# AGROFORESTRY IN THE BRAZILIAN AMAZON:

# APPROPRIATE TECHNOLOGIES AND RESEARCH PRIORITIES

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## ABSTRACT

Agroforestry refers to a set of land use systems that involve multipurpose trees, crops and/or livestock. There exist several agroforestry technologies currently being used in various parts of the American, Asian, and African humid tropics that can be adapted for maintaining the sustainability of food and wood production on deforested land and for recuperating the productivity of degraded land in the Brazilian amazon. These promising traditional and innovative agroforestry options include: "modified taungya", managed tree fallows, variations of alley cropping and alley farming, live fences, homegardens, and various forms of crop-tree-livestock systems.

Scientific agroforestry is relatively new. Given the variability and dynamic nature of human economic and ecological systems, various strategic and adaptive research priorities that will help to optimize ecological and economic sustainability and ensure the social acceptability of these agroforestry technologies are proposed. The research priorities discussed include: 1) characterization and evaluation of *terra firme* (upland) and *varzea* (river bank) land use systems in the Brazilian Amazon to help in deciding on best-bet agroforestry options based on farmer priorities, 2) identifying and understanding the key biophysical interactions between tree, crop and/or animal components of agroforestry technologies and the influence of management practices on these interactions, 3) selection, evaluation and management of multipurpose trees as fundamental components of any agroforestry technology, 4) adapting traditional systems and innovative technologies to help sustain productivity on recently deforested land and recover the productivity of degraded land, and 5) identifying the socio-economic constraints to the adoption of agroforestry technologies by farmers and developing land use policies and alternative economic models that provide the incentives to stimulate investment in agroforestry.

## Introduction

Food and wood production systems that involve the combination and management of trees, crops and/or animals simultaneously or in rotation on a given unit of land, are referred to as agroforestry. These systems are expected to play a major role in the sustainable development of tropical land use in the coming years. Agroforestry systems generally have low capital requirements and produce a range of food, wood and other economically useful goods (Nair and Fernandes, 1984). As deforestation increases, many forest products (fruits, nuts, fuelwood, medicinal plants) commonly gathered by rural populations are now increasingly in short supply. Agroforestry offers the possibility of substituting for these natural forest production systems via the production of fuelwood, building poles, fruits, and various other products within existing farming systems. In addition, agroforestry is characterized by a potential service roles such as soil conservation and the maintenance of soil fertility (Lundgren and Raintree, 1982). These service roles will be especially important in recuperating the productivity of degraded land and sustaining food and wood production on the 200 million hectares of mostly marginal soils that will be brought into cultivation for the first time this century (Dudal, 1980).

The potential of agroforestry systems to contribute towards a better quality of life for tropical farmers and enhance the potential for sustainability of their production systems is greatest when agroforestry is allied with other crop, livestock, and forest management systems (Anderson et al., 1985). It is worth noting that almost nowhere in the tropics does one find farmers reliant solely on agroforestry systems. Even the most complex and reportedly sustainable agrosilvopastoral systems in Java, Sri Lanka and East Africa are all associated with non-agroforestry systems for the production of basic staple food crops (Fernandes and Nair, 1986). An agroforestry system is considered sustainable if it continues to meet the increasing needs of people without degrading the basic resources upon which the system depends.

## Agroforestry Alternatives For The Brazilian Amazon

Brazil contains about 3.5 million km2 of tropical forests (Guppy, 1984) of which 2.5 to 2.8 million km2 are on upland ("terra firme") areas. Nearly 75 percent of the Amazon basin contains acid, infertile soils classed as oxisols and ultisols. Upland ("terra firme") soils are characterized by low nutrient reserves, high aluminum toxicity, and low phosphorus availability. The "varzea" or river bank soils of the white water rivers are generally more fertile due to the replenishment of nutrients via sediments deposited by flooding. Dark water varzeas are generally infertile sands and not normally used for agriculture.

The two main land use practices and proximate causes of deforestation in the Brazilian Amazon are cattle ranching and small-scale agriculture. To a lesser extent, logging, road-building, hydroelectric development, mining, and urban growth also play a role (Hecht, 1979; Mahar, 1988). In the case of small-scale agriculture the reasons for deforestation can be traced to poverty, unequal land distribution, rapid population growth, and low agricultural productivity. Small farmers get locked into a system that perpetuates subsistence agriculture and poverty. This vicious cycle has local, regional, and global impacts. The costs of deforestation include the irreversible loss of biodiversity and of forest products, soil erosion, flooding, siltation of hydroelectric facilities, and the release of carbon to the atmosphere.

Both small-scale agriculture and cattle ranching start with slash and burn of primary rainforest. Agricultural productivity of the cleared lands usually declines rapidly after the first year of cropping due to a combination of such factors as decreasing soil fertility, increasing weed infestation, unadapted crop varieties, and inappropriate management. The alternative is to clear and burn more rainforest for new pasture/crops for another year or to adopt improved technologies that increase output per unit of land. The latter normally requires greater labor and the use of inputs and usually results in farmers opting to continue the cheaper and less labor-requiring alternative of slash and burn cultivation or extensive, unmanaged pastures.

Agroforestry is not the solution to every land use problem, but in the case of the Amazon there are a number of agroforestry approaches which hold promise for the recovery of degraded or abandoned pastures and sustaining the productivity of recently deforested land. In both cases, the end result would reduce the need for further deforestation (Fernandes and Serrao, 1992). A schematic profile of the landscape and current land use along the lower and middle ranges of the Amazon river is presented in Figure 1.

1. Modified "taungya" for the recovery of degraded land

Introduced in Thailand in 1967 with the aim of reducing shifting cultivation and deforestation , the scheme offers landless shifting cultivators the opportunity to participate in a sustainable agroforestry economy while helping to establish and maintain forest plantations (Boonkird et al., 1984). Shifting cultivators are attracted to participate in forest establishment by various incentives such as community development, housing, clinics, schools, and tenure over permanent agricultural plots. The farmers are required to help establish and maintain forest plantations, in which they are permitted to raise agricultural crops during the first three to four years of establishment. In the Amazon, the modified "Taungya" scheme could be used to reforest the large areas of degraded uplands (Fig. 1). Incentives and credit facilities to permit intensification of land use on the farmer's permanent field plots would help towards self sufficiency in food production.

Fiscal incentives and capital costs for the modified "taungya" approach can be justified on the grounds of social equity, the fact that shifting cultivators would become agents of reforestation, the reduced need for timber harvests from primary rainforests if forest plantations are successfully established, and that the carbon accumulation by growing forest plantations is 20 to 100 times greater than that of degraded pastures (Houghton, 1990).

2. Managed fallows for food and wood production on degraded land

Both shifting cultivation and cattle ranching on extensive pastures in the Amazon have resulted in abandoned land with fallow vegetation. Overstocking and overgrazing of pastures generally result in reduced regrowth (number of species and biomass) of fallow vegetation (Uhl et al., 1988). The idea that it is possible to speed up the development of fallow vegetation and hence the recovery of the site via nutrient accumulation and weed control has led to the concept of "biologically enriched fallows" formed by planting of nitrogen-fixing species.

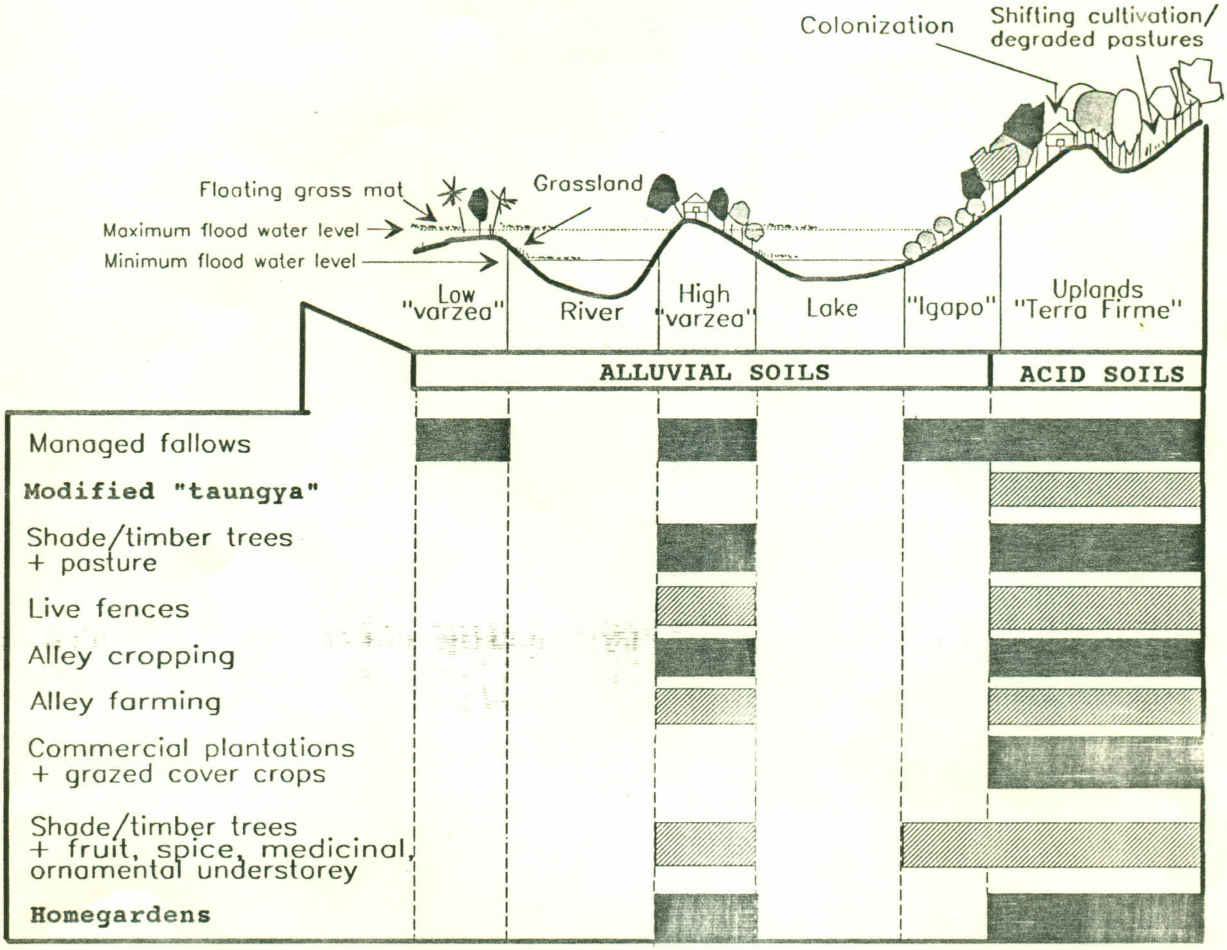


**Figure 1. Schematic landscape profile of the lower and mid Amazon River region. Agroforestry options for food and fibre production are indicated with respect to human activity in the landscape and major soil types**

Experimental data indicate a comparative advantage for weed control by some managed fallows relative to natural fallows (Szott et al., 1991). During the first 3.5 years of fallow regrowth, above-ground accumulation of nitrogen and phosphorus in most planted fallows were greater than those in natural fallows. Longer-term data on such planted fallows will be required in order to assess their impact on acid soils in the Amazon. Raintree and Warner (1986) speculate that interest in the adoption of biologically enriched fallows is not likely to arise until shifting cultivators have had experience with the struggle to maintain soil fertility. In the Amazon, the use of nitrogen-fixing, tree species tolerant to flooding may be one form of a biologically enriched fallow that would be adopted by varzea farmers (Fig. 2). These soils generally exhibit nitrogen deficiencies after one or two crops and would benefit from any biologically fixed nitrogen.

Enrichment of fallows with economically valuable species would appear to have greater potential for the Amazon. The planting of timber trees, fruit species (peach palm, graviola, cupuaçu, araça-boi ) and nut trees (Brazil nut) are likely to provide earlier and more substantial returns (relative to natural fallows). Kang et al.,(1991) report the use of oil palm (Elaeis guineensis) in Benin (West Africa) as a fallow species to accumulate nutrients and provide income via the production of palm wine. This "biologically enriched and economically valuable" fallow system .evolved from groves of trees originally planted for palm oil production and is currently estimated to cover 170,000 hectares in Benin and Togo. It is likely that several such potentially valuable species await discovery in the Amazon.

3. Alley Cropping on recently deforested land

Alley cropping has received considerable attention as an agroforestry technology with potential to sustain crop productivity via improved soil protection, nutrient cycling, and reduced weed pressure (Kang et al., 1990). The system involves the growing of food crops in the alleys formed by hedgerows of fast-growing, nitrogen-fixing trees. The hedgerows are pruned periodically to provide green manure or mulch for the crops in the alleys and to minimize shading and root competition by the hedgerows.

Experimental results from several studies on fertile soils (mainly Alfisols and Entisols) show that alley cropping can sustain crop yields, maintain soil nutrient status and prevent soil organic matter decline (Kang et al., 1990). Hedgerows planted along the contours on sloping land can physically minimize runoff and soil erosion. For the acid "terra firme" soils of the Amazon, however, the traditional model of alley cropping with crops such as rice and cowpea is unlikely to be sustainable. Low nutrient contents of Oxisols and Ultisols (the dominant soils in the Amazon) result in high competition between hedgerows and annual crops. Nutrient cycling by the hedgerows is often at the expense of the crop in the alley (Fernandes et al., in press).

Alley cropping on slopes with perennial crop species (*Bactris gassipaes, Theobroma grandiflorum, Bertholettia excelsa, Eugenia stipitata*) in the alleys is likely to prove more suitable for the Amazon. The chief function of the hedgerows would be to minimize runoff and erosion and control weeds via the provision of mulch. Suitable hedgerow species for acid soils include *Inga edulis, Gliricidia sepium, Cassia reticulata, Flemingia congesta, Calliandra calothyrsus*, and *Paraserianthes falcataria*. Since weed control is often a major factor reducing successful establishment and yields of many perennial crops, selection of commonly known species such as Inga edulis could significantly reduce weed pressures (Szott et al., 1991) and increase chances of the system being adopted by farmers.

The above modification to the traditional model of alley cropping could be used for the establishment of forest species as well. Hedgerows could be established with annual crops in the alley and after a year or so, forestry species planted in the alleys with the hedgerows serving as shade ("nurse") trees for the next 5 to 10 years. Thereafter, periodic lopping of the hedgerows would provide mulch to aid in weed control and recycle nutrients in hedgerow biomass.

The concept of "alley farming" involves the use of hedgerow prunings as high protein fodder for livestock (Kang et al., 1990). As a further modification, forage grasses could be planted instead of crops in the alleys and livestock allowed to "browse" the hedgerows. Such a system is generally more labor intensive as both livestock and hedgerows need management. In addition, the establishment of fodder hedgerows will require the application of fertilizers and possibly lime making the system reliant on capital investment. The system may, however, be cheaper to establish and maintain than improved, mixed grass and herbaceous legume pastures. Planting of hedgerows along the contours on slopes can also significantly aid in maintaining sustainability by minimizing loss of nutrients via run off and soil erosion. Given the extensive nature of pasture systems in the Amazon, however, it is unlikely that alley farming will be adopted without appropriate fiscal incentives.

4. Homegardens

The most intensive agrosilvopastoral systems (homegardens) are found where population densities range between 500 and 1000/km2 as in the case of Indonesia, East Africa, southeastern Nigeria and Sri Lanka. Agroforestry homegardens involve the deliberate management of multipurpose trees and shrubs in association with annual and perennial agricultural crops and livestock As many as 190 plant species at various stages of domestication have been recorded in these agrosilvopastoral systems (Fernandes and Nair, 1986). A similar system involving around 30 perennial and annual plant species has been developed by brazilian farmers in eastern Para, Brasil (Subler and Uhl, 1990).

Homegarden systems are found throughout the tropics. Such agrosilvopastoral systems have a high degree of ecological and biological sustainability coupled with good social acceptability. The factors that promote sustainability include diversified production, reduced risk of crop failure, enhanced labor efficiency, continuous production thereby minimizing post harvest losses, good nutrient cycling and reduced erosion because of good ground cover.

The high species diversity and sustainability of homegardens make them ideal for use in buffer zones around extractive reserves and protected forests and improves the chances for gene flow from wild to semi-domesticated populations of selected food and fruit species. In areas where deforestation is resulting in significant loss of biodiversity, homegardens could function as important secondary in situ germplasm banks of semi-domesticated species (Okafor and Fernandes, 1987).

5. Tree crop plantations with grazing of cover crops

Despite the beneficial effects of perennial crop plantations on soil conservation and nutrient cycling (Alvim, 1989), sustainable production of tree crop plantations (mainly rubber and oil palm) in the Amazon has rarely been possible due to a combination of pest problems and poor economic returns. The addition of the cover crop and animal component provides additional flexibility with respect to markets, economic returns and the purchase of required inputs. In addition to soil protection, leguminous cover crops (such as *Centrosema macrocarpum, Desmodium ovalifolium, Pueraria phaseoloides*) can contribute to soil N via nitrogen fixation. Even in the absence of leguminous cover crops, Tajuddin (1986) describes the successful integration of sheep, poultry and bees in rubber plantations in Malaysia. Sheep rearing under rubber proved to be socially and economically attractive and resulted in a 21 percent reduction in the cost of weed control in the plantations.

Given the unlimited national and international market potential for timber, the establishment of timber species in pastures would considerably improve the long-term economic returns and justify incentives and subsidies in the short term to help establish improved (grass-legume) pastures. A specified percentage of the pastures would be occupied by timber (e.g. *Carapa guianensis* Aubl., *Cedrelinga catenaeformis* Ducke., *Cordia goeldiana* Hub., *Dinizia excelsa* Ducke, *Swietenia macrophylla* King) and other economically important tree species. The use of fast-growing, "nurse species" (e.g. *Schizolobium amazonicum, Enterolobium cyclocarpum* Gris.)that yield economic returns in the short term while protecting the more valuable timber species will be required. Such mixed species associations may confer additional stability against pest outbreaks (e.g. shoot borer damage to high value timber species such as andiroba, mahogany, and cedro). The silvopastoral system outlined above would require more intensive management and thus provide greater employment opportunities as compared to traditional pasture systems.

6. Live fence posts and live fences

In all systems involving livestock, the use of fencing for animal control requires a large number of fence posts. The continuous removal of young trees from primary and secondary forests for establishing and maintaining fences is a serious and largely unnoticed form of deforestation in the tropics. The agroforestry practice of planting stakes that have the capacity to take root and continue growing results in live fence posts. Planting of such stakes more densely can result in a living fences. Species that are commonly used for live fence posts and living fences include *Gliricidia sepium, Erythrina* spp., *Spondias* spp., and *Pithecellobium dulce*. In areas where pastures predominate, live fence posts and living fences could have a significant impact against deforestation.

**Research Priorities to Ensure Suitable Agroforestry Alternatives for the Amazon**

Scientific agroforestry is urgently required to speed up the adaptation of existing traditional systems, develop innovative technologies, and promote the extension of these appropriate technologies to solve land-use problems. Given the variability and dynamic nature of human economic and ecological systems, various strategic and adaptive research priorities that will help to optimize ecological and economic sustainability and ensure the social acceptability of these agroforestry technologies are required.

a) If research is to design effective and transferable technologies, the first step will require the characterization and evaluation of the existing land-use (Lundgren and Raintree, 1983). Evaluating the performance of existing land-use systems would include the identification of problems that farmers have in meeting basic needs such as food, energy, shelter and cash. Once the key problems have been diagnosed, the constraints (causes of these problems) which limit the productivity and sustainability of the system need to be identified. The information from this diagnosis is then available for the identification of potentials for problem-solving agroforestry technologies.

b) The current knowledge about agroforestry technologies is still very limited. Even the most simple agroforestry technology is more ecologically and economically complex than a monocropping system. Identifying and understanding the key biophysical interactions between tree, crop and/or animal components of agroforestry technologies and the influence of management practices on these interactions will be vital to the development of appropriate technologies. Major research thrusts will include nutrient cycling and soil fertility maintenance, above and below ground competition for light, water and nutrients, organic and inorganic input management, tree-animal interactions (fodder, shade), and integrated pest management. The difficulty of studying these component interactions is further illustrated by the fact that none of the commonly used crop or forage grass genotypes currently used in agroforestry systems has been specifically bred for a mixed cropping system. As varieties more adapted to mixed cropping systems become available, the interactions can be expected to change.

c) Multipurpose trees are fundamental components of any agroforestry technology. Over 2000 species have been identified worldwide as potential candidates for agroforestry. In the Amazon, however, much remains to be done with respect to the identification and screening of native amazonian trees. In addition, the evaluation of promising exotic species for tolerance to constraints such as soil acidity and low nutrient availability is urgently needed. Included in this evaluation is the role of root symbionts (rhizobia, mychorrizal fungi), tree phenology, biomass production, and responses to coppicing and pruning. A major objective is to obtain improved multipurpose tree species and provenances with potential to improve the productivity and sustainability of agroforestry technologies.

d) To mitigate the deforestation and land degradation caused by slash and burn activities of small farmers and extensive livestock rearing, traditional and innovative agroforestry technologies need to be adapted to help. The six technological models described previously in this paper have the potential to improve the productivity on recently deforested land and recover the productivity of degraded land thereby reducing the need for further deforestation. A major objective is to improve existing systems rather than generating completely new ones. In addition, on-farm systems research is vital to improve the acceptability and eventual adoption of these systems by farmers.

e) The adoption of agroforestry technologies by farmers will depend on appropriate land use policies, institutional support, socio-economic constraints, and fiscal incentives. Slash and burn cultivation requires lower capital and labor investment than most agroforestry and alternative agricultural production systems. Land use policies and international financing which reflect the true international cost of deforestation and the resultant loss of potentially valuable species, destruction of soil resources, siltation, and increased emissions of greenhouse gasses. Policy makers must be provided with environmental indicators and models illustrating how the adoption of agroforestry technologies will impact on the economy before we can expect the incentives required to stimulate investment in agroforestry.

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