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PASTURES ON AMAZONIAN FORESTLANDS: A REVIEW OF ENVIRONMENTAL AND ECONOMIC PERFORMANCE

SUMMARY

During the past 3 decades, the rate of forest conversion in the Amazon has progressed rapidly in response to economic pressures, population growth, technological development, and programmes and incentives to open land for development. It is estimated that at least 40 million hectares of forest land have been cleared for different development purposes, and that over 50% of the deforestation was for pasture-based cattle production. Although forest conversion for ranching has been criticised because of the ecological and socio-economic implications associated with it, cattle herds continue to grow owing to socio-economic and political pressures.

Deforestation for pasture has been criticised from an 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 thus may lead to desertification; (3) pastures cause local and regional impacts on biodiversity; (4) they are associated with regional and global climate change. Agrotechnically, pastures on once-forested lands are criticised for their low agronomic stability which leads to pasture degradation through weed encroachment. Socioeconomically, criticism comes from low levels of economic and social returns per unit of land area, forest resources displaced and capital.

Pasture research and development experiences on once-forested land in the Amazon, 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; (5) the net release of carbon to the atmosphere is partially offset by carbon accumulation in the soil. While pasture-based ranching on deforested land in the Amazon may often be economic in the medium and long term, there are ecological costs involved. Societal costs are associated with nutrient loss, CO_2 release, increased fire danger, changes in regional climate and loss of biodiversity.

Cattle ranching should be developed on already deforested land 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 agrosilvipastoral models. Research and information dissemination play critical roles in the context of sustainable pasture development in the Amazon.

Research priorities should center on interrelated environmental, management and technological factors causing pasture degradation and on those promoting pasture sustainability. Research and development (R & D) activities should involve maximum farmer participation in order to increase the efficiency of the flow of information between the generators of knowledge, technology, services and products and their users. Suggestions for promoting sustainable pasture information dissemination are discussed.

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INTRODUCTION

Cattle pasture is the major use of cleared lands in Amazonia. Forest-derived pastures have been criticized because they involve the replacement of species-rich forest that appear to play an important role in regional, and perhaps global, climate patterns, with an agricultural system that has low returns to society. Despite these criticisms, pastures continue to expand across Amazonia, representing the most attractive land-use option for rural producers who desire a low-risk form of production that allows them to accumulate capital as they secure their claim on landholdings.

Conversion to pasture has been favored in Amazonia by: (a) biological and soil-related constraints to agricultural crop production; (b) low human population density (and, hence, shortage of labor); (c) lack of infrastructure for transporting agricultural inputs and consumable products (e.g., cattle can transport themselves to markets by walking long distances, regardless of roads and weather conditions); (d) tax incentives and favorable lines of credit for cattle ranching; (e) cultural traditions that give cattle ranchers respect and status regardless of production and profit; (f) priority ranking and protection by government; (g) high levels of regional, national and international demands for meat and milk ; and (h) land tenure regulations by which pastures become an important tool for securing land title (Toledo 1986; Serrão & Toledo 1992: Serrão & Homma 1993; Hecht, Norgaard and Possio 1987).

It is in light of this historical, and continuing importance of pastures in rural Amazonia that we have prepared this review of the environmental and economic performance of forest-derived cattle pastures. This review incorporates the results of several studies completed in the last 2-5 years. We begin the review with a discussion of agrotechnical aspects of Amazonia pasture development.

AGROTECHNICAL ASPECTS OF PASTURE DEVELOPMENT ON FORESTLANDS IN AMAZONIA.

Typically, pasture development in Amazonia begins with forest cutting and burning, after which grass seeds are sown. First-cycle pastures (pastures formed after slashing and burning of primary or mature secondary forests) have usually been established using a small number of forage grasses, such as guinea grass (*Panicum maximum*), *Hyparrhenia rufa* and *Brachiaria 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 because of their superior performance in the humid tropical environment.

In Amazonia pasture development, and perhaps elsewhere, the productivity of first-cycle pastures is generally high during the first 3-4 years after establishment, supporting stocking rates of up to one head (300-kg live weight) of cattle/ha. After this initial period, pasture productivity declines gradually but rapidly, as soil fertility declines and weed encroachment progresses. Advanced stages of degradation often occur 7-10 years after pasture establishment (Fig. 1). In the Brazilian Amazon, it is estimated that up to 50% of the ca. 25 million hectares of first-cycle pastures established in the past 25 years have reached advanced stages of degradation (Serrão 1990; Serrão & Homma 1993).

When first-cycle pastures reach advanced stages of degradation , their carrying capacity drops below 0.3 head of cattle (100 kg live weight/ha). The average carrying capacity over the lifetime of first-cycle pastures in eastern Amazonia, in the vicinity of Paragominas, is about 0,7 head/ha (Mattos and Uhl 1994).

In their average 6- to 7-year productive life, first-cycle pastures produce up to 250-300 kg of beef per ha. This level of productivity is very low, especially if compared with that of other agricultural production systems such as those of cassava, rice, maize, beans, cacao and Brazil nuts, in terms of protein and energy production as well as monetary value per unit area (Mattos and UhL 1994).

Research has shown that first-cycle pasture degradation is caused by (a) environmental factors, including low soil phosphorus and nitrogen levels, insect pests such as spittlebugs, weed invasion and water stress, (b) technological factors, such as the poor performance of pioneer forage grasses, mainly guinea grass (*Panicum maximum*), *Brachiaria decumbens*, and *Hyparrhenia rufa*; poor pasture establishment and subsequent management; underutilisation of forage legumes and fertilization, and (c) socioeconomic constraints, such as the low yields on inputs; inadequate development policies; a lack of governmental and non-governmental technical support, among others. Some of those first-cycle pastures formed with better-adapted forages such as *B. humidicola* , *B. brizantha* and *A. gayanus* have had considerably higher levels of agrotechnical sustainability than those formed with pioneer traditional grasses.

In the mid-70s, cattle production systems on Latin American forestlands began to intensify in response to the results of scientific research and to the experimentation by the cattle industry (Serrão *et al.* 1979; Serrão & Toledo 1990), increasing concerns over the environmental costs of pasture formation, 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 forestland prices. With the intensification of cattle production systems, much degraded first-cycle pastureland has been recuperated and converted to second-cycle pastures (Mattos and Uhl 1994).

In the second-cycle pasture generation, more modern pasture development technologies are being used. These technologies include disc-harrowing for seedbed preparation, reseeding or replanting with improved cultivars of *B. brizantha* , *B. humidicola*, *A. gayanus*, soil fertilization, higher quality forage seeds and improved pasture management. In the Brazilian Amazon, according to Serrão (1990), up to 10% of the total degraded first-cycle pastures to date are being reclaimed and converted to second-cycle pastures. Despite these recent improvements in pasture sustainability, agrotechnical, environmental and especially economic constraints still slow the expansion of second-cycle pastures. In eastern Amazonia, the high costs of pasture recuperation - about US$ 250/ha (Mattos and Uhl 1994) - and high-interest governmental and private bank credit have induced a logging and ranching link 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 forest impoverishment. This high cost of recuperating degraded first-cycle pasture may be reduced by planting cash crops, such as maize, rice and beans, in association with forage grasses and legumes at the onset of the recuperation process (Veiga 1986), thereby generating extra capital.

Second-cycle (or nth-cycle) pastures, as described above, are undoubtedly a significant improvement in pasture development in Amazonia and will continue to expand. However, at this point, a question must be raised: Is it appropriate to continue searching for higher levels of agrotechnical and economical sustainability in the humid tropics on the basis of the widespread monocultural pasture systems? Monocultures have been employed with limited success in the humid tropics because of serious agrotechnical and socioeconomic limitations. In Amazonia pastures, for example, the spread of spittlebugs (economically the most important pasture insect pest in the region) has probably been the result of extensive deforestation to form monoculture pastures of *B. decumbens, B. himidicola* and other less important *Brachiaria* species.

In order to overcome the environmental and socioeconomic constraints to pasture development in the Amazon, there must be continued development of alternative models of integrated pasture-crop-tree systems that are agrotechnically, ecologically, socially and economically more sustainable than those presently in use (Serrão & Toledo 1992).

Through improved pasture technology, productivity from cattle ranching in Amazonia can be doubled or tripled. Therefore, agrotechnically, there should be no reason to convert additional forests to pasture to meet the demand of local populations for milk, meat and other agricultural products until the second decade of the next century. Until then, plenty of already- cleared land could be used for improved and more sustainable cattle pasture development. Those areas of abandoned pasture that are not recuperated would provide sites for forest regrowth (Buschbacher *et al.* 1988; Uhl *et al.* 1988), and the recovery of many important ecological functions performed by these forests (Nepstad *et al.* 1990, 1991, 1994, 1995).

IS DEFORESTATION FOR PASTURE ENVIRONMENTALLY AND ECONOMICALLY SOUND IN THE AMAZON?

The previous sections try to put the question of deforestation for pasture in the context of agricultural development in the Amazon. In those sections, it was highlighted that deforestation for pasture has important implications agrotechnically, socioeconomically and ecologically. In this section, we will further explore these environmental and economic implications.

It is particularly appropriate time to revisit the debate regarding the conversion of tropical forests to pastures because new data are now available for analyzing this debate. Our goal in this review is to revisit the main environmental and economic issues that have been at the core of this debate.

WHAT ARE THE ENVIRONMENTAL IMPACTS OF AMAZON FOREST CONVERSION TO PASTURE?

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

Point 1. Forests are sacrificed to create pastures

One of the main criticisms of ranching in the Amazonia is that forest are removed to establish pasture. 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).

The total area of clearing was > 42 million hectares as of 1991 (INPE 1992) with most clearing found in the states of Pará and Mato Grosso. Two estimates of the area cleared by 1988 still varied by as much as 30% for some states of Brazilian Amazon (INPE 1992 and Skole & Tucker 1993). It is important to note that deforestation has not been mapped for the Brazilian Amazon since the 1991 study, so that there is no way of knowing how much deforestation has taken place from 1991-1995. We also do not know what portion of deforestation actually leads to the formation of cattle pastures.

One surprising fact relates to the area of the Cerrado savanna formation that has been cleared through land-use. Approximately 60,000 km^2 of Cerrado have now been planted with forage grasses, which is more than the combined sum of all deforested land in Amazonia (Klink *et al.* 1995).

Point 2. Pastures are fire-prone ecosystems

Another important criticism to pastures that have replaced Amazonian forest is that they are very susceptible to fire and can create potential fire hazards for adjacent forest and agricultural 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.

If the predicted drying of the Amazonian climate as a result of forest clearing is born out (Nobre *et al.* 1991, Lean and Warrilow 1989), then even primary forest may become susceptible to burning (Nepstad *et al.* 1995), (Fig. 2).

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 Amazon, could lead to "desertified" lands, that support very little biological activity (Goodland & Erwin 1975). This prediction lacks scientific support. It is clear that the general tendency is for wood plant colonization to proceed rapidly in the wake of pasture abandonment. 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 barriers to seed dispersal, seed survival, and seedling survival and growth, forest regeneration in abandoned pasturelands can be satisfactory (Nepstad *et al.* 1991, in press).

There are several ways of measuring forest recovery following pasture abandonment. The accumulation of biomass through forest recovery proceeds at the rate of 5 to 10t/ha/yr on abandoned pastures of eastern Amazonia, but the long term trajectory of this biomass accumulation is unknown (Uhl *et al.* 1988) Only where the land has been abused (including bulldozing and intesive use of herbicides) is natural forest regeneration uncertain, which, in general, is not the case in most of the Amazon.

Secondary forests appear to recover relatively rapidly some of the hydrologic functions of the primary forest. A 15-year-old secondary forest near Paragominas released 90% as much water to the atmosphere as water vapor during the dry season (through evapotranspiration) as the neighboring primary forests, while pastures released only 75% as much water (Nepstad *et al.* 1995).

Point 4. Deforestation for pasture establishment-management causes climate change.

Regional: Climatic change at the level of the Amazon Basin has been advanced as another implication of deforestation for cattle ranching. This prediction is the result of both modeling experiments and isotopic studies of the rate of recycling of rainwater through forest vegetation. In the first approach, climate models are adapted to Amazonia and used to predict the impact of replacing Amazonian forests with pasture vegetation. The most recent modeling experiments predict that rainfall will decline by about 25% and air temperatures will increase through such a replacement (Shukla *et al.* 1990, Nobre *et al.* 1991, Lean and Warrilow 1989). Isotope studies have demonstrated the high dependence of Amazonian rainfall on water vapor released from forests through evapotranspiration (Victoria *et al.* 1991, Salati *et al.* 1987), implying that the replacement of forests with pasture ecosystems that release less water to the atmosphere through evapotranspiration could cause a reduction in rainfall. It has not been possible to detect this predicted reduction in rainfall in the precipitation data for the region.

Model-based predictions of forest clearing effects on climate underestimate rooting depths of Amazonian forests, and therefore underestimate the reduction in evapotranspiration that accompanies forest conversion to pasture (Nepstad *et al.* 1994). During the El Niño drought of 1992, for example, 400 mm of water extracted from below 2m soil depth by a forest in eastern Amazonia - the climate models assume a rooting depth of only 1.3m. Roughly half of the forests of Amazonia evidently depend on water uptake from below 2m depth to maintain green, transpiring leaf canopies during dry seasons of 3-5 months (Nepstad *et al.* 1994, Negreiros and Nepstad 1994). Pastures withdraw less water from deep soil than the forests that they replace.

Hence, forest replacement with pasture causes substantial changes in the amount of water that is returned to the atmosphere through evapotranspiration. This difference is particularly pronounced in the dry season, when pastures respond to drought by browning up their leaves, while forests respond to drought by drawing on water stored deeply in the soil profile. This change in evapotranspiration is important implication for run-off from the land, since the soil beneath pastures is wet relative to that of forests, and can retain less incoming rain against run-off. One important effect of forest conversion to pasture is therefore the increased flow of water through streams and rivers, with accompanying changes in peak flow rates, flooding and soil erosion.

Differences in radiation balance between pasture and forest are a primary cause of differences in climate between two vegetation types. During ABRACOS (Anglo-Brazilian Amazonian Climate Observation Study) it was found that more radiation is absorbed by forest than by pasture. The difference is largely because pasture reflects more incoming radiation than forest, where the radiation is trapped by multiple reflections in the deep canopy. On average, the pasture reflects 18% of the solar radiation, whereas the forest reflects only about 13% (Fig. 3) (ABRACOS 1994).

Measurements made in ABRACOS have also shown that during rainy periods the proportion of available energy at the surface which is used for evaporation is similar for forests and pastures. However, during periods of several days or weeks without rainfall, the evaporation from the pasture is reduced, while the forest continue to evaporate water at the same rate. During dry periods the pastures return less water to the atmosphere, which in turn, reduces the likelihood of cloud formation and rainfall. In addition, less energy used for evaporation in the pasture means that there is more energy left to heat the air. This means that replacing the forests with pasture should therefore give hotter dry seasons with less rainfall. These changes will feed through the hydrological cycle and result in changes in river flow, and the severity of the impact will depend on the length of the dry season and on the soil type, which controls the water availability (ABRACOS 1994; Roberts *et al.* 1995).

Global: Supposing that, on average, each hectare of forest contains about 300t of biomass (Fearnside 1989), a loss of about 6 billion tons of plant biomass has taken place through forest-pasture conversion in Amazonia, 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 tons of carbon should have been liberated into the atmosphere as a result of fires and decomposition of organic matter in the pasture formation and management processes during the 1970s and 1980s in the Brazilian Amazon. "Greenhouse" gases like CO_2 affect climate (Salati 1987). It is (grossly) estimated that the conversion of forest to pasture in the Amazon would have contributed up to about 6% of the total global emission of carbon resulting from the conversion of tropical forests in those two decades (Serrão 1990). This rate of forest conversion-and, hence, the rate of carbon release to the atmosphere-has apparently declined in recent years (INPE 1992), although information is not available since 1991.

The amount of carbon that is released to the atmosphere through forest conversion to pasture is, of course, a subject of some debate. The largest pool of carbon in the Amazon forest is in the soil, where 300-400 t/ha are typically stored. Recent research (Nepstad *et al.* 1994, Trumbore *et al.*, in press) 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 Básin.

Figure 4 illustrates changes in carbon stocks during one sequence of primary forest converted to pasture, which is then abandoned. Carbon embodied in above-ground vegetation of pasture ecosystems after a decade of use is only about 10% of that found in the original forest. This carbon is reaccumulated following abandonment at a rate of ca. 5t/ha/yr. Below ground, the pool of carbon is larger, but the amount of reduction through conversion to pasture is relatively small. Most deep soil carbon is bound in chemical forms that are not easily released to the atmosphere.

It has been proposed that some pasture forage grasses planted in South American savannas have vigorous root production which can lead to the accumulation of carbon in the soil (Fisher *et al.* 1994). A similar result was found in an Amazonian pasture (Nepstad *et al.* 1994). Such an accumulation of soil carbon is dependent upon the management of the pasture, and can offset to a small degree the carbon that was released to the atmosphere when the forest was cut and burned (Davidson *et al.* 1995).

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 tons of biomass spread intricately over 40 m of vertical space, a field is created with a few dozen species containing some 10t of biomass per ha, compacted into 1m of vertical space (Uhl *et al.* 1988). The low, open structure of pastures results in higher peak air and soil temperatures and higher vapor pressure deficits compared with the forest understory (Nepstad in press).

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. 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 (da Silva *et al*, in press; Nepstad *et al.* in press). 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 "maçaranduba" (*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.

These considerations are summarized in Figure 5, which compares the number of species of different plants and animals in adjacent primary forest, pasture, and 15-year-old secondary forest near Paragominas. It was found that one-fourth of the primary forest tree flora, one half of the forest bat fauna, one half of the forest bird, and one fifth of forest ants had recolonized the secondary forest (Nepstad *et al*, in press, Figure 5). Hence, while the accumulation of biomass appears to be quite vigorous in most abandoned cattle pastures, the recovery of most of the original plant and animal species is uncertain. Moreover, many of the new species that comprise recovering secondary forests, such as cutter ants and seed-harvesting *Pheidole* and *Solenopsis* ants, may preclude the establishment of some plant species (Moutinho in press, Nepstad et. al. in press).

When one considers the environmental impacts of forest conversion to pasture on biodiversity, it is tempting to focus just on the small are 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.

WHAT IS THE ECONOMIC PERFORMANCE OF FOREST-DERIVED PASTURE IN AMAZONIA?

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 and Uhl 1994), 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. 6). The cost to make this shift to semi-intensive ranching is approximately US$ 260/ha (Mattos and Uhl 1994). 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. 6). In this land-use enterprise, capital investment is high but so are profits (US$ 125/ha/year) and returns on investment (16%) (Mattos and Uhl 1994).

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 Eastern Amazon, they may be, in some measure, applicable to other similar environmental and socioeconomic conditions in other similar region of the Amazon.

PASTURE IMPACTS ON FOREST RESOURCES

While the above economic evaluation of pasture-based cattle ranching in deforested areas may not necessarily be applicable to the whole the Amazon Region, it serves as reference to the following analysis of converting rain forest to pastures which may be extrapolated to other areas the region. 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, that 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. 7 shows a primary forest and an open pasture ecosystem, as well as their different losses and approximate costs. The primary forest contains many timber species that could supply wood indefinitely, but this option is forfeited when forests are removed for pasture or for other agricultural purpose. 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.

Approximately 400 tons of biomass are eliminated through forest conversion to pasture (Figure 3), resulting in the release of 200 tons of carbon to the atmosphere. One of the most recent attempts by economists to place an economic value on carbon, based on the assumption that rising concentrations of CO_2 in the atmosphere will lead to global warming and accompanying sea-level rise, places the average value of a ton of carbon at ca. US$ 20 (Fankhauser 1995.) Hence, ca. $4000 worth of carbon are liberated to the atmosphere through the conversion of one hectare of forest to pasture.

Considering the above two forest values (wood, and carbon), directly or indirectly, at least US$ 6000 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. 7), First, forest, 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 stabilizing factor of regional climates (Nepstad *et al.* 1994). Finally, forest 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 Amazon.

ALTERNATIVES FOR IMPROVING ECONOMICAL AND ENVIRONMENTAL SUSTAINABILITY OF PASTURES IN DEFORESTED LANDS

Existing pasture lands resulting from deforestation in the Amazon need to become sustainable environmentally and socio-economically (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 landholding, and semi-intensive integrated pasture-tree-crop (agro-silvipastoral) production enterprises for small and medium landholdings (Serrão 1992; Mattos and Uhl 1994). The last alternative enterprise can derive both from the insustainable extensive pasture-based beef cattle enterprise or from extensive shifting agriculture activities (Fig. 6).

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 (*Bysonima 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 Amazon 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. 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.

ADDITIONAL INFORMATION AND RESEARCH NEEDS

As sown pasture-based cattle raising becomes more important as a land use system with good potential for increasing environmental and economic sustainability, more information is needed about the following important topics:

- Deforestation and census information.
  No new deforestation estimates and no reliable census data have become available since 1991 and 1985 respectively. Trends in pasture formation and its geographical distribution is hardly known.
- "Pecuarização".
  More information is needed on the process of "pecuarização". Increasingly, cattle pastures are being developed by small-holders as a way of accumulating capital and land.
- The Pasture industry is now precariously dependent upon *Brachiaria brizantha*.
  There is an urgent need to encourage cattle producers to diversity their forage systems, to prevent possible calamity that might arise from disease or pest outbreak.
- Intensification of cattle production systems is taking place with favorable improvements in profit/hectare or profit/labor input.

How can this intensification be promoted in a broader scale?

Research priorities should center on interrelated environmental, management and technological factors causing pasture degradation and those promoting pasture sustainability.

The new scenario and models for pasture-based livestock development in the Amazon, as proposed in this paper, calls for research priorities in the search for alternative adapted forage germplasm, nutrient cycling in pastures, pasture production intensification, the use of legumes in association with grasses and in "protein banks", weed control, forage seed production and integration of livestock (pasture), crops and trees in feasible silvi- and agrosilvopastoral production systems for small-scale milk and beef production systems.

Urgently needed are improvements of agricultural production systems that begin with the rather sophisticated knowledge of the farmer. Such research, conducted in tandem with research designed to encourage the utilization of forest products, can lead to the stabilization of the agricultural frontier. The need is for multidisciplinary research conducted with a high degree of participation of farmers, ensuring that technological innovations will be compatible with the considerable innovations already in use by the farmer. The goal is for a set of case studies of successful intensification of agriculture and utilization of forest resources.

For cooperative research, it is recommended that case studies of local management of resources be carried out involving research and extension on local institutional organization (including cooperatives and syndicates), resource inventories, forest and water management, agricultural intensification on already cleared lands, fire prevention, commercialization and marketing.

INFORMATION DISSEMINATION

There are indications that the agricultural development in the Amazon region is presently going through the beginning of a transition from a largely unsustainable development phase towards a more sustainable situation. This trend will require a considerably more scientific knowledge and technology to support the increasing levels of land use systems' sustainability (Fig. 8), from an agrotechnical, socioeconomic and environmental point of view.

Although much techno-scientific information on pasture-based cattle raising in the Amazon is still needed, a considerable stock of scientific knowledge and technologies is available (as was seen above) in governmental and non-governmental research and development institutions in the region, EMBRAPA research centers being a major source, having accumulated significant amount of pasture and livestock information which can be used to support sustainable pasture-based livestock development activities.

Some of the available information has been transferred to users at the different levels (farmers, planners, decision-makers). However, much of it is still in scientific reports of different kinds and in the heads of researchers in local research and development institutions and universities, waiting to be disseminated.

Information on Amazonian land-use must be made available in a variety of formats to reach the broad audience that is interested in this topic. In particular, it is important that the peer-reviewed literature in both Portuguese and English, be viewed as the primary outlet for new research results regarding Amazonian agricultural and forestry development. In Brazil, these publications include for example, "Ciencia e Cultura", "PAB" - Pesquisa Agropecuária Brasileira. Outside of Brazil, the number of appropriate journals for Amazonian research is extensive. The advantage of disseminating research results through the peer-reviewed literature is that this literature is archived in the various electronic literature databases, and is easily retrieved around the world. Publication in this literature also guarantees a moderate level of scientific rigor, because of the peer-review process.

Important popular formats for disseminating research results in Brazil include periodicals such as "Globo Rural", "Manchete Rural" and their respective weekly television formats. Research institutions are beginning to realize that they have to develop their own radio and video programs directed to potential users of their available scientific and technological information

Most of the universities and research centers in Amazonia and elsewhere in Brazil now have access to the Internet through local nodes. This network is best used for informal communication of research findings, and for discussion of specific issues. Those centers that do not have Internet access should be encouraged and supported to acquire it.

At the practical land use level, research institutions, in strong association with extension organizations, must develop approaches and processes of technical assistance to farmers which include transfer of already tested pasture-livestock technologies and on-farm validation of those untested ones, with strong participation of farmers.

Improvement of information flow will come from on-farm research, with increasing emphasis on demonstration plots and experiments, allowing farmers to become engaged in the experimentation with production systems, making it very clear that agronomists do not have all the answers, and are learning together. Farmers could also perform as teachers/extensionists, showing farmers from other regions what they have learned on their own land. This could be a powerful multiplier.

One other means of improving information flow would be to strengthen the network of local communities and other organizations as the *de facto* institutions that are disseminating information on agricultural production.

MAIN OBSTACLES TO REALIZING SUSTAINABLE DEVELOPMENT

Smallholders have advanced most of the proposals for sustainable, multiple use of forested landscapes, but they are repeatedly frustrated in their efforts by violence in rural areas, difficulties in acquiring secure land titles and tenure, and difficulties in accessing credit. Sustainable development of Amazonia will be possible when the disenfranchised sector of the Amazon rural population that holds less than 100 ha of land-which is the most populous group in Amazonia-acquires greater control of their resources and receives adequate financial and technical assistance to achieve local management of these resources.

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FIGURES

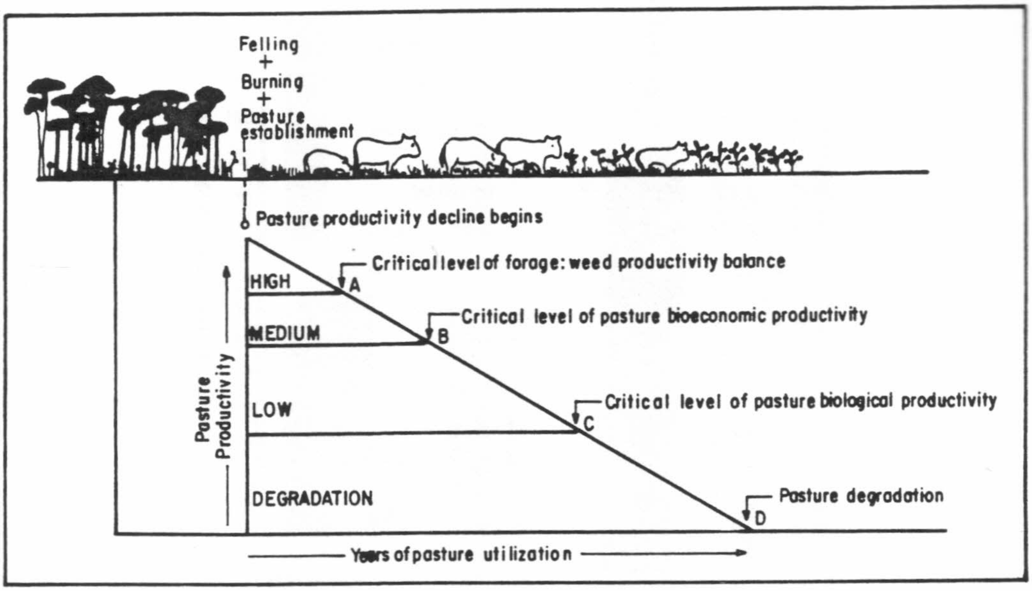

Figure 1 - Typical declining pattern of agrotechnical and economic sustainability of extensive first-cycle forest-replacing pastures formed managed with inapropriate pionner technology. Adapted from Serrão *et al.* (1979); Dias Filho & Serrão (1982); Toledo & Serrão (1982).

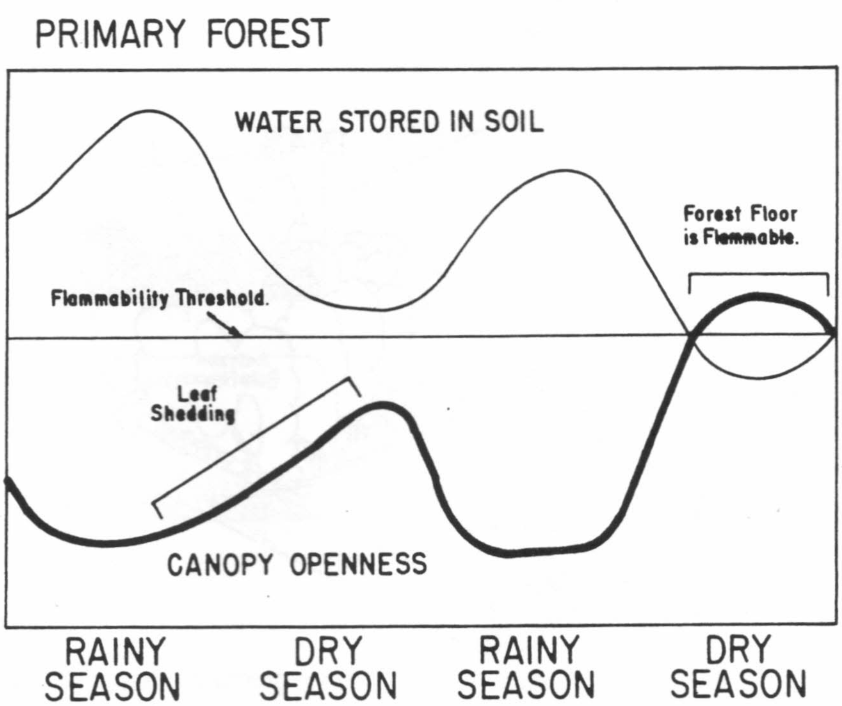

Figure 2 - A model of primary forest resistance to flammability. Because of its access to a very large soil volume (through deep-rooting), successive years of low precipitation are necessary to provoke enough leaf shedding for the forest floor to become flammable. The flammability of the forest floor is limited most years by the dense leaf canopy which maintains a cool understory with high relative humidity. Source: Nepstad *et al.* 1995.

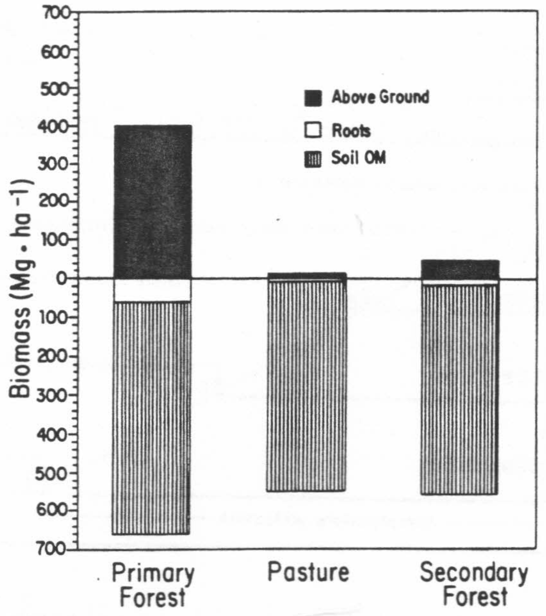

Figure 3 - Biomass of the ecosystems of Paragominas. Carbon stock are equal to roughly one half of biomass. The large pool of biomass in each ecosystem is soil organic matter. However, ca. 85% of this organic matter is refractory, cycling on scales of centures to millenia (Trumbore *et al.*, in press). Source: Nepstad *et al.* 1995.

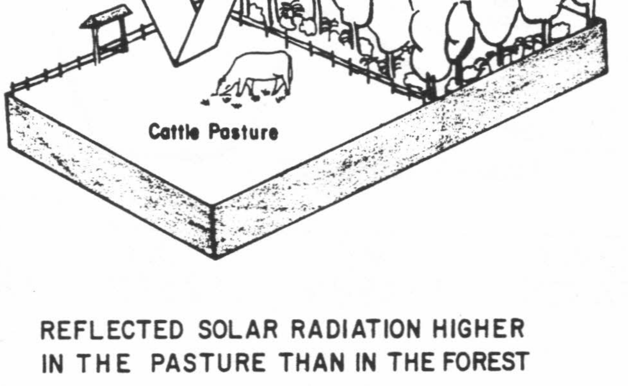

Figure 4 - Difference between reflection coefficient (albedo) from pasture (18%) and forest (13,4%) (ABRACOS 1994).

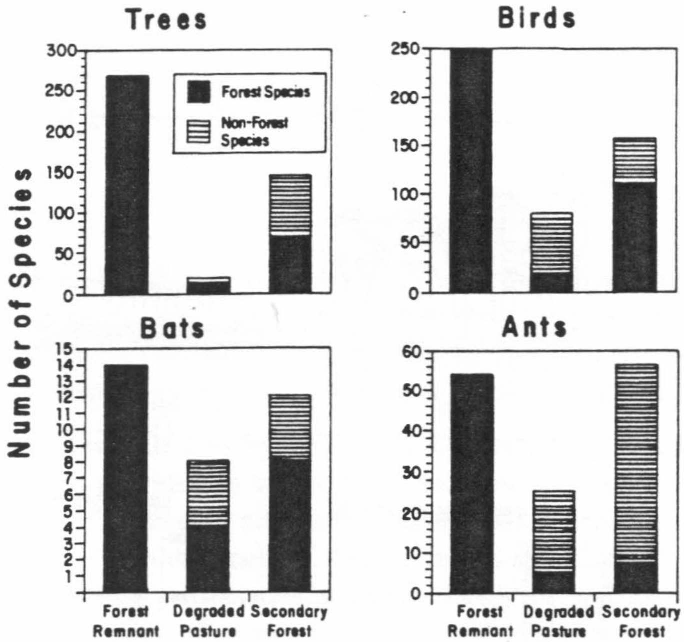

Figure 5 - Number of forest and non-forest tree, bird, bat and ant species in a primary forest remnant, an adjacent degraded pasture and a secondary forest on abandoned pasture (Fig. 2) at the Fazenda Vitoria, Paragominas. Source: Nepstad *et al.*, in press.

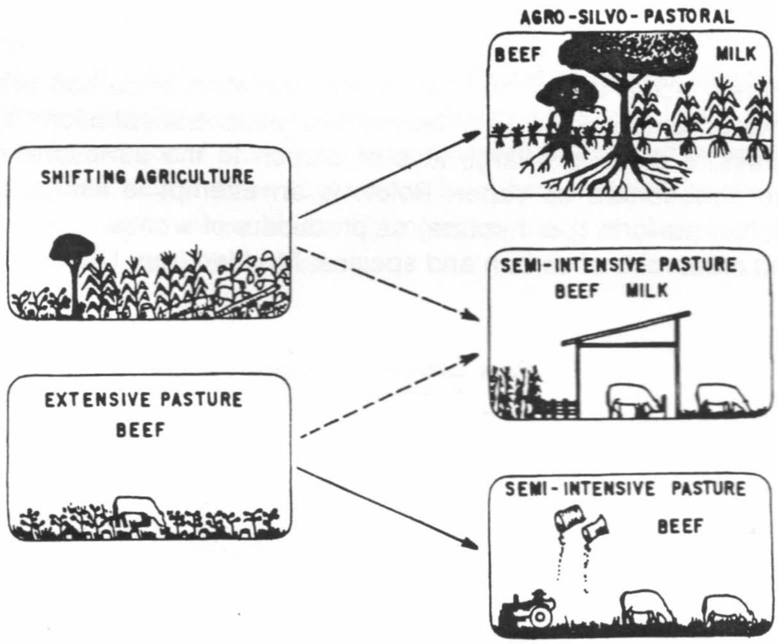

Figure 6 - Pasture-based ranching enterprises in deforested areas of the humid tropics should move away from unsustainable extensive beef cattle to more intensive and sustainable pasture-based systems such as: semi-intensive beef cattle enterprises; semi-intensive dual-purpose cattle enterprises; and semi-intensive agrosilvipastoral dual-purpose cattle enterprise. This last enterprise may be derived from either extensive pasture enterprises or from extensive shifting agriculture enterprises. Adapted from Mattos and Uhl (1994).

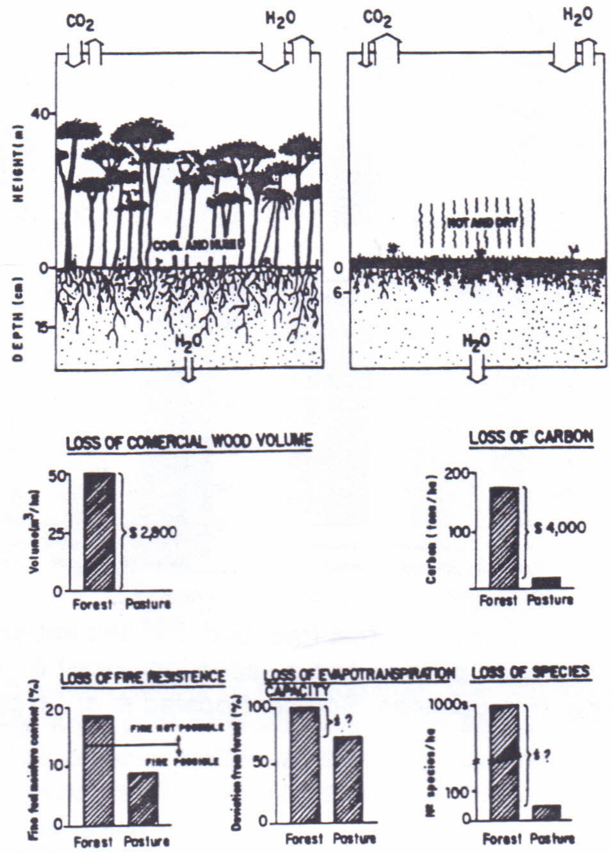

Figure 7 - In forest ecosystems the fixation and liberation of carbon are in equilibrium and most of the water entering as rain leaves via evapotranspiration. When the forest is converted to pasture there is a large loss of carbon to the atmosphere and less water is returned to the atmosphere as vapor. Below is an attempt to assign dollar values to the services that forest perform (per hectare) as producers of woods, cylers of water, barriers to fire spread, and reservoirs of carbon and species. Modifed from Uhl *et al.*, 1993.

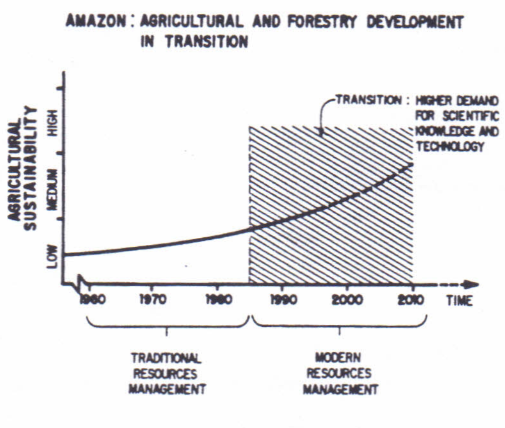

Figure 8 - Agricultural and forestry development in the Amazon is presently going through a transition from a largely unsustainable development to a more sustainable situation, where modern resources management will require more scientific knowledge and technology.