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THE EFFECTS OF CATTLE PASTURE ON SOIL FERTILITY IN THE BRAZILIAN AMAZON : CONSEQUENCES FOR BEEF PRODUCTION SUSTAINABILITY

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Abstract : Amazon rainforest is fast being replaced by cattle pastures as investors respond to financial incentives and the lure of new highways. The Brazilian government's encouragement of pasture is linked to claims that pasture improves soil fertility and therefore represents a "rational" means of development in the Amazon. A review of information related to the ongoing debate concerning soil fertility changes under pasture casts doubt both on the claims of improved fertility for pasture growth, and on the presumption of indefinitely sustainable yields of beef cattle.

Résumé : La forêt pluviale amazonienne est remplacée rapidement par le pâturage, les investisseurs répondant aux stimulants financiers et à l'attraction des routes nouvelles. L'incitation du gouvernement brésilien pour l'élevage est liée aux déclarations concernant l'accroissement de la fertilité du sol par la mise en place de pâturages que représenterait alors un moyen "rationnel" de développement de l'Amazonie. L'examen des changements de fertilité du sol met en doute, tant les déclarations relatives á l'augmentation de la fertilité en ce qui concerne la croissance de l'herbe, que celles relatives à la possibilité de maintenir des rendements identiques en viande.

Resumen : La selva pluvial amazónica está siendo rapidamente substituida por pastos de ganado mientras que los investidores respondan a los incentivos fiscales y a el atractivo de las carreteras nuevas. El incentivo del gobierno brasileño para los prados está conectado a las declaraciones que en el prado promueve la fertilidad del suelo y por lo tanto representa una manera "racional" de desarollo en la Amazonía. El examen de los cambios en la fertilidad del suelo coloca en duda tanto las declaraciones de promoción de la fertilidad del punto de vista de crecimiento del prado, quanto el supuesto de producciones indefinidamente sostentables de ganado.

Resumo : A floresta pluvial amazônica está sendo rapidamente substituida por pastagens de gado na medida em que os investidores respondem aos incentivos financeiros e ao atrativo das novas estradas de rodagem. O incentivo do governo brasileiro para pastagens está ligado às declarações de que a pastagem promove a fertilidade do solo e portanto representa um meio "racional" de desenvolvimento na Amazônia. O exame das mudanças de fertilidade do solo põe em dúvida tanto as declarações de promoção de fertilidade do ponto de vista de crescimento da pastagem, quanto a pressuposição de produções indefinidamente sustentáveis de gado de corte.

Key Words : Pasture, soil ferility, Amazon, Brazil, cattle, ranching, sustainable yields, tropical development, beef production, tropical pastures.

INTRODUCTION

The tropical rainforests of the Brazilian Amazon are rapidly being converted to cattle pasture both by such international giants as Volkswagen, King Ranch, and Armour-Swift, and by the hundreds of Brazilian investors who are being lured from Southern Brazil to establish ranches in the Amazon. Cattle ranching is being encouraged through a high priority program of tax incentives and low-interest

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financing with the avowed objective of "turning this sector into one of the most dynamic of the regional economy" (Brasil, SUDAM-BASA 1972).

The wisdom of the current rush to convert the Amazon rainforest into cattle pastures can, and should, be debated on many grounds. A current focus of this debate in Brazil is the question of how cattle pastures affect soil fertility in the region. Although not always appreciated by participants in this ongoing controversy, soil fertility maintenance is only important as a part of the larger question of whether yields will be sustainable as is anticipated by Brazilian planners.

Most of the debate concerns the use of the vast areas of "terra firme" (high ground) which are covered with high forest, rather than the more limited areas of "várzea" (Amazonian floodplain), the "campos naturais" ("natural" grasslands), or those areas of "cerrado" (upland scrub forest, characteristic of the Brazilian central plateau) which have been included in Legal Amazonia. The following discussion of the pasture soil controversy applies to the areas of "terra firme" in high forest.

THE PASTURE SOIL FERTILITY CONTROVERSY

The opinion has been expressed repeatedly at scientific meetings throughout Latin America in recent years that planting pasture improves the quality of the soil. Falesi (1974) found the following when soils under virgin forest were compared with soils under pasture of various ages both on the Belém-Brasília Highway at Paragominas in Pará and in northern Mato Grosso : "Immediately after burning (of forest) the acidity is neutralized, with a change in pH from four to over six and aluminum disappearing. This situation persists in the various ages of pastures, with the oldest pasture being 15 years old, located in Paragominas. Nutrients such as calcium, magnesium, and potassium rise in the chemical composition of the soil, and remain stable through the years. Nitrogen falls immediately after the burn but in a few years returns to a level similar to that existing under primitive forest" (Falesi 1974).

This is followed by the conclusion that : "The formation of pastures on latosols and podzols of low fertility is a rational and economic manner in which to occupy and increase the value of these extensive areas" (Falesi 1974).

Dr. P. de T. Alvim, technical director of Brazil's cacao research institute, told the participants at the meeting of the United Nations Man in the Biosphere Project held in Rio de Janeiro in 1974 that "A long period of fallow under *Panicum maximum* pasture will restore the phosphorus, calcium and nitrogen content of the tropical forest soil" (Lawton 1974). With the exception of the claim for phosphorus, this probably refers to preliminary results of Falesi's (1974, 1976) study.

The notion of pasture benefiting the soil has carried over into official recommendations for land use. In a 1974 report of the Brazilian Enterprise for Research in Agriculture and Cattle Ranching—Institute for Agriculture and Cattle Ranching Research of the North (EMBRAPA-IPEAN, since renamed CPATU) giving recommendations for the 10,686 km² area accessed by the 1760 km stretch of the Transamazon Highway between Itaituba and Rio Branco, the ubiquitous recommendation is : ".... the formation of pastures which, when well managed, cover the surface of the soils completely, protecting them from erosion, at the same time re-instating the biological equilibrium" (Brasil, EMBRAPA-IPEAN 1974).

The trend in official land use recommendations away from annual crops and toward pasture can be seen in the differences in recommendations between EMBRAPA-IPEAN's 1972 survey of the Estreito-Itaituba stretch of the Transamazon Highway (Falesi 1972) and the 1974 recommendations for the same soil types in the Itaituba-Rio Branco stretch. In 1974, yellow latosol (Ultisol) is recommended "rationally for perennial crops, reforestation and pasture" (Brasil, EMBRAPA-IPEAN 1974) with the observation that it is too costly to fertilize annual crops. In 1972 the same observations concerning perennial crops, reforestation, and pasture are made together with the impracticality of fertilizing, but hope for annual crops is given by citing EMBRAPA-IPEAN variety trials (Kass and Lopes 1972) which are described as showing "high productivity, using as soil not only heavily textured yellow latosol, but also those with medium texture, obtaining good experimental results without using fertilizers and correctives" (Falesi 1972).

The belief that pasture improves the soil goes hand in hand with the official recommendation that poor soils be used as pasture. In the 1974 EMBRAPA-IPEAN recommendations for the Itaituba-Rio Branco section of the Transamazon Highway, pasture is recommended as a rational land use for all of the soils encountered with the exception of two small areas : one a type of red-yellow podzol (Ultisol) with pebbels (Brasil, EMBRAPA-IPEAN 1974), and the other a section of "undiscriminated hydromorphic soils" with drainage problems (Brasil, EMBRAPA-IPEAN 1974). All other soils are recommended for pasture, even including an "hydromorphic laterite" with "moderate" drainage. Without entering into discussion of the often exaggerated claims of danger from laterite (plinthite) formation, the description of this soil unit, given together with its recommendation for use as pasture, illustrates the logical consequence of the premise that poor soils can be improved through the beneficial influence of use as pasture. The soil is described as having as an "intrinsic characteristic" : .... "beginning with the B_{21pl} a 'plinthite', which is a very hard material with a high content of iron and aluminum sesquioxides, rich in clay and poor in humus, tending irreversibly to 'hardpan'" (Brasil, EMBRAPA-IPEAN 1974).

The recommendation that the hydromorphic laterite be used for pasture is tempered with the qualification that "rational technical advice must be obtained with respect to formation of pastures with species adaptable to local conditions" (Brasil, EMBRAPAZIPEAN 1974).

The RADAM (Radar in Amazonia) Project has classified the land use potential for the Belém Quadrangle which includes the Altamira-Itaituba stretch of the Transamazon Highway. The entire area in the Belém Quadrangle is considered suitable for cattle ranching, although this recommendation "predominates in the lowest classes" of land use potential (Brasil, Departamento Nacional de Produção Mineral, Projecto RADAM 1974 : V/14 and V/23).

The rapid increase in the amount of pasture everywhere in the Amazon makes determination of the effects of pasture on soil fertility in the region urgent.

SOIL FERTILITY CHANGES UNDER PASTURE

Knowledge of soil fertility changes under tropical pastures is inadequate. There are a number of reasons why the claim of improved soil fertility under pasture

must be regarded as far from proven as a general statement about tropical American pasture soils. Although the soil results obtained in the Belém-Brasília Highway study (Falesi 1974 ; 1976) could be the result of true improvement in soil quality due to differences in the time spent under pasture, they may equally well be the result of natural variability between locations where the samples were taken. More studies are needed, especially studies based on repeated sampling of the same pasture locations over time.

The small sample size of the Belém-Brasília study may be one explanation for the results obtained. The soil data for a study of human carrying capacity on the Transamazon Highway (Fearnside 1978) have repeatedly shown the need for large sample sizes if the masking effect of random differences between locations being compared is to be penetrated so that treatment effects can be assessed. In the Transamazon Highway study, 1000 comparisons were made between pairs of soil samples, 642 of which were comparisons between "used" and adjacent virgin locations. "Virgin" locations refers to locations not previously used by settlers, although aboriginal peoples have inhabited all of these areas for centuries prior to the recent arrival of highways. Most of the comparisons did not involve pasture. The need for the large sample sizes collected has been amply confirmed in the various analyses performed on this data set (Fearnside 1978).

The study of soils on the Transamazon Highway has shown the need for extreme caution in picking virgin pairs immediately adjacent to the "used" fields. Often in the Transamazon Highway study, readily observable differences in appearance in soils within the same 100 hectare colonist lot made it necessary to obtain more than one virgin sample for comparison with fields in different parts of the lot. Soil maps show some of this fine-scale variation in soil quality (Fearnside 1978). Although the reports of the Belém-Brasília study do not give details of how the virgin pairs were selected, there are currently rather large distances between patches of virgin forest in the area around Paragominas, which may add additional variability to comparisons with pastures located some distance from the locations of the paired virgin samples.

The general appearance of pastures near Paragominas at the time of my visits to the area in 1973, 1975 and 1976 was one which belied the promotional posters, which bill Paragominas as "A Capital do Boi Gordo" (Capital of the Fatted Steer). Large expanses of pasture could easily be seen reverting to second growth (see Fig. 1). Weed invasion can run its course in tropical pastures either with or without soil fertility depletion, which indicates the need for special caution in interpreting soil trends, even if in the direction of improvement, as indicating the practicality of continuous use as pasture for the many new ranches in Brazil's Amazon area (Fearnside 1979a).

Examination of the soil results presented in the final report of the Belém-Brasília study reveals some indications that pasture production may not be as sustainable as the report's conclusions would indicate. Aside from the problem of weed invasion, which the report does mention briefly (Falesi 1976), the soil fertility changes themselves are not all favourable for pasture. Data from pasture fertilization experiments in Belém (Serrão *et al.* 1971), which are analyzed elsewhere (Fearnside 1979a), indicate that phosphorus is the best soil fertility predictor for pas-

Fig. 1. The expense of controlling invading second growth species can be anti-economic. Abandoned pastures, such as this one near Paragominas, are not uncommon.

ture grass yields under those conditions. The pH and other indicators for which the "beneficial" effects of pasture are claimed are not as relevant to pasture yields. The data presented in the Belém-Brasília study for phosphorus (Falesi 1976) while showing some variability, shows a clear downward trend in available phosphorus after the initial peak subsequent to burning the virgin forest (Fig. 2). Available phosphorus (P_2O_5) rises from 0.69 mg/100g in virgin forest to 4.18 mg/100g in new pasture, which can be attributed to the virgin burn rather than to the pasture. Burning forest is known to have a marked effect on phosphorus (Fearnside 1978). Following this, the nine additional data points in the Belém-Brasília study show a definite decline, with only slight variation, to a lower plateau value reached after five years. The value after five years is 0.46 mg/100 g, and remains in this neighbourhood up to the maximum age available when it is still 0.46 mg/100g in the tenth year. Less important than the fact that this is lower than the virgin value, is that it is an order of magnitude lower than the phosphorus peak reached after burning. The sensitivity of pasture yields to phosphorus levels means that decreases of this magnitude under

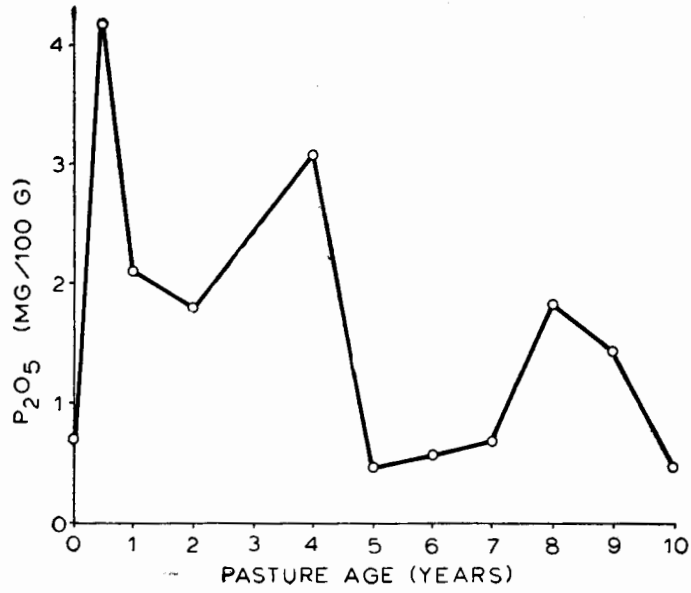

Fig. 2. Available phosphorus increases dramatically with the initial burning of the felled rainforest, and then falls to a lower level after about five years. Phosphorus has been found to limit pasture growth in several parts of the Amazon, including Paragominas on the Belém-Brasília Highway. Low levels of phosphorus result in poor pasture growth regardless of the levels of other soil fertility indicators. Data are from Falesi (1976).

pasture will have a negative effect on pasture yields over time.

The interpretation of the results of the Belém-Brasília study is crucial, especially with regard to the limiting element in this area : phorphorus. Alvim summarizes the results thus : "As a consequence of burning the forest, the soil fertility effectively increases in an appreciable form in terms of the availability of phosphorus, exchangeable bases, and the decrease of the percentage saturation of aluminum. After 10 to 11 years of exploitation as pastures on these soils, the level of fertility is conserved at a high level in comparison with the levels under primary forest" (Alvim 1978).

Aside from the fact that this comparison is not strictly true with respect to phosphorus (0.69 mg/100 g for P_2O_5 under virgin forest is slightly higher than the 0.46 mg/100 g value under ten-year-old pasture), the question of importance is not whether the value after ten years is higher or lower than the value under virgin forest, but rather whether phosphorus levels in older pastures are sufficient to maintain adequate growth of pasture grass and hence beef production.

The limiting effect of phosphorus on pasture growth in the area was recognized by EMBRAPA (CPATU) workers in the years following the original Belém-Brasília study, and applications of 200-300 kg ha^{-1} of equal parts of superphosphate and hyperphosphate have been recommended as a remedy (Serrão and Falesi 1977). Experiments in the area of Paragominas and northern Mato Grosso have shown strong responses to phosphate fertilization (Koster *et al.* 1977). The extremely high

prices of fertilizers in the Amazon (US $ 0.30 kg^{-1} for superphosphate in Belém in 1978) make it unlikely that ranchers will follow the government's new fertilizer recommendations. The lack of fertilizer use among ranchers in the State of São Paulo, which is much nearer Brazil's phosphate beds in the State of Minas Gerais than is the Amazon, reinforces the impression that the chances are poor for pasture fertilization being accepted by ranchers in the Amazon (S. Hecht, Personal communication).

Beef production on pastures grown on soils with such marked deficiencies of phosphorus as is common in the Brazilian Amazon are held down not only by the reduced productivity of pasture grass dry matter, but also by the necessity of cattle consuming more dry matter to produce a given live weight gain due to the low nutritional quality of grass grown on these soils. As phosphorus levels decline, the nutritional quality of the grass can be expected to decline as well.

General optimism in Brazil regarding the long-range potential of cattle ranching in the Amazon is noted by Kleinpenning (1975), who points to Brücher's (1970) endorsement of cattle ranching on the basis of improved cattle breeds and a pasture in Colombia which was planted in 1935 and reportedly was still doing well in the late 1960's. Brücher claims that "pastures remain productive for years without the application of fertilizers," but his endorsement carries the usual condition that "modern methods" be employed. Such modern methods, aside from fertilizer, can include legume interplantings, which have increased production in experimental pasture plots under Amazonian conditions (Santhirasegaram 1975). In Amazonian Peru some unfertilized pastures with natural legumes have been known to remain productive for up to 20 years (Sanchez 1976). Such methods are generally not being used by the ranchers who are rapidly occupying the Brazilian Amazon.

Much of the debate related to Amazonian pasture soils focuses on comparison of soils under grass with soils under high forest. Although this often distracts attention from the central point of beef production sustainability, it is worth noting that the literature on the subject contains many contradictory statements. Table 1 illustrates the range of results of studies comparing surface soil fertility under pasture and virgin forest in the American tropics. The Table includes information on a number of soil fertility measures in addition to phosphorus, which I have emphasized due to the role of this element as a limiting factor for pasture growth in the Brazilian Amazon.

Parsons (1976) gives a good capsule statement of nutrient cycling processes under pasture. Only 80% of the nitrogen, phosphorus, and potassium consumed by the cattle is returned to the soil as manure. Of this 80%, however, a far smaller fraction is actually incorporated into the soil where it can be used by grass due to uneven distribution of the excreta. Citing studies done under "the best of conditions" in Puerto Rico by Vicente-Chandler (1974), Parsons concludes that only about half of the nutrients in the feces are returned to the soil, the rest being lost to leaching and volitilization. One can easily see from Parsons's figures how soil fertility depletion could follows : only 50% of 80%, or 40%, of the nutrients would survive each cycle through the cattle. This, when combined with additional losses from burning and subsequent leaching of the ash, would mean that high rates of supply for the various nutrients would have to be operating if depletion were not to follow.

TABLE 1. *Representative virgin-pasture soil*

Item	Units	Land Use	Falesi (1974)	Falesi (1976)	Falesi (1976)	Falesi (1976)	Daubenmire (1972)
pH		forest	4	4.3	4.2	4.4	6.60
Al+++	ME/100g	pasture	6	6.2	6.3	6.0	6.45
		forest	present	1.09	0.90	1.77	0.12
		pasture	0	0.06	0.00	0.00	0.15
P_2O_5	mg/100 g	forest	..	0.53	0.69	0.23	..
		pasture	..	0.54	0.46	0.23	..
N	%	forest	"similar" in older (15-yr) pasture	0.09	0.05	0.16	0.17
		pasture		0.05	0.04	0.15	0.14(1)
C	%	forest	..	1.13	0.68	1.62	3.50
		pastrue	..	0.60	0.54	1.96	2.79
CEC	ME/100g	forest	..	6.86	4.16	10.02	24.90
		pasture	..	4.06	2.90	8.45	25.15
K	ME/100g	forest	higher in pasture	0.08	0.05	0.06	0.57
		pasture		0.18	0.05	0.22	0.59
Ca++	ME/100	Forest	higher in pasture[5]	0.31	0.19	1.09	14.75
		pasture		1.24	1.12	3.45	11.95
Mg++	ME/100g	forest	higher in pasture[5]	0.14	0.11	0.38	3.54
		Pasture		0.58	0.21	0.65	2.98
Age	years	..	up to 15	11	10	11	22.5
Rainfall	mm	..	2591	1776	2591	2591	1539
Depth	cm	..	0—20	0—20	0—20	0—20	0—10
Samples	number	..	..	..	..	"several ranches"	
Comparisons	number	..	..	..	..	..	1
location		..	Paragominas & Mato Grosso, Brazil	northern Mato Grosso, Brazil	Paragominas, Brazil	Paragominas, Brazil	Cañas, Costa Rica

* significant difference reported ($P < 0.05$).

(1) Daubenmire (1972) believes this value to be spuriously high.

(2) Estimated from graph at 20 cm depth (Bennema 1974 : 40).

fertility comparisons from the American Tropics

Daubenmire (1972)	Sombroek (1966)	Bennema (1975)	Krabs (1975)	Krebs (1975)	Dantas (1978)	Dantas (1978)
6.20	"slightly higher in forest"	..	5.41*	5.41	3.8(4)	3.8(4)
6.40		..	5.09*	5.41	4.3(4)	5.3(4)
0.12						
0.16						
	levels "comparable"					
	fixation rates "somewhat less" in savanna	..	..	..	..	..
0.17		..	0.52*	0.52	0.17	0.17
0.03		..	0.35*	0.53	0.13	0.08
2.92	0.5 more in forest	0.54(2)	4.45*	4.45	1.54	1.54
2.65		0.35(2)	3.55*	4.05	1.10	1.00
23.90	"somewhat higher in forest"	..	..	..	9.50(4)	4.30(4)
29.88					7.10(4)	7.10(4)
0.45		..	134 (ppm)	134 (ppm)		
0.71		..	99 (ppm)	160 (ppm)	..	..
12.45		..	384 (ppm)	384 (ppm)	..	..
13.45		..	257 (ppm)	362 (ppm)	..	..
3.08	..	..	..	..	..	..
3.62	..	..	..	..	..	..
22.5	..	..	9	15	1—5	1—5
1539	..	..	4700	4700	2000	2000
10—20	"topsoil"	20	0—10	0—10	0—20	0—20
2	9 (savanna)	2	8	8	8	8
1	9	1	1	1	4	4
Cañas, Costa Rica	Amapá, Brazil	Brazilian Amazon	San Carlos, Costa Rica	San Carlos, Costa Rica	Itacoatiara, Brazil	Itacoatiara, Brazil

(3) Pasture data for "extensive" exploitation system.
(4) Difference "significant" at $P < 0.10$ reported using simultaneous test procedure (STP).
(5) Ca++ and Mg++ together.

Unfortunately, Parsons tries to reinterpret Daubenmire's (1972) conclusions on the question of soil fertility changes. Parsons states (1976) that Daubenmire "found little change in the fertility .... of the soil after twenty-two years in planted pasture." Daubenmire's actual conclusion was : "in summary, by most criteria the level of fertility is lower in the savanna .... " (Daubenmire 1972). Daubenmire's data, some of which are presented in Table 1, speak for themselves.

There is some evidence that not all tropical soils under pasture are improved from the standpoint of fertility. One such study compares soils in Costa Rica sampled in virgin forest, a nine-year-old pasture and a fifteen-year-old pasture (Krebs 1975). Data from this study related to pastures are included in Table 1. It should be noted that somewhat dubious statistical methods were used in taking four samples from each field and counting them as four independent data points.

As can be seen from Kreb's data in Table 1, the nine-year-old pasture has values for all of the nutrients reported which are significantly lower than the virgin ofrest. If one can assume that the nutrient levels in the fifteen-year-old pasture have followed the path of the nine-year-old pasture, then after 15 years only carbon and magnesium have values significantly different from the virgin forest. Of the two elements still significantly lower than the virgin values, carbon would be increasing while magnesium would be decreasing. The fact that these samples came from only three different locations may mean that the differences, for example between the nine-year-old and the fifteen-year-old pastures, are not actually the result of nutrient levels dipping to the values listed for nine years and then rebounding to the values listed for 15 years, but rather are the result of the variation one finds between fields.

In spite of the problem of small sample size, findings such as those of Krebs add to the weight of evidence indicating that Brazilian planners should not assume that tropical pastures improve soil quality in the absence of convincing experimental evidence.

Data from soil samples taken in pastures of different ages in and near the Transamazon Highway Colonization Area of Altamira, Pará suggest that many changes in nutrient levels under pasture can best be viewed as short-term adjustments to new temporary equilibrium conditions (Fearnside 1978). Regressions for predicting nutrient level changes during the early years as pasture provide adequate information for constructing computer simulations of the system, since strong competition from invading weeds reduces grass yields to very low levels within a few years (Fearnside 1978, 1979b). In addition to the soil fertility changes which are the subject of the present paper, many other changes occur with consequences for beef production, including soil compaction (Fearnside 1978), erosion (Fearnside 1979c), and weed invasion (Fearnside 1979a).

THE QUESTION OF SUSTAINABILITY

The current debate in Brazil concerning the effect of cattle pasture on soil fertility is really only a part of the larger question of whether the cattle pastures being promoted in the Amazon will be capable of producing the sustained yields that planners envision. A few words of caution are necessary.

The question of soil nutrient level comparisons of virgin forest and pasture

soils has probably been accorded far too much importance in this debate (1) because the great majority of nutrients in the forest ecosystem are stored in the vegetation rather than in the soil, making comparison of nutrient levels in the soil alone a highly unfair proposition since the total nutrient stores in the forest are clearly far greater than the total stores in the pasture ecosystem, (2) because a finding that soil nutrient levels are higher under pasture than under virgin forest does not necessarily lead to the conclusion that pasture can provide an indefinitely sustainable yield, and (3) because ranch owners in the Brazilian Amazon may not be interested in an indefinitely sustainable yield anyway.

At high levels of government, statements of development objectives invariably are aimed at the ideal of sustainable yields. The lofty set of objectives adopted by the United Nations Man in the Biosphere Project in Rio de Janeiro in 1974 illustrates this (Lawton 1974). The Superintendency for the Development of the Amazon (SUDAM) has also claimed this as an objective of its incentives program for pasture (Brasil, SUDAM 1974). The very existence of the soil nutrient debate speaks for the concern of Brazilian planners for sustaining future yields. Unfortunately, these objectives do not necessarily apply to individual ranch owners.

The key factor from the point of view of the individual entrepreneur is the relative attractiveness of alternative investments, so long as he is free to reinvest elsewhere. After selling a ranch which ceases to be productive, even if for a minimal price, an entrepreneur may invest profits made during the period of his tenure either in a new ranch elsewhere in the Amazon, in a different industry elsewhere in Brazil, or—in the case of the increasingly visible multinational corporations—in another part of the world. Colin Clark (1976) has shown the complete mathematical rationality of individuals destroying potentially renewable resources as long as the rate of regeneration is less than the discount rate used in calculating the present monetary values of future returns. The much-studied case in point of the whaling industry illustrates this perfectly : corporations continue to invest in an industry with complete knowledge that current rates of exploitation will lead to destruction of the whale populations and an end to the industry within a few years (Clark 1973). The same relation of present values to expected future returns benefits those who are selling ranches after a few years of tenure on the Belém-Brasília Highway or in Mato Grosso to reinvest in new ones on the Transamazon Highway. There is no reason to expect that these people will not move and reinvest again, as has been the pattern in pioneer areas throughout tropical South America (cf. Denevan 1973).

In spite of these problems, the question of sustainability is vitally important to the future of the Amazon region. Should the development schemes prove not to be sustainable, the cost would be borne by the future generations of Brazilians who must live in the degraded areas after the current wave of entrepreneurs move elsewhere. The evidence reviewed here suggests that such sustainable yields are not to be expected from cattle pastures.

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