CHAPTER 6

AGROFORESTRY IN BRAZIL'S AMAZONIAN DEVELOPMENT POLICY: THE ROLE AND LIMITS OF A POTENTIAL USE FOR DEGRADED LANDS

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SUMMARY

Agroforestry is a use for deforested areas that is agronomically, socially and environmentally preferable to the cattle pastures that now dominate land use in Brazilian Amazonia. Agroforestry's advantages are for use in already deforested areas - native forest should not be cut to implant these systems. Much can be done to improve agroforestry systems themselves. Achieving the potential social benefits will require a clear definition of criteria for selecting the beneficiaries of the systems. Economic conditions must be created that remove the attraction of competing non-sustainable land uses, such as pasture, and increase the profitability of agroforestry. Evaluation of proposals for agroforestry projects must make use of criteria that assign appropriate weights to environmental and social functions and that do not eliminate the projects because of the relatively long time required for economic returns to begin. The place of agroforestry must be defined in the context of overall development policy.

Commodity market and resource limits severely restrict the area to which agroforestry systems can be expected to expand. These limits make agroforestry an illusion as a means of combating deforestation and recovering the vast areas of rapidly-degrading pastures in the region. Three important questions remain: what to do with the rest of the deforested land that cannot be converted to agroforestry, what to do with the rest of the forest that has not been cut, and what to do with the rest of the rural population that cannot be supported by agroforestry? These questions require fundamental policy

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decisions with respect to population, land tenure, taxes, financing, zoning, highway construction and the location and encouragement of industrial developments that offer employment alternatives to the agricultural misadventures that characterize Amazonia today. The size of the rural population must remain within the limits of the resources for its support. Agroforestry must be encouraged to fulfil its proper role in the region's development, but must not be used as an excuse for cutting forest, delaying effective measures to contain deforestation, or failing to recognize the limits of human carrying capacity in the region.

INTRODUCTION

Agroforestry, or the combination of trees (either planted or unplanted) with other trees, arable farming, or grazing, is justly recognized as a promising land use that should play a significant role in Brazil's development plans for the Amazon region (Dubois, 1979a,b; Fearnside, 1983a; Hecht, 1982; Weaver, 1979). However, it is easy to expect too much from this land use as a means of solving the region's environmental and social problems. Agroforestry is not an 'alternative to deforestation', but rather a land use for implementation on already deforested lands. Money and effort directed to agroforestry can have a positive effect on sustaining production in the region, but great care must be taken to ensure that such funds reach their intended beneficiaries and that the necessary conditions are created to allow this system to fulfil its promise. Defining the place of agroforestry within the overall development framework is necessary for guiding decision-making now, while the shape of development in much of the region is still within the power of national leaders to decide. Steps must be taken to:

(1) Improve agroforestry production systems;
(2) Establish criteria for selecting the beneficiaries of agroforestry;
(3) Create favourable economic conditions for agroforestry;
(4) Establish appropriate criteria for evaluating agroforestry proposals;
(5) Remove motives for competing non-sustainable land uses; and
(6) Define the place of agroforestry in overall development policy.

Agroforestry production systems

Much can be done to improve agroforestry systems and tailor technologies to the local environmental conditions and to the social needs in different parts of the region. Research must be carried out now because of the long lag time for obtaining results from experiments that include trees.

One category of needed improvement is increasing the diversity of species and combinations used (Montagnini, 1988). The tendency of fallows

Figure 6.1 Commercialization of rubber 'sernambi' (coagulated latex) on a floating market near Manaus, Solimoes River, Amazon, 1989. (Photo: S. Bahri)

managed in Amazonian Peru is toward greater diversity even without any stimulus from research initiatives (Unruh, 1990). Greater diversity carries the advantages of better cycling of nutrients, better use of light, water and soil inputs, possibly protecting against outbreaks of diseases and pests, greater protection against price variations in commodity markets, less pressure on the capacity of markets to absorb any one product, and use of the greater ability of small farmers to manage and harvest diverse plantings (as compared to management of such plantings by large enterprises).

Identification of species for inclusion in agroforestry systems should make maximal use of the accumulated knowledge of indigenous groups, *caboclo* farmers (poor, Portuguese-speaking residents born and raised in the Amazonian interior), rubber tappers and others. Many such people have centuries of experience with diverse plantings of tree and non-tree species; except for the marketing of forest products, many of these systems are themselves forms of 'agroforestry'. The wide array of fruits, spices, medicinal plants, etc., used by these groups could expand the value of both subsistence and commercially-oriented systems.

The choice of species for inclusion in the systems should be oriented towards producing high unit-value products with relatively small nutrient demands (oils, latex, resins, etc.) and a relatively small fraction of the production cycle spent as bare ground or annual crops between the tree crop

Figure 6.2 Rose wood timber (*Aniba rosaeodora* Ducke, Lauraceae), close to CIEX factory for extraction of linalol, Manaus, June 1992. (Photo: D. Mitja)

phases. For example, slow-growing but valuable hardwoods are better than wood for pulp or for charcoal. These patterns are difficult to follow in practice: products with high nutrient demands are often commercially valuable, and farmers generally choose the forms of production producing the fastest return, regardless of sustainability. As is the case with extractive systems, the wisest choices of products are those that can only be produced in Amazonia. New plants for producing pharmacological chemicals, for example, are not as easily substituted by other agricultural or industrial products as, say, sources of basic carbohydrates (although once medicinal value is recognized, drug companies quickly develop synthetic sources). Land uses in Amazonia must, to a large extent, be chosen to produce the products that the region is most capable of supplying in a sustainable fashion, rather than imagining that the region should rush to supply whatever markets elsewhere are eager to buy. The fact that consumers want beef or pig-iron, for example, does not mean that these are what should be produced in Amazonia.

For many of the products that Amazonia is capable of producing sustainably, the limiting factor lies in the organization of markets. Delicate balances exist between providing enough of a product to make it economically feasible and passing the limits either of market demand or of the region's capacity for sustainable production. If supply becomes too great, as is usually the common lot of commodities such as cacao, the world market price falls. The result is both loss of the hoped-for sustainability, when the costs of combatting agronomic problems such as the witches' broom fungus (*Crinipellis perniciosa*) become unjustifiable, and loss of the equally cherished maintenance of small farmer income levels.

The lack of an organized and reliable supply of a sufficient quantity of any one product presently renders many Amazonian products unsaleable. One Dutch timber merchant shopping for hardwoods at the Jari Project expressed this to me succinctly when he claimed that he could find an industrial market for *any* tree for which a sufficiently large and regular supply could be guaranteed (Henk Rodenhuis, personal communication, 1983). This raises the problem of producing sufficient quantities of single products while maintaining the diversity, the advantages of which were listed earlier, and controlling expansion of the system once the threshold is passed to make its growth economically self-perpetuating. For example, the 'total harvesting' of tropical rainforest now being practised by Japanese firms in lowland New Guinea – the term being a euphemism for clearcutting and chipping an entire forest independent of species – may produce a saleable product that is too tempting to control (Routley and Routley, 1977).

With these reservations, research to expand the use of Amazonia's forest products, and institutional arrangements to organize the purchase, transportation and marketing of these products, should continue. Parallel arrangements must be made, however, to keep such discoveries from fostering environmental destruction and implantation of non-sustainable land uses. Industrial processing research and marketing efforts should be directed toward uses that provide high-value products with little nutrient drain: resins and fibres, for example, should be favoured over wood intended for charcoal, alcohol, particle board and other bulk products. Fruits are also much better than wood: although they have highly concentrated nutrients, they also have high enough unit value to pay for nutrient inputs, provided that farmers are oriented towards sustaining production rather than simply moving on to new locations.

Much more investment needs to be made in agronomic research on the production systems themselves. This should start with systematic observations in examples of agroforestry systems already implanted by farmers in the region. Research institutions often have the tendency to scorn the 'unscientific' observations of humble farmers. In fact, the difference between a system that works and one that does not is usually readily apparent to the naked eye, requiring no carefully-controlled comparisons or statistical analysis. The most promising alternatives identified on the basis of folk knowledge can later be tested in controlled trials. Much time and money can be wasted in testing, on experiment stations, combinations of crops that traditional farmers have already found inviable. Starting from existing systems carries the additional advantage of greater acceptance when the improved technologies are subsequently promoted through extension programmes. A start in this direction is a survey of agroforestry systems in Brazilian Amazonia currently being undertaken by the National Institute for Research in the Amazon (INPA) together with the University of Amazonas (FUA), the Executive Commission for the Cacao Growing Plan (CEPLAC) and the Brazilian Enterprise for Agriculture and Cattle Ranching Research (EMBRAPA). Experimentation in Iquitos, Peru is obtaining promising results from systems based on local indigenous practices (Flores Paitán, 1988).

In addition to making maximum use of existing knowledge, the process of selecting the best combinations of species and spatial arrangements can be greatly speeded by increasing our capabilities to model agroecosystems in computer simulations. Advances are needed both in modelling and in data collection on the species and their interactions. Information is needed on such processes as root competition between species, relative growth rates, shading by different strata, tolerance to low levels of light, water and/or nutrients, allelopathic properties, nitrogen fixing and phosphorus solubilizing symbionts and ability to concentrate nutrients. Modelling offers a great potential improvement over the 'fruit salad' approach to designing agroforestry systems, where component species and spacings are haphazardly chosen for inclusion in the trials. The glamour of modelling must never be allowed to blind the investigator to the need for immense amounts of field data, the great value of the empirical knowledge of traditional peoples in the region, and the need for common sense. Models also do not substitute for actual trials to confirm the functioning of the theoretical systems identified. More advanced models that include economic scenarios and variability in weather and soils are also needed (Fearnside, 1983b).

Communication between researchers working on agroforestry should be facilitated. This is especially important because of the need for testing promising combinations in a wide variety of habitats and because of the barriers to communication through normal scientific channels. Most people working on agroforestry are not leading academics at major universities, but rather are employees of small tropical institutions that operate on very limited budgets. The researchers often have academic backgrounds that are wanting in both quantity and quality. Most subscribe to few or no scientific journals; most are monolingual. The Rede Brasileira Agroforestal – REBRAF (Brazilian Agroforestry Network), with its newsletter *Informativo Agroflorestal*, is a much-needed step (address: Rua Visconde de Pirajá, 111/713, C.P.70.060, 22.422 Rio de Janeiro-RJ, Brazil).

Finally, any agroforestry systems developed must be spread among the farmers through some sort of extension system. The ineffectiveness of the current system of short-courses and irregular field visits by young, inexperienced

Figure 6.3 Boiling of *Carapas* seeds for oil making, 1993. (Photo: J. Ferraz)

'agronomic engineers' is well known. Severe cultural impediments result in much inappropriate advice being offered and block acceptance of any appropriate suggestions that are given (see Fearnside, 1980a, 1986a; Moran, 1981). I would suggest use of a combination of on-farm demonstration plots where the farmers can see the systems for themselves, plus the establishment of a network of 'barefoot agronomists', recruited from within the farming population along the same lines as China's famous 'barefoot doctors'.

Beneficiaries of agroforestry development

The beneficiaries of any agroforestry development must be identified at the outset and the programmes designed to ensure that the benefits are not usurped by others. The question of 'development for whom?' must be answered before any other.

The most common conflict of interest in parts of the world where agroforestry is more widely used is between small farmers (or landless people) and large corporations or landowners. In India, for example, the 'social forestry' programmes now receiving increased support from the World Bank have benefited wealthy landholders and paper mills at the expense of the rural poor (Center for Science and Development, 1985: 51–62; Environmental Defense Fund, 1987). So-called 'wastelands' on public property such as roadsides or in unplanted portions of private landholdings provide critical supplies of firewood and animal fodder to poor villagers. When these lands are converted to *Eucalyptus* or other tree species, either by private owners or by village authorities, the poor are deprived of these resources. Ironically, India's 'social forestry' programme was launched with the avowed objective of helping the poor (see Eckholm, 1979: 48–56). While the present situation in Amazonia is quite different from that in India, similar conflicts of interest can arise.

One such conflict is between people already living in the region and those brought in from outside for special agricultural developments. Private colonization projects, such as those at Tucumã in Pará and near Alta Floresta and Sinop in Mato Grosso, have sold lots to farmers from southern Brazil who have sufficient capital to pay for them. Benefits for those already in the area are minimal. Settlement projects for promotion of agroforestry could similarly produce benefits only for outsiders. The rationale for directing developments in Amazonia only to the region's present residents and their descendants is argued elsewhere (Fearnside, 1984a, 1986a).

Agroforestry developments, like other forms of development, should be designed and implemented in full consultation with the participant population. The farmers should not be viewed as a 'target population' as though they were to be lined up and shot. Implanting the systems as a grassroots

Figure 6.4 Rubber extraction, Tefe region on Solimoes river, Amazon 1989 (Photo: S. Bahri)

effort has the advantages of better guaranteeing that the local people are benefited, ensuring greater dedication to the scheme on the part of the farmers, and allowing maximum adaptation of the technology to local edaphic and social conditions.

Economic conditions for agroforestry

A number of economic obstacles must be overcome to make agroforestry systems attractive. One is the impediment of competition from non-sustainable exploitation of the native forest: in the case of wood products, people cannot be expected to pay for wood produced by agroforestry when this raw material can be had for 'free' by destroying the forest. Within limits, the discrepancy in prices can be reduced by imposing taxes on forest products obtained in non-sustainable ways and by lowering the costs of agroforestry through tax benefits, price regulations, financing and other subsidies. Any concession of subsidies to agroforestry should be approached with great care – the subsidies given to non-sustainable enterprises such as ranches, sawmills and pig-iron smelters represent one of the principal reasons why agroforestry has not been competing successfully with destructive exploitation in Brazilian Amazonia.

The question of subsidies is a delicate one because of the potential for this type of support to deflect development in non-sustainable and environmentally destructive ways. This is amply illustrated by the history of cattle pasture in the Brazilian Amazon, which was planted with subsidies contributing up to 70% of its cost, despite obvious signs that beef production would be negligible (Fearnside, 1979a,b, 1980b; Hecht, 1985). Were agroforestry to be made highly profitable through subsidies, the vested interests that would form to defend continuation of these payments could maintain expansion until such ill-effects resulted as clearing of native forest for agroforestry, depression of product prices driving out unsubsidized competitors, and installation of poorly maintained and economically questionable plantations as a front for receiving government largesse.

Difficulty often arises in limiting subsidies to their intended beneficiaries. Subsidies in the form of price supports and tariff barriers against competition from imports can go to other interest groups within the country who are also producing the same product. Rubber, for example, is much more cheaply produced on plantations in South-East Asia, than in Brazil, because of the presence of the South American leaf blight fungus (*Microcyclus ulei*) in Brazil. The high price paid by Brazilian consumers of rubber products, although largely absorbed by intermediaries who purchase the latex from the rubber tappers in the forest, goes in part to subsidize the rubber tapper population. Tapping rubber is a potentially sustainable extractive system that has great benefit for society in maintaining the environmental functions of the forest, protecting from destruction unused and undiscovered products within the forest and providing a livelihood for a population of traditional residents (Allegretti, 1990; Fearnside, 1989a). The price subsidy is also enjoyed by landowners installing rubber plantations, especially in non-Amazonian parts of Brazil (however, the interests of the plantation owners, rather than the rubber tappers, are probably the primary reason for the government policies causing artificially high domestic rubber prices). As these plantations expand, the cost of purchasing rubber at the subsidized price could become prohibitive (presently only one-third of Brazil's natural rubber comes from domestic sources). Prices might well be lowered once the domestic market is saturated – possibly endangering the extractive system (unless the array of products marketed is increased). Such a scenario raises doubts about the feasibility of a dual price system where commodities produced by systems judged worthy of a subsidy would be purchased at higher prices than those produced in other ways. Presumably agroforestry would be awarded a subsidy, although it is well to remember that in the case of rubber it is plantations (some of which are installed through agroforestry) that threaten the sustainable and environmentally preferable extractive system.

The possibility of a dual price system raises the problem of controlling such an arrangement to ensure that production from non-sustainable systems is not simply certified as coming from one of the sustainable operations, thus allowing the subsidy to encourage the destruction it was intended to avoid. Wild animal breeding programmes provide the best example, having sometimes served as mechanisms for circumventing legislation that prohibits sale of animals and animal products from the wild. Any subsidy scheme for agroforestry would have to include sufficient controls to minimize similar abuses.

Initiating an agroforestry scheme requires that means be provided for the farmers to live until the trees begin to produce harvestable products. The best way of passing this barrier is to introduce agroforestry gradually, with annual crops interplanted between the young trees in order to provide food and income during the critical transition to forestry production.

Financial institutions can accelerate the spread of agroforestry systems by providing support for training, supply of seedlings and other inputs, and organizing processing and marketing. These arrangements require an institutional channel for funding small farmers. Such channels are difficult to establish and represent part of the reason for the traditional preference of multilateral banks for funding large public works instead of small farmers. Channelling money to small farmers requires a substantial administrative structure with great opportunity for inefficiency and corruption. Inspection of records and of farmers' lots represents a major task. Additional complications include the requirement of land titles as a prerequisite for receiving bank financing (many small farmers are excluded from official programmes because their land is untitled).

Institutions need to be fostered that actively promote the products among potential consumers and that minimize the share of the income that the farmers lose by selling to 'middlemen'. In the absence of co-operatives or other institutions the intermediaries between the farmer and the final consumer reap the vast majority of the financial benefits. Unless these losses are controlled, farmers remain poor no matter how valuable the products they produce may be. The wretched conditions of the rubber tappers during the height of the rubber boom (1850–1913) are testament to this (Bunker, 1985: 65–72). The co-operative at Tomé-Açu is the best example of a successful organization for supplying inputs and arranging sales of perennial crop production (Subler and Uhl, 1990). Finding buyers for diverse products is an essential function. Although the unique cultural traditions and social ties of the Japanese-Brazilians at Tomé-Açu make their example difficult to emulate by others in Brazil, much can be gained from their experience in overcoming one of the greatest impediments to agroforestry: the drain of money to middlemen.

Agroforestry requires that farmers stay in the same place for many years. While this fits the traditions of Asia, it runs against the norm in Amazonia. The turnover of small farmers in Amazonian colonization projects is extremely high. On the Trans-Amazon Highway, for example, the colonist population turned over during the first 4 years at a rate corresponding to a half-life of only 11 years (Fearnside, 1986a: 117). Because the new owner of a lot is likely to radically change the production strategy adopted, there is a danger that agroforestry plots initiated in any given lot may be abandoned or converted to other uses when a new owner takes over. Mechanisms are therefore needed to discourage the sale of lots. These could include bureaucratic impediments to transferring titles and heavy taxes on capital gains.

Evaluating agroforestry proposals

When proposals are analysed for financial support by national governments or by banks, the criteria normally applied would eliminate agroforestry projects. This is because of the high discount rates against which the expected financial returns of prospective projects are compared. Because the yield of forest products is limited by biological factors that have nothing to do with what can be earned on alternative investments in other parts of the economy, waiting for trees to grow to harvestable size or to begin to produce non-wood products is almost invariably judged to be uneconomic. Different criteria must be applied if the values of agroforestry and other slow-yielding land uses are to be recognized (Fearnside, 1989b).

Agroforestry has a social value in employing a significant number of people in productive labour. By generating income for presently poor sectors of society it could help to alleviate somewhat the great disparities in resource distribution. Fixing farmers on the land and encouraging local industry to process the products are both goals espoused by Brazil's government and by international lending agencies. Furthering these goals would require strict control over who benefits from agroforestry programmes, as mentioned earlier.

One of the values that must be recognized and somehow compensated is the value of forest in preserving environmental functions. The environmental value of agroforestry areas is less than that of native forest but is considerably greater than cattle pasture. The environmental value of agroforestry may be significant in some areas, such as the catchment basins of reservoirs in cases where conversion to pasture has already occurred.

Agroforestry, it should be made clear, is not a cost-effective remedy for deforestation in Amazonia. If prevention of deforestation is the main reason for supporting agroforestry, then the funds could better be spent in measures to remove the motivation behind the present rush to cattle pasture. Such measures will be discussed in the next section. Agroforestry's restraint on deforestation theoretically derives from the system's capacity to satisfy both the farmers' ambitions for increasing their wealth and the market's demand for forest products. The pioneer farmers in Amazonia have virtually limitless demand for material goods, in contrast to some traditional shifting cultivators. Rather than stop clearing when production is sufficient to feed the farmers and their families, clearing continues to the limits of the available financial and labour resources (Fearnside, 1980a, 1984b). In Rondônia, cacao, which has often been promoted as a restraint on deforestation, has frequently resulted in increased clearing when yields are high: the profits are invested in deforestation for cattle pasture (see Fearnside, 1987a). As for the possibility of saturating the markets for forest products, this is extremely unlikely in the most urgent case at present: the already-initiated scheme to produce pig-iron from charcoal in the Grande Carajás area. Use of agroforestry in this scheme is not recommended because the heavy nutrient drain caused by exporting large quantities of wood would make chemical inputs expensive to sustain production - and would create a strong temptation to abandon the system after degrading its nutrient capital. The planned smelters would require a *Eucalyptus* plantation almost ten times the area of managed plantations at the Jari Project, a possibility that is as unlikely to occur before all accessible native forest is sacrificed, as it is unlikely to function without major agronomic problems (Fearnside, 1988). With 18 billion metric tons of iron ore at Carajás the potential demand for wood for producing charcoal is virtually infinite.

The Carajás pig-iron scheme at its full 2.7×10^3 tons/year production rate implies a wood demand for charcoal equivalent to between 1000 km^2/year (Fearnside, 1989c) and 1500 km^2/year (Anderson, 1990) of deforestation. The price of pig-iron does not justify supplying the charcoal from plantations, but even if the price were high enough from the point of view of the pig-iron manufacturers, the existence of native forest virtually free of cost means that this resource would be the principal source of charcoal as long as forests exist in the area. In June 1990, the then-President Fernando Collor de Mello and then-Environment Secretary José Lutzenburger announced that 1×10^6 ha of plantations would be established along the Carajás railway, with the justification of absorbing carbon to diminish the greenhouse effect. It should be noted that these plantations, now being installed by Brazil's government-run mining firm Companhia Vale do Rio Doce (CVRD), will also supply a source of raw materials for pulp manufacture and possibly for the pig-iron programme. The greenhouse abatement benefits of the plantation scheme have, unfortunately, been exaggerated by a factor of two, since the calculation was done using the biomass of the plantations at the moment of harvest instead of the average over a landscape of plantations in different stages of growth (see Fearnside, 1990). The cheapest way to diminish Brazil's contribution to global warming would be to slow deforestation (Fearnside, 1989d), instead of trying to reabsorb part of the carbon in plantations. The same logic applies to agroforestry as to pure plantations, from the standpoint of carbon absorption.

The relative priorities given to different response options to global warming depend closely on the emissions impact attributed to deforestation versus other sources. To the extent that estimates of deforestation emissions are higher or lower than their true values, the priority of slowing deforestation changes relative to other options, such as facilitating carbon uptake by implanting agroforestry systems in unforested locations. Among other factors, the emissions from tropical deforestation depend on the biomass of the forest, higher biomass resulting in greater emissions when the forests are converted to other land uses. A lively controversy has surrounded the question of Amazonian forest biomass, with values used in global carbon calculations varying by approximately a factor of three (Brown and Lugo, 1984, 1992a,b,c; Brown et al., 1989; Fearnside, 1985a, 1986b, 1987b, 1991, 1992a,b, 1993; Fearnside et al., 1993; Lugo and Brown, 1986).

The lowest estimate is that of Brown and Lugo (1984), who derived a value of 155.1 t/ha for total biomass (dry matter, including roots) based on FAO forest volume surveys for 'tropical American undisturbed productive broadleafed forests'. Despite much evidence that the average total biomass of Amazonian forests is much higher than 155.1 t/ha, this biomass estimate still forms the basis of emissions estimates for tropical deforestation adopted by the Intergovernmental Panel on Climate Change (IPCC). The IPCC 1992 supplementary report (Watson et al., 1992: 33) opted not to revise the land-use change emission estimate of 1.6 gigatons (Gt = 10^9 t) (carbon) C/year derived in the IPCC's 1990 scientific assessment (Watson et al., 1990: 17). The IPCC estimate of tropical deforestation emissions is the midpoint of the 0.6–2.5 Gt C/year range of values for emissions in 1980 reported by Detwiler and Hall (1988) and by Houghton et al. (1985, 1987, 1988) (Watson et al., 1990: 11). All of the studies that produced these emissions calculations used the forest biomass estimates of Brown and Lugo (1984). Brown and Lugo have themselves abandoned their 1984 estimate, revising it upwards in subsequent studies (Brown et al., 1989; Brown and Lugo, 1992a,b).

Based on 2954 ha of forest volume surveys distributed throughout the region, the average total biomass (dry weight, including below-ground and dead components) for all unlogged mature forests present in the Legal Amazon is 412.4 metric tons per hectare (t/ha); the average pre-logging biomass for the forests cleared in 1990 was 389.6 t/ha – lower than the average for the region because deforestation is advancing into the Legal Amazon from its eastern and southern edges where forest biomass is less than the average (updated from Fearnside, 1992b). Preliminary estimates adjusting for logging lower total biomass over the region as a whole to 411.6 t/ha (a reduction of only 0.2%), and lower biomass at the time of clearing to 363.6 t/ha (a reduction of 6.6%) (Fearnside, 1992b). These estimates are all more than double the 155.1 t/ha value still used by the IPCC, indicating that slowing deforestation is even more attractive than it otherwise would be in comparison with other global warming response options, such as subsidizing agroforestry.

Removing motives for competing non-sustainable land uses

People cannot be expected to invest in sustainable land uses as long as non-sustainable alternatives produce greater returns. Agroforestry in Amazonia now competes with the highly profitable activity of land speculation. Land is cleared and planted to pasture as quickly as possible in order to secure title to the land and/or to prevent squatters or neighbouring ranchers from usurping the claim. Pasture, as the cheapest means of occupying the cleared land, results in a handsome profit when the land is sold – even if beef production is zero. Construction of highways greatly increases the value of nearby land, thus adding to the motive for clearing to secure speculative profits. The financial gain to investors planting pasture has been even greater in projects that have received incentives and special financing through the Superintendency for the Development of Amazonia (SUDAM) and the Superintendency for the Manaus Free Trade Zone (SUFRAMA). On 16

January 1991 a law (no. 167) limited incentives, only to be reversed on 17 April 1991 (Decree No. 101); not until 25 June 1991 was a decree issued barring 'concession of incentives that entail deforestation in areas of primary forest and destruction of primary ecosystems' (Article 15, paragraph 3). Care will be needed to see that this is interpreted to include already-approved incentives. Amazon pasture is not sustainable without heavy inputs that are unjustifiable on their own economic merits and ultimately are limited even if subsidized (Fearnside, 1979a, 1980b, 1985b).

Measures that would remove some of the profitability of pasture include:

(1) Disallowing this land use as an 'improvement' (*benfeitoria*) for establishing land tenure claims;

(2) Taxing pasture, perhaps with a heavier tax for degraded pasture;

(3) Heavily taxing the profits from land sales;

(4) Erecting bureaucratic impediments to transferring land titles to new owners;

(5) Attention to interpretation of the present decree regarding incentives for pasture such that tax advantages and a variety of other subsidies halt for all projects (including the over 300 SUDAM projects already approved); and

(6) Not building roads into presently inaccessible parts of Amazonia.

Since the above measures are all either administrative changes or stopping of public expenditures, they could all be acted upon at no expense (and in some cases at considerable saving) to the government.

Agroforestry in overall development policy

Agroforestry projects have an important role to play in Amazonian development, but the temptation to expect too much from these systems is very great. As already stated, agroforestry does not represent a cost-effective remedy for deforestation in Amazonia today. Agroforestry is often seized upon for promotion in such a role because it is non-controversial: no one opposes agroforestry. Such easy agreement is lacking for issues such as agrarian reform, population growth, questions surrounding Brazil's international debt, and vested interests in road construction, ranching incentives, etc. Agroforestry can only be expected to occupy a relatively small part of Amazonia's vast area of already deforested land. Markets for many of the commodities produced by agroforestry systems can only absorb the production of a relatively small area. Perennial crops such as cacao and rubber offer good examples of tree species, the expansion of which is sharply limited by markets (in addition to biological problems). Diversifying the crops used could expand the area potentially converted to agroforestry systems.

Soils are appropriate for agroforestry in only a small part of the region. The location of agroforestry programmes must be established in accord with an agro-ecological zoning that reflects the edaphic limitations of the area. So far, the record of settlement schemes in respecting such limitations has been dismal (Fearnside, 1986c).

Financial resources that can be devoted to agroforestry systems are only sufficient for a relatively limited area – especially on degraded lands requiring fertilizer inputs. The approximately 5 million hectares in Brazilian Amazonia indicated by an EMBRAPA estimate as already degraded pasture (Serrão and Toledo, 1990) represent an area more than fifty times that of the managed plantations at Jari. An additional 5 million hectares are indicated by the same estimate as having been recently planted to pasture, which is presumably still productive. This area, while not classified as 'degraded' now, can be expected to enter this category within a decade. The costs of establishing and maintaining such an area in any land use that requires planted trees would be colossal.

Agroforestry systems must only be promoted on already deforested land, even if virgin forest land is better from the point of view of the systems' productivity. Agroforestry can help alleviate pressure for clearing forest by providing wood products (Winterbottom and Hazelwood, 1987: 102), but insistence on not sacrificing native forest is essential if the planted trees are to fulfil their promise in slowing deforestation (Budowski, 1984: 74). Making this kind of requirement work in practice can be difficult, as is shown by the explosion of deforestation in Bolivia in 1991 in anticipation of a major World Bank project to begin in 1992 for the benefit of lands that have 'already' been cleared.

The temptation to use forested land is great because of the 'free' nutrient capital present at the outset. In Rondônia, for example, CEPLAC has insisted on virgin forest land as a precondition for financing cacao (Fearnside, 1984b). Use of degraded land, rather than virgin forest or high-biomass secondary forest, implies a cost in inputs and/or lower yields. One set of annual cropping systems proposed as transitions to agroforestry and other land uses is specifically not recommended for 'nutritionally depleted, compacted or weedy soils that are a product of mismanagement' (Sánchez and Benites, 1987: 1527; see also Benites, 1990). Indeed, the nutrient recycling advantages of agroforestry are lost if there are no nutrients to recycle (Sánchez, 1987).

Decision-makers pondering what to do with Amazonia's vast expanses of degraded pastures must confront the issue of how to pay for the increased costs and/or foregone production implicit in using these areas rather than prime virgin lands. This leads immediately to the question of who should benefit from such a programme. Much of the degraded land is on large ranches that have already received generous subsidies from Brazilian taxpayers in the form of fiscal incentives administered by SUDAM. Should these same firms and individuals receive further largesse in the form of subsidies to recuperate the degraded land for agroforestry? One solution would be to distinguish between 'new' and 'old' incentives. 'Old' incentives would be retained by their original beneficiaries, but would be diverted to agroforestry: provided that funds were used exclusively for implanting these systems on degraded land, the ranchers would continue to receive any money disbursed on the basis of 'acquired rights' to loans and tax incentives for ranching projects approved by SUDAM prior to the 1979 policy change that discontinued 'new' incentives in the high forest portion of the Legal Amazon, a change reaffirmed in October 1988 by the *Programa Nossa Natureza* (*Our Nature Programme*). The only use permitted for 'new' incentives, however, would be to recuperate the degraded lands for the benefit of small farmers.

The Brazilian government's agrarian reform programme for transfer of land from the failed cattle ranching schemes to small farmers is proceeding at a snail's pace because of resistance both inside and outside of the government. Almost all of the land transferred so far in the Amazonian part of Brazil has been virgin forest rather than degraded pasture. Whatever political decisions are reached with regard to the future scale of agrarian reform and of any programme to promote agroforestry in the degraded pastures, land and other resource limitations dictate that these measures will only make modest contributions to solving either the problem of degraded land or that of landless rural population (see Fearnside, 1985b, 1987c).

The limitations of agroforestry outlined above lead immediately to the questions of what to do with the still forested parts of Amazonia (since agroforestry should only be promoted in already cleared areas), what to do with the rest of the already deforested land that cannot be allocated to agroforestry, and what to do with the rest of the people who cannot be accommodated in the projects. The land which has not yet been deforested should be used for such activities as the extractive reserves proposed in Rondônia and Acre (Allegretti, 1990) and for systems of sustained management of native forest (see Fearnside, 1989b; Rankin, 1979). The approximately 2% of Brazil's Amazon region now allocated to National Parks and Forests should be increased by at least fivefold. The feasibility of land uses that maintain the presence of forest requires measures to slow deforestation. These include restricting road building and reforming decision-making procedures to ensure that environmental impact analyses are elaborated, publicly debated and impartially judged for approval before any decision is made as to the ultimate existence of the projects in question.

The issue of what to do with the portion of the already deforested land that cannot be converted to agroforestry systems has no solution at present. The inputs needed to maintain this land in production, either in pasture or in other uses, are currently unjustified and, in the case of systems requiring fertilizers, are incompatible with the limited stocks of these non-renewable resources. Options for many of these areas may be limited to allowing them to remain in secondary forest for the foreseeable future, thereby at least gaining some of the environmental functions of forest cover plus whatever production can be obtained from the stands as a result of enrichment with economically valuable trees.

What to do with the rest of the people who cannot be accommodated in agroforestry or other sustainable systems is a question that requires immediate answers. Agrarian reform is needed so that more rural population is supported in Amazonia and in the source areas from which the migrants to the region are coming. In addition to this, however, Brazil must address the question of rural-to-urban migration. Government policy has always been to do everything possible to prevent rural people from migrating to the cities, where the migrants cause problems such as increasing crime and the visibility of poverty precisely in the country's centres of political power. Problems occurring in remote Amazonian locations receive much lower priority. People in large cities also have a tendency to support opposition political parties, regardless of what party is in power (a phenomenon evident not only in Brazil but all over the world). Political leaders are therefore strongly motivated to divert to rural areas in Amazonia the flow of people leaving the countryside in other parts of Brazil.

The government facilitates the flow of population to Amazonia at great financial cost by building highways and establishing settlement projects. The expense would be even more prohibitive were account made of the long-term cost of providing the fertilizers and other inputs that would be needed to maintain indefinitely the agriculture implanted by the settlers. Environmental costs of encouraging population flow to Amazonia are also high: a person clearing forest in Rondônia has a much more negative impact on the environment than does someone living in São Paulo. From the standpoint of greenhouse emissions, the average rural person in Amazonia emitted greenhouse emissions through deforestation in 1990 equivalent to 150 Brazilians burning fossil fuels in other parts of the country (Fearnside, 1992b). People living in the countryside also tend to have more children than those in cities, thus further magnifying their future environmental impact. The percentage of the population living in rural areas has declined steadily from 69% in 1940 to 32% in 1980 (Brazil, Presidência da República, IBGE, 1987: 57). Brazil's agriculture is rapidly transforming into mechanized and extensive systems more similar to those in North America where less than 5% of the population is rural. The country can only buck the rural-to-urban tide for a brief moment in its history, but most or all of the Amazon forest could be lost in the process. Rather than trying to divert to Amazonia the exodus of rural population from Brazil's South and Central-South Regions, these people should be encouraged to move to urban areas, and employment providing an acceptable standard of living should be offered.

Ultimately Brazil's policy-makers must recognize the necessity of keeping the population within the carrying capacity of each region and of the country as a whole. Defining carrying capacity inevitably leads to specific decisions on the productive systems used and the limits of their sustainable levels of production, the distribution of wealth within the population, the average standard of living and the minimum level acceptable, as well as intergenerational allocation of resources. Although agroforestry should be an important component of land-use plans in Amazonia, many of the wider problems that policy-makers frequently hope to solve by promoting this land use are bound to remain unsolved unless the limits of agroforestry are recognized and the more difficult but more far-reaching decisions are taken to halt deforestation and bring population into balance with resources.

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REFERENCES

Allegretti, M. 1990. Extractive reserves: an alternative for reconciling development and environmental conservation in Amazonia. In: Anderson, A.B. (ed.) *Alternatives to Deforestation: Towards Sustainable Use of the Amazon Rain Forest*, pp. 252–264. Columbia University Press, New York.

Anderson, A.B. 1990. Smokestacks in the rainforest: industrial development and deforestation in the Amazon Basin. *World Development*, **18**(9), 1556–1570.

Benites, J.R. 1990. Agroforestry systems with potential for acid soils of the humid tropics of Latin America and the Carribean. *Forest Ecology and Mangement*, **36**, 81–101.

Brazil, Presidência da República, Instituto Brasileiro de Geografia e Estatística (IBGE). 1987. *Anuário Estatístico do Brasil 1986.* Vol. 47. IBGE, Rio de Janeiro. 628 pp.

Brown, S., Gillespie, A.J.R & Lugo, A.E. 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science*, **35**(4), 881–902.

Brown, S. & Lugo, A.E. 1984. Biomass of tropical forests: a new estimate based on forest volumes. *Science*, **223**, 1290–1293.

Brown, S. & Lugo, A.E. 1992a. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia*, **17**(1), 8–18.

Brown, S. & Lugo, A.E. 1992b. Biomass estimates for Brazil's Amazonian moist forests. In: *Forest '90: Anais do Primeiro Simpósio Internacional de Estudos Ambientais em Florestas Tropicais Úmidas*, pp. 46–52. Biosfera-Sociedade Brasileira para a Valorização do Meio Ambiente, Rio de Janeiro, Brazil.

Brown, S. & Lugo, A.E. 1992c. Biomass of Brazilian Amazonian forests: the need for good science. *Interciencia*, **17**(4), 201–203.

Budowski, G. 1984. The role of tropical forestry in conservation and rural development. *The Environmentalist*, **4** (supplement 7), 68–76.

Bunker, S.G. 1985. *Underdeveloping the Amazon: Extraction, Unequal Exchange and the Failure of the Modern State*. University of Illinois Press, Urbana and Chicago. 279 pp.

Centre for Science and Development. 1985. Social forestry. In: *The State of India's Environment 1984–85: The Second Citizens' Report*, pp. 51–62. Center for Science and Development, New Delhi.

Detwiler, R.P. & Hall, C.A.S. 1988. Tropical forests and the global carbon cycle. *Science*, **239**, 42–47.

Dubois, J. 1979a. Importância de sistemas de produção agro-florestal para a Amazônia. Paper presented at the '2°. Simpósio Nacional de Ecologia', Belém, Pará, 19–12 November 1979. (manuscript). 11 pp.

Dubois, J. 1979b. Los sistemas de producción mas apropriados para el uso racional de las tierras de la Amazonia. In: *Seminário sobre los Recursos Naturales Renovables y el Desarrollo Regional Amazonico*, pp. 79–130. Bogotá, Colombia, 28–30 May 1979. Instituto Interamericano de Cooperación Agrícola (IICA), Turrialba, Costa Rica.

Eckholm, E. 1979. Planting for the future: forestry for human needs. *Worldwatch Paper 26*. Worldwatch Institute, Washington, D.C. 64 pp.

Environmental Defense Fund. 1987. The failure of social forestry in Karnataka. *The Ecologist*, **17**(4/5), 151–154.

Fearnside, P.M. 1979a. Cattle yield prediction for the Transamazon Highway of Brazil. *Interciencia*, **4**(4), 220–225.

Fearnside, P.M. 1979b. The development of the Amazon rain forest: priority problems for the formulation of guidelines. *Interciencia*, **4**(6), 338–343.

Fearnside, P.M. 1980a. Land use allocation of the Transamazon Highway colonists of Brazil and its relation to human carrying capacity. In: Barbira-Scazzocchio, F. (ed.) *Land, People and Planning in Contemporary Amazonia*, pp. 114–138. University of Cambridge Centre of Latin American Studies Occasional Paper No. 3, Cambridge, UK.

Fearnside, P.M. 1980b. The effects of cattle pastures on soil fertility in the Brazilian Amazon: consequences for beef production sustainability. *Tropical Ecology*, **21**(1), 125–137.

Fearnside, P.M. 1983a. Development alternatives in the Brazilian Amazon: an ecological evaluation. *Interciencia*, **8**(2), 65–78.

Fearnside, P.M. 1983b. Stochastic modeling in human carrying capacity estimation: a tool for development planning in Amazonia. In: Moran, E.F. (ed.) *The Dilemma of Amazonian Development*, pp. 279–295. Westview Press, Boulder, Colorado.

Fearnside, P.M. 1984a. Brazil's Amazon settlement schemes: conflicting objectives and human carrying capacity. *Habitat International*, **8**(1), 45–61.

Fearnside, P.M. 1984b. Land clearing behaviour in small farmer settlement schemes in the Brazilian Amazon and its relation to human carrying capacity. In: Chadwick, A.C. & Sutton, S.L. (eds.) *Tropical Rain Forest: The Leeds Symposium*, pp. 255–271. Leeds Philosophical and Literary Society, Leeds, U.K.

Fearnside, P.M. 1985a. Brazil's Amazon forest and the global carbon problem. *Interciencia*, **10**(4), 179–186.

Fearnside, P.M. 1985b. Agriculture in Amazonia. In: Prance, G.T. & Lovejoy, T.E. (eds.) *Key Environments: Amazonia*, pp. 393–418. Pergamon Press, Oxford, U.K.

Fearnside, P.M. 1986a. *Human Carrying Capacity of the Brazilian Rainforest*. Columbia University Press, New York. 293 pp.

Fearnside, P.M. 1986b. Brazil's Amazon forest and the global carbon problem: Reply to Lugo and Brown. *Interciencia*, **11**(2), 58–64.

Fearnside, P.M. 1986c. Settlement in Rondonia and the token role of science and technology in Brazil's Amazonian development planning. *Interciencia*, **11**(5), 229–236.

Fearnside, P.M. 1987a. Rethinking continuous cultivation in Amazonia. *BioScience*, **37**(3), 209- 214.

Fearnside, P.M. 1987b. Summary of progress in quantifying the potential contribution of Amazonian deforestation to the global carbon problem. In: Athié, D., Lovejoy, T.E. & Oyens, P. de M. (eds.) *Biogeochemistry of Tropical Rainforests: Problems for Research*, pp. 75–82. Universidade de São Paulo, Centro de Energia Nuclear na Agricultura (CENA), Piracicaba, São Paulo, Brazil.

Fearnside, P.M. 1987c. Reply to comments. (on causes of deforestation) In: Dickinson, R.F. (ed.) *The Geophysiology of Amazonia: Vegetation and Climate Interactions*, pp. 57–61. John Wiley & Sons, New York.

Fearnside, P.M. 1988. Jari at age 19: lessons for Brazil's silvicultural plans at Carajás. *Interciencia*, **13**(1), 12–24; **13**(2), 95.

Fearnside, P.M. 1989a. Extractive reserves in Brazilian Amazonia: an opportunity to maintain tropical rain forest under sustainable use. *BioScience*, **39**(6), 387–393.

Fearnside, P.M. 1989b. Forest management in Amazonia: the need for new criteria in evaluating development options. *Forest Ecology and Management*, **27**, 61–79.

Fearnside, P.M. 1989c. O ferro-gusa do Programa Grande Carajás. (Edited transcript of a presentation given on 11 April 1989 in the Round Table *Programa Grande Carajás: Inquérito Civil*, Câmara dos Deputados, Brasília. Instituto Apoio Jurídico Popular-AJUP, Rio de Janeiro. (manuscript).)

Fearnside, P.M. 1989d. A prescription for slowing deforestation in Amazonia. *Environment*, **31**(4), 16–20, 39–40.

Fearnside, P.M. 1990. Comentários sobre o Projeto FLORAM. *estudos AVANÇADOS*, **4**(9), 288–289.

Fearnside, P.M. 1991. Greenhouse gas contributions from deforestation in Brazilian Amazonia. In: Levine, J.S. (ed.) *Global Biomass Burning: Atmospheric, Climatic,* *and Biospheric Implications*, pp. 92-105. MIT Press, Boston, Massachusetts, USA. 640 pp.

Fearnside, P.M. 1992a. Forest biomass in Brazilian Amazonia: comments on the estimate by Brown and Lugo. *Interciencia*, **17**(1), 19–27.

Fearnside, P.M. 1992b. Greenhouse gas emissions from deforestation in the Brazilian Amazon. *Carbon Emissions and Sequestration in Forests: Case Studies from Developing Countries.* Volume 2. LBL-32758, UC-402. Climate Change Division, Environmental Protection Agency, Washington, D.C., and Energy and Environment Division, Lawrence Berkeley Laboratory (LBL), University of California (UC), Berkeley, California. 73 pp.

Fearnside, P.M. 1993. Biomass of Brazil's Amazonian forests: reply to Brown and Lugo revisited. *Interciencia*, **18**(1), 5–7.

Fearnside, P.M., Leal Filho, N. & Fernandes, P.M. 1993. Rainforest burning and the global carbon budget: biomass, combustion efficiency and charcoal formation in the Brazilian Amazon. *Journal of Geophysical Research* [20 Sept. 1993], **16**,733–743.

Flores Paitán, S. 1988. Sistemas agroforestales experimentales basados em tecnologia indigena. Paper presented at the 'Simpósio Internacional sobre Alternativas para o Desmatamento' 27–30 January 1988, Belém, Pará. (manuscript). 25 pp.

Hecht, S.B. 1982. Agroforestry in the Amazon Basin: practice, theory and limits of a promising land use. In: Hecht, S.B. (ed.) *Amazonia: Agriculture and Land Use Research*, pp. 333–371. CIAT Series 03E-3(82). Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Hecht, S.B. 1985. Environment, development and politics: capital accumulation and the livestock sector in eastern Amazonia. *World Development*, **13**(6), 663–684.

Houghton, R.A., Boone, R.D., Fruchi, J.R., Hobbie, J.E., Melillo, J.M., Palm, C.A., Peterson, B.J., Shaver, G.R., Woodwell, G.M., Moore, B., Skole, D.L. & Myers, N. 1987. The flux of carbon from terrestrial ecosystems to the atmosphere in 1980 due to changes in land use: geographic distribution of the global flux. *Tellus*, **39B**, 122–139.

Houghton, R.A., Boone, R.D., Melillo, J.M., Palm, C.A., Woodwell, G.M., Myers, N., Moore, B. & Skole, D.L. 1985. Net flux of carbon dioxide from tropical forests in 1980. *Nature*, **316**, 617–620.

Houghton, R.A., Woodwell, G.M., Sedjo, R.A., Detwiler, R.P., Hall, C.A.S. & Brown, S. 1988. The global carbon cycle. *Science*, **241**, 1736–1739.

Lugo, A.E. & S. Brown. 1986. Brazil's Amazon forest and the global carbon problem. *Interciencia*, **11**(2), 57–58.

Montagnini, F. 1988. Agroforestry systems: current research needs. Paper presented at the 'Simpósio Internacional sobre Alternativas para o Desmatamento,' 27–30 January 1988, Belém, Pará. (manuscript). 26 pp.

Moran, E.F. 1981. *Developing the Amazon.* Indiana University Press, Bloomington, Indiana. 292 pp.

Rankin, J.M. 1979. Manejo florestal ecológico. *Acta Amazonica*, **9**(4) suplemento, 115–122.

Routley, R. & Routley, V. 1977. Destructive forestry in Australia and Melanesia. In: Winslow, J.H. (ed.) *The Melanesian Environment*, pp. 374–397. Australian National University, Canberra, Australia.

Sánchez, P.A. 1987. Soil productivity and sustainability in agroforestry systems. In: Steppler, H.A. & Nair, P.K.R. (eds.) *Agroforestry: A Decade of Development*, pp. 205–223. International Council for Research in Agroforestry (ICRAF), Nairobi, Kenya. 335 pp.

Sánchez, P.A. & Benites, J.R. 1987. Low-input cropping for acid soils of the humid tropics. *Science*, **238**, 1521–1527.

Serrão, E.A.S. & Toledo, J.M. 1990. The search for sustainability in Amazonian pastures. In: Anderson, A.B. (ed.) *Alternatives to Deforestation: Towards Sustainable Use of the Amazon Rain Forest*, pp. 195–214. Columbia University Press, New York.

Subler, S. & Uhl, C. 1990. Japanese agroforestry in Amazonia: a case study in Tomé-Açu, Brazil. In: Anderson, A.B. (ed.) *Alternatives to Deforestation: Towards Sustainable Use of the Amazon Rain Forest*, pp. 152–166. Columbia University Press, New York.

Unruh, J.D. 1990. Interative increase of economic tree species in managed swidden-fallows in the Amazon. *Agroforestry Systems*, **11**(2), 175–197.

Watson, R.T., Meira Filho, L.G., Sanhueza, E. & Janetos, A. 1992. Greenhouse gases: sources and sinks. In: Houghton, J.T., Callander, B.A. & Varney, S.K. (eds.) *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, pp. 25–46. Cambridge University Press, Cambridge, U.K.

Watson, R.T., Rodhe, H., Oeschger, H. & Siegenthaler, U. 1990. Greenhouse gases and aerosols. In: Houghton, J.T., Jenkins, G.J. & Ephraums, J.J. (eds.) *Climate Change: The IPCC Scientific Assessment*, pp. 1–40. Cambridge University Press, Cambridge, UK. 365 pp.

Weaver, P. 1979. Agri-silviculture in tropical America. *Unasylva*, **31**(126), 2–12.

Winterbottom, R. & Hazelwood, P.T. 1987. Agroforestry and sustainable development: making the connection. *Ambio*, **16**(2/3), 100–110.