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ENVIRONMENTAL IMPACTS OF, AND BIOLOGICAL AND SOCIO-ECONOMIC LIMITATIONS ON NEW CROP DEVELOPMENT IN BRAZILIAN AMAZONIA

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Abstract: Since the Native American population was decimated between 1550 and 1750 most agricultural development in Amazonia has involved new crops. Even when the crop being developed was native to Amazonia, e.g., rubber (*Hevea brasiliensis*), the production systems used were different from Native American systems and were therefore new cropping systems. Each new crop caused environmental impacts, because introduced production systems required complete forest removal. Depending upon the production system used, each new crop has a different long-term environmental impact. The most pronounced long-term impact is by pasture, while the least is by some new forest management systems, both for timber and for non-timber species. While new crops have impacts on the Amazonian environment, this environment also has impacts on the new crops. The main biological impacts are pests and diseases, since Amazonia's enormous biodiversity includes its fair share of aggressive and highly adaptable pests and diseases. A new disease, fatal yellowing, the causal agent of which has not yet been identified, is infecting African oil palm (*Elaeis guineensis*), which has a moderate long-term environmental impact. There are also significant socio-economic limitations to new crop development in Amazonia, including a small and fragile research & development corps, lack of financial support by banks or government, and a minuscule entrepreneurial contingent to take the necessary risks. An array of specific examples are presented to illustrate each case. Free-trade also limits new crop development in the region because socio-economic and biological limitations are less important elsewhere. Amazonia will only be developed sustainably if long-term environmental impacts are moderate to low and the new crops used do not suffer fatally-severe biological pressures and their profits are distributed equitably.

Introduction

Brazilian Amazonia is so extensive (5×10^6 km^2) that any major planting of a currently marketable crop is likely to depress its price significantly (Fearnside 1989), even if the crop is a staple, such as cassava (*Manihot esculenta*). Consequently, new crop development should be an essential research and development (R&D) activity in the region. Although new crops are likely to have good prices initially, if adequately marketed, their expansion causes environmental degradation and will ultimately be limited by this degradation, market forces, and current and emergent biological pressures that are part of Amazonia's biodiversity. The threat of climate change and the loss of planetary biodiversity are also important environmental limits to agricultural expansion in Amazonia (Myers 1984). The development of new crops in Brazilian Amazonia is strongly limited by socio-economic forces also, foremost of which are a small R&D community with few resources and a severe lack of entrepreneurs to take the best options to market. This paper reviews trends in environmental degradation by agriculture in Amazonia and examines some of the biological and socio-economic limitations to new crop development in the region. The focus is on the *terra firme*, the non-flooded plateaus of Amazonia, since this area occupies 94-96% of Brazilian Amazonia, the other 4-6% being floodplains.

Environmental impacts

Since the Native American population was decimated between 1550 and 1750, most agricultural development in Amazonia has involved new crops. Even when the crop developed is native to Amazonia, e.g., rubber (*Hevea brasiliensis*), the production systems used are different from Native American systems and are therefore new cropping systems. Each new crop causes environmental impacts because most introduced production systems require complete forest removal. Depending upon the production system used, each new crop has a different short, medium and long-term environmental impact. Fearnside (1983, 1990) and Serrão & Homma (1993) have examined these impacts in detail for different production systems, so I will only summarize the three of the major environmental impacts.

All modern agricultural production systems start by cutting and burning the forest. In the last two decades about 10% of the Amazonian forest in Brazil (~4 x 10^6 km^2) has been cut for various agricultural uses (Fearnside 1993), resulting in the elimination of forest from at least 4.26 x 10^5 km^2 as of 1991. The rate of deforestation depends upon the health of Brazil's, and the planet's, economic system (Fearnside 1993); during recessions it slows and during expansions it accelerates. Between 1978 and 1988, for example, the deforestation rate averaged 2.2 x 10^4 km^2 per year (although the decade included the second oil shock and Brazil's debt crisis in the first half, the economy was strong enough by 1988 to deforest 3.7 x 10^4 km^2), but by 1991 had dropped by half (to 1.1 x 10^4 km^2) as the Brazilian economy staggered from the results of the partial opening of its internal market to competition. A close examination of the deforestation x land tenure data reveal that the majority of deforestation is by large landholders, contrary to the common perception that the poor are deforesting Amazonia for want of jobs in other parts of Brazil (Fearnside 1993). This explains the close relationship of deforestation rate with the health of the economy.

The burning of the forest immediately transforms 30 to 50% of the biomass (127-666 t/ha) into carbon emissions and charcoal (Fearnside et al. 1993). Although there is considerable argument about the amount of carbon going into the atmosphere each year, everyone agrees that the deforestation of Amazonia plays an important part in yearly carbon emissions to the atmosphere. If the deforested area is used for pasture, fire is thereafter used to control weeds and burns not only the weeds but variable parts of the 50 to 70% of the original biomass not burned immediately. If the area is used for other agricultural options, a frequent first step to prepare the land is accumulating unburned wood and reburning it, thus releasing more carbon into the atmosphere.

Carbon stocks recover at different rates in different agricultural systems but only return to the original size if forest is allowed to return to the area (Fearnside & Guimarães 1996). More work on this subject has been done than on biodiversity recovery and is reviewed by EPA/LBL (1992) and Fearnside & Guimarães (1996). One important limitation to biomass recover is the degree of nutrient depletion at the site before it is allowed to return to forest.

The elimination of forest results in the immediate extinction of a large part of the biodiversity at the site (an unknown percentage of the mobile species leave during and soon after cutting of the forest and those that stay die in the burn). What this means in terms of the extinction of species, either locally or totally, is difficult to measure because there is not much information on species distribution and abundance in Amazonia (Prance 1990) and because the relationship between the rate of deforestation and the rate of species loss is unknown (Lugo 1988). Nonetheless, various authors (reviewed by Lugo (1988)) have made estimates of how continuing deforestation will reduce biodiversity in Amazonia. None are conservative estimates.

While biodiversity does not have a directly measurable value in the current economic model, it does contain genetic resources, both of potential new crops and of wild populations and wild relatives of current crops. Recently, the first wild populations of lowland tropical America's major contribution to world food supplies, cassava, were found along the southern fringes of the Amazon forest (Allem 1994), precisely the area suffering the greatest deforestation. Arkcoll & Clement (1989) reviewed Amazonia's potential as a source of new food crops, the genetic resources of which are threatened by current deforestation and the lack of equitable development in the region (Clement 1991). Van den Berg (1982) reviewed the known medicinal plants in 31 botanical families, the genetic resources of which are threatened also. Indiscriminant harvesting of mahogany (*Swietenia macrophylla*) is threatening the genetic integrity of its natural populations in the southern half of Amazonia (Newton et al. 1994), which may eliminate the chance of sustainably managing this species there. Other forest species are already or will soon experience similar threats to their genetic integrity as the forest resources of SE Asia are exhausted and the world market turns to Amazonia for hard wood (N. Higuchi, INPA, pers. com., 1996). Smith et al. (1992) provide a good review of the potential of tropical forests to supply genetic resources for future crop improvement.

After a burned area has been planted, biodiversity starts returning to the area and accumulates to a level determined by the agricultural production system used. Well managed, continually cropped, annual systems, including pasture, have the lowest biodiversity recovery rates and are also the least sustainable without major capital expenditures (Fearnside 1987); they only accumulate much biodiversity after being abandoned. The size of the disturbed area also affects the rate of recovery, with large areas of abandoned pasture accumulating biodiversity much more slowly than small areas (Uhl et al. 1990). At the other end of the scale of biodiversity recovery are the swidden-fallow systems used by Native Americans and traditional farmers. Swidden-fallow plots are always small scale (0.5-2 ha) and useful species are planted into the initial cassava monoculture and useful volunteer species are encouraged, resulting in a rapid increase in species diversity (Denevan & Padoch 1987). Figure 1 presents some hypothetical curves illustrating the time necessary for local biodiversity to return to part of its former level. Because of local extinctions at each site, there is no guarantee that biodiversity will return to its former level, even though exotic species become a part of the local biodiversity over time (Lugo 1988).

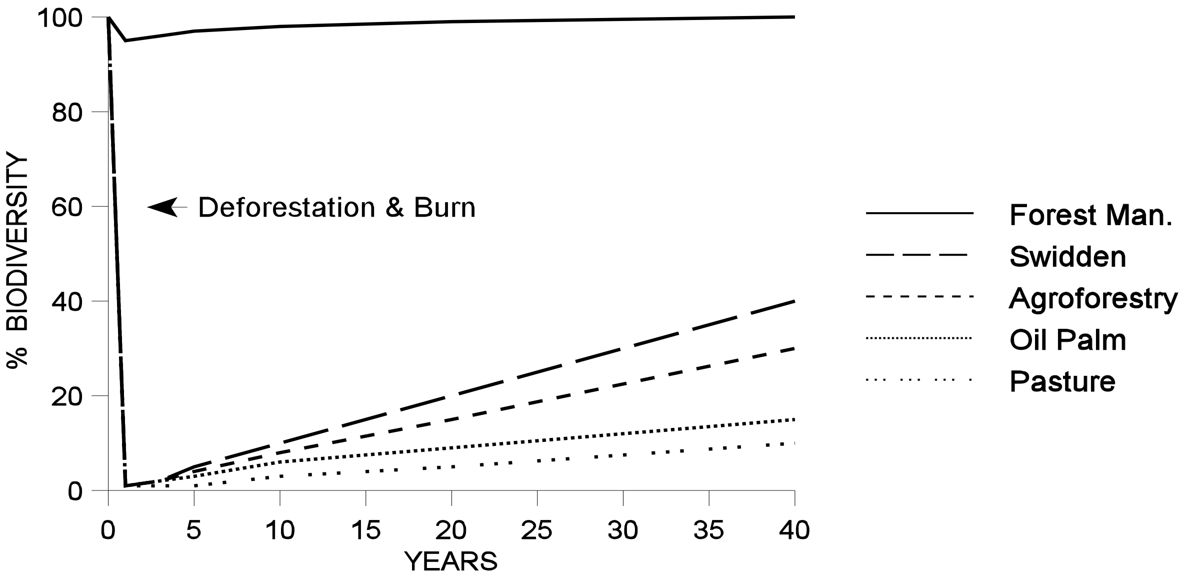

Figure 1. Hypothetical curves illustrating the recovery of biodiversity at small scale sites on poor soils in Amazonia. Forest management is the only production system that does not extinguish the majority of the site biodiversity immediately. Pasture recovers so slowly because it is assumed that there will be attempts to manage the pasture; in fact, most pastures are abandoned after 5 to 15 years and biodiversity recovery may be faster and more complete than illustrated.

While losses of biodiversity and contributions to the stock of carbon in the atmosphere receive most attention, clearing and burning the forest immediately contributes to other forms of degradation. The most immediately important for agriculture are those that limit the sustainability of yield at the site: direct nutrient depletion from the burn and from erosion and leaching before a new ground cover can be established. The burn also eliminates the soil's recycling system, since not only do the trees and other vegetation disappear, but the fire and subsequent lack of biomass inputs also kills the soil microorganisms essential to recycling. The denuded soil is subject to baking and is easily compacted, resulting in further erosion.

Approximately 75% of the soils of the Amazon basin are classified as acid, infertile Ultisols and Oxisols (Sanchez et al. 1982) and 90% are so deficient in phosphorous (< 7 mg/kg available P) that yields are low without inputs (Fernandes et al. 1996). On an infertile Oxisol near Manaus, there are ~32 kg/ha of P in the primary forest biomass (~425 t/ha) and ~12 kg/ha in the root biomass (~82 t/ha), as well as ~81 kg/ha of P in the topsoil (Fernandes et al. 1996). When the primary forest is burned, only about 6 kg P/ha are returned to the soil surface as ash. If a maximum burn efficiency (50%) is assumed, 12 kg P/ha are lost in smoke during the burn (27% of the original stock in the living or litter biomass). Nitrogen (44% of 1375 kg N/ha in the above ground biomass), potassium (44% of 331 kg K/ha) and other nutrient losses are as large or larger. Phosphorous, however, is the most critical element, since Brazil's P reserves are limited (Fearnside 1996). The nutrient stocks remaining at the site are sufficient for 2-3 years of annual cropping or to get a perennial plantation started, after which inputs are necessary (Fernandes et al. 1996).

Unlike biodiversity and carbon stock recovery, nutrient recovery is very slow, since the only natural source of new nutrients to the system is rainfall. Nitrogen inputs via rainfall vary from 5 to 22 kg/ha/yr, P inputs vary from 0.3 to 27 kg and K inputs vary from 4 to 25 kg (Proctor 1987), and are probably higher in eastern Amazonia because of the proximity of the ocean. Nutrient exports, via yield, tend to be much larger than these inputs (Fernandes et al. 1996), so this degradation can only be managed by long fallow cycles (20 to 40 years) or capital inputs (fertilizers).

Environmental degradation caused by processing of new crops is currently of minor official concern in most of Amazonia, since most agricultural production is primary and little industrial processing is done in the region. Nonetheless, locally important pollution does occur, mostly in the major cities. Unfortunately, Brazilian Amazonia's statistical data on these point sources is rudimentary, so their magnitude is currently unclear. The major pollutant in Amazonia today is mercury from small-scale gold mining, but this is unrelated to new crop development.

Although environmental degradation on a significant scale is likely to be the result of agricultural expansion in Amazonia, current trends point to further expansion regardless of the impacts. This is part of the "business as usual" scenario discussed by Meadows et al. (1992), because our current economic system considers these factors to be "externalities" and irrelevant to sustainable development. Nonetheless, degradation has significant future costs if society desires to maintain the productivity of these lands and work towards agricultural sustainability (Hecht 1992).

Biological limitations

While new crops have impacts on the Amazonian environment, this environment also has impacts on the new crops. These biological impacts are mainly pests and diseases, since Amazonia's enormous biodiversity includes its fair share of aggressive and highly adaptable pests and diseases. As agriculture expands into new areas and expands the area in any given crop, new agricultural pests and diseases are expected to emerge (Gilbert & Hubbell 1996, Real 1996), just as new human diseases are currently emerging from the tropical forests.

African oil palm (*Elaeis guineensis*), for example, which has a moderate long-term environmental impact, has been severely effected by a new disease, fatal yellowing, the causal agent of which has not yet been identified (Freire 1988). The disease in Brazil has symptoms similar to those reported from an unidentified disease in Colombia, Ecuador, Costa Rica and Panama, and is equally virulent. Consequently, it is impossible to identify the origin of fatal yellowing at this time.

The oil palm industry in eastern Amazonia was established in 1964 and remained free of important diseases until 1974, when fatal yellowing was first observed. A decade later the disease became extremely virulent and between 1984 and 1988 35,000 plants were eliminated in an effort to control its spread. This effort was unsuccessful and it has since spread to most new plantation areas, following the expansion of oil palm in Amazonia (Figure 2). Lack of resources at the Center for Agricultural Research in the Humid Tropics (CPATU-EMBRAPA, Belém) and investment by the plantation companies restricted research to such an extent that the causal agent and probable insect vector remain unknown (A.A. Müller, CPATU, pers. com., 1996). During the last decade, other oil palm diseases have appeared and some are expected to become important in the near future (Freire 1988).

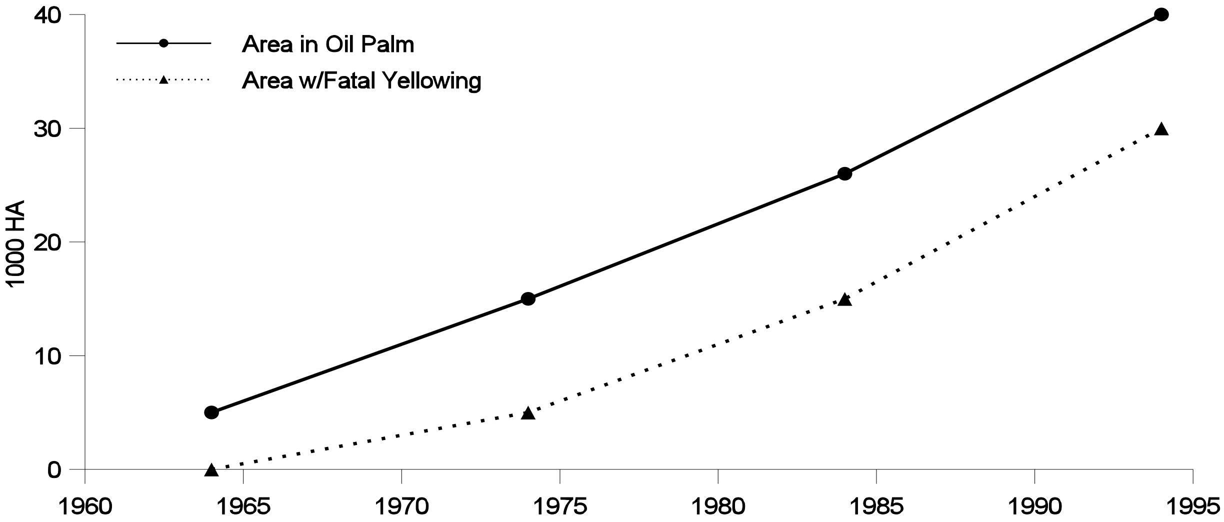

Figure 2. Growth in area planted to African oil palm (*Elaeis guineensis*) and approximate area with presence of fatal yellowing in Brazilian Amazonia (A.A. Müller, CPATU, pers. com., 1996).

The classic example of disease limitations in Amazonian agriculture, however, is South American leaf blight (*Microcyclus ulei*), which limits the expansion of rubber (*Hevea brasiliensis*) in monocultures (Wycherley 1995). In the forest, rubber occurs at a frequency of 1-2 trees/ha and is free of severe leaf blight attack. In extensive monocultures, with 350 to 450 trees/ha, leaf blight becomes a problem during the first rainy season, since the juvenile plants produce several leaf flushes during this period and are most susceptible when recently flushed (Williams et al. 1979).

After the rubber boom, Henry Ford tried to grow rubber in monoculture at Fordlândia/ Belterra, near Santarém, Pará, and was defeated by leaf blight (Hecht & Cockburn 1990). Shortly after World War II, researchers in Belém confirmed the defeat, but identified the possibility of planting small monocultures (2-3 ha) widely distributed in the forest. Rather than pursue this idea, Brazil's Ministry of Agriculture spent $2 x 10^9$ to subsidize medium and large-scale monocultures during the 1970s and early 1980s to make Brazil self-sufficient in natural rubber. Needless to say, this program was also defeated by the blight. Recently some of the inhabitants of the extractive reserves in Acre have decided to pursue the idea of small-scale monocultures (A. Sivieiro, CPAF-AC, pers. com., 1996), but it is still too early to determine if they will be successful.

Other well known disease limitations are Witch's broom (*Crinipellis perniciosa*) on cacao (*Theobroma cacao*) (Williams et al. 1979) and cupuaçu (*T. grandiflorum*) (Venturieri 1993) and fusarium wilt (*Fusarium solani*) on black pepper (*Piper nigrum*) (Fearnside 1980). Insects also limit agricultural expansion and sustainability in Amazonia. A good example is provided by a spittle-bug (*Deois incompleta* Ceropidae) on various pasture grasses in Amazonia. This bug has now caused Brazil's Agricultural Research Enterprise (EMBRAPA) to revise its pasture grass recommendations four times since 1970, from *Brachiaria decumbens* to *Panicum maximum* to *B. humidicola* to *B. briantha* and *Andropogon gayanus* (Fearnside 1996). In all these cases there was temporary genetic resistance provided by given genotypes or species that was soon overcome by the pest and new crop genotypes/species were developed or adopted. An insect that limits silviculture is the shoot borer (*Hypsipyla* spp.) on mahogany, which has made the plantation of this forest species completely impossible (Newton et al. 1994).

Sometimes new management strategies are recommended. One 'new' strategy that is often mentioned is interspecific diversity, i.e., agroforestry. It is doubtful, however, that low diversity agroforestry, the most widely adopted variant because of market, management and knowledge limitations, will provide much respite from pest and disease pressures. In a trial with 6 native and exotic fruit tree species in two designs, one of small monoculture plots (a mosaic) and one a planned mix of five species with the 6th as a "filler," stem borer (*Cratasomus* sp., Curculinidae) of soursop (*Annona muricata*) infested the agroforestry design as quickly as the small monoculture plots (Ferreira F° et al. 1985). The 'burning string' fungus (*Pellicularia koleroga*) infested both soursop and biribá (*Rollinia mucosa*) at the same rate in both designs also (M.L. Braz Alves, INPA, pers. com., 1986). It is possible that more diverse systems, such as home gardens, are more resistant to pest and disease infestations, but these diverse systems are mostly for subsistence and require considerable management and knowledge to maintain. The market seldom pays for the sustainability potentially available in these complex systems (Clay 1996).

Socio-economic limitations

Significant socio-economic limitations to new crop development in Amazonia include a small, underfunded research and development community, lack of financial support by banks or government, and a minuscule entrepreneurial contingent to take the necessary risks. Avoiding environmental degradation and managing biological limitations also requires capital and markets that will pay a premium for sustainably produced agricultural products. These socio-economic limitations often frustrate new crop development in Amazonia before the biological limitations set in.

In Brazilian Amazonia 9 states have universities and either a federal agricultural research center (the EMBRAPA system) or a state center. There are also two major federal research centers run by the Science and Technology Ministry, one of which has an agriculture department. Nonetheless, there are only a few researchers working with new crops; most work is with the established crops or related activities, such as soils, pests and diseases. No federal new crops program currently exists, nor do any of the states have one; a federal program was active in the mid-1980s but was canceled by a failed economic stabilization plan and never resuscitated.

The lack of established guidelines to direct work on new crops often results in a rush of institutional research on one species, while leaving dozens with similar potential unexplored. An example is our work with the peach palm (*Bactris gasipaes*), which started in 1976 (Clement & Arkcoll 1989). The peach palm has two major products, the fruit and the heart-of-palm. The fruit was most important to Native Americans because of good yields and nutritional quality similar to maize (*Zea mays*), so we directed most of our research towards that end since the fruit could feed not only humans but also animals. After 20 years of research the first entrepreneur has finally shown interest in the fruit! Along the way we identified a population of peach palm with spineless stems and leaf petioles which was interesting for heart-of-palm plantations in Brazil, where all previous harvesting of hearts had been from other spineless species of the genus *Euterpe*. As a result, more than 3000 ha of peach palm for heart-of-palm have been planted in southern Brazil in the last five years and every agricultural research station in Amazonia has active research on some aspect of the crop, even though there are less than 1000 ha planted in Amazonia. At a recent meeting we counted 50 researchers spending some fraction of their time on peach palm for either fruit or heart-of-palm. If those 50 researchers, and the scarce resources they have marshaled, were spread more equitably among the potential crops in Amazonia, a greater number of options would be available for the few entrepreneurs in the region.

Because there is little or no information available on most Amazonian crops (Arkcoll & Clement 1989), banks and government development agencies refuse to lend money for new crop development by entrepreneurs. While this is not unreasonable on the part of a bank, the government development agencies must transform this refusal to lend without information into a program to develop the necessary information, preferably in partnership with the entrepreneurs who first show interest in a new crop. Hearteningly, there are signs that some government agencies are coming around to this position, even if only as a way to show that they are indeed active in trying to promote sustainable development in Amazonia. A regional new crops program based in one of the major development agencies, such as the Superintendency for the Development of Amazonia (SUDAM), could help avoid the rush to one crop while generating useful information on many.

The scarcity of entrepreneurs with imagination and market savvy to take on the task of developing a market for a new crop is due both to an absolute lack of entrepreneurs in Amazonia (the region has 10% of Brazil's population and accounts for 60% of its territory, but it doesn't have 10% of Brazil's entrepreneurs!) and to past government policies that attracted entrepreneurs to non-sustainable activities by the easy availability of subsidies with few controls. The current economic plan has removed many subsidies to meet World Bank and IMF expectations for managing a more open economy and is forcing the entrepreneurial class to look for new alternatives. If the current plan is maintained, a new class of entrepreneurs may be scouting Amazonia for new crops within a few years.

Sustainable development, however, also requires social and political evolution, not merely economic growth. A dramatic lack of public education, community organization and political maturity is evident in Amazonia at present. Ameliorating these deficiencies is also essential to permitting the expansion of new crops in Amazonia, since the continued flow of economic benefits to the favored few is not sustainable (Fearnside 1996).

There are also direct economic limitation to the expansion of new and old crops in Amazonia. One has been mentioned in terms of environmental degradation: nutrient availability. Amazonia is rich in metals, but is poor in other minerals, notably P, Ca, Mg and K, all essential to plant growth and deficient in Amazonian soils. While Brazil has reasonable reserves of Ca, Mg and K, it is deficient in P, which is exactly the most limiting nutrient for plant growth in Amazonia (Fernandes et al. 1996). If all of Brazil's currently active pasture (~10^5 km^2) were to be fertilized according to current recommendations (50 kg P/ha/yr or 5 t P/km^2/yr.), this would consume 5 x 10^5 t of this non-renewable resource, a significant portion of Brazil's annual output (Fearnside 1996). If all of Brazilian Amazonia's currently deforested land (4.6 x 10^5 km^2 in 1994, P.M. Fearnside, pers. com., 1996) were to be brought into pasture [the cheapest possible management alternative (Hecht 1992)] and managed according to current recommendations, Brazil would have to stop fertilizing better agricultural land in other parts of the country to supply Amazonia or import enormous quantities of fertilizer to supply this demand. The diversion of P fertilizer from more lucrative uses in other parts of Brazil or the importing of that amount transforms a question of nutrient availability in Amazonia into a major economic limitation to agricultural development in the region. While other major nutrients are not as scarce as P at this time, planetary reserves are not infinite and prices will increase as scarcity looms in the future.

Considering that almost any other new or old crop requires more fertilizer than pasture, nutrient availability limits almost all crops in the region. The few exceptions are rubber and other latex producing species, since the latex is generally an almost pure hydrocarbon, and one oil crop (*Copaifera multijuga*) that produces a pure oil from trunk vessels similar to those in latex producing species. The search for new crops with low nutrient requirements and low nutrient exports must become an essential part of any new crops program in Amazonia, or elsewhere for that matter.

Another economic limitation to new and old crop development in Amazonia is the distance to market. During the World Bank's Polonoroeste project in Rondonia, cacao and coffee (*Coffea arabica* and *C. canephora*) were promoted without considering that world markets are a long way from Rondonia. Some of the coffee remains because of a recent price recovery on the world market, but large areas of cacao are being transformed into pasture. While Rondonia is the most striking example of this economic limitation, all of Amazonia away from the coasts experiences it to some extent. This limitation provides another criterion for selecting a new crop: it must have a high enough unit value, either immediately or after local processing, to make it worth while for the producer and shipper in Amazonia (Arkcoll & Clement 1989).

The final economic limitation that I want to consider here is free trade. The whole world is looking for new crops that they can market competitively in the free-trade economic system that reigns today. Any new Amazonian crop that develops a new market will immediately be taken into cultivation somewhere else, especially if that somewhere has a production edge on the Amazonian producer. From the long list of biophysical and socio-economic limitations considered in this paper, it is clear that many other countries will have lower production and marketing costs than Amazonia. Homma (1990) examined this limitation with respect to extractive products that provide the basis for the economies of the extractive reserves in Amazonia (Allegretti 1990), but, in fact, the same argument holds true for any crop in Amazonia. Even Amazonian African oil palm producers are unable to compete on the world market because they have higher costs in Amazonia (A.A. Müller, CPATU, pers. com., 1996) than Malaysians or Africans with similar germplasm. This is not a trivial limitation but can only be addressed by reversing the trend to globalize the economic system.

Final considerations

Amazonia will only be developed sustainably if the current economic system is transformed, if enough new crops are developed to occupy a significant portion of the currently deforested area, if long-term environmental impacts are kept to a minimum, if the new crops used do not suffer fatally-severe biological pressures and if their profits are distributed more equitably. All of this is possible.

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