Deforestation for pasture in the humid tropics: Is it economically and environmentally sound in the long term?

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ABSTRACT
During the past 5 decades, the rate of tropical forest conversion has accelerated in response to economic pressures, population growth, technological development, and programmes and incentives to open land for development. Deforestation rates rose substantially through the 1980s, and were highest in Africa (1.7%), followed by Asia (1.4%) and Latin America (0.9%). The greatest extent of deforestation, however, was in Latin America, especially in the Amazon, where much of the deforestation was for pasture-based cattle development. Although forest conversion for ranching has been routinely criticised because of the ecological and socioeconomic implications associated with it, cattle herds continue to grow owing to socioeconomic and political pressures. Deforestation for pasture has been criticised from the ecological point of view because (1) large amounts of carbon are liberated to the atmosphere in the form of CO_2 and other gases; (2) pastures are fire-prone ecosystems and this may lead to desertification; (3) pastures cause local and regional impact on biodiversity; and (4) they are associated with local and global climate change. Agrotechnically, pastures after deforestation are criticised for their low agronomic stability which leads to pasture degradation owing to weed encroachment. Socioeconomically, criticism comes from their low levels of economic and social returns per unit of area, natural resources and capital. Pasture research and development experiences in forested lands, especially in Latin America, indicate that: (1) desertification owing to deforestation for pasture is more a myth than a reality and lacks scientific support; (2) by controlling interrelated environmental and technological factors causing pasture degradation, it is possible to obtain agrotechnically sustainable pastures; (3) relatively shallow-rooted, drought-sensitive pasture ecosystems have lower annual evapotranspiration than the forest ecosystem and may lead to decline in regional rainfall; (4) pasture-based cattle ranching may be profitable relative to immediate economic values if appropriate pasture management measures are taken. While pasture-based ranching on deforested lands may often be economic in the medium and long term, there are ecological costs involved. Societal costs associated with nutrient loss, CO_2 release, increased fire danger, changes in regional climate and loss of biodiversity could exceed US$5000/ha. Cattle ranching should be developed on already deforested lands and, in the medium and long term, the unsustainable extensive ranching models should gradually be transformed into more sustainable semi-intensive beef cattle models, semi-intensive dual-purpose cattle ranching models, and intensive agro-silvipastoral models. Research plays a critical role in this context.

KEYWORDS: deforestation, environment, economic, forest values, humid tropics, pasture lands

INTRODUCTION
The humid tropical climate regime is characterised by consistently high temperatures, abundant precipitation and high relative humidity (Lugo & Brown 1991). Annual precipitation exceeds or equals the potential return of moisture to the atmosphere through evaporation. In general, seasons in the humid tropics are determined by variation in rainfall, not temperature. Most areas experience no more than 2 months of dry season (precipitation less than 100 mm/month) per year (National Research Council 1982).

About 45% of the world's humid tropics are found in the Americas (essentially Latin America), 30% in Africa and 25% in Asia. Small portions of the humid tropics can be found in other areas such as Hawaii and portions of the north-eastern coast of Australia.

Vegetation in the humid tropics consists of moist, wet and rain forests in the lowlands and in the hill and montane uplands. It is estimated that forests cover 1.46 billion ha, or about 48% of the land area of the humid tropic zone (about 3 billion ha) (Forest Resources Assessment 1990 Project 1991). Nearly 70% of the world's humid forests are found in Latin America, the remainder being split between Africa and Asia.

Oxisols and ultisols are the most abundant soils in the humid tropics, together covering almost 70% of the region (National Research Council 1982). Oxisols (generally deep, acidic, low in phosphorus, nitrogen and other nutrients) are found mostly in tropical Africa and South America, and ultisols (usually deep, well-drained red or yellowish soils, somewhat higher in weatherable minerals than oxisols but also acidic and low in nutrients) are the most abundant soils of tropical Asia, and are also found in Central America, the Amazon Basin and humid coastal Brazil. Younger soils, mainly inceptisols and entisols, account for most of the remaining soils of the humid tropics (about 16% and 14%, respectively) ranging from highly fertile soils of alluvial and volcanic origin to extremely acid and nutrient-poor sands. The vegetation within tropical moist forest thrives by retaining and efficiently recycling scarce but essential nutrients and micronutrients within the ecosystem.

The forest of humid tropics provides multiple goods, values and environmental services. They help maintain local and global climate patterns and biological diversity, they supply products and commodities, soil protection, stabilisation of hydrological systems, and they maintain water availability and quality and mitigate storm impacts.

Forest conversion is defined as the alteration of forest cover and forest conditions through human intervention, ranging from marginal modification to fundamental transformation (National Academy of Sciences 1980). Deforestation changes in land use that reduce forest cover to less than 10% represents the extreme of forest conversion. Between slightly modified forests and deforestation, conversion takes place in varying degrees, resulting in changes in forest structure, species diversity, biomass, successional processes and ecosystem dynamics.

Forest transformation occurs when the original forest is eliminated and replaced with permanent agriculture, plantations, pasture lands, and urban and industrial developments. It is estimated that about 600 million ha out of the estimated 1.5 billion ha of original tropical rain forest in the world have been cleared and converted (Ehrlich & Wilson 1991), Africa having lost the greatest proportion of its original forest (about 52%), followed by Asia (42%) and Latin America (37%) (Lean et al. 1990).

Rate of deforestation has been highest during the past two decades. In the 1980s, the rate was highest in Africa (1.7%), followed by Asia (1.4%) and Latin America (0.9%). The absolute rate of deforestation, however, was highest in Latin America (7.3 million ha) followed by Africa (4.8 million ha) and Asia (4.7 million ha) (Food and Agricultural Organisation 1991). In the past two decades, deforestation was highest in the Brazilian Amazon where about 35 million ha (Brazilian Institute of Space Research 1990) have been cleared for different development purposes.

Behind the increasing rate of forest conversion in the humid tropics, there are a variety of direct and indirect causes, usually acting in combination (Repetto & Gillis 1988; Hecht & Cockburn 1989). Leading direct and immediate causes include large-scale commercial logging conversion to pasture-based commercial livestock production, clearing for slash and burn by subsistence farmers, conversion of forest to perennial tree plantations and other cash crops, land speculation, exploration of wood for fuel and charcoal, and large-scale government colonisation projects.

These immediate causes of forest conversion are driven by a network of forces (indirect causes) operating at the national and international levels. Widespread poverty, unequal distribution of income, flawed food distribution policies, high population density and growth rates, high fiscal deficits, under-employment, tax policies, cultural forces (e.g., prestige of pastures, slash and burn tradition), forest concessions, rents, credits and other financial incentives act as exacerbating factors favouring forest conversion throughout the humid tropics.

It is difficult at present to determine with precision the magnitude of interrelated environmental, social and economic consequences of forest conversion for agricultural and forestry development because they depend on factors such as characteristics of the original forest, nature of conversion, methods used in the process of conversion, social and economic environment of conversion and subsequent use and management of the land.

This paper focuses mainly on environmental and socioeconomic consequences of forest conversion (deforestation) for pasture-based cattle production purposes in the humid tropics.

EXTENT AND CAUSES OF DEFORESTATION FOR PASTURE IN THE HUMID TROPICS

Conversion of forests to pasture in the humid tropics has been the focus of intensive debate due mainly to its environmental implications. In the last three decades, this type of land use has expanded very quickly, with the sacrifice of large expanses of forest lands in several parts of the world.

The importance of forest conversion to pasture varies from region to region and from country to country within regions. In Asia, cattle raising on pastures formed after slashing and burning of the forest takes place mainly in south-east Asia, especially in Indonesia (Kartasubrata in press), the Philippines (Garrity et al. in press), and Thailand (Toledo 1986), but it is not a very significant factor in increasing deforestation since deforestation for crop production has been the predominant land use system in those countries. There seems to be no reliable data on the extent and rate of forest conversion to pasture in Asia.

Livestock production in the humid forest zone of Africa is not considered to be very significant as an economic activity. Although some land is being cleared for cattle pasture, much of this land is not suitable for pasture beyond a few years because of soil erosion and low fertility (Brown & Thomas 1990). Besides, cattle in equatorial Africa are vulnerable to the effects of trypanosomiasis, which causes serious economic losses from poor growth, weight loss, low milk yield, reduced capacity for work, infertility, abortion and often death (International Laboratory for Research on Animal Disease 1991). As for Asia, no reliable estimates of forest conversion to cattle pasture are available for Africa.

Undoubtedly, it is in Latin America that deforestation for pasture has the greatest importance because of the large expanses of forests that have been converted to extensive cattle raising activities, mainly in the past three decades (Hecht & Cockburn 1989). Conversion to pasture has been favoured by: (a) biological and soil-related constraints for agricultural production; (b) low human population density; (c) lack of infrastructure for transporting agricultural inputs and consumable products (cattle can transport themselves to markets by walking long distances, regardless of roads and weather conditions); (d) tax incentives and favourable lines of credit for cattle ranching in some countries; (e) cultural traditions that give cattle ranchers respect and status regardless of production and profit; (f) priority ranking and protection by Latin American governments; and (g) high levels of regional and international demands for meat and milk (Toledo 1986; Serrão & Toledo 1992: Serrão & Homma in press; Gomez-Pompa et al. in press).

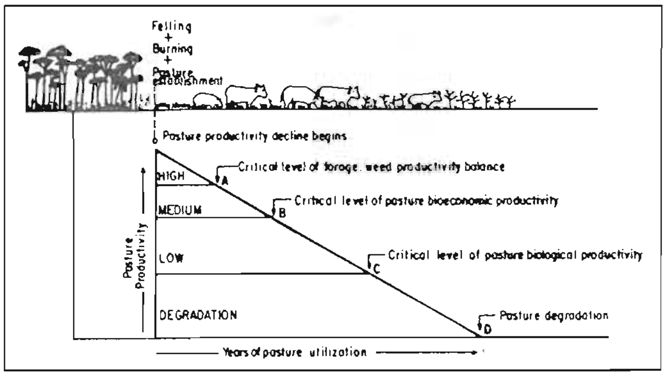
In the Amazon, Central America and Mexico, forest conversion to cattle raising is the leading cause of deforestation (Downing et al. 1992). In Central America, between 1950 and 1980, the pasture areas derived from deforested primary forest more than doubled. In the Brazilian Amazon, out of the almost 40 million ha of forest lands that have been converted for development (mainly agricultural) purposes (Brazilian Institute of Space Research 1990; Senado Federal 1990), about 25 million ha (nearly five times the size of Costa Rica) of tropical rain forest have been cleared to establish cattle pastures in the last 3 decades (Serrão 1990; Serrão & Homma in press; Serrão 1992).

AGROTECHNICAL ASPECTS OF PASTURE DEVELOPMENT THROUGH DEFORESTATION IN THE HUMID TROPICS

Typically, pasture development in forested areas includes cutting and burning forest biomass and then sowing grass seeds. In most cases, throughout the humid tropics, first-cycle, or "traditional" pastures (pastures formed after slashing and burning of primary or mature secondary forests) have been established with a small group of forage grasses, mainly guinea grass (*Panicum maximum*), *Hyparrhenia rufa* and *Brachiaris decumbens*. In the past two decades, new forage grasses such as *B. humidicola*, *B. brizantha* and *Andropogon gayanus* have been increasingly used, replacing traditional grasses owing to their greater adaptation to the humid tropical environment.

In Latin American pasture development, and perhaps elsewhere, primary pasture production is generally high during the first 3-4 years after establishment of first-cycle pastures, supporting stocking rates of up to two 300-kg (live weight) head of cattle/ha. After that period, pasture productivity declines gradually but fairly rapidly, accompanied by weed encroachment resulting in advanced stages of degradation that occur 7-10 years after pasture establishment (Fig. 1). In the Brazilian Amazon, from about 25 million ha of first-cycle pastures that have been established in the past 25 years, it is estimated that up to 50% have reached advanced stages of degradation (Serrão 1990; Serrão & Homma 1993).

Figure 1 Typical declining pattern of agrotechnical and economic sustainability of extensive first-cycle forest- replacing pastures formed and managed with inappropriate pioneer technology. Adapted from Serrão et al. (1979); Dias Filho & Serrão (1982); Toledo & Serrão (1982)



When first-cycle pastures reach advanced stages of degradation, their carrying capacity cannot exceed 0.3 head of cattle (100 kg live weight/ha). The average carrying capacity of first-cycle pastures during their life cycle is about 0.7 head/ha (Mattos et al. in press) which is considered too low for improved pasture standards.

In their average 6- to 7-year productive life, first-cycle pastures have produced as much as 250-300 kg of beef per ha. This level of productivity is very low, especially compared with that of other agricultural products such as cassava, rice, maize, beans, cacao and Brazil nuts, in terms of protein and energy production as well as monetary value per unit area (Mattos et al. in press).

The above low agrotechnical sustainability levels are typical of first-cycle pastures developed with "traditional" slash-and-burn processes and with traditional first-cycle forage grass species.

Knowledge obtained from research, especially in the last two decades, has shown that first-cycle pasture degradation is caused by an interrelation of (a) environmental (low phosphorus and nitrogen being the main limiting factors; high biotic pressures - principally of insects, spittlebugs for the most part - and weed aggressiveness; and water stress), (b) technological (poor performance of pioneer forage grasses, mainly guinea grass (*Panicum maximum*), *Brachiaria decumbens*, and *Hyparrhenia rufa*; poor pasture establishment and management; non-utilisation of forage legumes and fertilisation) and (c) socioeconomic constraints (unfavourable input/product ratios; inadequate development policies; governmental and non-governmental technical support, among others). A significant proportion of first-cycle pastures formed from the use of better-adapted forages such as *B. humidicola*, *B. brizantha* and *A. gayanus* has had considerably higher levels of agrotechnical sustainability than those formed with pioneer traditional grasses.

A higher degree of land-use intensification for cattle development in the humid tropics of Latin America in area where pastures have been replacing forests began to take place in the mid 1970s owing to increasing scientific and technological knowledge for pasture development (Serrão et al. 1979; Serrão & Toledo 1990), increasing pressures for environmental preservation, increasing degradation of first-cycle pastures, reduction of tax incentives and subsidies for cattle raising in some countries, decreased availability of primary forest areas in already established ranching projects, and consequent increases in land prices. With land use intensification, much degraded first-cycle pastureland has been converted to second-cycle pastures (those that are formed through the reclamation of degraded first-cycle pastures).

In the second-cycle pasture generation, more modern pasture development technologies are being used. These technologies include mechanisation for seedbed preparation and seeding of degraded pastures, soil fertilisation, better forage grasses (such as improved cultivars of *B. brizantha, B. humidicola, A. gayanus* and others), higher quality forage seeds and improved pasture management. These developments have been taking place especially in the Brazilian Amazon where, according to Serrão (1991), up to 10% of the total degraded first-cycle pastures to date are being claimed and converted to second-cycle pastures. Despite these recent improvements in pasture sustainability, agrotechnical, environmental and especially economic constraints are still pending for expansion of these improved pasture developments. For example, in the Brazilian Amazon, the high costs of pasture reclamation - about US$250/ha (Mattos et al. in press) - and high-interest governmental and private bank credit have induced a logging and ranching link (Mattos et al. in press), where selective logging of adjacent primary forests is carried out to cover the costs of reclaiming degraded pastures. This link is one more driving force toward deforestation. This economic constraint may be minimised by planting cash crops, such as maize, rice and beans, in association with forage grasses and legumes in the process of degraded pasture reclamation (Veiga 1986), which generates extra capital.

Second-cycle (or nth-cycle) pastures, as described above, is undoubtedly a significant improvement in pasture development in the humid tropics and will continue to expand. However, at this point, a question should then be raised: Is it appropriate to continue searching for higher levels of agrotechnical and economical sustainability in the humid tropics on the basis of traditional open monoculture pasture systems? Experience in humid tropical regions has shown that, in most cases, monocultures whether domesticated, naturalised or exotic that have replaced the humid tropical forest without taking into account its environmental (climatic, edaphic, biotic) and socioeconomic adversities, have had serious agrotechnical and socioeconomic limitations. In pasture, for example, dissemination of spittlebugs (economically the most important pasture insect pest in the humid tropics of Latin America) has probably been the result of extensive deforestation to form monoculture pastures of *B. decumbens, B. humidicola* and other less important *Brachiaria* species.

In order to overcome environmental and socioeconomic constraints for pasture development in the humid tropics, there must be a search for alternative models of integrated pasture-crop-tree systems that are agrotechnically (reduction of risks caused by pests and diseases, improved cycling and, consequently, better utilisation of nutrients in the system), ecologically (higher levels of biomass accumulation,, improvement of hydrological balance, improvement in soil conservation and environmental conditions for micro- and micro-flora and fauna), socially (production of different products, more direct and indirect employment opportunities, higher levels of labour specialisation) and economically (different sources of income) more sustainable than those presently in use (Serrão & Toledo 1992).

With low-input and knowledge-intensive pasture development and consequent improvement in the sustainability of forest-derived pastures, productivity from cattle raising in the humid tropics can be doubled or tripled. Therefore, agrotechnically, there should be no reason to convert additional forests to pasture in the humid tropics to meet the demands of local population for milk, meat and other agricultural products until the first decade of the next century. Until then, plenty of already-cleared land could be used for improved and more sustainable cattle pasture development. If this is true, and given the vigour of forest regeneration in degraded pasture ecosystems (Buschbacher et al. 1988; Uhl et al. 1988), a considerable amount of forest recovery in already degraded pastureland can also be achieved (Nepstad et al. 1990, 1991).

IS DEFORESTATION FOR PASTURE ENVIRONMENTALLY AND ECONOMICALLY SOUND IN THE HUMID TROPICS

The previous sections try to put the question of deforestation for pasture in the context of agricultural development in the humid tropics. In those sections, it was highlighted that deforestation for pasture in the humid tropics has important implications agrotechnically, socioeconomically and ecologically. In this section and, based on pasture research and development experiences in forest-replacing pastures, especially in the humid tropics of Latin America, we will further explore these environmental and economic implications.

Some of the analyses of pastures replacing forests for ranching have been made with some degree of partiality, depending on the academic and ideological background or particular interests of the analysts. On one extreme, cattle raising has been accused by environmentalists of being the principal cause of the rain forest ecosystem's degradation and tagged as unfeasible agrotechnically and socioeconomically. On the other extreme, developmentalists consider it capable of opening development frontiers and of making good use of land, capital and labour. In addition, most of the analyses that condemn ranching have been based on the most recent (the past 20 years) agricultural and forestry development in Latin America, especially in the Amazon where aggressive development opening forest frontiers has taken place with all of the problems typical of that kind of development, such as: reduced knowledge about the environment and, consequently, insufficient scientific and technological support; logistical difficulties; land speculation; insufficient monitoring of credits and incentives.

Controversies aside, and owing to geopolitical and socioeconomic factors, forest-derived pasture development in Latin America continues to expand.

The following points summarise the state of knowledge in trying to answer the question posed in this section.

Direct environmental implications

Point 1. Forests are sacrificed to create pastures: One of the main criticisms of ranching in the humid tropics is that forests are removed to establish pasture with a very significant biomass loss. For example, in the Brazilian Amazon, during the 1970s and 1980s, some 20 million ha of forest were cut down and burnt to form pastures for cattle raising (Serrão & Homma 1993).

Point 2. Pastures are fire-prone ecosystems: Another important criticism to pastures that have replaced humid tropical forests is that they are very susceptible to fire and can create potential fire hazards for adjacent forest areas, causing incalculable environmental (and economic) losses. Recent research (Uhl & Kauffman 1990) demonstrates that open pastures are very susceptible to burning, followed, in descending order, by forest vegetation in areas where there has been recent logging, and by secondary forest vegetation, the primary forest being practically immune to burning. Fires set in pastures for management purposes frequently escape into surrounding logged forests and secondary forests and may cause incalculable damage to the ecosystem. For example, when a 20-year-old secondary forest burns, it loses 20 years of forest succession with all its ecological and economic values.

Point 3. Pastures may lead to desertification: It has been argued that large-scale deforestation and burning for pasture formation and management, which has been typical in the humid tropics, could lead to desertification of large tracts of land in the Amazon (Goodland & Erwin 1975) and other similar ecosystems. This environmental implication lacks scientific support, although research on this topic has been very limited. General observations and recent research carried out in the Eastern Amazon (Uhl et al. 1988) show that rain forest regeneration in degraded and abandoned first-cycle pasturelands depends on its previous management and fire control. In spite of some difficulties of a physical and biotic order, forest regeneration in abandoned pasturelands can be satisfactory (Nepstad et al. 1991). In these conditions, accumulation of forest biomass varies 5-10 t/ha/year. Those research results and general observations lead to the conclusion that only where the land has been abused (including bulldozing and intensive use of herbicides) is natural forest regeneration uncertain, which, in general is not the case in most of the humid tropics. It is suggested (Uhl et al. 1988) that the Eastern Amazon ecosystem has a tremendous potential for recuperation. Most abandoned pastures can recover forest-like properties, but many of the complex interspecific interactions between co-evolved species that make rain forests unique may never be restored. Moreover, chronic disturbance of regenerating sites, mainly through fire, could lead to irreversible degradation of the regional ecosystem in the foreseeable future, mainly in terms of biodiversity, as will be seen in this section.

Point 4. Deforestation for pasture establishment-management causes climate change - Regional: Climatic change has been claimed as other implication of deforestation for cattle ranching. Deep roots in the rainforest ecosystem provide access to water deep in the soil and maintain the forest ecosystem an evergreen state. This contrasts with the pasture ecosystems where roots are shallower, thereby having less access to soil water and, consequently, lower annual evapotranspiration than the forest ecosystem (Nepstad et al. 1991). Pastures near Paragominas, Parei, Brazil, release roughly 30% less water vapour into the atmosphere through evapotranspiration than the forest from which they are derived (D. Nepstad & P. Jipp unpublished). Most of the reduction in evapotranspiration occurs during the dry season when surface soil moisture is depleted and the drought-sensitive leaves of pasture vegetation become brown and die. Much of the solar radiation that shines on a browned pasture is absorbed or reflected, heating up the air instead of being converted to the chemical energy contained in the water vapour. These impacts should lead to a decline in regional rainfall (Shukla & Nobre 1989). This, in turn, could lead to decline in regional rainfall (Salati 1987). Reduction in regional rainfall may lead to extended droughts, increased fire incidence and, ultimately, to vegetation changes. In addition, because evapotranspiration is reduced in pasture, runoff increases and so does the probability of regional flooding.

Global: Supposing that, on average, each hectare of forest contains about 300 t of biomass, a loss of about 6 billion t of plant biomass takes place, in addition to the immediate losses in genetic resources of the macro- and micro-flora and fauna. Moreover, considering that about 50% of the forest biomass is liberated as carbon in the form of CO_2 during combustion and decomposition, as much as 3 billion t of carbon should have been liberated into the atmosphere as a result of fires in pasture formation and management processes during the 1970s and 1980s in the Brazilian Amazon. These fires release "greenhouse" gases like CO_2 that also affect climate (Salati 1987). It is (grossly) estimated that the conversion of forests to pasture in the Amazon would have contributed to about 6% of the total global emission of carbon resulting from the conversion of tropical forests in those two decades (Serrão 1990). This would not be too alarming if deforestation were not accelerating unnecessarily over the last three decades. The largest pool of carbon in the Amazon forests is in the soil where 300-400 t are typically stored. Recent research (Davidson et al. unpublished) reveals that this pool continues to release carbon to the atmosphere even 20 years after pasture formation. This source of carbon resulting from forest conversion to pasture is not reflected in current estimates of carbon release from the Amazon Basin. Carbon embodied in pasture ecosystems after a decade of use is only about 10% of that found in the original forest (Nepstad 1989). Hence, some 140 t of carbon are liberated to the atmosphere where forests are converted to pasture. This carbon release could contribute to global warming.

Point 5. Pastures affect local and regional biodiversity: When a hectare of rain forest is converted to pasture, the entire plant-animal-air-soil matrix is transformed, resulting in a simplified ecosystem. Instead of thousands of plant and animal species composing several hundred tonnes of biomass spread intricately over 40 m of vertical space, a field is created with a few dozen species containing some 10 t of biomass per ha, compacted into 1 m of vertical space (Uhl et al. 1988). The low, open structure of pastures results higher peak air and soil temperatures and higher vapour-pressure deficits compared with the forest understorey (Nepstad 1989).

Some hearty forest species do persist in first-cycle pastures. In 13 abandoned pastures in the Eastern Amazon (Uhl et al. 1988), 94 tree species were found as sprouts, many of which were present in the original adjacent forest. Some flying animal species also occur in both forests and adjacent open pastures. For example, studies in pasturelands in the Eastern Amazon found that 14 of 387 bird species in the region of Paragominas, State of Para, have been observed moving between forest and open pasture environments (J.M. Cardoso da Silva, unpublished). Some limited habitat overlap also exists for insects, reptiles, large mammals and small rodents. However, only a small proportion of the many plant and animal species present in the forest can tolerate the open conditions prevalent in previously forested pasturelands. This subset of tolerant species will make up the future fauna and flora of Amazonia.

Future flora will be composed of those species that persist in cleared areas and/or those that are able to establish in these areas. Hence, species that sprout readily, resist fire, have seeds and foliage that are unattractive to predators, can withstand and avoid drought, for example, may dominate these altered landscapes. Species that will disappear include dozens with economic value, such as "andiroba" (*Carapa guyanensis*) and "macaranduba" (*Manilcara huberi*).

It is the animal species with extremely flexible feeding and habitat requirements that may thrive in these pasture lands. Such a future biota, composed of hardy. generalist-type species, could encompass only a very small portion of the biodiversity now present in the forest ecosystem.

When one considers the environmental impacts of forest conversion to pasture on biodiversity, it is tempting to focus just on the small area that has been denuded, regarding the difference in species richness between the virgin forest and the cleared land as the loss of biodiversity. But forest conversion to pasture could also be affecting "pristine" ecosystems far removed from the pasture areas. For example, forest conversion to pasture in the Eastern Amazon (based on calculations from Buschbacher et al. 1988) leads to the loss of some 1600 kg of nutrients (NPK). These nutrients eventually move into nearby streams and rivers and could increase productivity leading to the dominance of certain aquatic plant and animal groups and elimination of others.

Global warming, as was seen above, could also contribute to attendant effects on regional biodiversity. Taken together, it is easy to at least imagine that changes in terrestrial ecosystem functions, caused by conversion of forest to pasture, could represent a more general threat to regional biodiversity.

Economics of pasture development and production

This is a rather difficult analysis for generalisation in the humid tropical regions of the world, mainly because of the many differences in socioeconomic environment and pasture-based production systems among humid tropical regions and among countries within humid tropical regions. Owing to its importance in Latin America, the case of the Eastern Amazon is used here to analyse this point.

Ranching in the Eastern Amazon is practised by large, medium and small property owners using extensive and semi-intensive pasture-based production systems. Large- and medium-scale landholders (forest clearing for pasture > 500 ha) generally practise extensive beef cattle ranching, mainly on first-cycle type pastures (as described above) (Fig. 1), characterised by low grazing stocking rates (0.5-0.7 animals/ha), large individual paddocks (generally>50 ha) and minimal pasture and herd management (Mattos et al. in press). Average live weight animal gain on such ranches is 45-65 kg/ha/year; profits range from US$8 to 24/ha/year; and return on investment varies between 6 and 11%.

Some ranchers with large and medium holdings are recuperating degraded first-cycle pastures. Restoration generally consists of removing debris, ploughing, fertilising and reseeding with improved forage varieties (Fig. 3). The cost to make this shift to semi-intensive ranching is approximately US$260/ha (Mattos et al. in press). Capital for this shift frequently comes from logging (the logging and ranching link) still-forested segments of the ranch property. Live-weight production on reformed pastures is 150-250 kg/ha/year, profits ranging from US$50 to 100/ha/year and the return on investment is 13-14%.

Small property holders (<100 ha) are also adopting semi-intensive approaches of pasture-based ranching, the emphasis, however, being on dual-purpose (calf and milk production) cattle raising (Fig. 3). In this land-use enterprise, capital investment is high but so are profits (US$125/ha/year) and returns on investment (16%) (Mattos et al. in press).

Even though the above-mentioned economic figures are of interest to the particular situation of the forest-derived pasture-based animal production system in the Brazilian Amazon, they may be, in some measure, applicable to other similar environmental and socioeconomic conditions in other similar humid tropical regions, mainly in Latin America.

Economics of embodied forest values

While the above economic evaluation of pasture-based cattle ranching in deforested areas may not be applicable to all humid tropical regions of the world, it serves as reference to the following analysis of converting rain forest to pastures in Brazil, which may be extrapolated to many areas in other similar humid tropical regions of the world.

Although the information above indicates that deforestation for ranching may be profitable, there are important forest values that, in addition to traditional and immediate economic considerations, should be taken into account when evaluating the wisdom of converting forest to pasture. This evaluation is discussed next, based on available information and extrapolations.

Fig. 2 shows a primary forest and an open pasture ecosystem, as well as their different losses and approximate costs. The primary forests contain many timber species that could supply wood indefinitely, but this option is forfeited when forests are removed for pasture or for other agricultural purposes. The timber present at the time of forest conversion is worth about US$2800/ha after processing (Verissimo et al. in press). In the process of deforestation for pasture, in general, this wood has been burnt instead of harvested. On the other hand, during the pasture-use period, a significant portion of the nutrients embodied in the slashed forest biomass is leached from the ecosystem. This loss could be valued at US$2500/ha, at current prices of NPK fertiliser in Brazil. We do not mean to suggest that this much fertiliser would be necessary to restore soil fertility in degraded pastures. The amount necessary is much less than this. Nor do we want to imply that these are closed systems with regard to nutrients. Clearly, nutrients enter these ecosystems via atmospheric deposition and weathering. Our point is that measurable quantities of nutrients are lost in the conversion of forest to pasture and we need to begin to think about how to estimate the costs of these losses.

As was seen above, some 140 t/ha of carbon are liberated to the atmosphere during burning and decomposition in the process of pasture formation and management, contributing to global warming. Nordhaus (1991) has developed an empirical rationale for accounting for the cost of this carbon release. He considers the degree to which CO_2 emissions could reduce the Gross Planetary Product (GPP) and, in a rather conservative set of projections, he concludes that each tonne of carbon liberated to the atmosphere would account for a US$7.33 reduction in GPP. Using this value, the cost of conversion of forest to pasture directly linked to carbon emissions is approximately US$1026 (140 t x US$7.33)/ha.

Considering the above three forest values (wood, nutrients and carbon), directly or indirectly, at least US$5000 of value are lost each time a rain forest is converted to pasture (Uhl et al. in press).

Considering that the net profits from extensive unsustainable first-cycle pastures are about US$10-25/ha/year, it would take a minimum of 200 years for pastures to pay off these environmental costs.

At least three other no less important environmental costs, although more difficult to quantify, are implicit in converting forests to pasture (Fig. 2). First, forests, with their leafy canopies high above the ground and their cool understories, provide a humid micro-environment that insulates against wildfires (Uhl et al. in press). Second, the deep root systems of forests are considered to be an important stabilising factor of regional climates (Nepstad et al. 1991). Finally, forests house species and these species have value. As forests are converted to pasture, species that could serve society, or that might perform irreplaceable ecological functions, will be lost. These phenomena are still too poorly understood to allow the assignment of approximate monetary value, but the cost may be very significant.

The above forest value economic analysis of deforestation for pasture in the humid tropics, although overlooked or ignored in the past, should from now on be considered more seriously because of ever-increasing misuse of ever-declining natural resources in the humid tropics.

Figure 2 Top. In forest ecosystems the fixation and liberation of carbon are in equilibrium and most of the water entering as rain leaves via evapotranspiration. When the forest is converted to pasture, there is a larger loss of carbon to the atmosphere and less water is recycled. Bottom. A first attempt of assigning values to the services that forests perform (per ha) as producers of wood, cyclers of water, barriers to fire spread, and depositories of nutrients, carbon and species. (Uhl et al. in press)

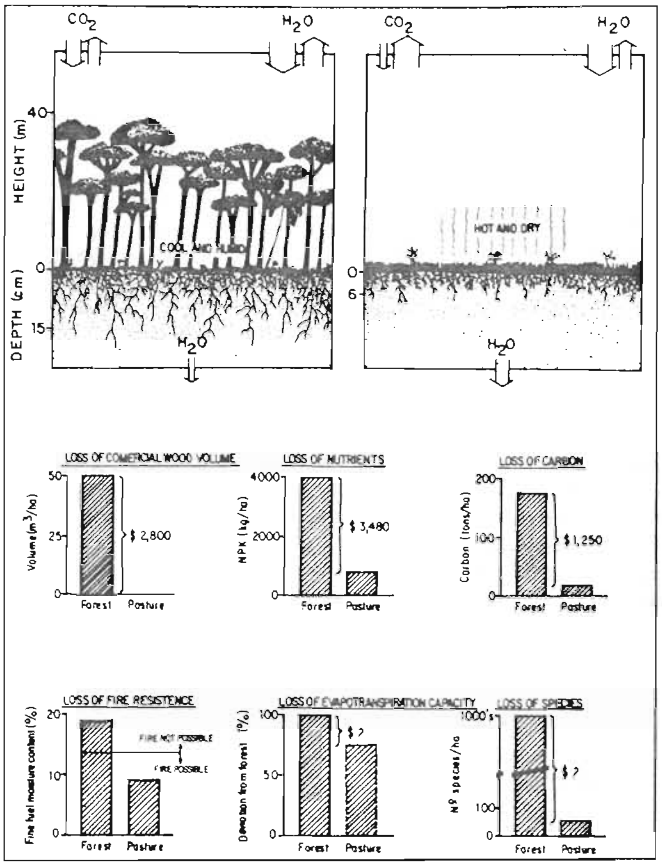
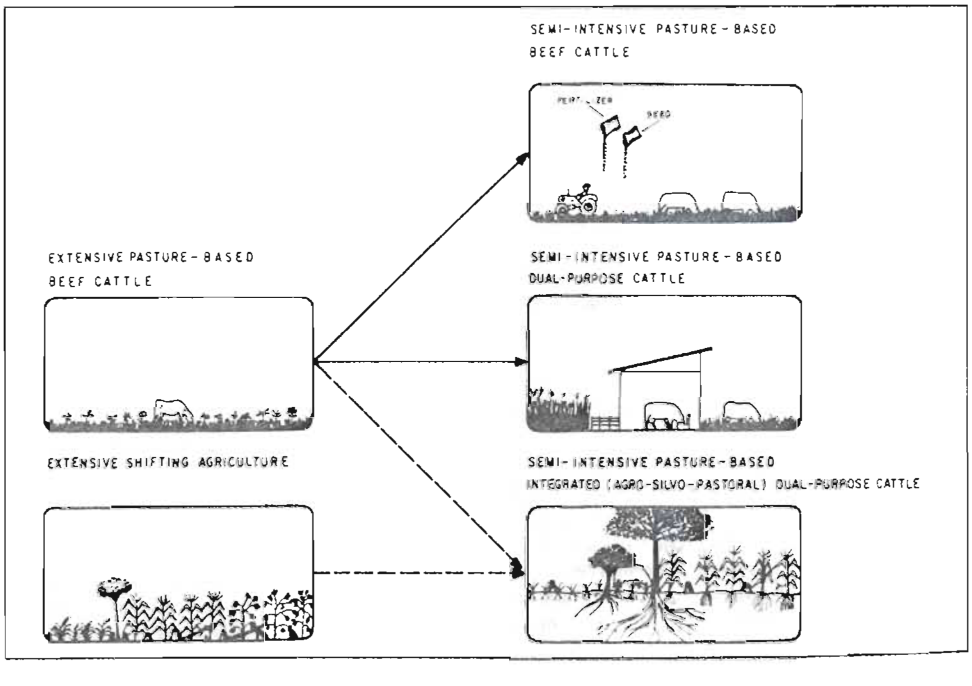


Figure 3 Pasture-based ranching enterprises in deforested areas of the humid tropics should move away from unsustainable extensive beef cattle to more intensive and sustainable pasture-based systems such as: semi-intensive beef cattle enterprises; semi-intensive dual-purpose cattle enterprises; and semi-intensive agro-silvipastoral dual-purpose cattle enterprise. This last enterprise may be derived from either extensive pasture enterprises or from extensive shifting agriculture enterprises. Adapted from Mattos et al. (in press)



Improving economical and environmental sustainability of pasturelands in deforested lands

Existing pasture lands resulting from deforestation in the humid tropics need to become more sustainable environmentally and socioeconomically (Serrão & Homma 1993). Abandoned and active pasture lands that resulted from deforestation have to produce animal and plant protein and other products and services and, at the same time, minimise palpable immediate negative environmental implications and embodied forest value losses owing to deforestation for pasture.

From a more economic than ecological approach, future ranching development should be concentrated for at least the next 20 years on already deforested lands and, for increasing sustainability, it should move away from the present predominantly unsustainable extensive pasture-based beef cattle ranching enterprise towards more sustainable, low-input, knowledge-intensive alternatives of pasture-based production systems such as semi-intensive beef cattle enterprises for medium and large landholdings, semi-intensive dual-purpose cattle-raising enterprise for small and medium landholdings, and semi-intensive integrated pasture-tree-crop (agro-silvipastoral) production enterprises for small and medium landholdings (Serrão 1992; Mattos et al. in press). The last alternative enterprise can derive both from the extensive pasture-based beef cattle enterprise or from extensive shifting agriculture activities (Fig. 3).

From a more ecological than economic approach, it has been shown that the conversion of forest to pasture is reversible by some means, such as biomass accumulation (Uhl et al. 1988; Nepstad et al. 1991). It has also been observed that certain hardy economic species grow reasonably well in severely degraded pastures. For example, in weed-infested pastures that had been subjected to grazing for 16 years, introduced seedlings of cashew (*Anacardium occidentalis*), urucu (*Bixa orelana*) and muruci (*Byrsonima crassifolia*) begin producing fruits within 2 years of planting. Seedlings of timber species such as taxi (*Sclerolobium paraensis*) and mahogany (*Switenia macroplyllum*) are growing 2-4 m in height each year in these same degraded pasture ecosystems. However, depending on local abundance of resources and uncertainties with perennial tree cropping, the restoration of degraded pastures with trees in the humid tropics may not be an economically attractive investment.

If the above-indicated policy and appropriate technological approaches are followed, deforestation for pasture in the humid tropics may be economically and environmentally sound in the long term. This achievement will require a major and constant effort of research in the search for increasing levels of sustainability of present and future pasture-based ranching models.

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