferae	Lacre
Nectandra sp.	Lauraceae	Louro preto
Manilkara huberi	Sapotaceae	Massaranduba
Qualea paraense	Vochysiaceae	Mandioqueira
Jacaranda copaia	Bignoniaceae	Para Para
Tachegalia sp	Leguminosae (Caesalp)	Tachi
Pouteria sp	Sapotaceae	Abiurana
Platonia insignis	Guttiferae	Bacuri
Voshysia sp	Vochysiaceae	Quaruba

Source Dantes + Rodrigues (1980) Hecht (1989, 1981)

Table 6. Tree species for forage with ancillary benefits for Agropastoral systems

Species	Fodder Fruits	Fodder Foliage	Soil Improvement	Shade	Wood Prodution Fuel	Wood Prodution Construction	Other comments
Acacia albida	x	x x	Probable	moderate	x	x	Coppices, grazing tolerant
Albizia lebbek		x(30% prot.)	"	"			
Brosimum alicastrum	x	x	"		x		Rapid regrowth
Cassia spectabilis	x	x	"				
Cajunus cajun	x	x	'	light			Can serve as a human source of protien
Desmanthus virgatus		x(22% prot)	?	moderate			tolerant of heavy grazing
Desmodium distorotum		x 22% Prot)	Probable	"			"
Enterolobium Schomberkii		x	"	light		x	
Leucaena leucocephala	x	x(30% prot.)	Yes		x	x	Rapid growth, but high levels of mimosine
Prosopsis palida	x		Probable	"	x		
Pithecollobium saman	x		Yes	"			
Parkia sp.		x(26%)	Probable			x	
Sclerolobium paniculatm		x	Probable	moderate			
Stryphnodendron pulcherrimum	x	x	"	"		x	Fire tolerant
Sesbania granifolia	x	x	"	"	x	x	Living fences, green manure

Compiled from NAS (1979) Peck (1979) Combes and Budowski (1979) Hecht (1981)

Table 7. Nitrogen content in soils under leguminous and non Leguminous trees and grasses

Species	Depth		Grass
	0-20	20- 40	
Erythrina poeppigiana	.35	.15	8.37
Pithecellobium saman	.38	.18	6.73
Gliricidia sepium	.32	.18	6.54
Cordia alliodora	.24	.15	6.17
Control	.28	.16	6.0

Source: Deccarett and Blydenstein (1968), Deccarett (1967).

Table 8. Biomass nutrient storage in forest, brush and pasture ecosystems

Ecosystem	Biomass (mt/ha)	Element accumulation (kg/ha)				
		N	P	K	Ca	Mg
Forest (Brazil)	501	3294	67	500	528	274
Second Growth (Colombia)						
2 years	19	162	16	119	88	26
5 yrs	68	357	22	320	181	40
16 yrs	203	712	55	495	558	156
Pasture (Brazil)						
1 yr	9.7	383	7.6	87	397	145
2 yrs	6.o	237	4.8	54	234	90
3 yrs	4.0	158	3.2	36	156	60
4 yrs	3.1	122	2.4	27	120	46
10 yrs	1.5	60	1.2	13	58	22.5

Source: Compiled from Klinge et al (1975) Silva (1978) and Serrão et al (1979)

Table 8

SOIL EROSION AND DIFFERENT LAND USES IN ~~TROPICAL LATIN AMERICA~~ AMAZONIA AND AREAS OF HUMID CONDITIONS

Land use	Location	Rainfall	Erosion rate (t/ha)	Slope	Source
Rainforest	Maraba, Brasil	1,425 mm	15 t/ha	n.a.	Fearnside (1978)
Cacao plantation	"		20 t/ha	n.a.	Fearnside (1978)
Rainforest	Caqueta, Colombia	4,600 mm [1]	1.53 t/ha	17%	McGregor (1980)
Pasture	"		.94	31%	"
Agricultural fields	"		1.41-4.49	8-17%	"
Bare	Colombia	2775 mm	225.4	22%	Suarez de Castro (1952)
Pasture			7.1	22%	
Coffee Plantation			1.8	45%	"
Coffee Plantation with terraces			o.2	45%	

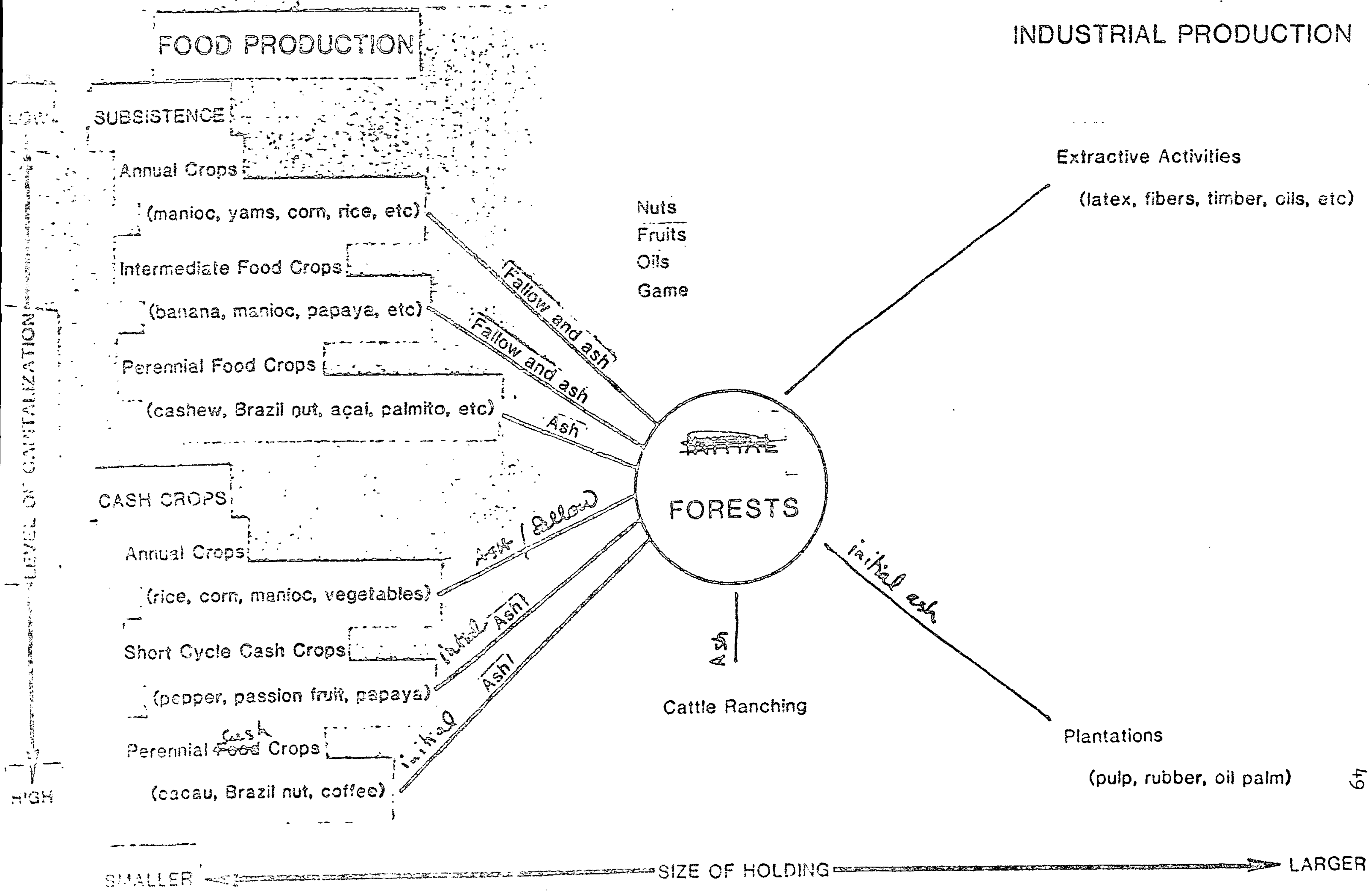
1. Estimate.
These results were derived using different methodologies and measuring over different time periods.

Table 13. Foliar nutrient content of some Amazonian weedy species

Species	N %	P %	K %	Ca %	Mg %
Amazonia augustifolia	2.58	0.16	3.06	0.32	0.56
Bauhinia spp.	1.50	0.12	1.53	0.67	0.18
Mimosa sp.	2.74	0.31	2.30	0.33	0.19
Palicourea marcgravii	1.99	o.10	1.76	0.85	0.32
Psychotria colorata	1.55	0.05	1.84	0.73	0.40
Solanum grandifolium	1.51	0.23	1.76	2.93	0.33
Solanum lancifolium	2.38	0.18	3.14	0.11	0.44
Pteridium aquilinum	1.96	0.17	3.23	o.24	0.21
Cecropia leucocoma	1.96	o.09	2.64	0.25	0.23
Heliconia sp	1.05	0.55	.63	0.24	0.79

Compiled from Tergas and Popenoe (1971), Scott (1978), Hecht (1981).

Production Systems ~~based on Forest Resources~~ in the Amazon



based on Forest Resources in the Amazon

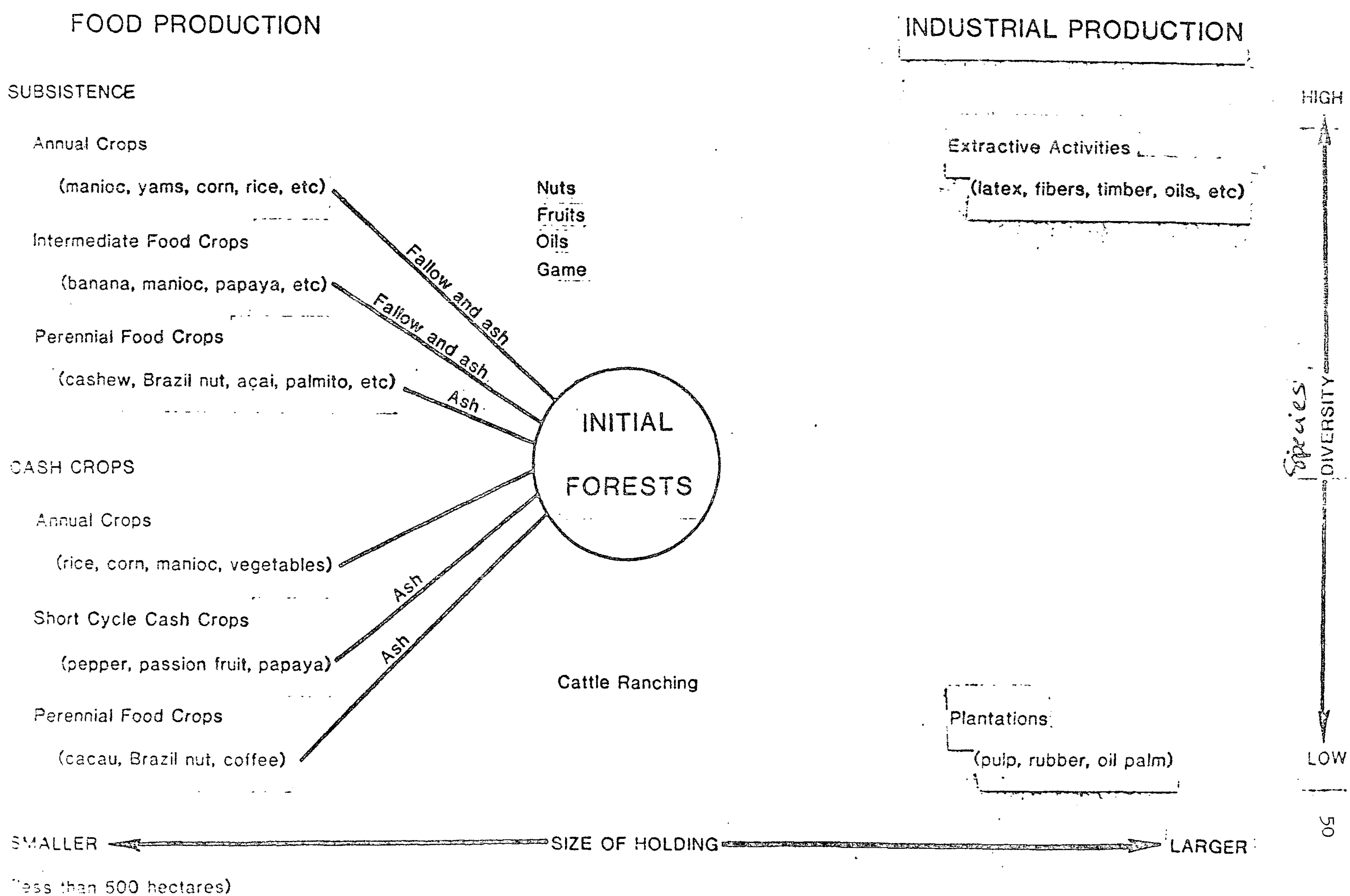
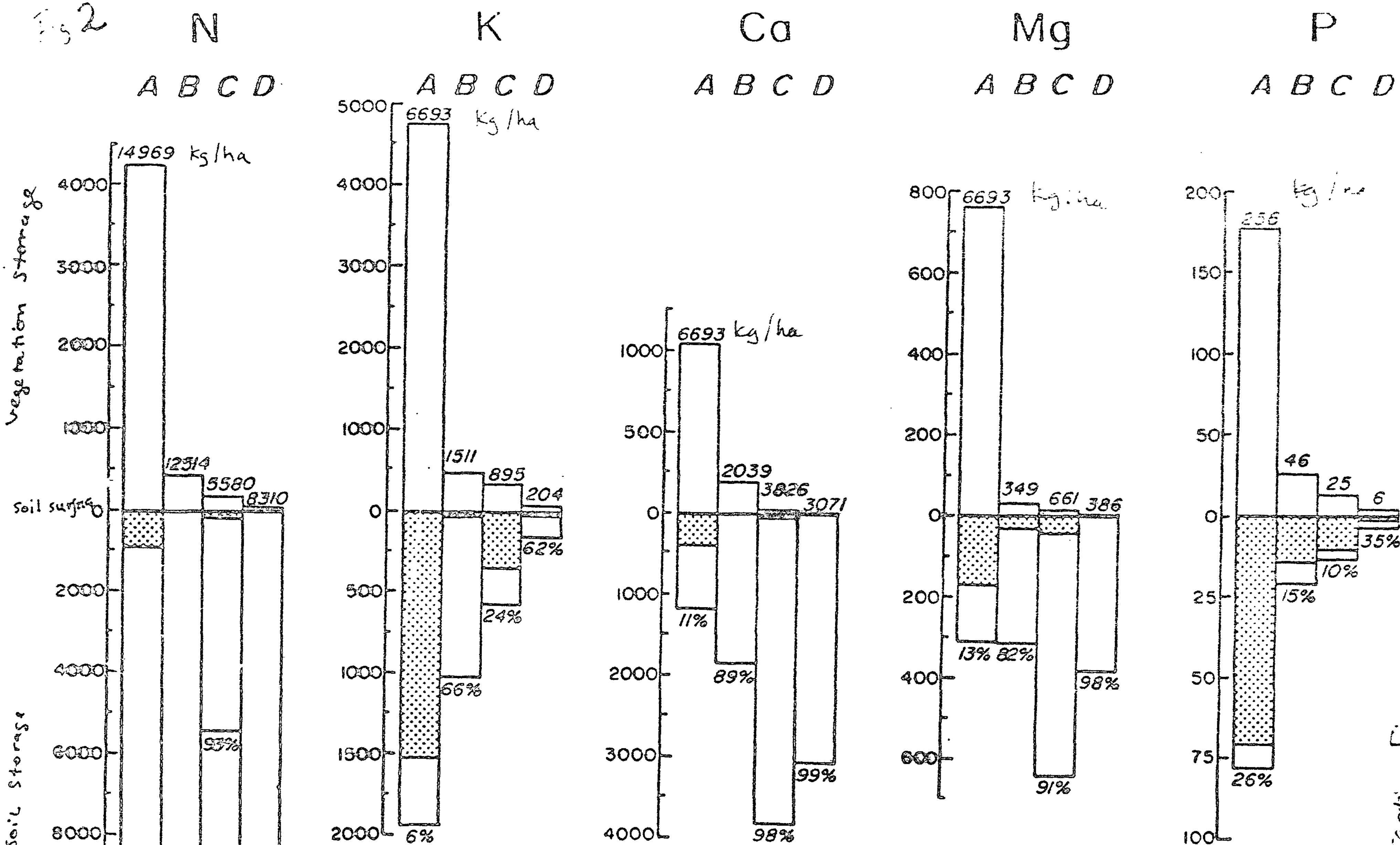


Fig 2



% soil storage

Roots (when roots are not indicated they are insignificant storage sites and are included in the biomass estimate)

A Montane tropical forest
B 3yr old successional forest on abandoned shifting cultivation plot
C Chac-chac, a *Pteridium aquilinum* dominated deflected succession