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AGROFORESTRY DEVELOPMENTS AND POTENTIAL IN THE BRAZILIAN AMAZON

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ABSTRACT

Much attention in the media and scientific literature has focused on the destruction of tropical forests in Amazonia since the early 1970s, especially in the Brazilian states of Rondônia, Acre, Pará and Mato Grosso. Concern is mounting that the peeling back of the forests is wiping out biodiversity, destroying soil resources, possibly exacerbating global warming, and provoking land conflicts, among other socioeconomic and ecological problems. Yet little regard has been paid to some of the promising agricultural developments in the region that are helping to counteract pressures on the remaining forest while recuperating debilitated areas. In particular, a pronounced trend towards planting a mix of tree crops on small farms throughout the basin augers well for the future of the rainforest and more sustainable agriculture. Agroforestry developments in Amazonia underscore the linkages between conserving biodiversity and more productive and resilient agricultural systems.

KEY WORDS biodiversity; home gardens; agroforestry; Brazilian Amazonia; Bahia; plant domestication

INTRODUCTION

Agricultural development in Amazonia is often portrayed as a textbook example of how not to develop the humid tropics. Ambitious rubber plantations in the 1930s, far-flung colonization efforts on the uplands in the 1960s and 1970s, and intensive rice production by a large corporation on the Amazon floodplain in the 1970s have all contributed to the notion that agriculture is largely unsuccessful in the region and only exacerbates environmental problems. However, rural populations were even denser before the arrival of Europeans, although indigenous people apparently did not undercut the natural resources nor trigger a massive loss of biodiversity (Goulding *et al.* 1995; Smith *et al.*, 1995). Amazonia has the potential to be a major agricultural zone, while still maintaining a broad range of habitats for native flora and wildlife. While much remains to be learned as to how people in the past managed natural resources, some current developments promise to reverse environmental damage. A large number of farmers, ranging from small operators to large firms, are currently exploring ways to boost incomes while helping to protect the natural resource base. The experience of small farmers with innovative agroforestry systems is explored here.

Small farmers are developing a large array of agroforestry configurations throughout the Amazon basin on their own initiative. To better appreciate the growing importance and potential of agroforestry in the region, the spatial and temporal dynamics of some existing polycultural systems are analyzed. The number of species deployed and the most popular crop combinations are described to underscore the innovative spirit of small farmers as they respond to market opportunities. The importance of home gardens as arenas for plant domestication and as testing grounds for introduced crops is highlighted. The

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Table I. 85 plant species observed in 142 polycultural fields involving perennials in upland areas of the Brazilian Amazon, 1988-1994.

Plant	Local name	Scientific name	Fields
Açaí	Açaí	*Euterpe oleracea*	8
African oil palm	Dendê	*Elaeis guineensis*	2
Ameixa	Ameixa	*Eugenia cumini*	1
Andiroba	Andiroba	*Carapa guianensis*	3
Angelim pedra	Angelim pedra	*Dinizia excelsa*	1
Annatto	Urucu	*Bixa orellana*	4
Arabica coffee	Café	*Coffea arabica*	6
Araça-boi	Araça-boi	*Eugenia stipitata*	1
Avocado	Abacate	*Persea americana*	11
Azeitona	Azeitona	*Roucheria punctata ?*	1
Bacabinha	Bacabinha	*Oenocarpus mapora*	1
Bacuri	Bacuri	*Platonia insignis*	1
Banana	Banana	*Musa* spp.	26
Barbados cherry	Acerola	*Malpighia glabra*	4
Biribá	Biribá	*Rollinia deliciosa*	6
Black pepper	Pimento do reino	*Piper nigrum*	27
Brachiarão	Brachiarão	*Brachiaria brizantha*	2
Brachiaria	Brachiaria	*Brachiaria decumbens*	2
Brazil nut	Castanha do Pará	*Bertholletia excelsa*	15
Breadfruit	Fruta pão	*Artocarpus altilis*	1
Cacao	Cacao	*Theobroma cacao*	30
Caimito	Abiu	*Pouteria caimito*	1
Canela	Canela	*?*	1
Carambola	Carambola	*Averrhoa carambola*	1
Caribbean pine	Pinheiro	*Pinus caribaea*	1
Cashew	Caju	*Anacardium occidentale*	7
Cedar	Cedro	*Cedrela odorata*	4
Cerejeira	Cerejeira	*?*	2
Coconut	Côco	*Cocos nucifera*	23
Common bean	Feijão	*Phaseolus vulgaris*	1
Cotton	Algodão	*Gossypium* spp.	1
Cupuaçu	Cupuaçu	*Theobroma grandiflorum*	32
Erythrina	Erytrina	*Erythrina* spp.	1
Faveira	Faveira	*?*	1
Freijó	Freijó	*Cordia goeldiana* and *C. alliodora*	10
Gandu	Gandu	*Cajanus cajan*	1
Genipap	Jenipapo	*Genipa americana*	1
Grosela	Grosela	*Eugenia uniflora?*	1
Guaraná	Guaraná	*Pranceana cupana*	3
Guava	Goiaba	*Psidium guajava*	7
Guinea grass	Colonião	*Panicum maximum*	1
Inajá	Inajá	*Attalea maripa*	1
Ingá	Ingá	*Inga* spp.	2
Ingá-cipó	Ingá-cipó	*Inga edulis*	2
Ipê	Ipê	*Tabebuia* spp.	2
Jack bean	Feijão de porco	*Canavalia ensiformis*	1
Jackfruit	Jaca	*Artocarpus heterophyllus*	5
Jarana	Jarana	*Holopyxidium jarana*	1
Jucá	Jucá	*Caesalpinia ferrea cearensis*	1
Kapok	Sumaúma	*Ceiba pentandra*	1
Lima	Lima	*Citrus* spp.	2
Lime	Limão	*Citrus aurantifolia*	7
Macacaúba	Macacaúba	*Platymiscium ulei*	1
Mahogany	Mogno	*Swietenia macrophylla*	10
Maize	Milho	*Zea mays*	3
Mamey	Abricó	*Mammea americana*	3
Mango	Manga	*Mangifera indica*	13
Manioc	Mandhioca	*Manihot esculenta*	28
Muiracatiara	Muiracatiara	*Astronium gracile*	1

Table I. *Continued*

Plant	Local name	Scientific name	Fields
Muruci	Muruci	*Byrsonima crassifolia*	1
Orange	Laranja	*Citrus sinensis*	37
Palhateira	Palhateira	*Clitoria racemosa*	1
Papaya	Mamão	*Carica papaya*	5
Paricá	Paricá, pinho cuiabano	*Schizolobium amazonicum*	3
Passion fruit	Maracujá	*Passiflora edulis*	12
Patauá	Patauá	*Oenocarpus bataua*	1
Peach palm	Pupunha	*Bactris gasipaes*	9
Pineapple	Abacaxi	*Ananas cosmosus*	8
Piquiá	Piquiá	*Caryocar villosum*	2
Pitinga	Pitinga	*Eugenia uniflora ?*	1
Quicuio	Quicuio	*Brachiaria humidicola*	2
Quince	Marmelo	*Cydonia oblanga*	1
Robusta coffee	Café	*Coffea canephora*	15
Rubber	Seringa	*Hevea brasiliensis*	23
Soursop	Graviola	*Annona muricata*	4
Sweet potato	Batata doce	*Ipomoea batatas*	1
Sweetsop	Ata, pinha	*Annona squamosa*	3
Tangerine	Tangerina	*Citrus reticulata*	8
Taro	Taro	*Colocasia esculenta*	1
Teak	Teca	*Tectona grandis*	1
Tucumã	Tucumã	*Astrocaryum vulgare*	1
Tutaruba	Tutaruba	?	1
Uxi	Uxi	*Endopleura uchi*	1
Watermelon	Melancia	*Citrulus lanatus*	1
Yellow mombim	Cajá, taperebá	*Spondias mombim*	1

relevance to Amazonia of the Bahian experience with polyculture is explored. Bahia is undergoing a widespread diversification of its agricultural economy as a result of the introduction of witches' broom disease among the State's cacao orchards, and some useful lessons can be learned from a region with similar growing conditions. The current agroindustrial infrastructure in the Brazilian Amazon is examined and bottlenecks to value-added processing are identified. Existing and potential markets are discussed, with an emphasis on regional and national outlets for agroforestry products grown in Amazonia.

Policy options that might promote agroforestry in Amazonia and other humid tropical regions are explored. A long term commitment is needed to safeguard genetic resources in tropical forests as reservoirs of traits for improving existing crops, and as sources of new plants for domestication. The conservation of biodiversity is essential for the long-term productivity of agroforestry.

AGROFORESTRY DYNAMICS AND DIVERSITY

Much of the experimentation underway with agroforestry systems in the Brazilian Amazon is being conducted by small farmers who are drawing from a wide array of indigenous and exotic species in designing their agroforestry systems. Hundreds of different crop combinations are being tested on different soils with varying distances from sizable markets. Rather than rely solely on a top-down experiment station approach, this generous pool of experiments could prove invaluable in further promoting agroforestry in the Amazon.

Spatial variation and species diversity

A total of 111 different agroforestry configurations were noted in a survey of 142 polycultural fields, mostly in the 1–10 ha range. Farmers are clearly experimenting with a wide array of crop combinations, some of which could prove promising for more widespread adoption. Farmers have also deployed an impressive number of species in their agroforestry plots. We noted 85 crops, mostly perennials, along major highways and associated side-roads from Acre to Pará (Table I).

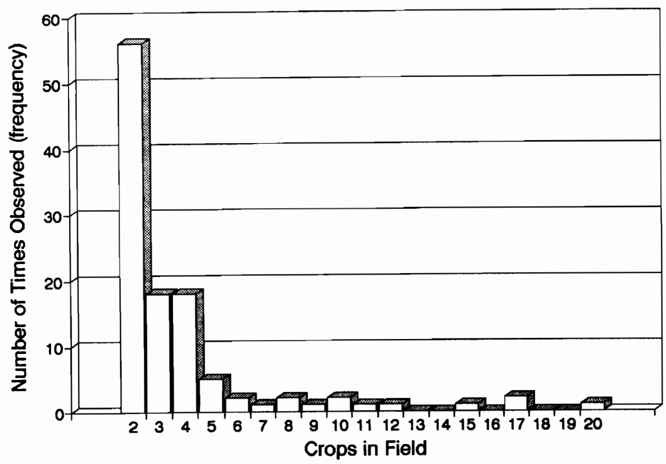

Figure 1. Observed frequencies of interplanted crops

Farmers are undoubtedly trying out hundreds of crop combinations, dominated by perennials, throughout Amazonia. The extraordinary diversity of agroforestry systems, and the large number of species employed, attests to the creativity and entrepreneurial spirit of small farmers in the Amazon. The creativity of farmers in Amazonia is mirrored by the willingness of farmers in other regions of the tropics and sub-tropics to try out novel crop combinations. In southern Yunan, for example, Chinese farmers are working with at least 110 different agroforestry combinations (Brookfield and Padoch, 1994). The trend towards agroforestry is widespread among farmers with lots in the 10–100 ha range in both older settled areas, such as the 'Bragantina Zone' near Belém, and along pioneer highways.

Although some polycultural fields contain as many as 20 perennials, most are in the two- to four-crop range. Approximately half of the sampled agroforestry plots contained two intercropped species (Figure 1). Note that both the mode and median of the sample distribution shown in this histogram are equal to two, supporting a tendency to observe a simple pairing of crops in polycultural settings.

The distribution also yields a computed mean of 3·77 crops per field (with a standard deviation of 3·32 crops per field), with a coefficient of variation of 88·06 per cent and a Pearson's measure of skewness of approximately 1·6. These statistics suggest a marked variability in the number of observed crops per field, attributable to several outlying values, and a distribution that is positively skewed. Nonetheless, market forces and management considerations streamline many of the agroforestry plots. Farmers tend to concentrate on a handful of crops in most demand. The most commonly observed associations in the sample of 142 polycultural fields were

- black pepper/sweet orange (5 locations)
- manioc/sweet orange (5 locations)
- coconut/sweet orange (4 locations)
- cacao/rubber (4 locations)
- manioc/banana (4 locations)

Species most frequently associated with major agroforestry crops

Of particular interest to agronomists are the types of crops most commonly planted alongside the more important species in agroforestry plots. The most commonly encountered crops in the sample were orange, cupuaçu, cacao, manioc, black pepper and banana (Table II). In order to gain an understanding of the incidence of other species found with the common crops, a more detailed statistical analysis was carried out. A subsample of k = 22 major crops in the agroforestry systems was first identified by con-

Table II. Frequently encountered crops in a sample of 142 agroforestry fields in the Brazilian Amazon, 1988-1994.

Crop	Number of fields encountered	Native region
Orange	37	Tropical Asia
Cupuaçu	32	Eastern Amazonia
Cacao	30	Western Amazonia
Manioc	28	Neotropics
Black pepper	27	South Asia
Banana	26	Southeast Asia
Coconut	23	Pacific/Indian oceans
Rubber	23	Amazonia

sidering only those crops observed in at least 5 per cent of the polycultural fields comprising the overall sample; i.e. crops occurring with a frequency of seven or more times. In addition, the subsample was limited to $n = 114$ observations (out of a possible 142) comprising the set of polycultural fields containing no less than two of the 22 identified major crop types. An (nxk) binary data matrix $\boldsymbol{X}$ was then constructed, whose elements $\{x_{ij}\}$, for a given ith row and jth column, denote the presence (when $x_{ij} = 1$) or absence (when $x_{ij} = 0$) of a jth crop type in an ith polycultural field, where $i = 1, \ldots$ n and $j = 1, \ldots, k$. A more detailed statistical analysis of this subsample was carried out, highlighting six of the eight most frequently encountered crop types (Table II).

To analyze statistically the joint occurrence of crop types, binomial logit models using binary data on the joint occurrence or non-occurrence of crops (as described by matrix $\boldsymbol{X}$) were run for each of the six most frequently observed crops (Table III). In each instance, the column associated with the crop of interest was removed from the matrix and assigned as a dependent variable (Y). The implied model is one where the dependent variable $Y_i = 1$ if the crop type was observed and $Y_i = 0$ if the crop was not observed in a given ith polycultural field, as a function of the presence or absence of other crop types (as depicted by predetermined independent binary variables). Removed from the matrix were the column vectors associated with any crop that failed to occur jointly in at least two polycultural fields with the crop represented by the dependent variable. In other words, column vectors of $\boldsymbol{X}$ containing fewer than two non-zero values were not considered. For each of the six most frequently observed crops, a logit model (LM) was estimated to explain the presence or absence of a crop as a function of the presence or absence of other major crops at the 90 per cent confidence level (Table III).

The statistical analysis indicates that orange is most likely to be planted alongside manioc, coconut or tangerine. Tangerine is not a particularly common intercrop in agroforestry systems, but when it is incorporated in polycultural plots it is usually accompanied by orange. Cupuaçu is often found associated with banana since the latter frequently serves as a shade crop for cupuaçu seedlings.

Cacao is most often intercropped with rubber or Brazil nut. On the other hand, cupuaçu and orange are rarely observed with cacao. Cupuaçu is not a good intercrop for cacao because both suffer from witches' broom, a serious disease caused by the fungal pathogen *Crinipellis perniciosa*. Orange is not a suitable companion for cacao because it occupies the same stratum in agroforestry plots and thus competes directly for space. Bananas were not so commonly observed in polycultural fields containing cacao because the sampled cacao plantings were generally well established. As in the case of cupuaçu, banana is typically only grown with cacao during the latter's formative period.

Manioc is most commonly associated with banana and orange. In the past, manioc was often the last crop before abandoning a field to second growth. Some farmers are attempting to keep fields in long-term production by planting longer-lived perennials that generate income, such as bananas and orange. Some swidden systems are thus in transition to relatively permanent agroforestry plots. In some areas that have been farmed for generations, such as in the Amazon estuary and in parts of the Peruvian Amazon, cultural forests have been established that are tapped for a wide range of products, ranging

Table III. Results of logit models explaining the presence or absence of selected crops as a function of the presence or absence of other major crops

Dependent variable	Independent variable	Estimated coefficient	t	Significance level
Orange	Constant	−1·3038	−4·299	0·00002
	Banana	−1·8761	−2·521	0·01169
	Coconut	1·0571	1·957	0·05035
	Manioc	1·6260	2·793	0·00524
	Tangerine	1·3999	1·774	0·07609
	χ^2 (with 4 degrees of freedom) = 16·13969			
	Significance level: 0·002837			
Cupuaçu	Constant	−1·5374	−5·382	0·00000
	Avocado	1·5349	2·120	0·03400
	Banana	1·6273	3·293	0·00099
	χ^2 (with 2 degrees of freedom) = 15·96922			
	Significance level: 0·000340			
Cacao	Constant	−1·0255	−2·897	0·00377
	Avocado	1·6034	1·867	0·06186
	Brazil nut	1·0320	1·539	0·12392
	Cupuaçu	−1·3275	−1·985	0·04717
	Orange	−1·8728	−2·376	0·01748
	Rubber	0·9563	1·636	0·10177
	χ^2 (with 5 degrees of freedom) = 21·52941			
	Significance level: 0·000643			
Manioc	Constant	−2·3926	−5·448	0·00000
	Banana	2·1003	3·688	0·00023
	Orange	1·4234	2·549	0·01079
	χ^2 (with 2 degrees of freedom) = 18·16777			
	Significance level: 0·000113			
Black pepper	Constant	−0·6670	−2·428	0·01517
	Banana	−2·9918	−2·639	0·00831
	Cacao	−2·6501	−2·505	0·01226
	Mango	1·3575	1·580	0·11413
	χ^2 (with 3 degrees of freedom) = 23·02713			
	Significance level: 0·000039			
Banana	Constant	−1·3683	−2·801	0·00510
	Black pepper	−2·9012	−2·501	0·01238
	Cacao	−2·4764	−2·094	0·03627
	Cupuaçu	1·3639	2·256	0·02406
	Mango	2·0392	2·245	0·02478
	Manioc	1·7502	2·527	0·01149
	Orange	−2·0616	−2·444	0·01451
	χ^2 (with 6 degrees of freedom) = 46·34776			
	Significance level: 0·0000002			

from latex, to nuts, and fruits (Padoch, *et al.*, 1985; Hiraoka, 1986, 1989; Anderson, 1988; Anderson and Ioris, 1992).

The results for black pepper show that although this introduced vine occurs frequently with a wide variety of other crops, mango is the only crop that is positively associated with black pepper in a statistically meaningful way. The apparent lack of other positive relationships in the case of black pepper is probably linked to the widespread use of this crop throughout agroforestry systems.

Banana is most commonly planted with cupuaçu, manioc and mango. However, banana is rarely a permanent fixture of an agroforestry plot because the crop is usually phased out after a few years. Banana is highly susceptible to several diseases, and usually gives way to longer-lived perennials.

Empirical evidence suggests that several sets of complementary and non-complementary relationships occur among the various major crops found in the sample. Much work remains to be done, however, to ascertain which crop combinations might be most effective or compatible under the varying ecological and socioeconomic conditions across the Amazon basin. What works well in one area may not prove satisfactory for another. The rich reservoir of experience of small farmers can provide valuable guidance, but it is only a beginning.

Species diversity and sustainability

The relevance of species diversity in agroecosystems and their stability is still debated. Some would argue that the greater the number of crops in a field, the better the chances of avoiding serious pests outbreaks, but increased species diversity in a field may boost productivity only up to a point. Few agroforestry fields appear to be commercially productive with more than 15 species, presumably because of competition for light and nutrients. Agronomists note little gain in productivity when fields exceed four or five intercropped species (Baskin, 1994), a rule of thumb apparently born out in the Brazilian Amazon. Only 11 per cent of the agroforestry fields sampled contained more than five crops. In most cases, two to four crops appears to be the best trade-off between generating revenue and the optimal use of soil nutrients, light and water in fields. Nevertheless, some commercial farmers maintain six or more crops in their fields, perhaps as a shield against weather fluctuations in market prices, to provide greater variety in the diet, and as insurance against catastrophic outbreaks of diseases or pests.

Another noteworthy feature of agroforestry systems in upland portions of the Brazilian Amazon is the importance of exotic crops (see Table I). Only three of the eight most frequently encountered crops in agroforestry plots are native to Amazonia: cupuaçu, cacao and rubber. The most common crop in polycultural fields is sweet orange, a native of Asia.

Three lessons can be drawn from the spatial patterns of agroforestry systems in upland Amazonia. First, even the most popular crop combination occurred only five times, suggesting that considerable experimentation is still underway. Agroforestry systems are heterogeneous, thereby helping to avoid ecologically simplified landscapes that are more prone to disease and pest epidemics. Second, some farmers prefer to cultivate a dozen or more perennials in their agroforestry plots in order to dampen the effects of fluctuating market prices and to provide more variety to the diet. Schemes to promote agroforestry should not rest on just two or three crops, which can be vulnerable to plunging prices. Third, exotics figure prominently in the most popular crop combinations, and excessive reliance on indigenous species for agroforestry development is thus unwarranted. Farmers are interested in crops that will help them earn a living, whether they arise locally or come from abroad.

A PERENNIAL RELAY-RACE

Agroforestry plots in the Amazon are highly dynamic with some species eventually dropping out while others come on line. Farmers often deploy a mix of cultivated bushes and trees that produce returns in the near- to mid-term, as well as long-lived perennials that are harvested after a decade or two. Some perennials, such as banana, papaya and passionfruit, typically last for only two or three years in agroforestry systems. Banana often serves as a shade tree while other perennial crops, particularly cacao, become established. Several crops serve as medium-term investments: Barbados cherry and black pepper are examples. Sweet orange or cupuaçu is often intercropped with black pepper before the latter succumbs to *Fusarium* wilt after about eight years.

Tropical fruits are an increasingly attractive proposition, so farmers intercrop a large assortment of indigenous and exotic fruit trees as a medium- to long-term investment. Fruit trees indigenous to the Amazon basin that are planted in agroforestry plots include açaí palm, araça-boi, bacuri, biribá, various species of *Inga*, peach palm, piquiá, soursop, tucumã palm and uxi. Several long-lived perennials are cultivated for a variety of purposes, such as Brazil nut which provides a good quality oil for the cosmetics industry and nuts. Cashew produces 'fruits' for direct consumption or to make juice, as well as nuts with a high market value.

For long-term income generation, an appreciable number of agroforestry farmers invest in timber trees, particularly cedar, cerejeira, freijó, jarana, paricá, macacaúba and mahogany. Timber trees are interplanted with a wide variety of other crops, but are particularly common in cacao groves. Forest trees that provide essential oils, such as andiroba and copaíba, are also increasingly seen in agroforestry plots. Andiroba also yields a fine wood. A veritable relay race of crops is thus underway in many multiple-purpose orchards, thereby assuring farmers of a continuous stream of income.

THE PIVOTAL ROLE OF HOME GARDENS

Dooryard gardens are an often overlooked resource in agricultural development in tropical America, yet they are important staging grounds for the domestication and testing of crops. Home gardens are valuable *in situ* genebanks, and their richness depends in part on the survival of nearby forest. Some of the current agroforestry 'stars' in the Brazilian Amazon, such as cupuaçu and the açaí palm, were recruited from the forest and domesticated in home gardens. Home gardens are low-cost experimental grounds for farmers, and they often contain much pre-adapted material suitable for wider planting.

Home gardens are rich pockets of genetic resources for improving agroforestry in the region. A total of 76 plant species, mostly perennials, were found in a survey of 32 home gardens in upland areas of rural Pará. Home gardens contain a rich mix of plants for a wide variety of purposes in both older settled areas and in pioneer areas after about ten years of colonization. If ornamental and medicinal plants had been included, several hundred species would likely have been recorded. In general, home gardens contain more perennial species than agroforestry fields. A sample of 18 home gardens on the Amazon floodplain in the vicinity of Manaus and between Juriti and Santarém revealed 80 perennial species (Figure 2).

The large number of perennial crops found in home gardens on the Amazon floodplain points to some intriguing possibilities for promoting agroforestry in this threatened environment. Much of the Amazon floodplain from Manaus to the estuarine area is being converted to pasture for cattle and water buffalo. Home gardens may hold the key for helping to arrest this destructive trend by offering an attractive alternative: tree farming. In addition to fruit trees with wide market acceptance, such as mango, cashew and guava, home gardens on the Amazon floodplain contain several wild trees from floodplain forest in various stages of 'proto-domestication'.

Some of the trees in the early stages of domestication in home gardens on the Amazon floodplain could emerge as useful cash crops. For example, several forest fruits are used frequently for fish bait and are either planted or encouraged around homes. Fruits from floodplain forests are all avidly sought by several commercially valuable fish, such as tambaqui (*Colossoma macropomum*), and could be more extensively planted to provide feed for aquaculture. Although tambaqui thrive on commercial livestock rations, their flavor would be enhanced by incorporating some natural food items in their diet, particularly when they approach market size.

Agroforestry is no panacea for the agricultural development of the Amazon floodplain. Other land uses, such as plantation forestry, monocropping with cereals or root crops, pasture or forest extraction, are also part of the picture, and help underpin a vibrant rural economy. Agroforestry has hitherto overlooked potential on the floodplain, particularly in the largely deforested middle stretch of the Amazon. Profitable agroforestry systems would help stem the tide of deforestation, thereby helping to conserve biodiversity.

THE BAHIAN EXPERIENCE

Bahia and Amazonia have much to learn from each other with respect to environmentally sound and profitable agriculture. Both regions have hot, humid climates and soils of varying fertility, with relatively

Figure 2. A home garden with annatto, banana and cashew, among other perennials, on the Amazon floodplain. Home gardens are active centers of plant domestication and contain varieties suitable for more wide-scale planting. Igarapé do Jari, near Arapixuna, Pará, Brazil, 31 August 1993

poor soils predominating on the uplands. Bahia is a propitious region for extracting lessons for farmers in Amazonia because cacao has been grown there since 1746, often with one or more other trees providing shade. Cacao is an understory tree and is one of the earliest forms of commercial agroforestry in the New World. Farmers in Bahia have thus had prolonged experience with cacao agroforestry systems and the crop has served as the traditional mainstay of the State's agricultural economy. Also, widespread diversification is underway among cacao farmers in Bahia.

Bahia has historically dominated cacao production in Brazil. Cacao is currently grown on 750 000 h in the State. A major reason for this pre-eminence is that Bahia has, until recently, been free of the single most serious disease of cacao: witches' broom. Cacao and witches' broom are native to Amazonia, but warm, humid Bahia is separated from the Amazon basin by dry savanna, thereby allowing cacao plantations to flourish in the State. In 1989, however, witches' broom was inadvertently introduced to Bahia, triggering a wide-scale effort to diversify the State's agricultural base. Another factor spurring the search for alternative cash crops, such as banana, is the relatively low cacao prices that have prevailed since the mid–1980s (Schulz, *et al.*, 1994).

A precedent exists for the exchange of agricultural technology between Bahia and Amazonia. Japanese–Brazilian farmers at Tomé-Açu in central Pará, for example, visited Bahia in the early 1970s to observe cacao planting methods and obtain superior planting material (Barros, 1990: 58). Farmers at Tomé-Açu were attracted to cacao by the rising prices for the commodity at that time and by their desire to diversify their agricultural operations, which were based mainly on black pepper. Today, farmers at Tomé-Açu continue to cultivate cacao, in spite of the price drop, but they have intercropped their cacao orchards with timber and fruit trees.

Although cacao was promoted as a viable cash crop in Amazonia in the late 18th century, plantings were mostly confined to higher floodplain areas of the Amazon and lower Tocantins. Many of these plantings were subsequently cut down, or were engulfed by forest. In 1972, however, a second 'push' to plant cacao in Amazonia was undertaken, this time focused on the uplands. Assisted by credit and extension services provided by the National Cacao Research and Extension Service (Comissão Executiva do Plano da Lavoura Cacaueira—CEPLAC), farmers began planting small groves of cacao on more fertile soils (mainly alfisols) along pioneer roads, especially in Rondônia and parts of Pará, Mato Grosso and Acre. Government support for promoting cacao in the Amazon stemmed from CEPLAC's success in raising cacao yields in Bahia from an average of 450 kg ha^{-1} to 750 kg ha^{-1}. The marked increase in cacao yields in Bahia between 1960 and 1980 was made possible by investing in scientific research linked to extension efforts.

The well coordinated program to promote cacao planting in Brazilian Amazonia paid off, and approximately 100 000 ha of cacao are now growing in the region. With an annual production of some 60 000 tons of cacao, the Brazilian Amazon is now the third most important producer of the commodity in the western hemisphere, after Bahia (350 000–400 000 tons per annum) and Ecuador (80 000–100 000 tons per annum). However, with a steep decline in world prices for cacao, which by the early 1990s had plunged by approximately 70 per cent from the peak prices of 1977 and 1978, cacao growers in the north began a search for alternative crops, including intercropping in cacao orchards. By the mid–1990s, cacao prices had rebounded somewhat, revitalizing many orchards and improving the profitability of agroforestry systems based on cacao.

In Bahia, about 300 000 ha of cacao are planted under various shade trees, some of them economic species in their own right. In Amazonia, farmers generally prefer shade trees that also provide some salable product, such as timber, fruit or nuts. Experience in Bahia is relevant here. In this State, farmers have found it profitable to interplant jackfruit, genipap, yellow mombim, coconut and clove (*Syzygium aromaticum*) in their cacao groves. In both Amazonia and Bahia, peach palm is an especially promising intercrop for cacao.

Bahian farmers plant a wide variety of other perennials, often in polycultural plots. In the Municipality of Valença, for example, African oil palm is intercropped with kudzu (*Pueraria phaseoloides*) to enrich the soil with nitrogen, suppress weeds and provide protein-rich fodder for cattle. Cattle are introduced to the oil palm/kudzu association in the fourth or fifth year, when the palm fronds are out of reach of the grazing animals. Cattle are rotated on different parts of oil palm plantations to allow kudzu to regrow. Oil palm is also often planted with kudzu in Amazonia, but cattle have not been introduced to the system there. While oil palm groves are becoming established, smaller growers in Bahia often interplant annual crops, such as maize, squash, watermelon, papaya, cardamom and pineapple.

Several other perennials crops are grown in polycultural systems to provide staggered income. In southeastern Bahia, some 13000 ha are in clove production and maize, manioc, papaya, and pineapple are typically interplanted while the clove bushes are still young. A similar pattern prevails with macadamia (*Macadamia* spp.), a relatively recent introduction to Bahia. Space between recently grafted macadamia is typically taken up by such crops as beans, vegetables, passionfruit, papaya, black pepper and robusta coffee. In southern Bahia, a large paper-making company has begun promoting the interplanting by small farmers of squash and watermelon among eucalyptus seedlings. A variety of agroforestry 'packages' are thus being developed in Bahia for large, medium and small-scale operators, many of which could prove useful in Amazonia as a means to boost rural incomes and counteract land degradation.

AGROINDUSTRY AND MARKETS

Although a trend to planting diverse agroforestry systems is well pronounced across the Amazon basin, the area devoted to polycultural fields with perennials is still small when compared with pasture, annual crops and secondary growth in abandoned fields and degraded pasture. More facilities for processing fruits, nuts and oils, and improved access to markets would undoubtedly spur further planting of perennial crops in the region. The market for exotic tropical fruits and nuts is growing (Clay and Clement, 1990; Inés, 1991; Silva and Donato, 1992; Smith, *et al.*, 1992). Farmers could better capitalize on this trend with improved infrastructure and better organized growers' associations.

At the moment, a wide variety of products is being sold on international markets based on materials 'sustainably harvested' from tropical forests, including Amazonia. All of these products can also be grown in agroforestry systems. Markets are being developed for 'green' timber (i.e. from 'managed' forests), and a similar exigency is likely soon for agricultural products grown in the tropics, particularly in rainforest areas. Consumers in industrial countries, and increasingly in many parts of Brazil, are concerned that the chocolate, tropical fruits and juices, and cosmetics they buy do not contribute to deforestation, and are grown or gathered in a way that does not degrade the environment, such as by the excessive use of pesticides. For example, some mangoes imported into the United States carry a sticker certifying that they are 'organic'.[1] Diverse agroforestry systems require few if any agro-chemicals.

A credible 'green' labeling program for agroforestry products in Amazonia and other tropical regions will require monitoring and greater investments in research on integrated pest management, including the deployment of crop varieties that are genetically resistant to pests and diseases. Plenty of already cleared, and in some cases degraded, areas exist in Amazonia to support agroforestry. A 'green' label should ensure that the fruits, nuts or other products have not come from fields cleared from primary forest.

A relatively large number of companies in North America and Europe are selling products based on items that are allegedly extracted from Amazonian forests (Table IV). In some cases, 'rainforest' products are gathered in forest as well as grown in agroforestry systems within Amazonia or other parts of the tropics.

Cupuaçu and guaraná are the only agroforestry products from Amazonia that have penetrated international markets on any scale. Foreign markets may be more glamorous, but competition is severe. While scope certainly exists for the aggressive marketing of Amazonian fruits and nuts in Europe and North america, agroforestry producers in Amazonia would be wise to continue focusing on the regional and national markets.

To make further inroads in international and national markets, suppliers of tropical fruits, nuts and oils in Amazonia will need to maintain high quality standards and ensure that the products are not based on farming practices that harm the environment. One way to achieve this goal is to foster strong growers' associations and cooperatives that can attract the necessary credit to establish processing plants and ensure quality standards. With modest incentives, more entrepreneurs might also be enticed to invest in agro-industrial plants geared to freezing fruit pulp and producing oil or nuts. In March 1994, the Brazilian government passed a law (Lei 8·864) to encourage the development of small companies; the setting-aside of fiscal incentives to commercialize fruits and nuts produced in Amazonia would undoubtedly help put agroforestry on a more sound financial footing in the region.

POLICIES TO PROMOTE AGROFORESTRY AND PREVENT LAND DEGRADATION

Given the benefits of agroforestry for the environment and society, a number of steps are warranted to spur its further development. First, more small- and large-scale agroindustries for processing tropical fruits, nuts and industrial products should be established. Second, agricultural research organizations would benefit by working more closely with farmers when setting their priorities and in the design and implementation of research programs. A research station approach to agroforestry is likely to be several years behind the farmers.

Tropical fruits warrant high priority in agricultural research programs (Evans, 1993: 372). Especially promising candidates for further agroforestry development in the Amazon include peach palm, cupuaçu, passionfruit, soursop, guaraná and commercially valuable cultivars of mango that are adapted to the varying conditions of the region. Peach palm has the added advantage of providing a high-quality heart-of-palm (palmito), and the waste from the palmito industry can be fed to livestock.

A number of other steps are necessary if the potential of agroforestry is to be realized. Well-run nurseries are needed to produce high-quality planting material. Growers' associations and private companies are best suited to this task. The efficiency of extension services needs to be improved so that large numbers of farmers are reached with appropriate planting material and other necessary technologies;

Table IV. Some plants used in products marketed by companies in North America and Europe that are suitable for commercial agroforestry in Amazonia

Plant(s)	How used	Product name	Company
Cosmetics			
Various essential oils of Amazonian trees	Perfume	Amazone	Hermès, Paris
Annatto	Shampoo	Emerald Forest	Natural Nectar Corporation, Santa Monica, CA
Avocado	Body lotion	Avocado Body Lotion	Crabtree & Evelyn, UK (specific product made in Switzerland)
Passion fruit	Cleansing gel, bath beads	Passion Fruit Cleansing Gel; Passionfruit Bath Beads	The Body Shop (main HQ in UK)
Brazil nut	Hair conditioner	Brazil Nut Conditioner	The Body Shop (main HQ in UK)
Papaya	Shampoo	Papaya Miracle Shampoo	Freeman Cosmetic Co., Beverly Hills, CA
Beverages			
Cupuaçu	Fruit juice	Tropical Rain Forest Cupuassu	Knudsen & Sons, Chico, CA
Soursop	Fruit juice	Guanabana Nectar	Goya, Bayamon, Puerto Rico
Soursop	Fruit juice	Guanabana	Libby's Brand, Nestlé Beverage Co., San Francisco, CA
Mango	Fruit juice	Mango Nectar	Libby's Brand, Nestlé Foods Corporation, Purchase, NY
Annatto	Colorant for orange soda	Sunkist	Coca-Cola & Schweppes Beverages Ltd., Uxbridge, UK (Sunkist is a registered trademark of Sunkist Growers, Sherman Oaks, CA 91423)
Preserves/Jams/Jellies			
Guava	Jelly	Pure Guava Jelly	Palmalito Brand, Palmetto Canning Co., Palmetto, FL
Mango	Jam	Mango Jam	Goya Foods, Inc., Secaucus, NY
Desserts			
Annatto	Food colorant	Rhubarb Custard Style Yogurt	Safeway, UK (main HQ in USA)
Mango	Sherbet	Mango Sorbet	Sharon's Sorbet, Old Chelsea Station, NY
Brazil nut	Ice cream	Rainforest Crunch	Ben & Jerry's, Waterbury, Vermont
Cereals/Snacks			
Brazil nut	Breakfast cereal	Rainforest Crisp	Rainforest Products, Inc., Berkeley, CA
Brazil nut	Cocktail snack	Rainforest Tropical Mix	From the Rain Forest, Inc., New York, NY

both the public and private sectors have a role to play here, especially non-governmental organisations (NGOs).

The resiliency of agroforestry hinges on a continuous supply of new varieties and crops, which in turn depends on an adequate pool of genetic materials. All of the perennial crops used in agroforestry systems in Amazonia arose in the tropical forests of Latin America, Africa, Asia and Polynesia. Tropical forests still contain wild populations of crop plants, near relatives that might be suitable for domestication or plant breeding, and traditional varieties maintained by indigenous people and peasants. Recognition of the importance of tropical forests as reservoirs of plant resources is growing. In Rondônia, for example, some landholders are leaving forest stands on their properties in response to the growing demand for seed of commercial timber trees. Unless tropical forests around the world are better protected and managed, many of the genetic resources vital for sustaining agroforestry systems will be lost forever.

ENDNOTE

[1]Some mangoes on sale in a supermarket in Vienna, Virginia, in March 1994 bore stickers stating 'Certified Organic'. The slender yellow mangoes, resembling the Manila variety popular in Mexico, were imported from Haiti.

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