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Cows, colonists and trees: rethinking cattle and environmental degradation in Brazilian Amazonia

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Abstract

This paper examines the role of cattle production in the evolution of smallholder farming systems in a frontier region of Brazilian Amazonia. There are many incentives for smallholders to raise cattle, but the success of cattle enterprises depends on a number of factors, both endogenous and exogenous to individual farms. A key factor in the intensification of cattle production is pasture management. We identify three models of pasture management, reflecting different levels of specialisation and intensification of production systems. Contrary to conventional wisdom, our findings indicate that pasture quality and degradation are related to under-utilisation and low stocking rates. This suggests that more intensive systems may be more ecologically sustainable in some contexts. However sustainable intensification strategies, which could potentially contribute to frontier stabilisation, depend on investment in infrastructure, markets and social capital beyond that of individual farms or farmers.

Keywords: Sustainable agriculture; Livestock production systems; Frontier agriculture; Agricultural colonisation; Amazonia

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1. Introduction

Until very recently popular and scientific views on the dynamics of colonisation of Amazonia highlighted the unsuitability of the land for agricultural production. Land degradation following production under slash and burn and pasture establishment is commonly identified as fuelling high rates of migration in the region. Cattle production particularly is perceived as one of the most damaging forms of land use in the Amazonian region (Hecht, 1985; Fearnside, 1990). Recent studies from different parts of Amazonia have produced new evidence suggesting that, contrary to this conventional wisdom, many settlements have been more successful in terms of agriculture and economic development (for example, Almeida and Campari, 1995). Studies have shown that, despite the loss of subsidies, cattle ranching is still expanding (Faminow, 1998; Mattos and Uhl, 1994, Almeida and Uhl, 1995; Arima and Uhl 1997). Moreover, the problem of continued migration further into the forest is now regarded as a result of land markets and other economic incentives rather than the consequence of environmental degradation per se (Reynal at al., 1995; Schneider, 1995). Despite these more optimistic views however, high colonist migration rates and the role of pasture establishment in widespread deforestation remain constraints to sustainable development of frontier regions (Richards, 1997).

Cattle are a key component of the land use systems of Amazonia. One of the recurrent problems of economic, ecological or agronomic analyses of the livestock sector in Latin American rainforest areas is they almost exclusively focus on ranching, as shown for example in the debate around the so-called 'hamburger connection' (Myers, 1981; Uhl and Parker, 1986) or studies by authors such as Hecht (1989) and Parsons (1993). These analyses tend to overlook smallholder enterprises, which represent the most numerous group of producers in Amazonia. Through a detailed study of a sample of farms in three localities in the Marabá region, Southern Pará, Brazil, this paper analyses the role of cattle in the dynamics of farming systems, and the implications of intensification of cattle production for frontier stabilisation in Amazonia.

Our analysis of pasture management in particular causes us to re-assess the processes of pasture degradation and the environmental impacts of pasture establishment. This re-assessment conforms to recent conceptualisations of land degradation and advances in understanding pasture ecology. However, as sustainability encompasses not only ecological and environmental aspects of farming systems, the paper also addresses the economic sustainability of livestock production, analysing production costs and markets for dairy products. Finally, by placing these analyses within the wider context of frontier dynamics, the paper assesses whether the current process of intensification of livestock production can contribute to farming systems sustainability and to more sedentary land uses in Amazonia.

2. The role of cattle in smallholder farming systems

The Marabá region comprises an area of so-called aging frontier in eastern Amazonia, where colonisation by migrant farmers has taken place since the late 1960s.

Colonist agriculture now occupies 33% of the land area, ranches or *fazendas* 48%, with the remainder shared by Indian land and indigenous reserves, biological reserves, urban and other land uses (LASAT, 1998). Forest clearance has occurred at a rate of 1.6% per year during the last two decades and 36% of this clearance has been for agriculture. Colonist farmers were responsible for one third of this change (LASAT, 1998). As Fig. 1 shows, most of the cleared areas have been converted to pasture.

The key drivers of pasture-led deforestation in Amazonia are generally identified as the property rights regime and land speculation. Rights to land are secured when pasture is established thereby providing an incentive for forest conversion. In addition, land is significantly more valuable under pasture than other uses (for example, perhaps three times the price per hectare than forested land). Furthermore, animal husbandry for meat or milk production has significant appeal to both large and small farmers, and cattle production is one of the most attractive economic activities in the area. Cattle play a key role in smallholder farming systems at the frontier for a number of reasons and have a number of advantages for colonist farmers, as summarised in Box 1 (see Hecht, 1993; Loker, 1993; Nicholson et al., 1995; Reynal et al., 1995). The importance of cattle in different farming systems varies according to the length of occupation and the dynamics of particular settlements. A 'standard' evolution sequence of the farming systems in the Marabá region has been described by the LASAT team (Reynal et al., 1995; Muchagata, 1997), identifying three phases outlined in Box 2, showing an increasing emphasis on cattle production with time.

Our study examined the strategies of smallholder colonist farmers in three localities in the Marabá region, Maçaranduba, Murumuru and Nova Canaã. These localities have been settled for different periods of time and reflect the evolutionary

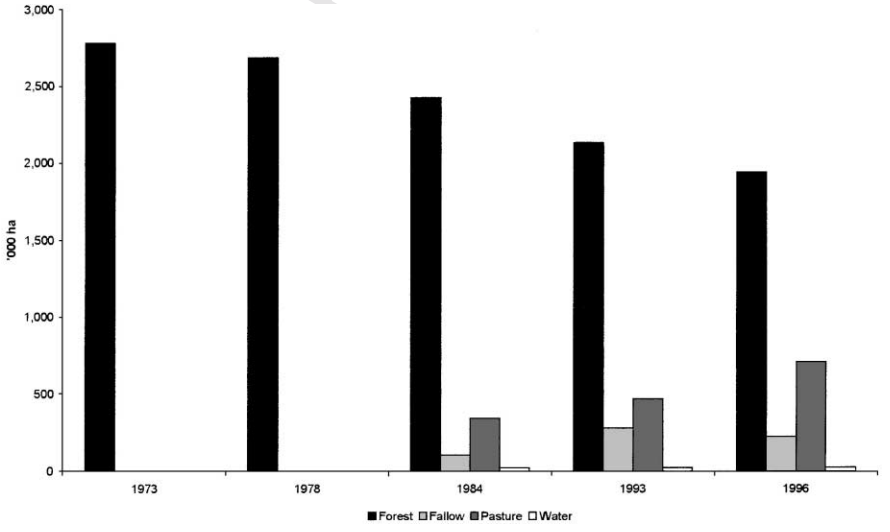

Fig. 1. Evolution of forest cover and other land uses in Marabá 1973–1996.

Box 1. Advantages of cattle rearing in Amazonia.

1. Land Rights	Pasture as a means of securing land Pasture increases the value of land up to three times that of forest Pasture can provide income and other benefits through rent Pasture has low opportunity costs Pasture can be a strategy for extending the useful life of a cleared plot
2. Production	Low risk compared to crops Cattle prices are more stable than other products Markets—cattle are easier to transport and have established market chains which are easy to access Flexible and low labour demand, with little seasonality Dual purpose production, with cash flow from dairy production

Table 1
Characteristics of the study sites

Locality	Number of farms monitored	Farm size (ha)	Forest cover (%)	Pasture cover (%)	Fallow cover (%)	No. of cattle per farm	Years since first colonisation of the area	Average length of settlement of monitored farms (years)
Maçaranduba	5	50–100	51	15	13	6–10	11	9
Nova Canaã	8	20–215	14	44	18	3–45	24	14
Murumuru	6	55–225	10	81	4	20–200	23	7

pattern outlined in Box 2. Table 1 summarises the characteristics of the study sites. Maçaranduba is a relatively newly settled area, with a high proportion of forest cover remaining. It is part of a newly established Agro-extractivist settlement. Such settlements have been designated as a result of legislation in 1990 and aim to integrate smallholder farming with forest conservation. Farmers are supported, with credit and other inputs, to establish livelihood systems based on extraction of forest products, such as collection of Brazil-nuts or latex, which aim to limit crop and livestock development. However the locality generally has poorly developed infrastructure and limited access to markets. Murumuru has developed very rapidly mainly due to its proximity to the urban centre of Marabá. The landscape is dominated by pasture and specialised cattle production systems based on dairying have

Box 2. Standard evolution of farming systems in Marabá.

First phase—installation:
A farmer occupies a plot or *lote* completely covered by forest, in a recently settled locality, with no infrastructure or services. The farmer clears an area in the forest (around 3 ha on average) in a slash-and-burn system, and installs the first rice crop. The farm household is very dependent on the forest resources: almost everything in the house is made by members of the household, and timber and non-timber products are important sources of income. Another important cash source can be labour, sold to neighbouring *fazendeiros*. Given the instability of land tenure, the *lote* boundaries are not clearly defined and need to be protected. Moreover, many farmers are not sure whether they will stay in the area in the long-term, so they will try to sell as much timber as possible and establish pasture to add value to the land.

Second phase—system diversification:
After four to five years of settlement the *lote* changes significantly. The family have improved their house and built structures to produce cassava flour; they also produce beans and maize, mainly for household consumption but they sell any surplus. They may start a small but diversified orchard around the house and have some poultry and pigs. Although the forest cover remains important, most *lotes* have some pasture around the house and some fallow land. Farmers who have more capital initially may have acquired cattle, generally 10–15 animals.

Third phase—system specialisation:
At this stage local infrastructure is well developed and farmers are able to sell milk or cheese. Livestock production becomes the principal activity: main sources of income are dairy products and sale of calves. Herds are at least 40 cows and some farmers will have up to 120 animals. Pasture covers most of the farm area. Crops like rice or cassava remain for subsistence, if at all, and the forest is kept only as a nutrient reserve, that is, to be cleared in the future for crops or pasture, not for production per se. This imposes serious restrictions on the sustainability of the farming systems, as the forest is being reduced each year.

developed. The area has daily collections by a large dairy company and also has a number of small, family based cheese production units. Nova Canaã on the other hand, has more diversified farming systems and little forest cover. Farming systems are gradually becoming more specialised, and where farmers keep cattle they produce cheese which is sold at relatively low prices. In each of these localities, a series

of participatory exercises, meetings, workshops and interviews were held, and a sample of farms were monitored for a period of 15 months.[1]

3. Cattle production in Marabá

This section outlines the main characteristics of cattle production in Marabá, highlighting the levels of intensification on farms and different management practices of smallholders. The level of intensification of cattle production varies considerably between localities and farms within the region. Intensification may be evaluated on the basis of stocking rates, use of specialised breeds, health care and animal husbandry, or quantity and quality of fences and other equipment. These indicators reflect the amount of capital and labour available for investment in production. Farmers' practices, however, are shaped not only by labour and capital availability, but also by their knowledge and access to information. For example, some farmers with relatively high capital were found to be ineffectively immunising their animals against foot and mouth disease because they lacked information on the timing of treatment. Technical knowledge is associated with the farmer's previous experience, and with their neighbours' practices (Muchagata and Brown, 2000). Sections below compare some of the different practices and evaluate their impacts on production and implications for economic and ecological sustainability.

3.1. Herd composition and management

Herds reflect the dual purpose production for meat and dairy, and also the links with the large-scale ranching sector (the *fazendas*). Herds tend to have zebu (*Bos indicus*) cattle, preferred by the ranchers for meat production, mixed with specialised dairy breeds (*Bos taurus*). Smallholders exchange or sell male calves, and keep the females on the farm. Farmers try to introduce dairy breeds as soon as they can, mainly through exchange with other dairy producers. So, in newly settled localities such as Maçaranduba, only two breeds are found, while in Murumuru 12 were found, either dual purpose or dairy breeds. Farmers' main strategy is to increase the size of the herd. Table 2 presents herd performance indicators, and shows that growth rates decrease from Maçaranduba to Murumuru, and culling and exploitation rates increase.

[1] Farms were visited monthly between September 1997 and December 1998. Monitoring was concerned with the different components of farming systems: yields, cash flows and consumption, labour, herd characteristics and management, pasture management. Early interviews were interested in family history and farm structure. Twenty-one farms were studied in depth with continuous year round data collected for 18 farms. Workshops with farmers in later phases of research facilitated the comparison of farms, the analyses of the different levels of sustainability, constraints and opportunities to improve livestock production according to farmers' own perspectives.

Table 2
Cattle performance indicators for the period November 1997–October 1998 at the three sites

	Maçaranduba	Nova Canaã	Murumuru
Fertility (%)	100.0	69.9	92.50
Mortality (%)	3.50	8.9	1.4
Herd growth rate (%)	57.5	11.1	14.7
Interval between births (months)	11.4	13.9	14.2
Average weight gain (kg/year)	n.a.	108.7	127.3
Farm monthly milk production			
Dry season (l)	81.5	682.8	2077.2
Rainy season (l)	99.7	690.8	1963.8

Herd management is quite simple as feeding is based exclusively on pasture. Only two farmers in our sample supplied cassava to animals during the dry season. When production is not very specialised and with small herds, all animals are kept together in the same paddock, and are brought to a corral or close to the farmstead each evening. They are milked and tended once a day, early in the morning, before being let out to graze. In Murumuru farmers divide the herd into two groups; the suckler herd and calves are brought into the corral every evening, and the other group remains further from the farmstead for days at a time.

As the production systems become more intensive, vaccination and other health treatments are applied more frequently and systematically. In general, we find that older localities tend to have more health problems than newer ones; hence health problems are more severe in Nova Canaã than in Murumuru partly because pasture management is poor and animal management less intensive, possibly related to poor investment and lack of technical knowledge. Although health problems are common they are not serious, so mortality rates remain low (Table 2). The most serious problem is related to mineral deficiency, reflecting the limits of exclusive pasture feeding and lack of mineral supplement mixes formulated for Amazonian conditions. In addition, although farmers often state that they are providing animals with adequate amounts of mineral, when cross-checking their information with their monthly expenses it is apparent that they often provide less than half that needed. This has important consequences for animal performance, as reproduction and milk production are directly affected by mineral deficiencies (see Brown and Muchagata, 1999).

3.2. Herd performance

When analysing smallholders' herd performance it is important to recognise that farmers' objectives of dual purpose production will generate lower rates of both milk and meat production compared to more specialised systems (Nicholson et al., 1995). Claving interval and herd fertility are related to environmental health and farmers' practices. Where pasture is in good condition and herds are quite small, they can be managed more intensively, and the interval between births is low and fertility high,

as in Maçaranduba. Nova Canaã demonstrates the poorest indicators of performance. The breeding season is generally not actively managed by farmers, and births are concentrated at the beginning of the dry season. Generally cows produce less than 500 litres of milk per year (less than two litres of milk per day per lactation) (Table 2). Although milk or cheese represents the main sources of cash for farmers, production is highly variable throughout the year, revealing a lack of management of production cycles. Farmers tend not to interfere in the natural cycle, and during the dry season it is easier to look after new calves. Despite forage availability during the wet season, milk production is greater during the dry season, in contrast to practices in other regions of Brazil. Wet season production also decreases because many farmers stop milking the cows, sometimes because roads become impassable, preventing the transport of milk or cheese. The absence of markets is an additional reason milk production is so low in Maçaranduba.

Weight gains average around 110 kg per year, although male animals fattened for market may weight up to 240 kg by the end of their first year. This figure is similar to cattle from ranches in central-north Brazil, where cattle are slaughtered at four years. Animal performance in Marabá is equal or often better than other areas of Amazonia, including intensive systems in Northern Pará, based on data presented by Faminow (1998). However, despite comparatively good production rates, there is still the opportunity for further intensification of the production systems and for increases in milk yields and shorter intervals between births.

4. Pasture establishment and management

Our findings suggest that pasture management is the key to enhancing the sustainability of colonist farming systems and the intensification of livestock production. Farmers conventionally see the need to increase pasture areas as herds increase in size, and this threatens forest. This is reflected in Fig. 2, which presents the expansion of pasture areas in the farms studied at the three localities in the past twenty years. This shows that in last 30 years the pasture on these farms has expanded from under 100 to 900 ha; a nine-fold increase in area of pasture. This is in line with the expansion shown for the region in Fig. 1, mirrored by a reduction in forest cover.

The main pasture species are *Brachiaria brizantha*, *Brachiria decumbens* and *Panicum maximum*. The importance of each species in a given locality depends on the length of settlement. For example, *P. maximum* was very popular during the 1970s and 1980s due to good propagation and establishment, palatability and nutritional value. This species was used to establish new pasture areas, and thus supported the rapid expansion of cattle production. However, *P. maximum* is tussock-forming and this can lead to erosion and degradation, and so other species such as *B. humidicola* and *B. brizantha* are required for more intensive and durable pastures. *B. mutica* grows in low-lying wet areas, and is useful for providing fodder for animals during the dry season when other pasture is unavailable. Farmers' strategies are thus to have paddocks of different pasture types. In practice they establish

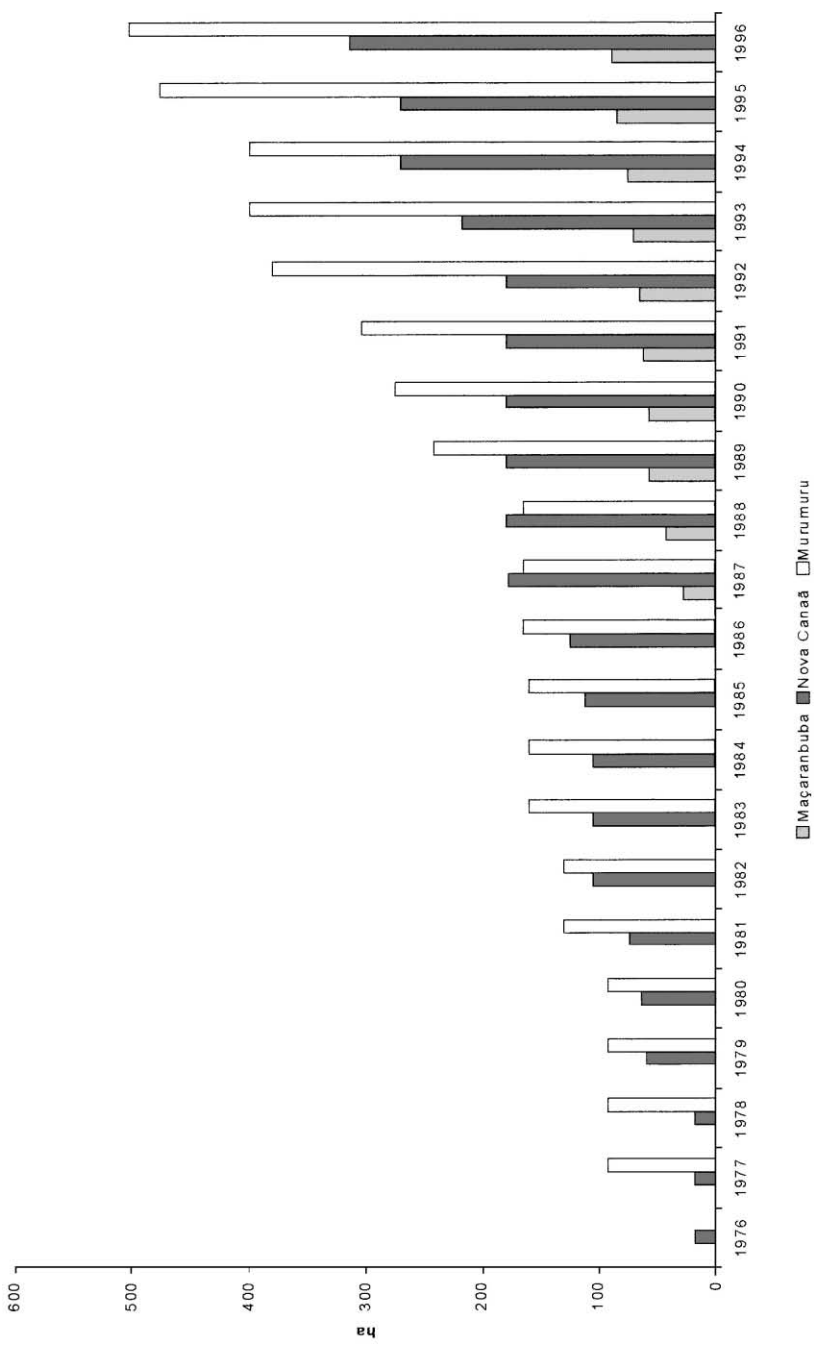

Fig. 2. Expansion of pasture area on the farms monitored in three localities.

a paddock with a single species and over time they introduce other species. At Murumuru, when farmers noticed the first signs of *P. maximum* deterioration they began to reclaim pasture areas by sowing some *B. brizantha* every year, gradually changing the species mix of the pasture. In less intensive systems in Nova Canaã, *P. maximum* continues to be the dominant species, with the gradual introduction of other species. This practice of sowing new seeds every year was found amongst all the farmers monitored. Maçaranduba, which was settled after the popularity of *P. maximum* had waned, only has the species in small areas, where it is planted to provide grazing for horses and young animals.

The method of planting pasture depends on farmers' fertility management strategies. Sowing pasture directly after forest burning is a comparatively rare practice on smaller farms and is practiced only on large ranches. Smallholders generally sow rice immediately after the forest is burned, and then pasture is planted with seeds or seedlings when the rice is well developed. Often, pasture is sown a year later, when cassava, established soon after rice, is about to be harvested. The other options are either to leave the area in fallow for 3–5 years, then sow pasture after the fallow is slashed and burnt, or to sow pasture straight after fallow is burnt.

Farmers, with varying degrees of success, generally adopt a rotation system for pasture grazing, and they have several paddocks. The more specialised the system, the greater the number of paddocks. This can be seen in Table 3, where the number and size of paddocks are shown for each locality. The extremes—again reflecting the length of settlement and degree of intensification—show that some farmers in Maçaranduba have only one small paddock, whilst another in Murumuru has twelve. Greater number of paddocks is often presented as an advantage (see, for example, Simão Neto, 1995, although Pearson and Ison, 1997, identify animal biomass as a key factor). However, this is true only if there is a good rotational grazing system which does not appear to be the case in Marabá.

The rotation system and stocking rates fluctuate through the year, as farmers often send and/or receive animals from neighbours or relatives. Management decisions are related to pasture conditions, water availability, animals' particular needs and labour availability. Decisions related to rotational grazing are tactical rather than strategic; they are conditioned more by limits and opportunities experienced by

Table 3
Characteristics of pasture in the farms monitored in the three localities

	Maçaranduba	Nova Canaã	Murumuru
No. of farms monitored	5	8	6
No. of paddocks—total	11	19	30
Paddocks per farm—average	2.2	2.4	5
Paddocks per farm—min–max	1–4	1–3	3–12
Average paddock size (ha)	8.2	16.54	16.77
Paddock size—min–max (ha)	3.6–19.2	2.4–38.4	2.4–43.2
Total area of paddock (ha)	90.2	314.4	503.2
Main species	*B. brizantha*	*P. maximum*	*B. brizantha*
Year *B. decumbens* introduced	1987	1986	1990

farmers each year than a result of overall or long-term land use or resource planning. Farmers respond to situations of perceived forage shortages rather than preventing them; they are reactive rather than pro-active. In this sense their management is similar to the opportunist strategies found in rangeland management in Africa (Behnke and Scoones, 1993). However, in the Amazonian context this results in an inefficient use of the forage produced. The monitoring of rotations and stocking rates over the period of one year enabled us to identify three models of grazing, shown in Fig. 3.

In the first model farmers have one or very few paddocks, managed as if they were just one, with the gates linking them always open. Stocking rates are very low, between 0.2 to 0.7 AU/ha, and cattle do not consume all the grass produced, and as a result there is much dried forage early on in the dry season. The paddock is not rested and there is a build-up of parasites. In Nova Canaã particularly, these areas have the greater incidence of accidental fires due to high dry matter.

In the second model, farms have 3–4 paddocks. The first paddock is closest to the house where water is available, and *P. maximum* dominates. This is the most frequently used paddock. Stocking rates oscillate during the year from 0.8 to 1.8 AU/ha. Other paddocks are used, but not often (less than 50 days per year), and because they are smaller, they have higher stocking rates (2.1–2.4 AU/ha). A final paddock is never used. Although the first paddock is generally well maintained, the others produce more grass than is consumed. Given that grass growth is stimulated by consumption (up to a certain limit), then production is actually constrained by poor utilisation. Although a significant amount of biomass is produced, the weed invasion is considerable, and the risks from fire high.

The third model, employing high stocking rates, was found on two farms only; one in Murumuru and one in Nova Canaã. This is the only model characterised by high stocking rates of between 0.9 and 5.4 AU/ha, depending on season and paddock size. Consumption of grass is high on both farms, but the two farms demonstrate quite different outcomes because of the specific practices associated with the model. At Murumuru this model produces excellent pasture, as the grazing is strictly controlled. This stimulates the sprouting of grass and helps to keep pasture free of weeds. In Nova Canaã, however, grazing is not well controlled and fire is used frequently, the model produces poor grass cover with high weed invasion, and a significant proportion of the pasture areas are still under first cycle *P. maximum*. The model then has quite different results in terms of pasture quality depending on precisely how grazing is managed. At Murumuru the pasture is effectively used, but in Nova Canaã the changes observed in the pasture quality might be associated with over-utilisation.

5. Pasture degradation

Can we detect changes in pasture quality or degradation as a result of these different management practices? In any analysis of the pasture degradation process it is important, as proposed by Chauvel et al. (1997), to make a distinction between

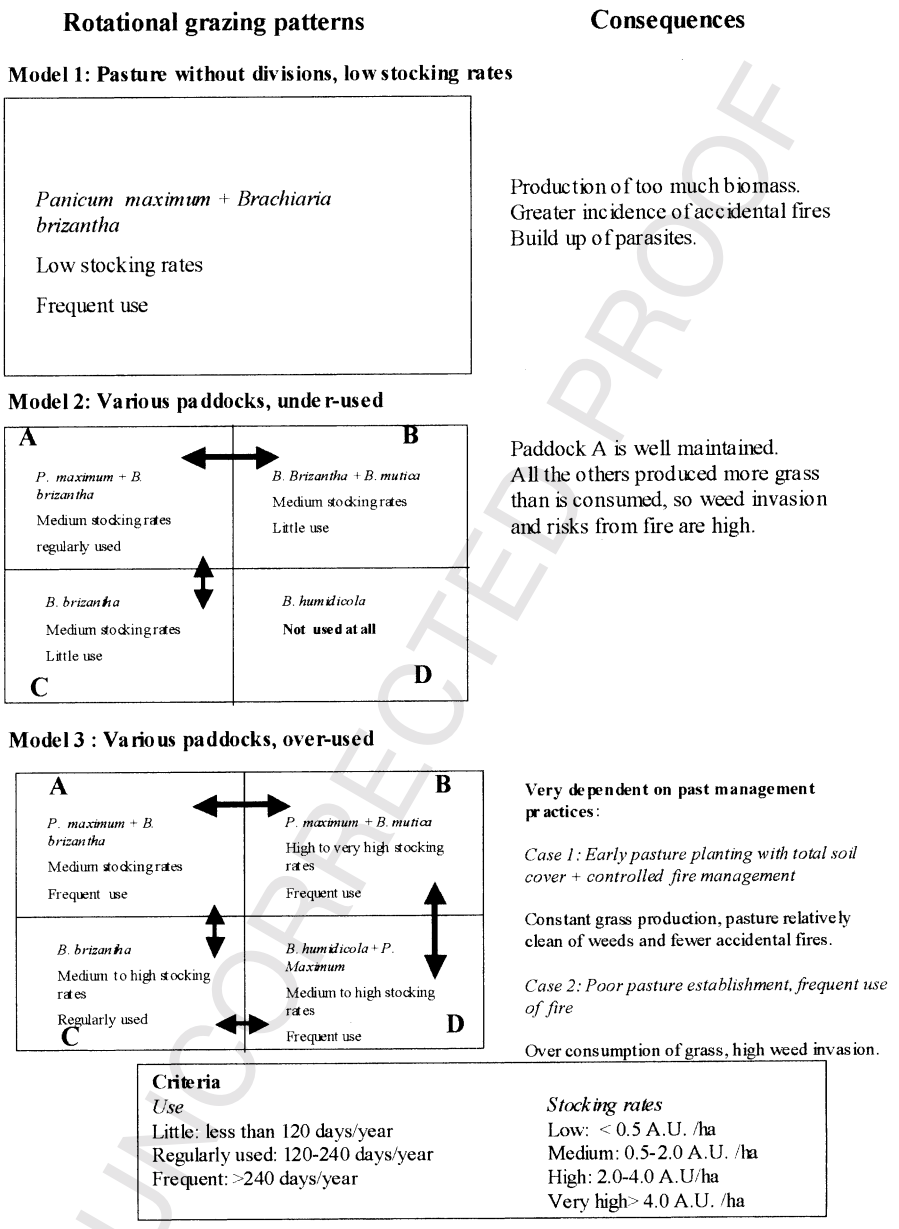

Fig. 3. Models of pasture management.

forest ecosystem degradation, which means the environmental damage caused by forest conversion to other land uses, and *agroecosystem degradation*, that is, the subsequent environmental changes that cause a decline in agricultural productivity. This is a useful distinction, because it helps us to clarify what we consider to be

degradation, since from a forest ecosystem perspective, the process of pasture degradation is in reality a first step in forest recovery.

The concept of degradation also needs to be critically viewed. As proposed by Abel and Blaikie (1989), "Range degradation is an effectively permanent decline in the rate at which land yields livestock products under a given system of management. 'Effectively' means that natural processes will not rehabilitate the land within a timescale relevant to humans, and that capital and labour invested in rehabilitation are not justified. The definition excludes *reversible* vegetation changes even if these lead to temporary declines in secondary productivity. It includes effectively irreversible changes in both soils and vegetation".

According to this definition, traditional thinking on the process of vegetation change after pasture establishment in Amazonia could be considered a process of pasture degradation. Until very recently pasture degradation was associated with a steady decrease of grass productivity caused by the decline of available soil phosphorus (see, for example, Fearnside, 1980, and Toledo and Serrão, 1982) sometimes coupled with overgrazing. This interpretation has been challenged by detailed studies about the dynamics of soil fertility and research related to forest regeneration. A first set of studies analysed soil under forest and pasture of different ages in different parts of Amazonia (Falesi, 1976, in Mato Grosso and Paragominas; Hecht, 1985, in Paragominas; Correa and Riechardt, 1995, in Manaus; and Moraes et al., 1996, in Rondônia). They show that the most important soil changes happen during the first 5 years, as a result of burning and initial establishment of cultivated grass or crops. Immediately after the burn there is an increase in pH and nutrients. After 5 years of use there is a constant decline in soil nutrients and minerals, but levels still remain higher than under forest. This contradicts the conventional model which presents a rapid decline in fertility, and even in pastures 81 years old the level of nutrients have been shown to be higher than their original level under forest. The soil organic matter, although showing a decrease in original levels after burning, increases with pasture development.

Studies of forest regeneration (Nepstad et al., 1991; Uhl et al., 1989a, b, 1991; Buschbacher et al., 1988; Vieira et al., 1996) show that forest recovery after pasture abandonment is not a difficult process, the feasibility and speed of recovery being related to the intensity of use. The effects of intensity of pasture use on the soil nutrient concentration at the succession sites observed in these studies were remarkably small (Buschbacher et al., 1988). If we interpret forest re-growth in pasture as pasture 'degradation' it can be observed that the role of pasture management and weed control are key elements to understand changes in pasture vegetation.

Studies conducted in Marabá have also emphasised the role of pasture management and weed control, thus challenging the hypothesis of soil deficiency as a primary cause of change. Topall (1995) has pointed out that farms in the same region, using the same type of grasses and with similar technical resources, can produce different levels of pasture degradation. The process is influenced by farmers' practices from early phases of pasture establishment. Important determining factors are the species used and the effectiveness of sowing or planting. Low initial plant densities allow not only weed growth, but also increase erosion. *P. maximum*, with its

growth in tussocks, leaves spaces between individual plants, and it is also more sensitive to spittle-bug attack, which can dramatically decrease grass density. Species like *B. humidicola* and *B. brizantha* have fewer problems in this respect.

Topall (1995) and Duru (1994) show that low stocking rates are partially responsible for poor grass cover, since animals do not consume enough to stimulate grass sprouting. Keeping animal numbers below a minimum density may result in a less productive climax (Behnke and Scoones, 1993). The low intensity of grazing results in an accumulation of dry matter, making the use of fire necessary to stimulate grass germination. The frequent use of fire has very negative effects: the death of some plants, and the decrease in plant density; and the selection of fire resistant weeds, making their control more difficult. When pasture is dominated by fire resistant weeds, pasture recuperation or natural forest recovery becomes very difficult. It is only at this level that changes in pasture vegetation can be called degradation under the definition proposed by Abel and Blaikie (1989), not before that. Although the expression 'pasture degradation' has been commonly used by farmers and researchers, its occurrence as defined above has been rare in Marabá region.

During our monitoring we observed that, although farmers frequently state that they burn pasture every year, this is not the case. For a farmer, fire is the best way to control weeds and to stimulate the growth of grass at the end of the dry season, when dried grass, inadequate for cattle consumption, dominates the pasture biomass. Farms that are not specialised in cattle production employ fire each year, as this is necessary with low stocking rates. Most farmers prefer to set fire before the rain, when the burn is more efficient and new pasture is produced early on in the season. For the long term sustainability of grazing, a burn after the first rain would be preferable as it will have a lower temperature, kill a smaller number of grass plants, and have less damaging impacts on physical and biological properties of the soil.

We can also model how farmers consciously or unconsciously manage their pasture to deal with degradation processes. There are three options that could be applied to a single paddock. In the first (option A), weed invasion and grass vegetation is controlled by constant weeding or use of herbicide, higher stocking rates (above 1.5 AU/ha) and limited use of fire. If it is needed there is a constant sowing of grass in areas where density of plants is decreasing. This keeps the pasture free of weeds and productive for very long periods. The second option (B) is the opposite: poor weeding, frequent use of fire and poorly controlled grazing, with either low or high stocking rates. This leads to degradation. In a third option (C) farmers use pasture while it is new and abundant. With the increase in weeds and shortage of labour, farmers will allow forest re-growth. The herd can still graze the area for a period, but will be selective and often feed from fallow plants. Fire will not be set for a few years, allowing biomass to grow. The burn of this area has the same effect as a traditional fallow, killing weeds and fertilising the soil. Grass re-grows quickly, and frequently there will be sowing of new grass.

These options can be simultaneously observed on the same farm. For example, farmers in Mumurumu who adopt the grazing pattern model 1 (see Fig. 3), would apply the option A to the paddock close to the house and the option C to another

paddock that is not very frequently used. As this decision is often tactical rather than strategic, it can be that the farmers adopt option C almost unconsciously. They will try to keep the paddock weeded, but when weeds become unmanageable, will opt for fallow regeneration.

5.1. Carrying capacity

The received wisdom is that in Amazonia stocking rates should be in the region of 1 AU per hectare, and it is on this basis that grazing pressure has been evaluated in most studies. However, no studies indicate the parameters used to establish this value. It is very difficult to define appropriate stocking rates in any situation, as they are dependent on the combination of a series of factors such as forage species, season, soil, fire management, patterns of animal feeding and so on. According to Biot (1993) "stocking densities which are most suited to any one situation are conditioned primarily by the management objectives of the producers, and the socio-economic and ecological environment in which they operate. . .carrying capacity of a given tract of rangeland is not only a management oriented concept but management-dependent concept". Even if it is not possible to define a single value to establish carrying capacity, it is important to stress the current lack of information to support informed decisions for farmers and development agents. General stocking rate, that is, the area needed for a certain herd size for a desired output is not known, nor is the maximum rate appropriate for a short time.

Even without specific parameters with which to compare the effects of grazing pressure on pastures we hypothesise that, in contrast to the common view, the processes of decreasing productivity in pasture in the region are more frequently associated with low stocking rates rather than with over-grazing, although stocking rates are only one component contributing to degradation. The avoidance of pasture degradation is critically related to farmers' management practices and the process of intensification of production. This intensification, in certain circumstances and under specific conditions, leads to more durable pastures and potentially more sustainable farming systems. However, even if a single farm can intensify production in this way, the long-term sustainability of the farming system depends on a number of other factors and the interactions between ecological social and economic factors in a given locality (Brown and Muchagata, 1999). Our paper now briefly reviews some of the economic factors at the farm level which contribute to the sustainability of colonist livestock production systems.

6. Economic and market factors

Current analyses of the development of livestock systems in Amazonia are concerned with economic profitability as well as with environmental degradation. Critics assert that ranching is only financially viable with government subsides, profits from land speculation and non-sustainable land-uses (i.e. overgrazing). These arguments have been reviewed (for example, Mattos and Uhl, 1994; Arima and Uhl,

1997) showing that they are not valid under current circumstances. Faminow (1998) reviewing studies from the early 1980s (such as Hecht, 1985) argues that even then, cattle production was profitable without subsidies. Our monitoring examined the profitability of cattle production by smallholders on the farms we monitored in the three localities. Once more the analyses reveals the changing role of cattle in the evolution of farming systems, but also the importance of other factors such as access to markets.

Fig. 4 shows that, on average, cattle production is profitable in two out of the three localities. On farms where livestock activity is still at an early stage (the case of most farmers in Maçaranduba) the cost of infrastructure development is large and herd size small, and markets for milk are almost absent, so the activity runs at a loss. As shown in Fig. 4 the main source of income from cattle is sale of animals, except in Maçaranduba, where in order to increase herd size, farmers will avoid selling animals except in emergencies. However, the importance of dairy production increases with specialisation of farming systems, the highest being Murumuru.

Generally there is little cash expenditure, with the most important cost being labour, which accounts for more than 60% of total costs in all places. Labour is divided between daily activities that are unavoidable (such as milking, health treatments); and pasture management, where activities are related mainly to weed control. Changes in pasture management would potentially lower these costs. Labour expenses are not generally recognised by the small farmers, since most of the work is done by family. Likewise, although they know that the cost for infrastructure development is very high and often represents a major constraint to expanding cattle production, farmers rarely take this cost into account on an annual basis. The expenses related to other inputs vary according to level of intensification and are

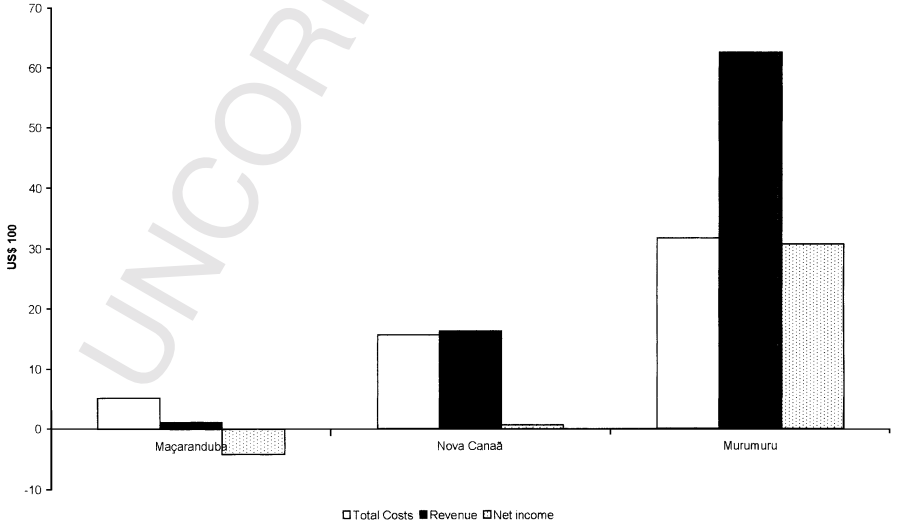

Fig. 4. Costs, income and net revenue of livestock production in the three localities.

thus found to be highest in Murumuru. The costs of seeds, incurred on almost every farm, reflects the process of pasture rehabilitation, conducted every year, where farmers replace *P. maximum* with other species, and also replace plants killed by fire.

Increasing revenue is very dependent on access to markets, and this was found to be the key factor motivating farmers to intensify cattle production. In distant regions, when the herd starts to increase in number there is a need to commercialise milk production, but it is impossible to sell unprocessed or fresh milk. This is the case in Maçaranduba. This makes cheese production the main option, and cheese has become a source of income for many farmers in Nova Canaã. However, the revenue is not regular; prices change dramatically according to the season. Cheese can be sold to middle-men locally or at urban centres, and it is then exported to other regions. Another option is to sell it to small shops or weekly markets at urban centres, at better prices. Selling fresh milk however, is a privilege of farmers living close to urban centres, where dairies are established and organised milk collection occurs daily only where there are all weather roads. This is happening in Murumuru. Even if farmers receive low prices per litre of milk, currently between US$0.10 and US$0.17, this represents a better price than cheese, particularly given the extra labour and investment necessary for cheese production. Farmers' production strategies are therefore strongly influenced by their geographical location which critically determines the marketing options for different dairy products.

7. Conclusion—what role for cattle in frontier stabilisation?

As shown in earlier sections of this paper, cattle play a key role in the evolution of frontier farming systems in Amazonia, and there is a tendency towards intensification of livestock production. This intensification in not just a result of length of settlement but is related to other factors, particularly changes in the physical environment and economic conditions, especially better access to markets. Although intensification may lead to an increase in the value of land, overall it is unlikely to result in a significant increase in deforestation. This is because in Maraba at least, land speculation is no longer a key factor inducing deforestation and migration. Rather, increasing herd size is the major motivation in this region of the frontier. So although intensification will not affect other driving forces of deforestation, such as the arrival of new migrants from other regions, or the development of roads opening up new areas, it is more likely to ameliorate rather than exacerbate environmental degradation caused by deforestation by contributing to slower rates of forest conversion on farms and thus declining rates of onward migration.

Our analysis and re-visiting of the process of pasture degradation shows that pasture can potentially be managed sustainably in the long term, even under current farmers' practices in the more specialised systems. This implies an apparent contradiction, that in the forest fringe regions, under present conditions, the systems that can achieve ecological and economical sustainability are those where little or no forest is present. The continuing existence of family based agriculture in these

regions depends not only on these ecological factors. Stabilising the frontier demands the development of infrastructure and investment in social capital.

Cattle will continue to play an important role in farmers' strategies to improve their living standards, and intensification of livestock will certainly contribute to overall sustainability of farming systems. The main issue is how this can be achieved without further loss of forest cover and agrodiversity. This is a necessity perceived by farmers themselves and is further discussed in Brown and Muchagata (1999) and Muchagata and Brown (2000). For farmers, crops represent stability, as less dependence on markets means greater food security. The exhaustion of forest resources represents more than a constraint to increasing agriculture and livestock areas. It also means the loss of income sources, food and many other products critical for livelihood of farming households, such as building materials or fuel for cooking (Muchagata, 1997). So successful farming systems are also diverse with sub-components, including cropping, forest, fallow and livestock, well integrated (Brown and Muchagata, 1999).

Our analysis has shown that pasture is frequently under-utilised, and this may be a critical factor leading to pasture degradation. For very poor farmers moving further into the frontier is necessary to built capital for more permanent occupation. It may well be that intensification is a process that can start only after a certain level of capital and/or stable occupation has been reached. Environmental degradation is a process that affects small farmers more than ranchers. The latter have more capital and land either to cushion them against the impacts of degradation on production. Further research to improve smallholder livestock production has the potential to provide important returns both to production and environmental conservation and in addition bring economic and social benefits to colonist communities. Refining pasture management practices adapted to smallholders that include less use of fire, higher stocking rates and consequently decrease labour demands in weeding, would provide incentives for farmers to slow expansion of new pasture areas, both on their current farms and eventually to avoid further encroachment into new forested areas. We conclude that the intensification of cattle production by smallholders, in certain contexts and with a supportive policy and economic environment, can potentially contribute to frontier stabilisation.

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References

Abel, N.O.J., Blaikie, P., 1989. Land Degradation, Stocking Rates and Conservation Policies for the Communal Rangelands of Botswana and Zimbabwe (Pastoral Development Network No. 29). ODI, London.

Almeida, A.L.O., Campari, J.S., 1995. Sustainable Settlement in the Brazilian Amazon. Oxford University Press, New York.

Almeida, O.T., Uhl, C., 1995. Developing a quantitative framework for sustainable resource-use planning in Brazilian Amazon. World Development 23, 1745–1764.

Arima, E., Uhl, C., 1997. Ranching in the Brazilian Amazon in a national context: economics, policy, and practice. Society & Natural Resources 10, 433–451.

Behnke, R., Scoones, I., 1993. Rethinking range ecology: implications for rangeland management in Africa. In: Behnke, R., Scoones, I., Kerven, C. (Eds.), Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaptation in African Savannas. ODI, London, pp. 1–30.

Biot, Y., 1993. How long can high stocking densities be sustained? In: Behnke, R., Scoones, I., Kerven, C. (Eds.), Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaptation in African Savannas. ODI, London, pp. 152–153.

Brown, K., Muchagata, M., 1999. Modelling the Sustainability of Frontier Farming at the Forest Fringe [Final Technical Report to Department for International Development (DFID)]. Overseas Development Group, University of East Anglia, Norwich, UK.

Buschbacher, R., Uhl, C., Serrão, E.A.S., 1988. Abandoned pastures in Eastern Amazonia. II Nutrients stocks in the soil and vegetation. Journal of Ecology 76, 682–699.

Chauvel, A., Barbosa, E.M., Blanchard, É., Grimaldi, M., Ferraz, J., Martins, P.S., Topall, O., Barros, E., Desjardins, T., Filho, N.L., Miranda, I.P.A., Sarrasin, M., Mitja, D., 1997. Mise en valeur de la forêt et modifications écologiques. In: Théry, H. (Ed.), Environment et Développement en Amazonie Brésilienne. Belin, Paris, pp. 42–75.

Correa, J.C., Reichardt, K., 1995. Efeito do tempo de uso das pastagens sobre as propriedades de um latossolo amarelo da Amazônia Central. Pesquisa Agropecuária Brasileira 30, 107–114.

Duru, M., 1994. Rapport de Mission à Marabá, Brésil. INRA-SAD.

Falesi, I., 1976. Ecossistema de Pastagem Cultivada na Amazônia Brasileira. EMBRAPA, Belém (Boletim Técnico 1).

Faminow, M.D., 1998. Cattle, Deforestation and Development in the Amazon. An economic, Agronomic and Environmental Perspective. CAB International, Oxon.

Fearnside, P.M., 1980. Os efeitos das pastagens sobre a fertilidade do solo na Amazônia Brasileira. Acta Amazonica 10, 119–132.

Fearnside, P.M., 1990. Predominant land uses in Brazilian Amazon. In: Anderson, A. (Ed.), Steps Towards Sustainable Use of the Amazon Rain Forest. Columbia University Press, New York, pp. 233–251.

Hecht, S., 1985. Environment, development and politics: capital accumulation and livestock sector in eastern Amazonia. World Development 13, 662–684.

Hecht, S., 1989. The sacred cow in the green hell: livestock and forest conversion in the Brazilian Amazonia. The Ecologist 19 (6), 229–234.

Hecht, S., 1993. Land speculation and pasture-led deforestation in Brazil. In: Colchester, M., Lohmann, L. (Eds.), The Struggle for Land and the Fate of the Forests. Zed Books, London, pp. 164–178.

LASAT, 1998. Desmatamento & Agricultura na Região de Marabá. Convênio FATA-LASAT Projeto DFID-FATA.

Loker, W.M., 1993. The human ecology of cattle raising in the Peruvian Amazon: the view from the farm. Human Organization 52, 14–24.

Mattos, M.M., Uhl, C., 1994. Economic and ecological perspectives on ranching in Eastern Amazon. World Development 22, 145–168.

Moraes, J.F.L., Volkfoff, B., Cerri, C.C., Bernoux, M., 1996. Soil properties under Amazon forest and changes due to pasture installation in Rondônia, Brazil. Geoderma 70, 63–81.

Muchagata, M.G., 1997. Forests and People. The Role of Forest Production in Frontier Farming Systems in Eastern Amazonia (DEV Occasional Paper OP 36). University of East Anglia, Norwich.

Muchagata, M., Brown, K., 2000. Colonist farmers' perceptions of fertility and the frontier environment: in Eastern Amazonia. Agriculture and Human Values 17 (4), 371–384.

Myers, N., 1981. The hamburger connection: how Central America's forests become North America's hamburgers. Ambio 10 (1), 3–8.

Nepstad, D.C., Uhl, C., Serrão, E.A.S., 1991. Recuperation of a degraded Amazonia landscape: forest recovery and agricultural restoration. Ambio 30, 248–255.

Nicholson, C.F., Blake, R.W., Lee, D.R., 1995. Livestock, deforestation, and policy making: intensification of cattle production systems in Central America revisited. Journal of Dairy Science 78, 719–734.

Parsons, J.J., 1993. The scourge of cows. In: Place, S.E. (Ed.), Tropical Rainforests. Latin American Nature and Society and Transition. Jaguar Books, Wilmington, pp. 36–48.

Pearson, C.J., Ison, R.L., 1997. Agronomy of Grassland Systems, second ed. Cambridge University Press, Cambridge.

Reynal, V. de, Muchagata, M.G., Topall, O., Hébette, J., 1995. Agricultures Familiales & Dévelopment en Front Pionnier Amazonien. GRET-UAG UFPa, Paris-Point a Pitre-Belém.

Richards, M., 1997. Missing a Moving Target? Colonist Technology Development in the Amazon Frontier. ODI, London.

Schneider, R.R., 1995. Government and the Economy of Amazon Frontier. The World Bank, Washington. (World Bank Environmental Paper number 11).

Simão Neto, M., 1995. Pastagens no Ecossistema de Trópico Úmido: Pesquisas para o Desenvolvimento Sustentado. Anais do Simpósio sobre Pastagens nos Ecossistemas Brasileiros. Pesquisas para o Desenvolvimento Sustentável. XXXII Reunião Anual da Sociedade Brasileira de Zootecnia, SBZ.

Toledo, J.M., Serrão, E.A.S., 1982. Pasture and animal production in Amazonia. In: Hecht, S. (Ed.), Amazonia: Agriculture and Land Use Research. CIAT, Cali, pp. 281–309.

Topall, O., 1995. L'arbre et l'herbe en zone tropicale humide. Gestion des pâturages sur une frontière agricole amazonienne dans la région de Marabá, au sud de l'Etat du Pará, Brésil. In: Fertilité du Milieu et Stratégies Paysannes sous les Tropiques Humides. Montpellier, pp. 260–265.

Uhl, C., Parker, G., 1986. Is a quarter-pound of hamburger worth half a ton of rainforest? Interciencia 11 (5).

Uhl, C., Buschbacher, R., Serrão, E.A.S., 1989a. Abandoned pastures in Eastern Amazonia. I Patterns of plant succession. Journal of Ecology 76, 663–681.

Uhl, C., Nepstad, D., Buschbacher, R., Clark, K., Kauffman, B., Subler, S., 1989b. Disturbance and regeneration in Amazonia: lessons for sustainable land use. The Ecologist 19, 235–240.

Uhl, C., Nesptad, D., Silva, J.M.C., Vieira, I., 1991. Restauração da floresta em pastagens degradadas. Ciência Hoje 13, 23–31.

Vieira, I.C.G., Salamão, R.P., Nesptad, D.C., Roma, J.C., 1996. O renascimento da floresta no rastro da agricultura. Ciência Hoje 20, 38–44.