THE FOREST MARGINS AND SAVANNAS OF LATIN AMERICA: A UNIQUE OPPORTUNITY FOR CONTRIBUTING TO NATURAL RESOURCE MANAGEMENT[1]

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Agricultural expansion in the margins of the rain forests in Latin America has been internationally regarded as an environmental catastrophe for years. A viable strategy for management of the forest margins (FM) is however yet to be developed and implemented. The lowland acid soil savannas of tropical America are a vast expanse of grassland occupying about 240 m ha (Sanint et al., 1992). They have been described as, "the last agricultural frontier in the world" (Borlaug, 1994). The savannas are generally regarded as having a very significant potential to be economically exploited for agricultural and livestock production, and are widely considered to be environmentally robust. In sharp contrast, there is a considerable body of opinion that believes that there should be no further development in the FM primarily in the interests of preserving biodiversity and reducing atmospheric carbon dioxide[4]. This paper shows that the conjunction of a number of national and international developments makes this a highly propitious time for mounting a concerted effort for improving the management of the natural resources in the FM and savanna. It also points out the interactions that exist between the savanna and the FM ecosystems in Latin America, and the need for an integrated strategy across ecosystems.

Essentially all countries in the western hemisphere from 20 degrees N to 20 degree S have areas included in the forest margins, but savannas, are found only in a few countries. There is then one group of countries that have the potential to take advantage of the opportunity for savanna development. This may give them greater prospects for economic growth and may perhaps offer an alternative to the development induced destruction of the forest margins. These countries include Brazil, Colombia, and Venezuela. These countries contain over 90% of the total savanna area. In addition, Bolivia and Guyana also include land that is environmentally similar to the savannas, but in both countries this land is currently so remote from markets that it is not yet an option for development.

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[4] Definition of the FM and savannas in Latin America, their comparability with TAC's agroecological zones, and CIAT's strategic reasons for prioritizing these agroecosystems are given in Appendix 1.

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The other group of countries does not have the savanna option for development. These countries in Central America and the Andes have historically had the hillsides (<2000m) and highlands (>2000m) as the major areas of settlement and agricultural development. The hillsides remain an important agroecosystem in these countries, but due to high population density, farm sizes tend to be small, income low, and pressure is high to degrade the hillsides natural resource base or migrate to other agroecosystems. the major significant rural development alternative for these countries is expansion of the frontier in the forest margins, precisely because they do not have the savanna resource.

Contrasts between savanna and forest margin/hillsides countries

It is useful, therefore, to distinguish between two groups of countries: those favored with the potential to develop the savannas, and those with no option but to exploit the hillsides and forest margins. While the differences between these two groups of countries are treated elsewhere in detail (Pachico et al., 1994), here only a few particularly crucial comparisons are highlighted.

The population of the savanna countries is triple that of the hillsides/forest margin group (204 vs. 67 million), making the savanna countries important in the aggregate. Per capita incomes are two and half times greater in the savanna countries, making the forest margins/hillsides countries considerably disadvantaged ($2648 vs. $956). Countries that have the advantage of the savanna resource for future development, already have higher per capita incomes than countries which lack this option. Moreover, in the period 1980-91 economic growth rates of the savanna countries have been generally higher than in the hillsides/forest margin group (2.6%/yr vs. 2.0%/yr).

These differences in economic growth are reflected in other development indicators. The proportion of the population that is urban is much higher in the savanna countries (76% vs. 57%). At the same time, projected population growth rates for the period 1991-2000 are lower in the savanna countries (1.6%/yr vs. 2.4%/yr). Thus, the savanna countries have higher per capita income and income growth, as well as being more urbanized with a slower rate of population growth.

Although data for poverty are available for a somewhat restricted set of countries, some patterns do emerge (Pachico et al, 1994). Poverty rates are higher in the rural than urban populations. In the savanna countries 40-60% of the rural population are in households with incomes below the poverty line, while the corresponding figures for the forest margin/hillsides countries range between 70-80% (excluding Costa Rica which has the lowest incidence of poverty of all countries considered). For urban households in the savanna countries, 30-40% of the population is below the poverty line compared to 50-60% of the hillsides/ urban population. Despite lower rates of poverty, the total number of poor in the savannas countries is greater than in the hillsides/forest margin countries, 87 million vs. an estimated 42 million.

In the agricultural sector, growth rates in agricultural output in the decade 1980-91 have been higher in the savannas countries than in the hillsides group (2.9%/yr vs. 1.7%/yr). This slower growth in agricultural output is more serious for the forest margin/hillsides countries because agriculture represents a larger share of total GDP, 20%, versus only 11% in the savanna countries. Nonetheless, the agricultural GDP per capita is greater in the savanna than the hillsides countries ($266 vs. $179). The contrast is even greater in terms of agricultural GDP per rural inhabitant, with this figure being three times higher in the savannas than in the hillsides ($1115 vs. $350). Thus, growth in agricultural output has been greater in the savanna countries where agricultural GDP per capita and per rural inhabitant is higher, even though agriculture contributes a smaller share of total output.

In summary, then, two distinct groups of countries with different agroecological endowments can be observed in Latin America. One group of countries has the opportunity for agricultural expansion in the savannas.

The other group of countries do not have the opportunity to develop a savanna agroecosystem resource. As population growth in the hillsides has led to increasing poverty and resource degradation, the major agricultural development alternative for these countries has been the settlement of the lowland forests. This group of countries that lacks the savanna resource base have lower, and slower growing, incomes and agricultural output. They also have a greater dependence on agriculture, but lower agricultural production per rural inhabitant and lower per capita nutrition availability. Poverty and food imports are higher while health and welfare indicators are generally less favorable. Due to this complex of interrelated problems, this group of countries faces severe pressure to intensify deforestation in the forest margins while accelerating resource degradation in the hillsides.

Land use trends: national level

Since the savanna countries represent the most promising prospect of sustainable agricultural development, this paper will now turn to an examination of the current structure of, and trends in, land use in these countries. Forest and natural vegetation remain the most important land use in the savanna countries ranging between 34% and 51% of total area (Table 1). Except for Venezuela, the proportion of land that is still in a undisturbed state is about 50% greater than the average of the forest margin/hillsides countries. Thus, the savanna countries are characterized by not yet having so seriously depleted their natural vegetation and still having greater potential for frontier expansion or resources for conservation.

Pastures are generally the second most important land use in the savanna countries, ranging between 22% and 39% of total area. Only a very small proportion of land is in annual or perennial crops, with crops accounting for between 2% and 7% of total land. This is much lower than in the forest margin/hillsides countries where crops on average occupy 13% of land area. There is little doubt, then , that most natural vegetation that is being converted to agriculture is going to pastures rather than crops.

This is borne out by data on changes in land use from 1961 to 1990 (Table 1), where it can be seen that in Colombia the area expansion of pastures was 16 times greater than crop area expansion, while the comparable figures for Venezuela is four times and Brazil twice as great. By far the largest part of conversion of native vegetation is occurring in Brazil, which alone cleared 65 million hectares of forest compared to 22 million hectares for the rest of the savanna countries combined. Brazil is also somewhat different in the greater importance of expansion of crop area compared to the other countries.

This is confirmed by data on the per cent increase in different land uses 1961 to 1990. In Brazil crop land more than doubled, compared to a 60% increase in Bolivia, 9% in Colombia, and 12% in Venezuela. Relatively speaking, there has been little expansion of cropped area in Colombia and Venezuela. Likewise, area in pastures increased 51% in Brazil and only 22% in Colombia and 12% in Venezuela. Thus, there has been some frontier expansion in Colombia and Venezuela, but this has been dwarfed both absolutely and relatively by Brazil.

Despite this massive destruction of natural vegetation, the per cent decline in forest area has been least in Brazil over the last three decades. In Brazil area in natural vegetation fell 12% from 1961 to 1990, while the corresponding decreases for Colombia and Venezuela are 15% and 22% respectively. Brazil still has twice as much forested land per capita (3.28 ha/capita) compared to Colombia and Venezuela (both 1.53 ha/capita).

In summary, of the savanna countries, Brazil has had the largest absolute and relative expansion of crop and pasture area. Nevertheless, Brazil still has the largest share of land still in undisturbed native vegetation, and a relatively large amount of forest per capita, and a relatively low per cent decrease in forest land over the last three decades. Only Bolivia has a lower rate of deforestation and more forest land per capita. Like Brazil, Bolivia and also had a very significant increase in cropped area. Thus, Brazil and Bolivia still have a greater endowment of undisturbed land despite having had a greater expansion of the frontier.

In contrast, Colombia and Venezuela bear some of the characteristics of hillsides countries, with a low per capita availability of crop land (0.16 ha/capita and 0.20/capita compared to 0.23 for the hillside/forest margin countries). Much less than Brazil have these countries pursued expansion of crop land or pasture during the last three decades. Thus, these countries still have an important savanna land resource available for potential development, but this process is far less rapid than, or advanced as, in Brazil.

The main focus of this paper is on the FM and savanna in the savanna countries. A separate paper (Pachico et al., 1994) focuses on the hillsides countries.

LAND USE DYNAMICS: ECOSYSTEM LEVEL

Historical land use

Historically the rain forests of Latin America have been home to dispersed indigeneous populations, without property rights, who practiced shifting cultivation and collected forest products, such as nuts. The second half of the nineteenth century, and the beginning of this century saw boom and bust periods for extractive primary industries, such as quinine, rubber and precious minerals. Commercial centers were established in isolated places, which were bases for later colonization (Brucher, 1968; Sawyer, 1984). Wood was not exploited due to high extraction and transportation costs (Acosta, 1994).

The savannas of Latin America were originally inhabited by nomadic, indigenous hunters and gatherers. Cattle raising has been a traditional activity since the colonial period, transhumant grazing being followed later by extensive cattle ranches. Sporadic influxes of people took place in search of precious materials, but the modest reserves were soon exhausted, and the savanna essentially remained an area of extensive cattle grazing with an extremely small and dispersed population until rapid frontier expansion occurred during the last two decades.

The only exceptions were the center-south (C-S) of the Brazilian savanna, and the western savanna in Venezuela. Rail connections to Sao Paulo stimulated the use of the abundant natural pastures of the Campo Grande area as a source of beef for urban markets in South-east Brazil, with the Minas Gerais triangle becoming the main marketing entrepot. The construction of Brasilia in the late 1950s and infrastructure linking it to South-east Brazil further stimulated the commercial importance of this area (Mueller et al., 1992). In Venezuela oil revenues were used to provide incentives for agricultural production in the relatively fertile soils in the western savanna. This area, which had originally been semideciduous forest, was almost totally deforested by the 1950s and converted to mechanized high input commercial production of cereals, oil seeds and sugar cane (Arias, 1994).

Trends in land use in the savanna and FM display certain predominant features which are described below.

1. Rapid frontier expansion

Both the savanna and the forest margin are frontier areas, ie areas where increasing amounts of the natural ecosystem are being brought under human intervention. Frontier expansion has been extremely rapid in both areas particularly since the 1970s. In the Brazilian savanna (cerrado) the area affected by agriculture increased from 19.2 m ha. in 1970 to 50.8m ha. in 1985, a 2.6 fold increase, equivalent to an average annual increase of 2.1 m ha. (Mueller et al, 1992). In the Colombian savanna the area under agriculture expanded by 87% between 1986 and 1990 (Ortiz et al, 1994). In the Brazilian Amazon the rate of deforestation between 1978 and 1988, using remote sensing data, is estimated to be between 1.5 m to 2 m ha./year (Skole et al., 1994). In Central America estimated rates during the eighties range from 0.3 m to 0.4 m ha/year (Kaimovitz, 1994). Although the frontier has expanded rapidly, vast areas of unaltered land remain (with the exception of the Central American forest). Six percentage of the closed forest in the Brazilian Amazon (Skole, et al, 1994) , or about half the FM has been cleared. About a quarter of the cerrado, or about a third of the potentially cultivable area is currently under occupation (da Sil· ı, 1994). Thus there is considerable opportunity for influencing the future pattern of land use change in these ecoregions.

2. Dominance of pasture

In the cerrado, in 1985, over 60% of the cleared area consisted of pastures with only 19% devoted to crops and planted forest. Another 20% was cleared but not used. About half the total area within farm boundaries was left uncleared, and it is likely that much of this was used for extensive grazing. Thus upto 82% of the area within farm boundaries may have consisted of natural or planted pasture (Mueller et al., 1992). The importance of pasture appears to increase as agriculture development advances. Distinguishing between an older, "modern", commercial subregion (the center-south of the cerrado, around Uberlândia and Goiânia: C-S), and the rest of the cerrado shows that the proportion of cleared area devoted to pasture is higher in C-S, while cleared but unused land is lower. A pattern similar to "modernization" is also visible over time in both subregions (Table 2).

The situation in the FM is more complex. The conventional wisdom is that pastures are the dominant form of land use. This is supported by census data, in which typically 60 to 70% of the incorporated land area is found to consist of pastures (Table 3: columns 1 and 2). Pasture area has increased sharply over time, although rates of growth declined to around 5% in the 1980s, after very rapid expansion in the 1970s. Indepth field surveys show that a substantial portion of the pasture area may initially have been crop land. Small scale farmers in the FM typically plant annual crops for two to five years immediately after deforestation. As the land declines in fertility, it is usually planted to pasture or in rare cases left fallow (Millikan, 1988). Pastures established by small scale settlers are often consolidated into large scale holdings by ranchers. Thus land consolidation and transience in land use and land users is a characteristic of the FM.

3. Land concentration

Land concentration and dualism are characteristics of both ecosystems. Small scale and large scale farmers coexist, with almost all the land being concentrated in the hands of a small group of large operators. In the cerrado, farms less than 50 ha. represent more than 50% of the total number of farms, but 87% of the land is in farms ranging from 200 to >10000 ha (Mueller et al., 1992). As agricultural development occurs, land concentration declines, but still remains very high. Trends over the 1970 to 1985 period show that in the "modern" C-S there is an increasing dominance of farms in the 200 to 10000 ha category. This has occurred at the expense of a small decline in the proportion of small farms (<50 ha), and a decline in the proportionate number and area of very large farms (> 10000 ha). A similar trend is visible in the Colombian savanna, where average farm size in a field survey was found to have declined from 5000 to 1000 ha. between 1979 and 1989, and farms were smaller in areas of better infrastructure (Cadavid et al., 1991).

In the forest margin land concentration is declining, but still high. Between 1975 and 1985 the Gini coefficient for the FM in Brazil declined from 0.86 to 0.79, while the figure for Brazil remained constant at 0.85 (World Bank, 1993). The decline is probably due to the colonization programs for small scale farmers. In Rondônia (a small scale settlement area) the Gini coefficient is 0.65. At the same time, in the Para/Tocantins area where government incentives for large scale ranching were provided, average farm size increased from 222 to 338 ha. between 1970 and 1985, although 65% of farms had <40 ha. (Mueller et al, 1992). Although small and large scale farmers coexist in the FM, there is a high degree of social conflict particularly between large scale absentee ranchers and resource poor small scale squatters.

4. Agricultural technology

Technology development in the past has sought to increase land productivity through the replacement of natural vegetation and traditional species with new varieties (crops, pastures, livestock), chemical inputs, particularly those that overcome soil constraints, mechanization, and irrigation of dry areas.

The new technologies were enthusiastically adopted by large scale farmers in the C-S region of the cerrado, where high land values, good infrastructure and proximity to markets made these technologies worthwhile. Adoption also occurred in parts of the Venezuelan savanna, driven by good infrastructure and high levels of subsidies (Arias et al., 1994). In the Colombian savanna as infrastructure improves, driven by major oil discoveries in the eastern savanna, adoption is also increasing (Cadavid et al., 1991). In the areas where adoption has occurred agriculture is regarded as highly successful. In Venezuela the savanna is the most important agricultural area in the country (Arias et al., 1994), and in Brazil the cerrado provides over 25% of Brazil's soybean output, and contains about a third of the nation's cattle. The bulk of this comes from the "modern" C-S which supplies 83% of the cerrado's soybean production and containes 64% of the cerrado's cattle. Yields of commercial crops in the C-S are comparable to national yields, inspite of the highly acid soils in the region (Mueller et al., 1992). In the more remote areas of the savanna, where land values are lower, technology adoption has been very limited, and extensive traditional cattle ranching is the norm (Mueller et al., 1992, Ortiz et al., 1994). Technology adoption is also unlikely to have occurred among small scale savanna farmers although very little systematic information is available.

In the FM adoption of improved pastures has occurred, but extensive management practices remain the norm in large scale ranches. Among small holders annual crops are grown with minimal external inputs. In Brazil, yields of rice, maize and cassava have decreased sharply over the 1984 to 1990 period, in contrast to significant yields increases at the national level (Mueller et al., 1992).

The structure and recent trends in some major agricultural commodities of the savanna and FM are presented in Tables 4 and 5. Rice is a major food staple throughout the lowlands. However, in Colombia and Venezuela most rice is grown in favored irrigated systems in river valleys, not in the upland production system of the savanna or forest margins. Upland rice accounts for an estimated 3% of total production in Venezuela, 25% in Colombia, and 50% in Brazil (CIAT, 1993). National rice yields are much lower in Brazil because of large areas of upland rice there. An estimated one fourth of all rice, or half of Brazil's upland rice is produced in the savannas and forest margins (Mueller et al., 1992).

Maize is another major crop adapted to the lowlands, though a large share of maize production in some countries also comes from the hillsides. For example, one third of the Colombian maize crop is grown in the hillsides. Maize is still not grown in any significant quantities in the savannas or forest margins of Colombia though these agroecosystems in Brazil account for an estimated 19.5% of total national production (Mueller et al., 1992).

Soybeans, and to a lesser extent beans, have been major crops with expanding and significant production in the savannas of Brazil. Some 32.4% of total national soybean production in Brazil is estimated to come from the forest margins and savannas (Mueller et al., 1992). Neither is an important crop in Colombia or Venezuela, and little of these minor crops are grown in the savannas or forest margins there. However, 16.8% of Brazil's common beans are produced in the savannas and forest margins. While beans are principally a small farmer crop in the forest margins, in the savannas, where almost twice as many beans are produced as in the forest margins, beans are typically produced by large farmers in highly intensive systems with central pivot irrigation.

Cassava is a major crop in Brazil that has an important role as a crop for small settlers in the forest margins and savannas. While more important in the forest margins which alone produces 11.9% of total cassava in Brazil, it is also produced by the often overlooked small holders in the savannas, where 5.2% of Brazil's cassava is produced (Mueller et al., 1992).

Sorghum is not yet a major crop in the forest margins or savannas, but with the development of acid tolerant germplasm it could emerge as an important crop. Sorghum is the main feed grain in Colombia and Venezuela, a position occupied by maize in Brazil. Production growth of sorghum has been rapid in Colombia during the last decade. This vibrant growth is linked to very strong expansion in poultry production and consumption which has also occurred in Brazil. The trend towards cheap poultry and rising production displacing beef consumption may be expected to continue, particularly in Brazil and Colombia (Sere and Jarvis, 1989). This opens the potential for strong demand for animal feeds, which could drive a powerful derived demand for soybeans and sorghum in the savannas, and maize in the savannas and forest margins.

5. Labor absorption in agriculture

There have been major population movements into the FM. In Brazil population growth rate in the FM was around 8-11% during the 1970s. Although the growth rate slowed down considerably in the 1980s, it still remained at more than twice the national growth rate of 2%. In spite of migration into the area, population density remained low. In Rondônia, the number of inhabitants/km^2 was under 5 (Schneider, 1991). There has also been considerable labor absorption in agriculture. Employment in agriculture increased three fold between 1970 and 1985 in the Para/Tocantins area of Brazil, and by almost 7 times in the Acre/Rondônia area of small scale settlements. The number of workers/100 ha of agricultural land ranged from around 65 to 85 (Table 6).

Movement of population into the savanna was much less than in the FM. In 1991 there were large areas in the Cerrados with <5 inhabitants/km^2. Most of the population in the cerrados was concentrated in the C-S which, while occupying about a third of the land area, contained 60% of the population. In contrast to the FM, the increase in population in the cerrado was related to urban rather than rural phenomena. Although rural population increased in frontier areas, where land was being incorporated into agriculture, rural out migration appears to have occurred in areas of advanced agricultural development. In the municipality of Uberlândia in the C-S of the Cerrado, rural population in 1980 was only 47% of the level in 1950 (Salazar,1983). Labor absorption in agriculture has been low, and has declined over time. The number of workers/100 ha of agricultural land declined from 7 to 4 between 1970 and 1985, the phenomenon being even more advanced in the "modern" C-S (Table 6). This is consistent with Sawyer's (1984) analysis which indicates that between 1970 and 1980 rural out migration occurred simultaneously with rapid urban population growth in the "advanced" agricultural areas in the cerrado.

Major Environmental Effeccts

The environmental effects of current practices of land use in the savannas and forest margins have local, regional, and global impacts. The major effects are:

a. Fragmentation and reduction of natural habitats, due to deforestation for crops and pastures.

b. Exhaustion of forest resources and overexploitation of valuable species, associated to selective or clear cut deforestation of large areas for timber or charcoal and firewood.

c. Loss of ecosystems, species, and biomass, and changes in the hidrological cycles and generation of health hazards due to the building of large dams.

d. Soil and water pollution, deforestation and erosion associated to goldmining activities.

e. Compactation, loss of fertility and soil erosion, pest explosions, soil and water pollution, associated with the intensification of agriculture.

f. Significant emissions of greenhouse gases due to large-scale deforestation for agricultural uses.

In general, the impacts of the intensification of the use of the land do not appear as prevailing or as serious as those impacts associated with general socioeconomic processes and subsidies leading to deforestation, inadequate location of dams and of agricultural colonization projects (Mueller et al., 1992), World Bank, 1992). Furthermore, natural resources are often wasted. For instance, during the period 1980-85, it is estimated that about one third of the deforested area was not used, being burnt because of speculation (Mueller et al., 1992).

Gold-mining in the Tapajos river resulted in the spilling of 2,000 tons of mercury in the rivers between 1980 and 1990 (World Bank, 1992).

In the Cerrado, in 1980, pesticide use reached 1.8 kg active ingredient (ai) per ha of crops, equivalent to 9.4% of national consumption, compared to the national average of 0.75 kg a.i./ha of crop (da Silva, 1994).

Large areas of the Cerrados have been used for production of charcoal. Between 1970 and 1980 an estimated 350,000 to 450,000 ha of dry forest were felled for charcoal (Lanly, 1985), leading to fuelwood and other forest resources scarcity.

However, the conversion of land to agriculture could have positive inputs in the Cerrados, in terms of substituting fuel for biomass energy. Brazil produces currently bioethanol at a large scale. In 1990-91 it produced 12.7 million liters which replaced 200,000 barrels of oil (Hall & House, 1992), thus reducing carbon dioxide emissions.

Biodiversity loss is a serious problem. Contrary to common belief, the risk of species extinction is higher in the Cerrados and tropical dry forests than in the lowland forests, where the forest margins are mostly located. This is because of the differences in the relative amounts of the ecosystem left. For instance, in 1988, forest losses in the Brazilian Legal Amazon amounted to 2 million hectares of closed forests and 1.8 million hectares of open forests. By 1989, 33% of the open forests (mostly Cerrados) in Legal Amazonia were deforested as compared to 6.4% of closed forests (Fearnside, 1990; Fearnside et al., 1990). The protected areas in the forest margins represent 4% of their surface, the protected areas in the Cerrados cover only 2% of their extension.

Regarding the emission of greenhouse gases the problem is serious. Deforestation is a process leading to a large net addition of carbon dioxide and the greenhouse gases to the atmosphere, with contributing to the risk of global warning. This is closely associated with the forest margins. However, the tropical savannas of South America, including the Cerrados, seem to be acting as a net sink for carbon, sequestering huge amounts of this element below ground (Fisher et al., 1994). This is associated with the amount of improved pastures in relation to the natural savannas.

In summary, expansion of the agricultural frontier has been a fundamental characteristic of the evolution of the savanna and FMs. Pastures are the dominant form of land use. However, the FM is characterized by transience, both in land use, and in the users of the land. Frontier expansion in the savanna has been characterized by productive mechanized agriculture by large scale farmers, which has made the savanna, in areas of good infrastructure, a key contributor to agricultural production. This has however been achieved at the cost of environmental degradation, and rural out migration. The FM has made a contribution towards providing a livehood for substantial numbers of the poorer segments of the population. However this has been achieved at the cost of massive environmental degradation and social conflict without any compensating contribution to agricultural production. Loss of cultural diversity, through the displacement of indigenous populations has been a feature of both the savanna and the FM.

CAUSES OF RECENT FRONTIER EXPANSION

There is ample evidence that roads stimulated frontier expansion in both the savanna and the forest margin. Satellite data show that in the Brazilian FM, most of the changes in land cover between 1970 and 1980 occurred along the Belem-Brasilia, and Acre-Brasilia high ways (Skole et. al., 1994). Statistical analysis from Central America supports a positive relationship between distance from roads and the extent of deforestation, and estimates a deforestation area of influence of 400 to 2000 ha per each new kilometer of road (Kaimovitz, 1994). Development of the C-S of the Cerrado was stimulated by road connections between Brasilia and South-east Brazil, and the Cuiaba-Brasilia road paved the way for the opening up of the western cerrado (Mueller et al., 1992). While roads stimulate frontier expansion, they are not the root cause. In Colombia, for example, although the government constructed roads across the Andes from two forest locations (Putumayo and Caquetá) in the 1930s, major migratory movements did not occur until much later (Brucher, 1968). The root cause of rapid frontier expansion in Latin America has been identified as the "style of development" (Gutman, 1988). Two features have been particularly important in this respect. First, a large section of the population has been excluded from the benefits of growth and development. Second, macro-economic conditions have resulted in inadequate and uncertain returns to financial assets. Thus the frontier has been an escape valve for the discontent of the poor, and the capital of the rich. Table 7 presents data from three middle income countries (Brazil, Colombia and Venezuela) where relatively high levels of per capita income and annual rates of growth have been accompanied by a high incidence of poverty, and infant mortality.

One cause of inequality has been identified as the high level of capital intensity in both agriculture and industry, which started in the 1960s, when population growth rates were above 3% This anomaly had its roots in colonial history, when indigenous people's access to land was severely restricted, leading to high levels of concentration in land and capital. The lack of land reform after independence, accompanied by import substitution policies which protected domestic production, and subsidized mechanization, stimulated capital intensive agriculture and industry. In addition urban bias resulted in major discrepancies in social amenities between rural and urban areas (Salazar, 1983), which led to high rates of migration to urban areas. This further stimulated mechanization in rural areas, while the lack of employment opportunities in urban areas led to the proliferation of crime and violence. Population pressure and land degradation in North-east Brazil also led to rural out migration from that area. In Colombia two other factor stimulated migration to the frontier. One was the desire of people to flee the political violence which erupted in the late 1950s and early 1960s. Another was population pressure in the Andean region which was a result of the indigenous population's access to land being restricted during the colonial period (Brucher, 1968). In Brazil strongly negative real rates of interest during the 1970s and early 1980s further stimulated the capital intensity of production processes and limited employment opportunities for the unskilled (Mueller et al., 1992). Thus the poor looked to the frontier as an escape valve.

Negative real interest rates, high unstable inflation and protection of the banking sector reduced the return on financial assets, and caused people to turn to land as a hedge against inflation. Speculation in land at the frontier was particularly lucrative, because penetration roads pushed up land prices in surrounding areas. Data from Central America show that land prices doubled immediately after road access was provided, and frontier land along penetration roads cost 4 to 12 times as much as land with poorer access (Kaimovitz, 1994). Also title to public lands could be claimed if land could be shown to be used for productive purposes. In Brazil land ownership provided the additional benefit of access to credit at strongly negative real interest rates. This led to significant increases in land prices in real terms (Brandao, 1988).

In Colombia since the 1970s illicit cultivation and processing of coca has provided an additional incentive for land acquisition at the frontier, where government surveillance is difficult (Ortiz, 1994). Thus frontier land prices in Latin America contained an additional component which pushed prices well beyond actual production values. Thus the frontier was an escape valve for the capital of the rich.

In addition to these factors, direct government incentives promoted frontier expansion. The Brazilian government had geopolitical motives for wanting to incorporate the Amazon into the mainstream of the Brazilian economy. This led to incentives for large scale ranching in Pará/Tocantins, and small scale settlements in Acre/Rondônia. In the Cerrado selected areas in the C-S which were considered to have high agricultural potential were provided with improved infrastructure, and large farms in these areas ere provided with cheap credit if they followed "advanced" practices. Uniform fuel prices during the 1970s throughout the cerrado contributed to the expansion of agriculture into remote areas of the cerrado.

Although government incentives were clearly a factor, their effect should not be overestimated. Most incentives were provided to large scale farmers. Yet, in the Brazilian FM the bulk of the increase in cattle numbers occurred in small herds (World Bank, 1993). In Panama only 7-10% of deforestation was estimated to be due to government credit schemes which were limited mainly to established ranchers in traditional ranching areas (Kaimovitz, 1994). Also, in the cerrado incentives for agriculture occurred simultaneously with export taxes and over valued exchange rates. Thus the net effect of government intervention is not clear (Mueller et al., 1992).

Market factors, particularly the booming export market for beef in the 1960s and 1970s is also believed to have been a driving force behind deforestation (Myers, 1981). Kaimovitz (1994) has shown, however, that while flourishing export markets promoted pasture expansion and deforestation, declining beef exports in the 1980s led to a decline in cattle population mainly in the traditional livestock regions of Central America, while pasture expansion and deforestation continued in frontier areas. It appears therefore that while most deforested land is converted to pasture, livestock is not the root cause behind deforestation. Once deforestation occurs, pasture is the most convenient form of land use.

In summary, therefore, it appears that the enormous response to the frontier was caused by push factors in the case of the poor, which lowered the returns to their labor in established rural and urban areas; and pull factors in the case of the rich, which increased the returns to their capital in frontier areas. The most notable feature is that these push and pull factors were mainly caused by government policy, including policy outside the agricultural sector (Figures 2 and 3).

EXPLAINING LAND USE PATTERNS

The frontier is an area where economic activity has just become viable. An area becomes a frontier either because a new exploitable resource is discovered there, or because construction of penetration roads makes the development of commodity markets viable, by reducing the cost of transporting frontier production to markets, and consumer goods to frontier settlements. The development of commodity markets is followed at a later stage by the development of land and labor markets (Sawyer, 1984). The frontier is therefore characterized by abundance of land relative to people, high transport costs which reduce the profitability of economic activity, minimal social services, and poorly enforced property rights.

In view of these characteristics, settlers at the extreme frontier are likely to have low levels of human and physical capital, and therefore low opportunity costs. As the frontier matures, and transport infrastructure and government services improve, people with higher levels of human and physical capital find it possible to cover their opportunity costs at the frontier. These later settlers can bid earlier settlers off the land because of better access to capital markets and government services, such as legalization of land ownership (World Bank, 1993).

Small-scale settlers at the extreme frontier in the FM, attempt to use the abundant land resource to increase the returns to their labor. In the absence of labor markets, expansion of farm size is limited by family labor availability. Therefore an area of a few hectares is cleared at the start. Annual cropping, dominated by nutrient demanding crops such as rice and maize, is the most common practice immediately after deforestation, because this allows the immediate exploitation of nutrients which have taken centuries to build-up. Annual crops are grown both for subsistence and cash. As fertility declines after a few years of crop cultivation pastures, which are less nutrient demanding, are established, and new land is deforested for growing annual crops (Millikan, 1988; Kaimovitz, 1994). As the frontier matures, settlers with higher opportunity costs move in. Given the poor social amenities, this later wave is unlikely to reside at the frontier. In this situation extensive cattle ranching is the preferred land use system, as it can be carried out with minimal levels of management. Given land abundance, these absentee owners also seek to keep capital expenditure per unit land area to a minimum. Savings in costs of deforestation and pasture establishment are achieved by buying out the pastures established by small holders, who have deforested and established pasture at a low cost by using family labor. While some authors have depicted the sell out by small holders as "distress sales" caused by the non viability of agriculture on FM soils (Millikan, 1988), others (Moran, 1989) show that these conclusions may reflect the initial attrition of a segment of the migrant population in the early adaptation stage after settlement. In fact data show a statistically significant positive relationship between farm turnover and economic performance (World Bank, 1993).

Since later arrivals are capable of obtaining better long term returns to land due to their better access to capital markets, they are able to offer a price in excess of the returns early settlers can expect through cultivation (World Bank, 1993). Also selling out provides early settlers with another opportunity to capture economic rent by deforestation and annual crop cultivation on another patch of new land. Thus the economic logic of the frontier provides a temporal niche for large and small scale settlers. Thus land consolidation and transience in land use and land users is a characteristic feature of the FM.

The availability of new frontiers, through expansion of new penetration roads is, of course, a pre-requisite for these phenomena to work. While these phenomena meet the objectives of both early and late settlers, the environmental costs are enormous because of the resulting increase in deforestation. Nor is it economically efficient from society's point of view, as the ability of later arrivals to buy out earlier settlers is due primarily to their better access to capital markets, and not due to any productive advantage. In fact, while small scale settlers attempt to maintain their pastures and use them productively until a buyer can be found, pastures on large scale ranches in frontier areas degrade, and are often regarded as abandoned, because land values are too low to justify intensive management.

There is a different logic behind land use patterns in areas where government policies subsidize large scale ranching or promote land holding for speculative motives. These policies induce land acquisition and deforestation at the extreme frontier by people with higher opportunity costs, who would have normally arrived a later stage when the frontier had matured. Absentee ownership and poor enforcement of property rights at the extreme frontier cause squatting by people with lower opportunity costs. The result is massive social conflict. In fact, in Brazil there is a striking correspondence between areas of fiscal incentives and areas of agrarian violence (World Bank, 1993). Pasture degradation is also exacerbated. As speculation, and not production, is the main motive, pastures are established to demonstrate productive use merely for securing land titles. Once this is achieved, pastures are abandoned. Furthermore, at the extreme frontier, commercial production is not viable for those with higher opportunity costs, particularly as the area has to be first deforested. Economic analysis shows that enterprises would not be economically worthwhile in the absence of speculative increases in land values (Hecht et al., 1988). Thus there is little incentive for pasture maintenance squatters too have no interest in sustainable land use, due to the insecurity of land tenure.

Turning next to the savanna, the same basic frontier logic manifests itself in very different patterns of land use, due to differences in the biophysical resource base. There are three major biophysical differences between the savanna and the FM that are particularly important for land use patterns. First, biomass production and therefore initial fertility after land clearing is much lower than in the FM. This combined with high levels of soil acidity results in very low returns to nutrient demanding annual crops, such as rice and maize, without the use of soil amendments. Second, land clearing costs are much lower in the savanna, due to the nature of the vegetation. Third, the native vegetation can be used for extensive cattle grazing, with minimal levels of management and capital expenditure. The nature of the soils make it difficult for early settlers to make a living from small holdings. Early settlers therefore go to the small niches of relatively high fertility, which are usually lower down the landscape, along the river beds. These are also often areas of gallery forests, where deforestation enables them to exploit a short period of high fertility, after which they usually cultivate crops such as cassava and beans which are more tolerant of low fertility. Later settlers who arrive when the frontier is more mature establish extensive ranches, initially grazing cattle on native grasses. These later settlers do not attempt to bid earlier small scale settlers off the land as the topography of the areas occupied by small holders impedes land consolidation and mechanization. Also, unlike in the FM, there is no need to piggy back on the land clearing services of early settlers as land clearing costs are low, and extensive cattle grazing is possible on native vegetation.

As the frontier matures and infrastructure improves, land uses which give higher returns to land drive out less productive land uses. Also as transport costs decline with maturing frontiers, production of more perishable high bulk commodities which are intensive in transport cost become viable (World Bank, 1993). Thus in the savanna, the general pattern as the frontier matures is for extensive grazing on native grasses to give way to intensively managed pastures with higher stocking rates and intensively managed field crops. Finally, in the peri-urban area there is cultivation of perishable horticultural products and intensive dairying. As infrastructure improves, the need for intensive management leads to fragmentation of the largest farms. Also cash strapped small scale farmers get better returns from selling out than from farming. In the absence of employment opportunities on large scale farms due to high levels of mechanization, rural out migration occurs. This explains why the older settlement areas in the C-S of the cerrado have the highest proportions of farm land devoted to annual crops and planted pasture, and why the C-S has experienced rural out migration. Government intervention can lead to changes in this pattern. Thus, as in the FM, incentives for speculation and subsidies for large scale ranching can lead to premature land acquisition by relatively better off migrants at the extreme frontier and, as in the FM this leads to squatting by small scale settlers for speculative purposes, resulting in social conflict. Because the objective of land acquisition is speculation, and not production, environmental degradation occurs as land occupation extends into areas unsuitable for farming. Government incentives which favor remote areas, such as uniform fuel prices and uniform guaranteed minimum output prices, can also lead to premature expansion of intensive annual cropping. These areas usually revert back to pasture once subsidies are removed. However, as land values are still relatively low, little effort is made to rehabilitate the land after intensive cropping.

Thus, in frontier regions of the savanna there is a spatial niche for small scale farming, which though small in geographic terms, is sufficiently distinct to prevent sell outs to later arrivals. This explains the dualistic structure of farming in frontier areas of the savanna, and why transience is not a pervasive frontier characteristic. As the savanna intensifies it absorbs capital, but expels labor. Biophysical characteristics of the savanna play a major role in this pattern of development. Therefore, while the savanna may relieve pressure on the FM by providing an outlet for the capital of the rich, it is unrealistic to expect it to absorb resource poor migrants, except on a very limited scale.

EMERGING TRENDS

In the last decade certain changes are visible in the patterns described above, and in the root causes behind these patterns. Most importantly, some of these new trends indicate a reversal of some of the most damaging features of the past, thus giving rise to a unique opportunity for contributing to natural resource management.

Slow down in frontier expansion

Data is now emerging from the analysis of remote sensing data which indicate that deforestation rates in the Brazilian FM are much lower than previous estimates have indicated (Skole et al., 1994). Even more important, there appears to have been a reduction in deforestation rates in the Brazilian FM since the late 1980s. Skole et al (1994) claim that current rates are now half of what they were in the late 1980s. Reductions in the deforestation rate in Brazil are also reported by Moran (1993), and Kaimovitz (1994). CIAT's informal contacts also indicate that a major reduction in deforestation rates in the 1990s is consistent with unpublished data of the Brazilian national institute for space research (INPE).

Some authors, such as Moran (1993) have linked the reduction in deforestation to the dismantling of incentives for large scale ranching which started in the early 1980s. As shown earlier, however, the main effect of these incentives was the rapid increase of land prices in real terms. Thus the major factor was that the removal of incentives reduced the incentive for land speculation. Other changes contributing to the reduction in the speculative motive, in Brazil, were the elimination of provisions linking legalisation of land ownership to land clearing, and the improvement in the returns to financial assets.Although inflation remained extremely high (2000%) until the last few months when a new stabilization plan was initiated, real interest rates in the 1992-1994 period were between 23 and 43%, on low risk government bonds. This was because at this period high interest rates were the main economic policy instrument available to contain inflation (EIU 1994). Preliminary indications are that the new stabilization plan appears to be successful in controlling inflation and restoring confidence in the economy. This should provide productive opportunities for investment, and reduce aquisition of land in the FM for speculative purposes. Land prices have also begun to stabilize. The construction of penetration roads has been reduced, and government policy has changed from land settlement to preservation of indigenous lands, and relatively tight control over deforestation (A.S.P.Brandao, pers comm). As a result the speculative motive for land aquisition has begun to decline in Brazil.This is supported by census and farm survey data which show that the rate of pasture establishment began to decline since the beginning of the 1980s in areas which provided incentives for large scale ranching in the past (Table 8).

In Colombia land continued to be acquired for providing opportunities for money laundering, and cultivation and processing of narcotics.

Turning next to factors leading to smallholder migration, there was little change in the push factors of land concentration and mechanization in areas of high agricultural development. Environmental degradation continued to reduce the capability of the hill sides to absorb population. Land degradation and population increase (though at a lower rate) continued to cause outmigration from the North East of Brazil. Increasing urbanization however began to provide an alternative escape valve for the poor. This combined with a reduction in population growth rates led to a reduction in the rate of population increase in the FM. In Brazil the population growth rate declined from 11.4% in 1970-80 to 6.3% in 1980-91 in the area of small scale settlers (Mueller et al 1992). In Colombia the growth rate in the Caqueta region of the FM declined from 6.5% in the 1960s to 3.9% between 1973 and 1985 (Ramirez et al 1990). On the other hand, a pull factor began to emerge. Recent data from Brazil show that migrants in the FM generated incomes four times higher than Brazil's minimum wage (World Bank 1993).This is consistent with data on cattle numbers which show that herds smaller than 50 grew by over 70% between 1980 and 1985 (World Bank 1993). Thus migrants are able to condiderably increase incomes, if not overall quality of life by moving to the FM.Thus pressure on the rain forest is likely to continue, both from migration, although at a reduced rate, and also from natural increase among existing migrants.

Another alarming factor is that extactive activities such as mining and logging have grown in importance in the Brazilian FM in recent years.Pig iron smelters using locally produced charcoal have been established. 43.6% of Brazil's roundwood production came from the Amazon in 1984 vs 14.3% ten years earlier. Selective logging has a devastating impact on the surrounding forest. In addition penetration roads left by miners and loggers provide access for later migrants (Moran, 1993).

Reduction of the speculative motive should have stabilized the frontier in the savanna as well. Data are not available but the general perception is that frontier expansion has slowed down, aided by the removal of uniform fuel and output prices. In Colombia, by contrast, oil discoveries in the eastern savanna is leading to major road constuction programs. This is likely to lead to a major increase in agricultural development in the savanna. Land acquisition for speculation and motives related to the drug trade is also likely to increase. In Venezuela the oil boom had already dealt a blow to agriculture and frontier expansion in the savanna. The country's recent economic crisis has further destroyed confidence, although there are reports that the steep currency devaluations and the free trade agreements with Colombia and Venezuela are promoting exports.

In summary, new trends have moderated a major source of pressure in the FM, viz the speculative motive for land aquisition. Pressure from small scale settlers and extractive activities continues. Frontier expansion in the savannas of Brazil and Venezuela appears to be stabilizing. The Colombian savanna is poised on the brink of a major increase in agricultural development.

New perspectives in technology development

The most promising feature is that a number of developments provide new opportunities for integrated ecosystem management by ecologists and "conventional" technology developers such as soil scientists and germplasm specialists. Traditionally the role of technology, from the ecologist's point of view, has been to reduce environmental degradation. The new ecological paradigms emphasize a new positive role for technology development: that of environmental improvement. Gallopin (1994) points out that technology development can increase the domain within which the ecological system has the capacity to regenerate by decreasing the extinction threshold, increaseing the carrying capacity, and optimizing the basic regeneration rate of systems. This provides a new focus for technology development which while ecologically sound, is more compatible with growth and human intervention. In this new spirit a finding which is particularly relevant is that tropical ecosystems, including rain forests, which ecologists had previously regarded as highly fragile, and difficult to rehabilitate, are now seen as resilient. The new evolving paradigms in tropical ecology therefore emphasize management from a resiliency (as opposed to a stability) point of view (Lugo, 1994). In concrete terms this has resulted in intensive studies of the mechanisms underlying the dynamics of secondary vegetation and forest regeneration after human intervention. A major focus has been on the identification of practices which can modify the trajectory of a disturbed ecosystem towards the fulfillment of its original ecological functions. (Buschbacher et al., 1988, Uhl et al., 1982, Lugo, 1994). Satellite imagery from Brazil illustrates the importance of secondary growth after extractive activities, or after pasture degradation. Data from Altamira in the Brazilian FM show that secondary growth is the predominant form of land cover in deforested areas, and is increasing rapidly (Table 2:columns 3 and 4). These studies also show that cleared secondary growth has the potential to divert pressure from primary forests. In Altamira, between 1988 and 1989, 42% of new agricultural land was created by clearing secondary growth (Skole et al 1994). A similar trend of increased secondary growth after pasture abandonment is also emerging in Central America (Kaimovitz, 1994). These data illustrate that the payoff to the new ecological paradigms may be high.

Complementing these new ecological paradigms is the new technoloical revolution combining advances in information technologies with opportunities for knowledge intensive technologies through biotechnology, new materials, and new energy sources. This has the potential to generate dramatic restructurations of society (Gallopin 1994).

Another favorable development in the technological field is that environmental perspectives are becoming increasingly important not only in the world community at large, but also in national research systems in Latin America. The Brazilian national system, EMBRAPA, has been reorganized to include a natural resource management program. EMBRAPA activities now include conservation technologies, characterization of native species, a germplasm bank of native vegetation, tree crops, recuperation of degraded pastures and strategies to reduce fertilizer use. EMBRAPA has also developed a land use plan for the cerrado (Macedo 1994). In Colombia university level resource management courses are being developed in collaboration with faculties in the US. Organic agriculture, diversification and agroforestry are among the activities of nationl systems (Ortiz 1994). In Venezuela an interesting development is the attempt to develop sustainable exploitation of native fauna in the savanna (Arias 1994).

A number of innovative technologies that have the potential to be useful components in an integrated strategy for the management of these ecosystems have been developed. Improved grass-legume pastures which double animal live weight gain (LWG) per head, and pure grass pastures which increase LWG per ha by 20 - 30% vs native grasses have been developed. Pure grass pastures were planted on 31 m ha in the Brazilian cerrado in 1985 (Mueller et al., 1992). An integrated crop pasture system which has been shown to increase profitability, while improving soil physical and chemical properties is also available (Vera et al.,1992). The most interesting aspect of this technology from the ecological point of view is that recent evidence indicates that these improved pastures appear to be acting as a net sink for carbon, and could have a major role to play in stabilizing the global carbon cycle and minimizing the greenhouse effect (Fisher et al.,1994). Other innovative component technologies include the acid tolerant rice variety, Sabana 6, which reduces liming requirements fron 2t/ha to 300kg/ha while providing yields of 3.5 to 5t/ha (Sarkarung and Zeigler, 1991), and an acid tolerant maize, Sikuani, which yields 3 t/ha on the highly acidic soils of the Columbian savanna (Shivaji Pandey, pers comm). Legumes have found it hard to persist under heavy grazing in grass-legume pastures. A solution to this problem now appears to be available in the form of a forage legume *Arachis Pintoi*, which provides 40 to 80 kg nitrogen/ha/year, and whose inclusion in pastures has increased LWG by 20 to 200% vs pure grass pastures (Lascano, 1994). An interesting feature of this legume is that it is indigeneous to the cerrado, thus indicating the importance of maintaining the biodiversity of the native savanna vegetation. Tha fact that the improved pastures mainly replace native vegetation indicates the complexity of managing these ecosystems.

A new comparative advantage

An idea that is increasingly being put forward is that developing countries may now be able to benefit from a new comparative advantage: the provision of ecological services (Gallopin, 1994; World Bank, 1993). The idea is to use international trade between countries, based on their comparative advantage to achieve global ecological targets. Thus a developed country government or private sector company could purchase carbon storage services in developing countries, in order to meet required carbon reduction goals, if these services were cheaper than at home. The Amazon rain forest provides Latin American countries with an asset capable of providing substantial ecological services. Brazil has 3.8 m sq km of closed tropical forest. The Amazon has been described as the single richest region of the tropical biome, and is beleived to host about 50% of the world's species (Moran, 1993). It is a major carbon store, with estimates ranging from 136 to 225 t C/ha (World Bank ,1993). The ability of planted pasture to act as a net carbon sink in the savanna provides another potential source of a comparative advantage in ecological services. Estimates indicate that the gains from trade in the carbon market could be substantial. According to one estimate (World Bank, 1993), the value of carbon storage in the Amazon rain forest ($976 to$7200/ha) is 2 to 30 times the value of forest land, even if the value of carbon in pasture is subtracted. While a carbon market would provide funds to developing countries to maintain the quality of the environment, problems raised in this context include loss of national soveregnity and the high transactions costs of implementing such mechanisms. Many of these problems can be overcome by having markets in short term rental contracts (as opposed to land purchases), or by franchising contracts between local authorities and the world community (World Bank, 1993). The Costa Rican government is attempting, for instance, to develop a market in government guaranteed carbon storage certificates (Umana, 1994) .Such mechanisms enable national land owners to select their own land use strategies, as long as they meet specified environmental standards. The role of research centers would be to develop appropriate land use systems, which approximate the owner's objectives as closely as possible, in order to reduce enforcement costs.

Symbiotic interaction

This section shows how these new developments interact to make this a unique opportunity for resource management research.

Transience of small settlers, which is a major cause of deforestation occurs because the cost of gaining access to a new plot is less than the income lost because of yield decline on the old plot. Research can stabilize yield decline on the old plot. Increasing the cost of acquiring new land is difficult to achieve through research. Changes in policy however are having this effect, by reducing the construction of penetration roads. Secondly, the reduction of speculative land demand from ranchers reduced the opportunity small holders had of paying for new land by selling out the old plot. Thus the frontier is closing, and under this situation research may be able to reduce transience by reducing yield declines.At the same time favorable macro policies such as reduced inflation also benefit the poor, particularly if complemented by programs for primary and secondary education. This reduces the attractions of the frontier. The new ecological paradigms and knowledge intensive technologies provide new approaches for stabilizing small scale agriculture, by, for instance recultivation of secondary vegetation. At the same time participation in the global market for ecological services provides mechanisms and funds for enforcing frontier closure, and for funding innovative research. Most importantly, these market based instruments, if complemented by technologies for sustainable sustainable extraction of forest products, might channel the increase in extensive logging towards sustainable exploitation of forests. Figure 4 illustrates the complexity of the interactions between the driving forces, and indicates that in situations such as these only an integrated technology development strategy based on a sound understanding of the dynamics can be effective. A static component technology approach is unlikely to capture where technology can intervene, and how.

So far we have discussed how lower inflation and greater business confidence in the economy as a whole might move capital away from the frontier areas in the FM into more productive uses. Increasing the returns to capital investment in savanna agriculture may be another way of contributing to the diversion of capital from the FM. Supporting evidence for this is available from the Colombian savanna. A recent survey showed that 55% of farms in an area of good infrastructure had acquired new owners (mainly urban residents) between 1980 and 1992. Investment in agriculture, rather than speculation appears to have been the motive for land aquisition, as statistical analysis showed that adoption of improved technologies, and investment in machinery, material inputs and trained managers was significantly higher for these new land owners than for traditional resident cattle ranchers (Cadavid and Botero, 1992). The new free trade pacts being negotiated between Latin American countries should stimulate this proccess, as economic analysis in the cerrado shows that the savanna has a comparative advantage for livestock. Soybean has a comparative advantage up to 2000 km from ports. Maize currently does not have a comparative advantage. Nor does upland rice at distances greater than 700 km from ports (da Silva, 1994). Advances in agricultural technology, such as the new acid tolerant rice and maize varieties, could however increase international competitiveness. One danger to the returns to agricultural investment in the savanna, is overvalued exchange rates. The Colombian peso is currently over valued, and in Brazil there has been some currency overvaluation since the introduction of the stabilization plan. Over valuation would penalize agricultural exports, and bring in cheap agricultural imports.

Currently agriculture in the areas of good infrastructure in the savanna are threatened by serious soil compaction and erosion problems (da Silva, 1994, Arias et al, 1994). Farmers are attempting to overcome this problem through zero tillage, accompanied by even higher levels of herbicide use (Miguel Ayarza, pers comm). This indicates the need for public sector research on the externalities of intensification in the savanna. It also indicates that savanna farmers are willing to invest in maintaining the long term productivity of the land. The possibility of carbon sequestration services being provided by improved pastures in the savanna implies that in the current environment of free trade, and the potential development of markets for ecological services, the savanna could contribute to improving the environment, both directly through carbon sequestration, and indirectly through diverting capital from the FM.

SIMULATING LAND USE PATTERNS UPTO 2020

We present here a model for simulating land use over time under a set of specified scenarios (Winograd ,1989; Gallopin, 1992). The model divides land in each ecosystem into different ecological categories, with different productive capacities and different ecological functions.The model simulates movement of land between different categories, the rate of change being defined by the scenarios.The specification of the model,and its flowchart is given in Appendix 2. It should be emphasized that the model is presented more as an illustration of a approach, as currently we only have results of a preliminary run, without any sensitivity analysis. Also, at this stage, the model was run separately for the cerrado and the FM in Brazil. Interactions between the two ecosystems, which we hypothesize are important, were not incorporated at this stage. This may also lead to changes in the results.

The scenarios specified for the model varied with respect to two factors, which on the basis of our analysis of land use trends, were judged to be important for the savanna and FM in Latin America: government policy, and technology development strategy.

Government Policy

Scenario 1:

Opening up of economy increases imports, and puts pressure on increasing agricultural exports.Agricultural development of the cerrado perceived as a mechanism for achieving this.Penetration roads into FM slowed down, subsidies for large scale cattle ranching removed. Land titling no longer linked to deforestation.Mining and logging continues.High inflation. Currency overvaluation.Protected areas exist but cannot be enforced.

Scenario 2:

Same as Scenario 1, except for stable moderate inflation, stable real exchange rate, business confidence.

Scenario 3:

Same as Scenario 2 plus social programs:increased access of poor to primary and secondary education, social amenities in rural areas, including established frontiers, better enfocement of property rights. Market based instruments for international trading in global services allow better enforcement of protected areas.

Technology Development Strategy

Scenario A:

High chemical input, mechanized technologies for maxmizing production. Component technology development focusing on individual commodities, and individual resources such as soils and pests.

Scenario B:

Sustainable development: a land management strategy for improving the quality of life by achieving a sustainable increment in production while minimizing ecological degradation.

Elements of this strategy include:

1. An integrated strategy for land management based on a sound understanding of the dynamics of land use systems, which is used to identify where technology can intervene and how.

2. Stabilization of small scale cultivation in the FM, to reduce transience.

3. Management of secondary vegetation, in both the FM and forest areas in the savanna: rehabilitation for agro forestry, production of wood and forest products, as well as for forest regeneration on the one hand, and recultivation on the other hand.

4. Sustainable exploitation of timber and non timber forest products, particularly for use in mechanisms for trading in ecological services.

5. Enhance comparative advantage in providing ecological services, for example, by enhancing carbon sequestration abilities of pastures.

6. Increase returns to capital investment in savanna agriculture. Component technologies play a vital role here but need to be situated within an overall strategy for ecosystem management.

7. Technologies and institutional mechanisms for internalizing the externalities of intensification in the savanna,including protection of gallery forests, preservation of native grasses, prevention of sedimentation and contamination of rivers.

8. Technological pluralism, to cater to the diversity of socioeconomic and ecological conditions. In particular technologies for the resource poor, which have been neglected in the past, are required, to reduce poverty and minimize rural outmigration.

9. Win-win technologies which both increase profitability, and benefit the environment, such as improved pastures in the savanna.

10. The design of evolving, as opposed to static, land use systems, such as the succession over time of annual crops, followed by pasture, followed by agroforestry or plantations of tropical fruit or nut trees combined with legume cover crops.

11. Increase resilience of ecosystems.

12. Technological blending:grafting of new innovations on to indigeneous practices, and native species, which are often better adapted socioeconomically and ecologically.

Results

The model is run for each combination of policy and technology development strategies, for the cerrado and FM in Brazil.

Partial results from a preliminary run are given in Appendix 2. Comparison of Scenarios 3A and 1A shows what policy can achieve without sustainable technology. The difference between 1A and 1B shows what technology can achieve without policy. 3B is the ideal scenario with favorable policy and sustainable technologies.

The presented results mainly show quantitative changes in land use .Qualitative changes, refecting changes in productivity and changes in environmental quality, are not yet fully available. Some of the results available so far show that :

1. With favorable policies and sustainable technologies deforestation in the FM will be 37% lower, by 2020, than it would be with unfavorable policies, and without sustainable technologies.

2. Without policies, sustainable technologies achieve little change in land use in quantitative terms. In scenarios 1A and 2A, deforestation remains high, and even when sustainable technologies are introduced in 1B, there is little effect, because the speculative motive for land aquisition still exists, and leads to deforestation and nutrient mining. Between 1980 and 2020 deforestation for speculative purposes, ie land deforested and transformed for a brief period, or left unused, is 7 to 13 m ha.

3. With intensification over time, in the cerrado, grain production more than doubles in all scenarios between 1980 and 2020. The increase is highest (an almost 6 fold increase) in scenario 3B, where favorable policies complement sustainable technologies. Furthermore

in 3B the increase is achieved with a reduction in externalities such as contamination of rivers, because sustainable technologies exist, and institutional mechanisms to internalize the externalities exist. In 1A, 2A, 3A increased production is achieved at the cost of considerable environmental pollution, particularly offsite. Cattle numbers increase in all scenarios.The increase is greatest in Scenario 1A (cattle numbers more than double by 2020), because in this scenario land is aquired for speculative purposes and used for extensive grazing. The increase in cattle numbers is lowest in Scenario 3B (cattle numbers increase by 83%), because frontier expansion is controlled and encroachment of protected areas is prevented with the help of institutional mechanisms.Production per animal should be higher in 3B than in the other scenarios, since reduction in land availability will stimulate the adoption of intensive practices, but these figures are not available as yet. By 2020 fuel wood and charcoal production is higher in 3B than 1A, 2A, and 3A. Whereas in the "A" scenarios this comes from deforestation, in 3B it is from sustainably managed plantations.

4. Planted pastures in the cerrado increase to 50 to 55 m ha, and sequester 150 to 750 m t C/ha in 2020.

5. In Scenario 3B, 15m ha of land in agroforestry stores 85 t C/ha. The adoption of agroforestry systems is achieved through an understanding of the dynamics of land use systems, which indicates where agroforestry can be targeted, to fit in with farmers objectives and ecological requirements. Market based mechanisms are also available to promote adoption.

CONCLUSIONS

Environmental degradation appears to be the most serious problem in ecosystem management in the FM and savanna of Brazil, Colombia and Venezuela.The massive environmental problems that have resulted from deforestation in the FM have been well publicized. The environmental problems of the savanna are less well known, but deforestation in proportionate terms has been much higher than in the FM. In addition in intensified areas elimination of native grasses, soil degradation, siltation and pollution of rivers are becoming serious problems.

These environmental problems merit more attention than growth in agricultural production. Growth in the agricultural sector has in general kept up with population growth rates, and per capita incomes are high by developing country standards.

Another major problem in these countries is equity. Land ownership is highly concentrated, levels of poverty and illiteracy are high, relative to per capita incomes.

Analysis of land use dynamics in the savanna and FM shows that government policy, including inequitable distribution of land and incomes, has been behind the root causes of deforestation. Many of these policies originate outside the agricultural sector. The role of population pressure is relatively minor. The analysis shows that technology development on its own can do little to improve environmental quality, if unfavorable policies persist. Fortunately however many of these unfavorable policies have been dismantled, and deforestation has sharply decreased. The same policies have also slowed down speculative frontier expansion in the savanna, particularly in Brazil. his therfore appears to be a particularly propitious time for mounting a concerted effort on natural resource management in these ecosystems. Reinforcing this, is the rise of new ecological paradigms, biotechnology, informatics, and the newly established resouce mangement programs and Ministries of the Environment in Latin America. A development of major potential significance is the emerging international trade in environmental services. Both the FM and the savanna in Latin America appear to have a comparative advantage in this field, and this could make a major contribution towards financing sustainable development.

A major new threat to deforestation remains:logging and mining. This threat may increase further in importance as Asian wood supplies dry up. A strong national committment to the environment, and the ability of government to make this prevail over local interests is essential. As shown in the paper, little can be achieved if steps are not taken to close the frontier. Innovative technologies for sustainable use of forest products, in combination with institutional mechanisms for participating in global markets for environmental services, may be able to make a contribution in this regard. Also pressure on the FM from migration by resource poor settlers, and transience and natural increase among existing settlers, remains. Inflation control and better access of government services, particularly education, to the poor is therefore of key importance.

A land use model which simulated land use upto 2020 confirmed the importance of combining policy and sustainable technologies. It illustrated that while technology could achieve little in the face of unfavorable policies, in a favorable policy environment, an integrated approach to ecosystem management based on a sound understanding of land use dynamics, can contribute to goals of sustainable development far more than component technologies alone.The model also illustrated that substantial increases in agricultural production could be sustainably achieved in the savanna given the right policy environment, and technology development strategy. Component technology development has an important role to play in achieving this, provided it is guided by an overall land management strategy. The free trade aggreements being negotiated by Latin American countries should stimulate agricultural development of the savanna, given its international comparative advantage in livestock and crop production.This could enable the savanna to divert capital investment from the FM, and thus make a multifaceted contribution to the protection of the environment. Overall therefore our analysis indicates that the present constellation of events relating to the savanna and forest margin of Latin America provides a unique opportunity for successful and effective resource management research.

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Table 1. Land use in savanna lowland countries.

	Cropland	Pastures	Forest	Other
Land Use 1990 (%)				
Bolivia	2	25	51	22
Brazil	7	22	58	13
Colombia	5	39	48	8
Venezuela	4	20	34	41
Forest Margins/ Hillsides Countries	13	28	34	25
Land Use Changes 1961-1990 (m ha)				
Bolivia	866	-2,000	- 4,860	5,994
Brazil	31604	62,065	-65,170	-28,499
Colombia	450	7,400	- 8,700	850
Venezuela	413	1,950	- 8,.410	6,047

Source: FAO Agrosbat Data.

Table 2. Land use in the Brazilian savanna (Cerrado)[1].

	Cerrado		**Modern Sub-region (C-S)[2]**		**Rest of cerrado**	
Total area (m. ha)	155		50		105	
	1970	**1985**	**1970**	**1985**	**1970**	**1985**
Area within farm boundaries (% of total)	53	70	70	85	45	63
Cleared area within farms (% farm area)	23	47	28	61	20	37
			% cleared area			
Crops (including planted forest)	16	19	20	19	12	19
Planted pastures	45	61	69	75	31	46
Cleared but unused	39	20	20	6	57	35

[1] Source: Mueller et al., 1992.
[2] Center-South of Cerrado: area around Uberlândia/Goiânia: See Mueller et al., 1992.

Table 3. Land use in the forest margins of Brazil.

	Pará/Tocantins[1]	Acre/Rondonia[1]	Altamira[2]	
	1985	1985	1985	1991
	%			
Agriculture (annual/perennial)	7	29	4	7
Pasture	73	57	2	9
Secondary growth				
4- 6 years	n/a	n/a	12	13
6-10 years	n/a	n/a	9	20
> 10 years	n/a	n/a	2	6
Total	20	14	23	39
Forest	n/a	n/a	57	55

1 Source: Mueller et al., 1992: % incorporated land.
2 Source: Moran et al., 1994

4- 6 years: bush fallow
6-10 years: Woody species
> 10 years: close to mature forest

n/a = not available.

Table 4. Production, area and yields of major lowland commodities in countries with savannas and forest margins (1989-91).

	Rice	Maize	Sorghum	Cassava	Soybeans	Beans	Beef	Poultry
Production (m tons)								
Brazil	9,322	23,505	247	24,195	19,577	2,432	2,800	2,614
Colombia	1,913	1,177	737	1,843	201	113	823	257
Venezuela	441	1,008	529	320	5	52	370	340
Area (m ha)								
Brazil	4,446	12,071	160	1,891	11,070	5,090	-	-
Colombia	463	806	256	199	103	144	-	-
Venezuela	119	476	247	40	3	88	-	-
Yields (kg/ha)								
Brazil	2,093	1,943	1,559	12,799	1,751	477	-	-
Colombia	4,140	1,458	2,875	9,783	1,941	788	-	-
Venezuela	3,653	2,115	2,145	7,574	1,866	591	-	-

Source: CIAT Trend Highlights, 1993.

Table 5. Recent trends in production, area and yields of major commodities in countries with savannas and forest margins (% annual growth rates 1981-91).

	Rice	Maize	Sorghum	Cassava	Soybeans	Beans	Beef[1]	Poultry[1]
Production								
Brazil	1.3	1.6	1.6	0.3	3.1	0.7	5.1	8.9
Colombia	-0.2	3.5	3.7	0.4	8.2	4.7	5.4	9.7
Venezuela	-3.3	10.2	5.4	0.0	29.7	7.0	3.2	-0.8
Area								
Brazil	-2.8	0.6	4.4	-1.1	2.9	0.3	-	-
Colombia	0.2	3.3	0.4	0.9	8.6	2.6	-	-
Venezuela	-6.8	6.5	2.4	-0.5	15.7	5.0	-	-
Yields								
Brazil	4.1	1.1	-2.8	1.4	0.1	0.4	-	-
Colombia	-0.3	0.2	3.3	-0.6	-0.4	2.0	-	-
Venezuela	3.4	3.7	3.0	0.5	14.1	2.1	-	-

Source: CIAT Trend Highlights, 1993.
[1] Period 1984-91.

Table 6. Employment and demographic change in the forest margins and savanna of Brazil[1].

	Forest Margin		Cerrado	
	Pará/Tocantins	Acre/Rondônia	C-S	Cerrado (Total)
Population growth rate (%)				
1970-1980	8.4	11.4	3.4	2.7
1980-1991	4.9	6.3	2.5	2
Workers/100 ha of agricultural land				
1970	85	85	7	6
1985	67	70	4	3

1 Source: Mueller et al., 1992.

Table 7. Selected macro indicators: Brazil, Colombia, Venezuela.

	Brazil	Colombia	Venezuela
Per cápita			
(constant 1980$)			
1970	1112	897	4839
1980	2019	1125	4100
Incidence of poverty[1]			
1970	49	45	25
1980	39	39	22
Illiteracy			
1970	34	19	24
1980	26	12	15
Infant Mortality (per 1000)			
1970-75	91	73	49
1980-85	71	41	39
Mechanization			
(No. of ha/tractor)			
1970	205	221	182
1980	90	183	99
Urbanization (%)			
1970	56	57	72
1980	68	64	83
1990	77	70	91
Inflation rate[2]			
1971	12	18	4
1980	83	27	22
1990	2928	32	41

1 Househoulds with income less than twice the basket of basic foods.
2 IMF. International Financial Statistics. 1981. Contraloría General de la República. 1.994. Balance del cuatrienio. Revista Económica Colombiana (July-August).

Source: CEPAL. 1993. Anuario Estadístico de América Latina y El Caribe, Edición 1992. United Nations.

Table 8. Planted pastures in Para, Brazil.

	1970-75	1975-80	1980-85
Increase pasture in area (m.ha)[1]	0.75	1.95	1.3
		Cleared before	
	Before 1973	1973-78	1979-84
Forest cleared to form pasture (ha)[2]	16890	25570	6730

1 Calculated from census data quoted in Mueller et al., 1992.

2 Data from farm survey quoted in Buschbacher, 1986.

APPENDIX 1

The warm humid tropics cover an immense area of Latin America and the Caribbean. Defined by TAC as an agroecological zone, it has been assigned by the highest priority for research on natural resources management in the neotropics (TAC, 1990). This zone is defined purely on climate. All months have a monthly mean temperature, corrected to sea level, above 18 degrees centigrade with rainfed available soil moisture greater than 50% for at least 275 days. However, this ecozone is so broad and varied as to not lend itself to effectively focussed problem definition or research. It includes, for example, all of Central America.

Approximately at the same time as the TAC study, CIAT was conducting a study to define and prioritize for research, agroecosystems of sufficient similarity in climate, soils, and land use so that problems amenable to research would likewise be similar (Jones et al., 1991). An outcome of this study was the definition of the acid soils savannas and the forest margins as agroecosystem clusters with high priority for research in terms of resource problems and opportunities (Figure 1). These agroecosystems, along with the hillsides agroecosystem also defined by CIAT, all fall within the TAC definition of the warm humid tropics.

The savannas agroecosystem is characterized by both environmental and land use variables. It is a lowland environment with elevation less than 1100 meters. Soils are acid ($pH<5.3$) and the climate is seasonally wet, with mean rainfall exceeding 60% of potential evapotranspiration during 6-9 months annually. Average temperature during the growing season is greater than 23.5 degrees centigrade. Predominant land use is either extensive grazing alone, or extensive grazing with mechanized agriculture. Population density is generally low, and half or more of the land is in native vegetation, which is often grazed. Considering only land that is within 30 km of an all weather road, railway or navigable river, this agroecosystem covers 76,000,000 ha. Relaxing the above conditions to include, for example, more remote or poorly drained lands, total area of the savannas is approximately 240,000,000 ha (Sanint et al., 1992).

The other lowland agroecosystem prioritized by CIAT is the forest margins. Again soils are acid an the climate is seasonally wet with a warm growing season. The typical land use includes manual cropping, shifting cultivation, and extensive grazing. It is estimated that overall 15% of the land is cropped, 30% is under extensive grazing, and 15% is under bush fallow, though the latter rises to 30% in some areas. Population density is generally low. Natural vegetation is semi-evergreen forest. In parts of the agroecosystem deforestation is taking place while other areas are included that have been cleared of forest for often on land less accessible or less desirable for agriculture. Including only land within 30 km of road or navigable waterway, the agroecosystem consists of some 44,000,000 ha. Not included are national parks, forest reserves or indigenous reserves. Further, this definition specifically rules out the forest with high rainfall for more than nine months of the year. In such environments burning is difficult and is not commonly employed for forest clearence. Thus, large areas of the Amazon basin is excluded from this definition of the forest margin (Jones et al., 1991).

Figure 1. Agroecosystems Selected for Research by CIAT.

FIGURE 2. **Causes of deforestation**

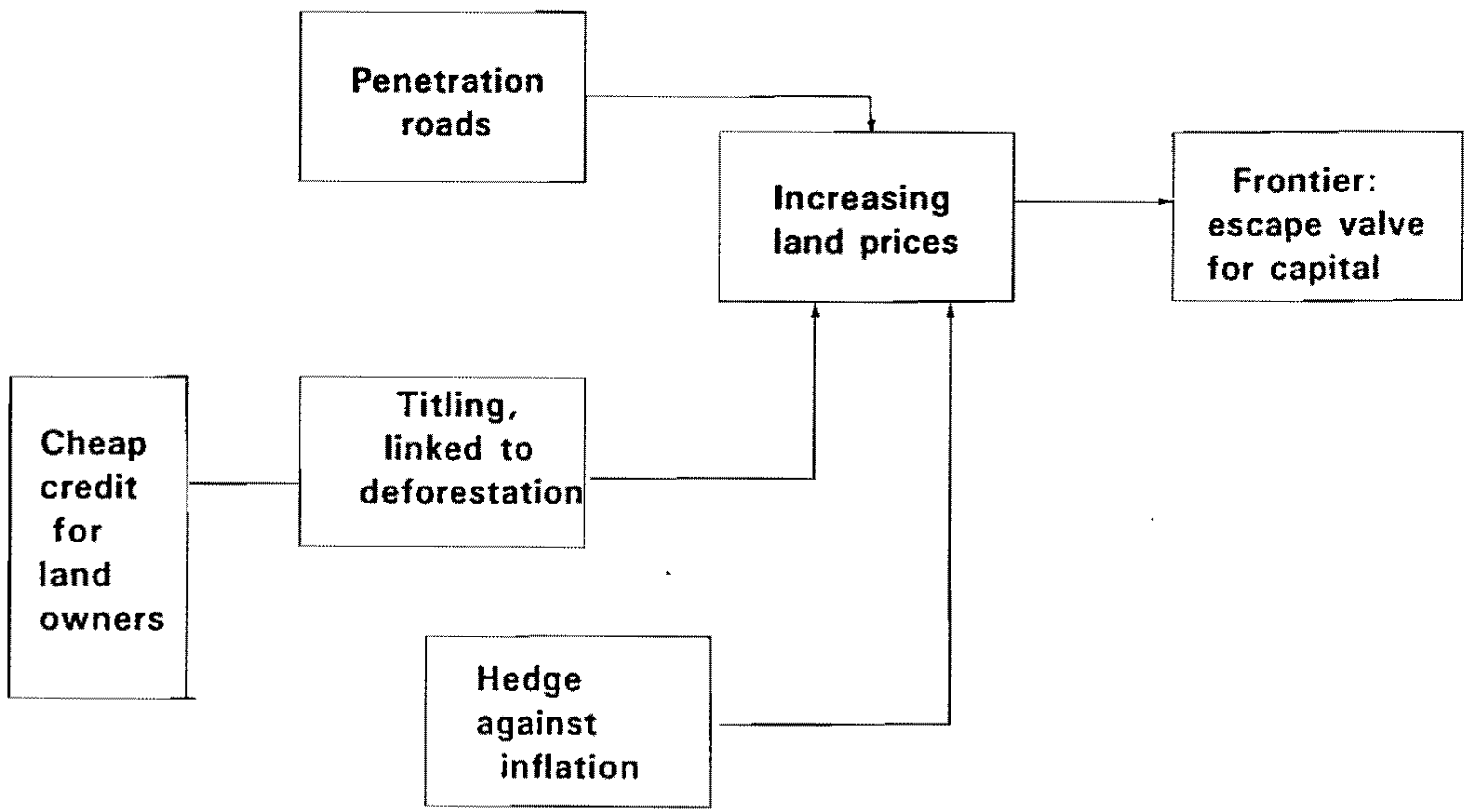


FIGURE 3. **Causes of deforestation**

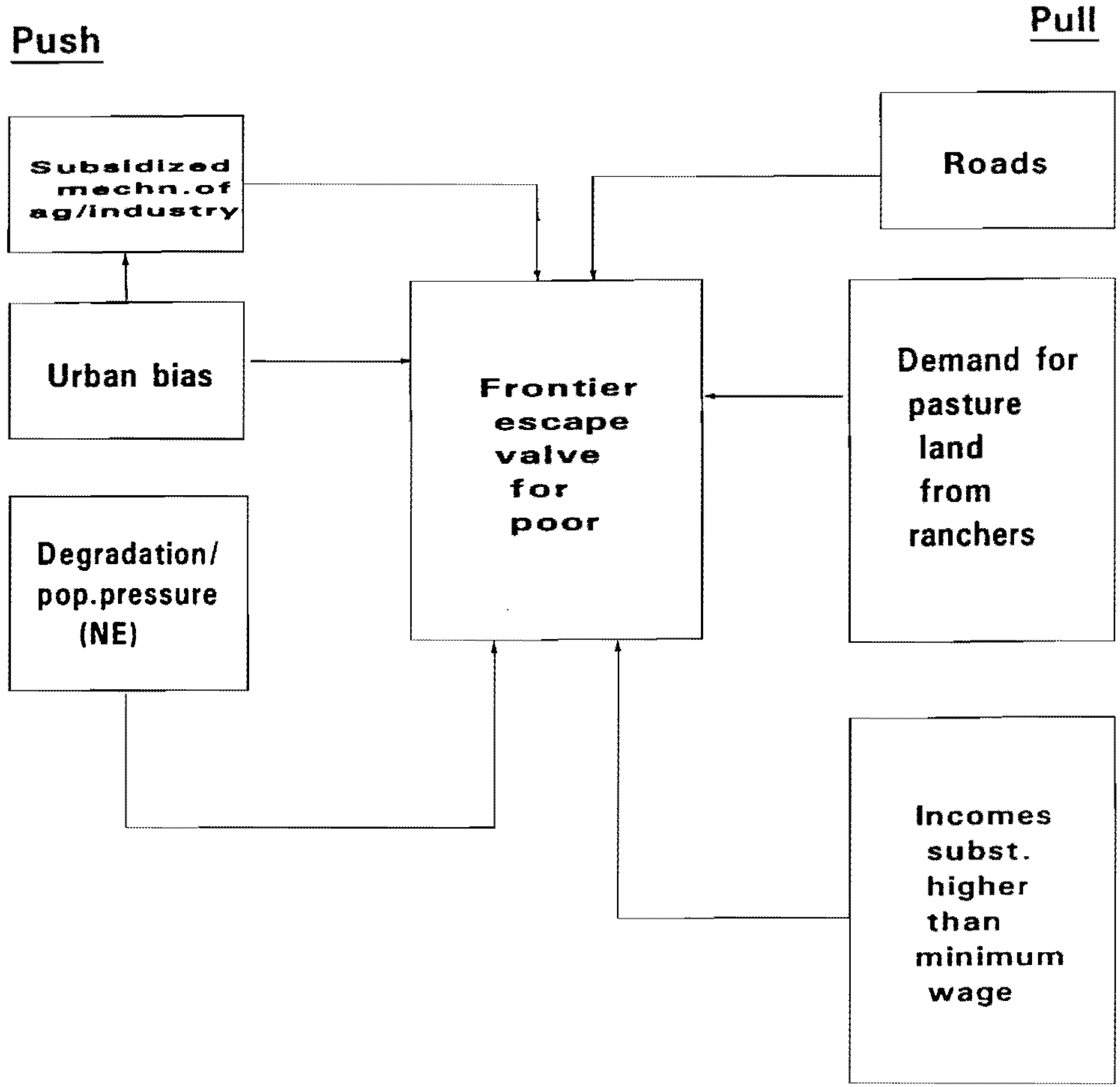
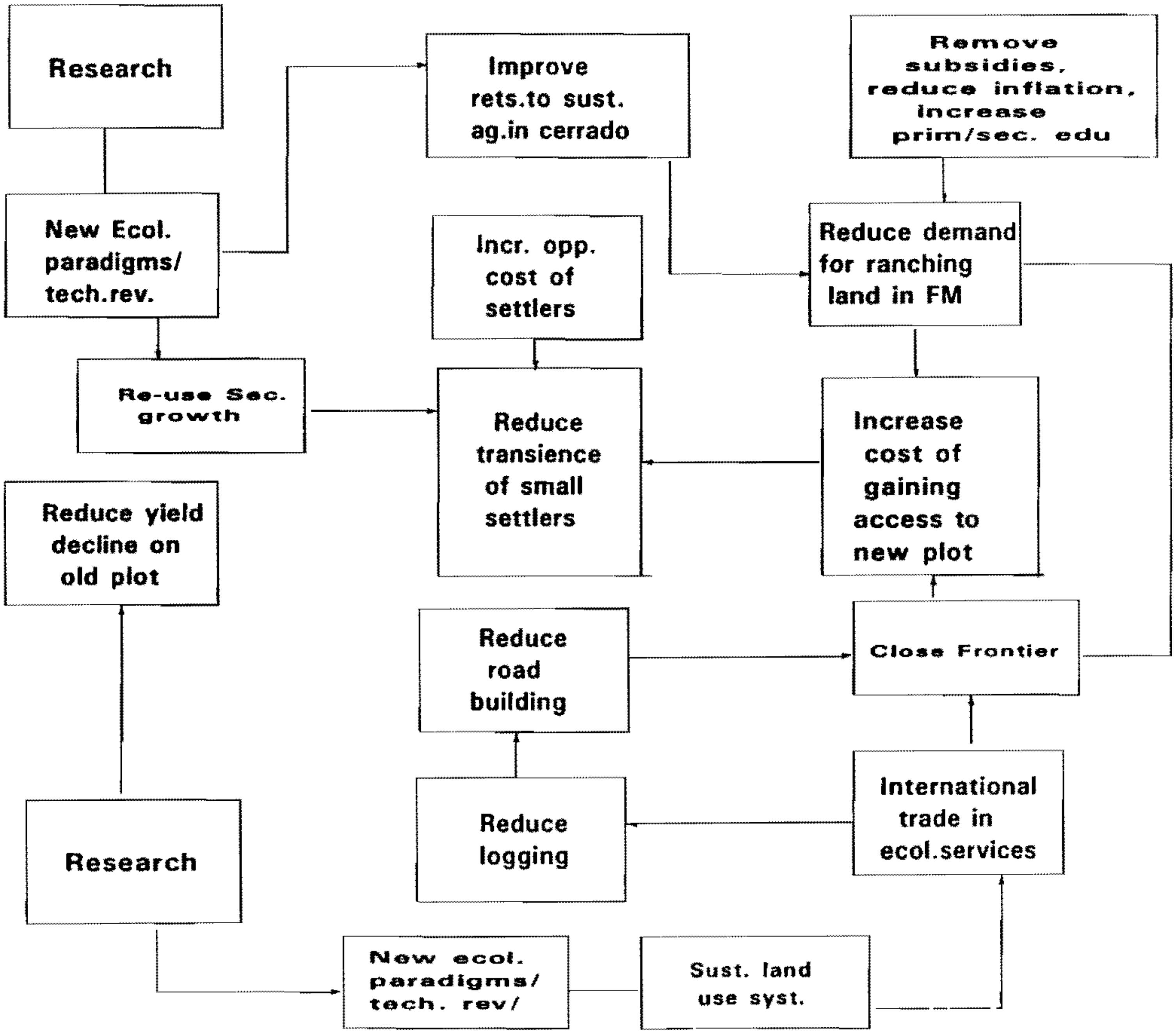


FIGURE 4.

A Unique Opportunity for Resource Management



APPENDIX 2

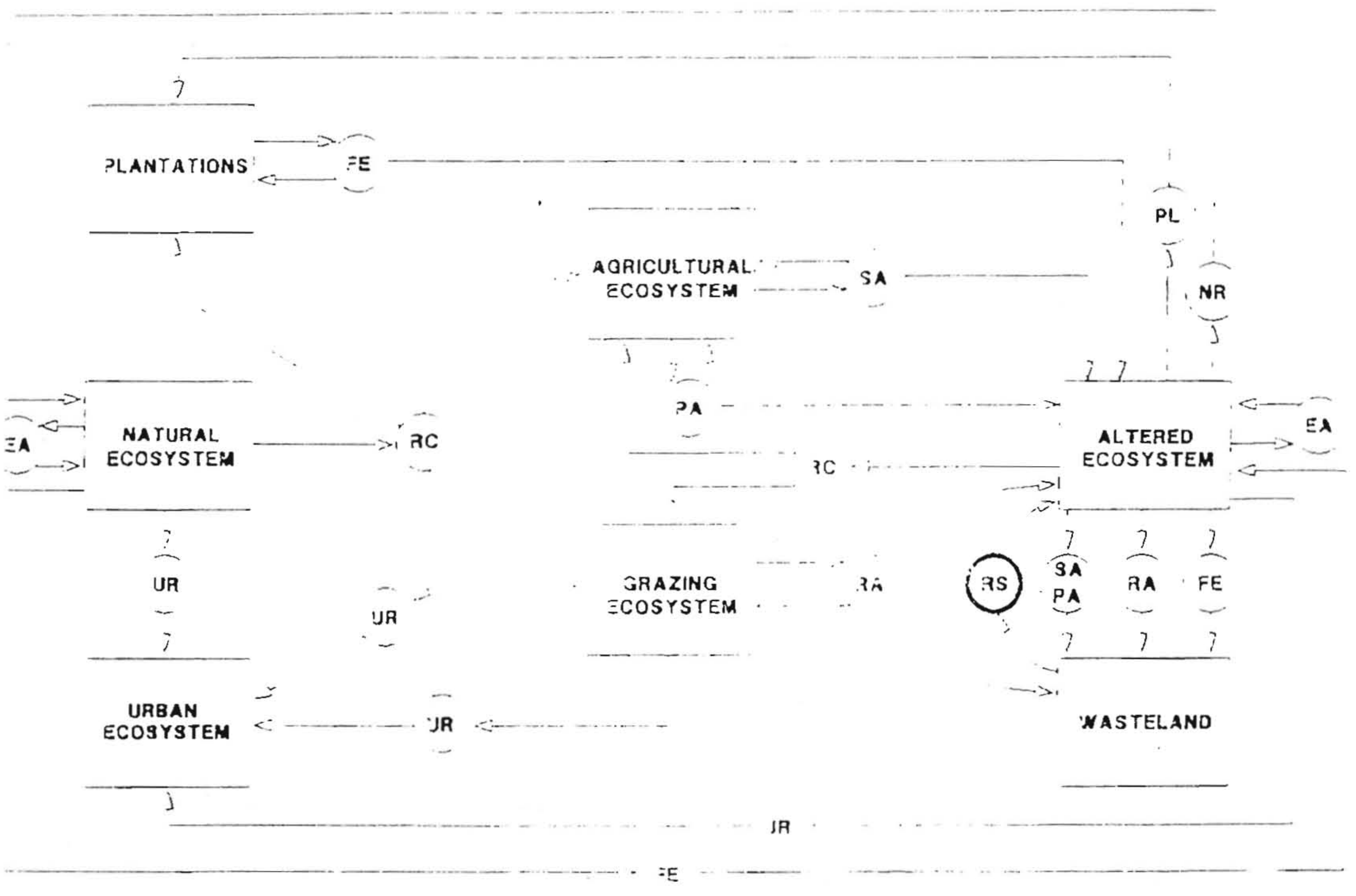
Each life zone or ecoregion is modeled as a set of compartments representing major different ecological categories or conditions and with different structural, functional and productive characteristics. The following 7 categories were defined:

1) Natural: virgin areas (forests, shrub formations, savannas, semideserts and deserts) and areas with past alteration but currently similar to the original ecosystems.
2) Plantations: reforested areas used for industrial and non-industrial forestry.
3) Agricultural: annual, permanent, non-traditional and illegal crop areas, including fallow from permanent agriculture.
4) Pastures: ranching areas with natural or planted pastures.
5) Altered: denotes a mosaic of patches of land under production coexisting with patches of original and secondary vegetation, and areas with slight to moderate soil erosion. Fallow from shifting cultivation and peasant agriculture is included.
6) Urban: urbanized areas (mainly the cities)
7) Wastelands: unproductive lands irreversibly transformed in their structure, dynamics, flora and fauna by extreme soil erosion and desertification.

Every year land shifts from one category to others according to the intensity and nature of the human activities (defined by an assumed scenario) and the natural processes .
Simulations span from 1980 to 2020, to have 10 years (1980-1990) to gauge parameters and data. A simple compartment model was used. each compartment represents the surface of a land category, for each life zone, and it changes according to the following equation:

$$S^{i}_{t+1} = S^{i}_{t} + \Sigma Inflows_{t,t+1} - \Sigma Outflows_{t,t+1}; \; 0 \leq S_t \leq S_{max}$$

where S= surface of a given land category (in hectares); Inflows= surface of land of other category converted into the considered category in a given year (hectares/year); Outflows= surface of land of the considered category converted into other category (including itself) in a given year (hectares/year); S_{max}= maximum potential surface of the category (hectares); I= set of all land categories. The scenario yearly defines the process generating the transformations for each category and life zones or ecoregion, specifying the portion of the category affected by the activity and the rates of conversion to other categories. The scenario is exogenously defined, taking into account the current situation, the assumed rate of growth of the activity and the availability of land. In the present state the models do not calculate productions, but only surfaces of land under different categories and production systems, the estimation of production are based upon the expected agriculture yields in function to scenarios and land in each category or production system.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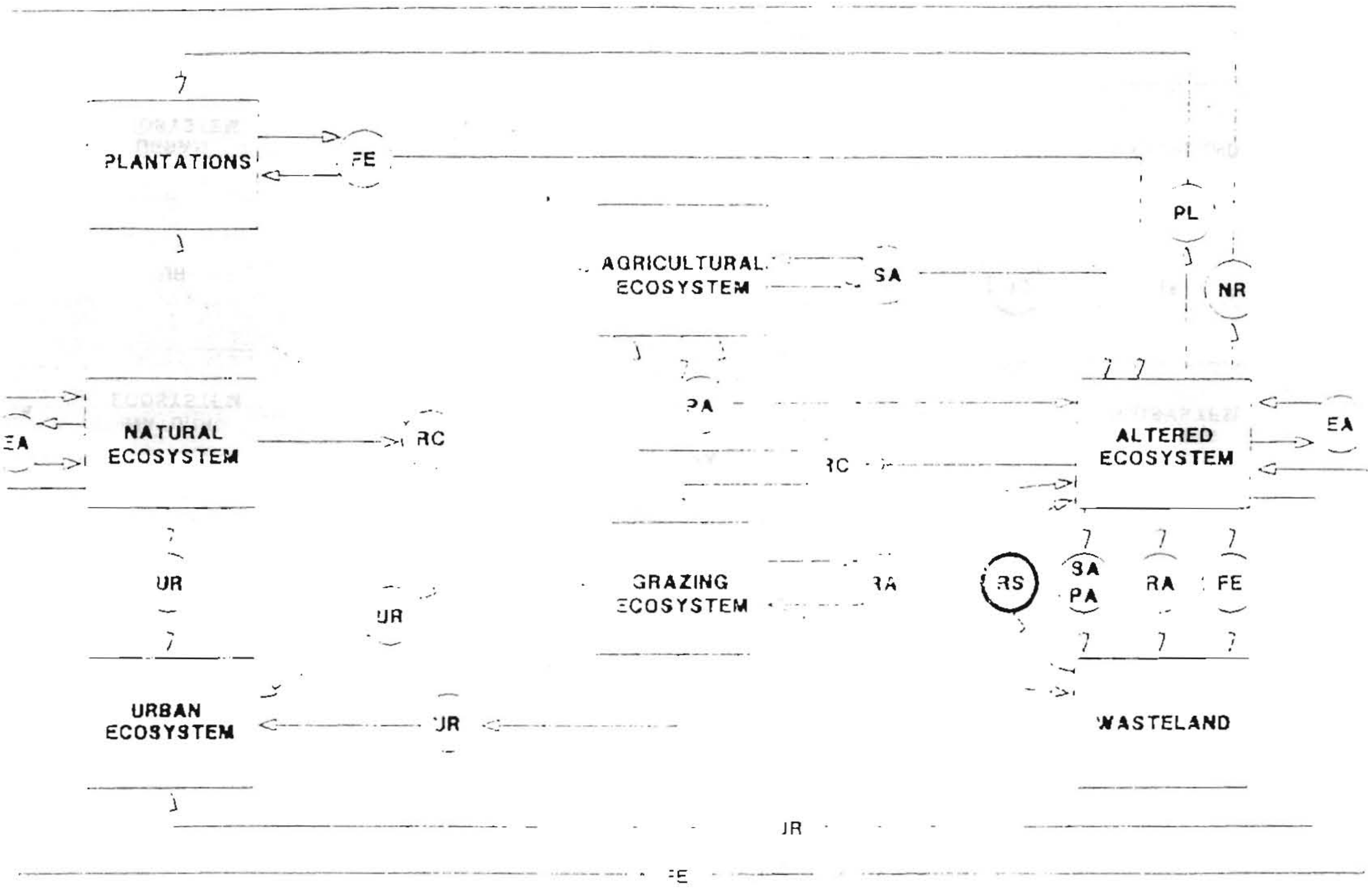
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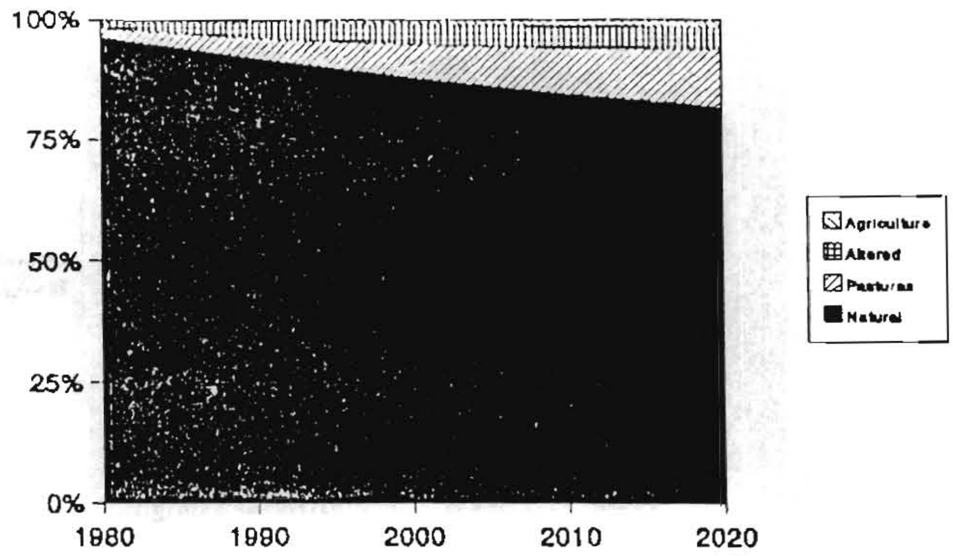
Scenario 2A North Region of Brazil: Land Use Changes
(in percent)



Note: categories with less then 0.5 percent not appear

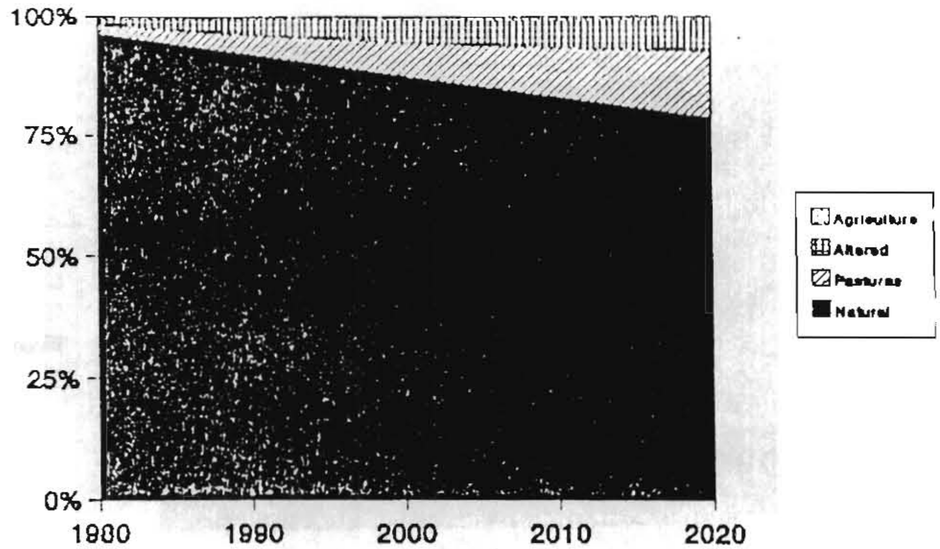
Scenario 2A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.5	306.4	294.5	284.9
Urban	0.1	0.2	0.3	0.4	[illegible].5
Plantations	0.15	0.2	0.3	0.35	0.4
Pastures	7.8	15.3	24.6	33.5	42.4
Agriculture	2	2.6	3.2	4.7	5.7
Altered	4.35	11.2	15.2	16.6	16.2
Wasteland	0	0	0	0	0

Scenario 2A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	17.2	28.5	42
Logs (10^6 m^3)	19.8	24	27	29	30
Fruits (10^6 T)		TO BE ADDED			

Scenario 1A North Region of Brazil: Land Use Changes
(in percent)



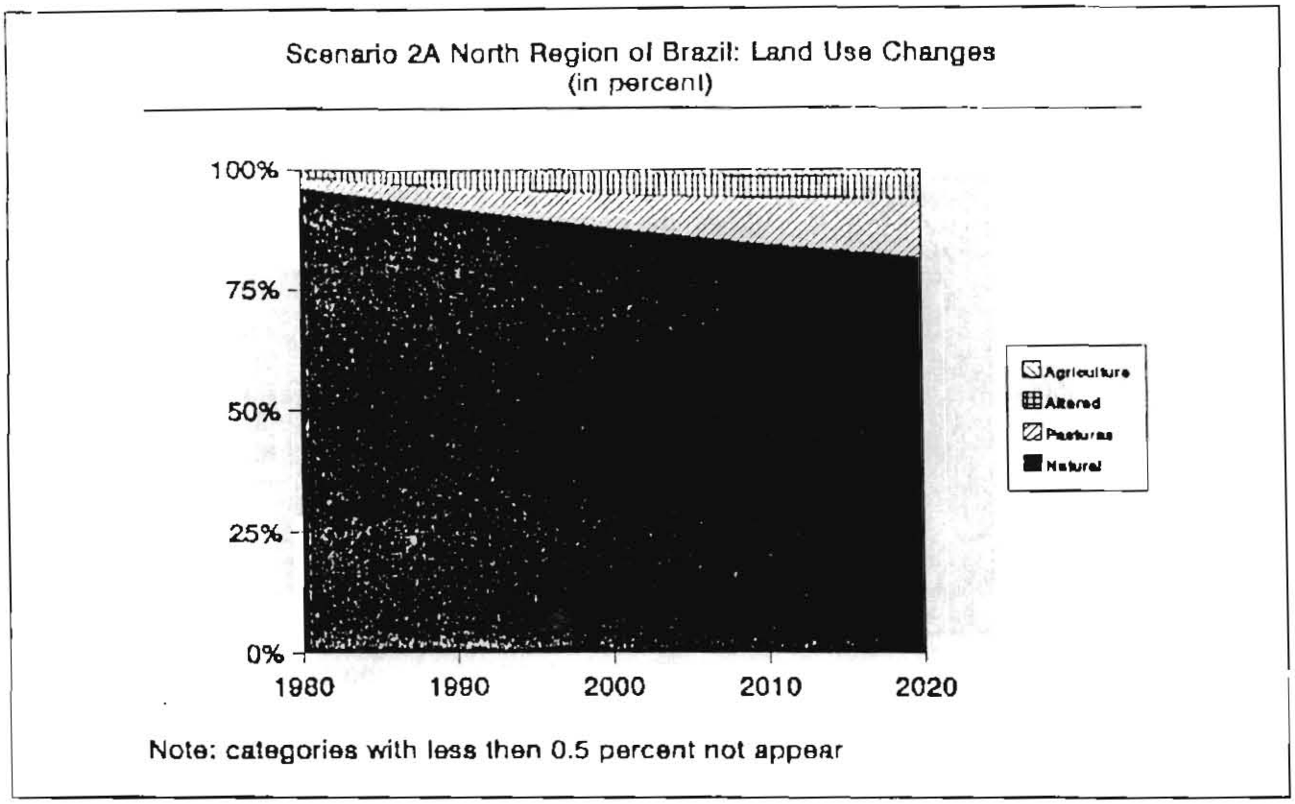
Note: categories with less then 0.5 percent not appear

Scenario 1A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.4	305.1	289.6	274.5
Urban	0.1	0.2	0.3	0.4	0.5
Plantations	0.15	0.19	0.22	0.26	0.29
Pastures	7.8	15.5	25.5	36.7	48.5
Agriculture	2	2.4	2.6	2.8	3
Altered	4.35	11.2	15.9	18.6	23.1
Wasteland	0	0	0	0	0

Scenario 1A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	15.3	23.8	34
Logs (10^6 m^3)	19.8	24	31	39	48
Fruits (10^6 T)		TO BE ADDED			



Scenario 2A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.5	306.4	294.5	284.9
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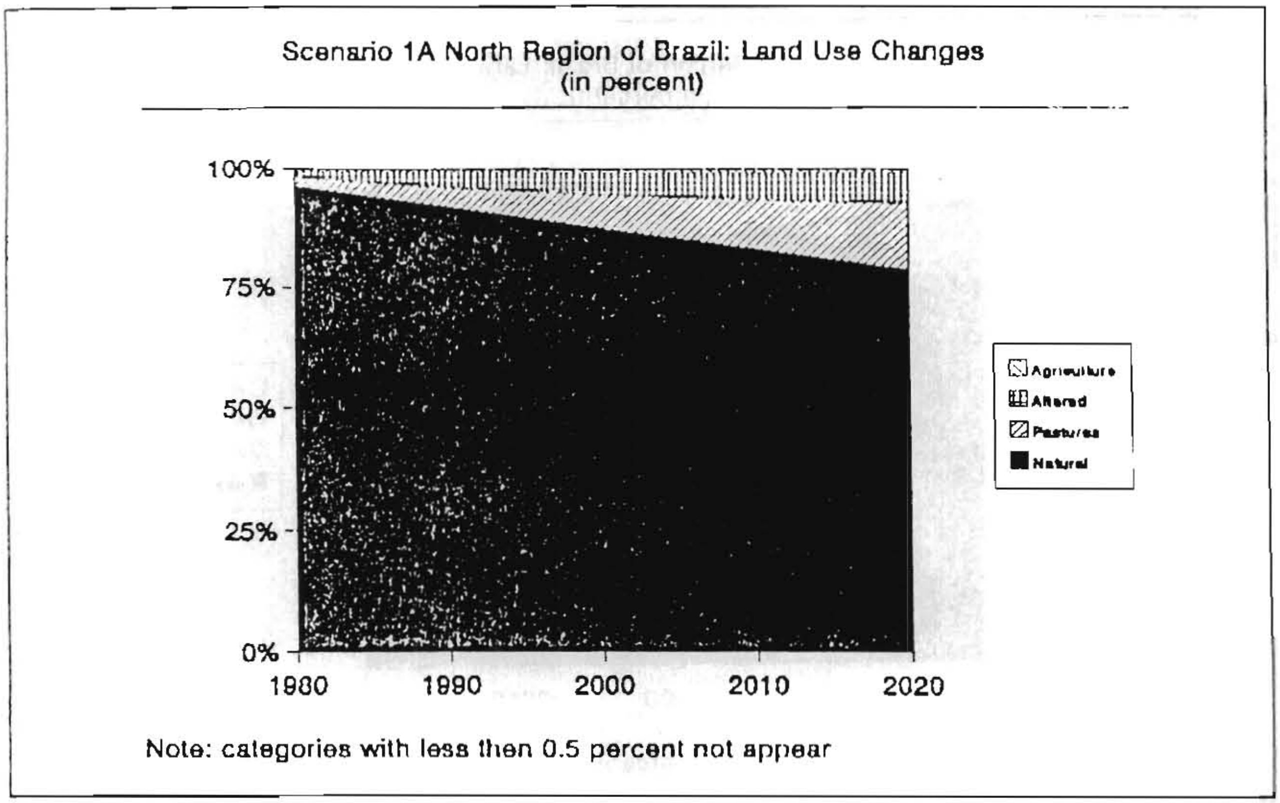
Pastures	7.8	15.3	24.6	33.5	42.4
Agriculture	2	2.6	3.2	4.7	5.7
Altered	4.35	11.2	15.2	16.6	16.2
Wasteland	0	0	0	0	0

Scenario 2A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	17.2	28.5	42
Logs (10^6 m^3)	19.8	24	27	29	30
Fruits (10^6 T)		TO BE ADDED			

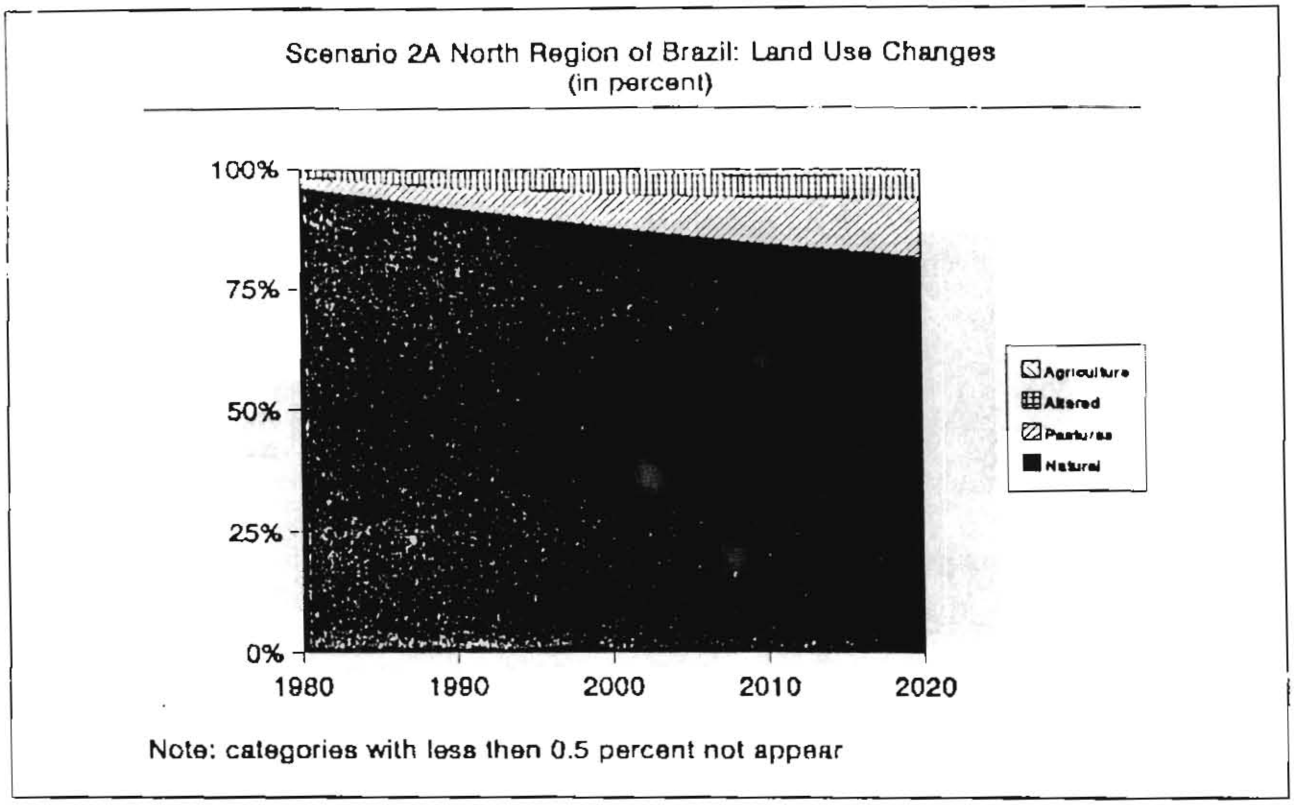


Scenario 1A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.4	305.1	289.6	274.5
Urban	0.1	0.2	0.3	0.4	0.5
Plantations	0.15	0.19	0.22	0.26	0.29
Pastures	7.8	15.5	25.5	36.7	48.5
Agriculture	2	2.4	2.6	2.8	3
Altered	4.35	11.2	15.9	18.6	23.1
Wasteland	0	0	0	0	0

Scenario 1A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	15.3	23.8	34
Logs (10^6 m^3)	19.8	24	31	39	48
Fruits (10^6 T)		TO BE ADDED			

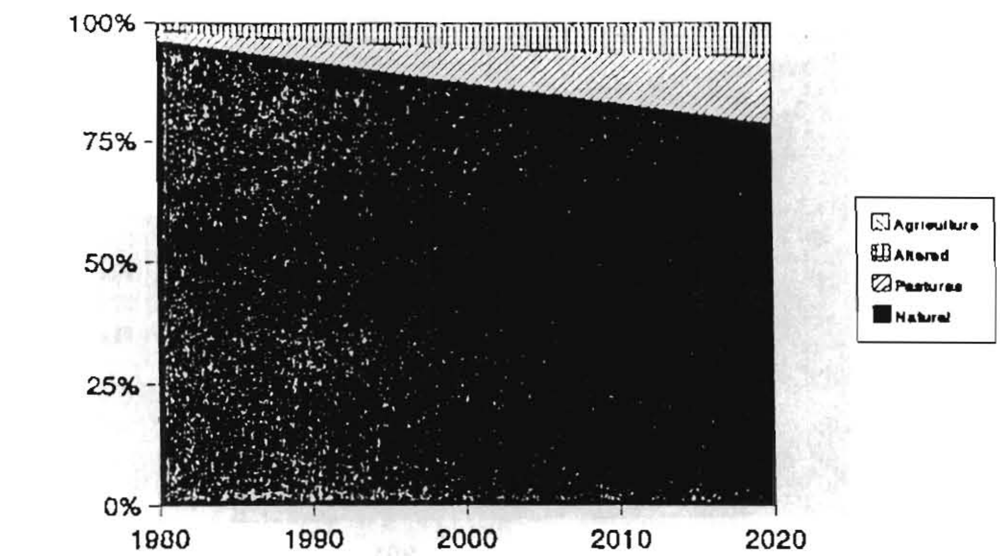


Scenario 2A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.5	306.4	294.5	284.9
Urban	0.1	0.2	0.3	0.4	[illegible].5
Plantations	0.15	0.2	0.3	0.35	0.4
Pastures	7.8	15.3	24.6	33.5	42.4
Agriculture	2	2.6	3.2	4.7	5.7
Altered	4.35	11.2	15.2	16.6	16.2
Wasteland	0	0	0	0	0

Scenario 2A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	17.2	28.5	42
Logs (10^6 m³)	19.8	24	27	29	30
Fruits (10^6 T)		TO BE ADDED			

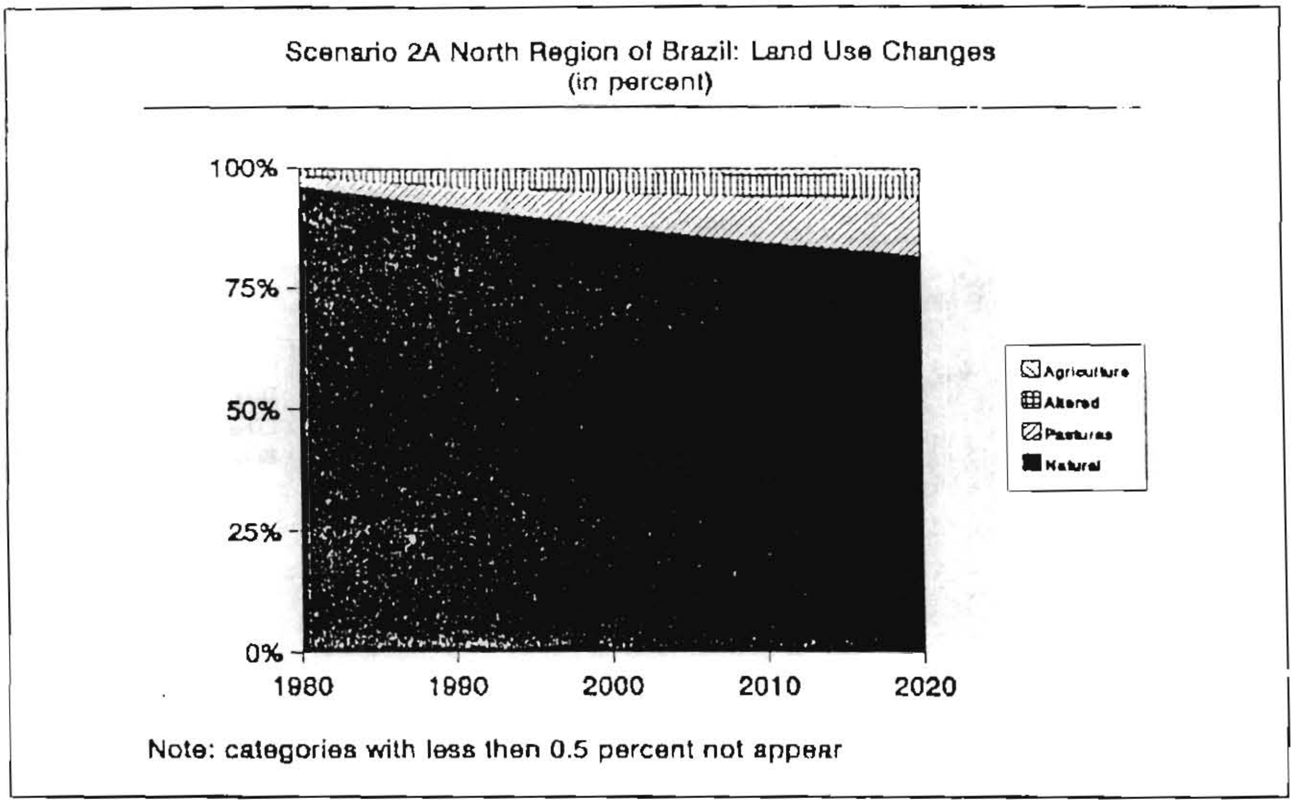


Scenario 1A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.4	305.1	289.6	274.5
Urban	0.1	0.2	0.3	0.4	0.5
Plantations	0.15	0.19	0.22	0.26	0.29
Pastures	7.8	15.5	25.5	36.7	48.5
Agriculture	2	2.4	2.6	2.8	3
Altered	4.35	11.2	15.9	18.6	23.1
Wasteland	0	0	0	0	0

Scenario 1A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	15.3	23.8	34
Logs (10^6 m^3)	19.8	24	31	39	48
Fruits (10^6 T)		TO BE ADDED			

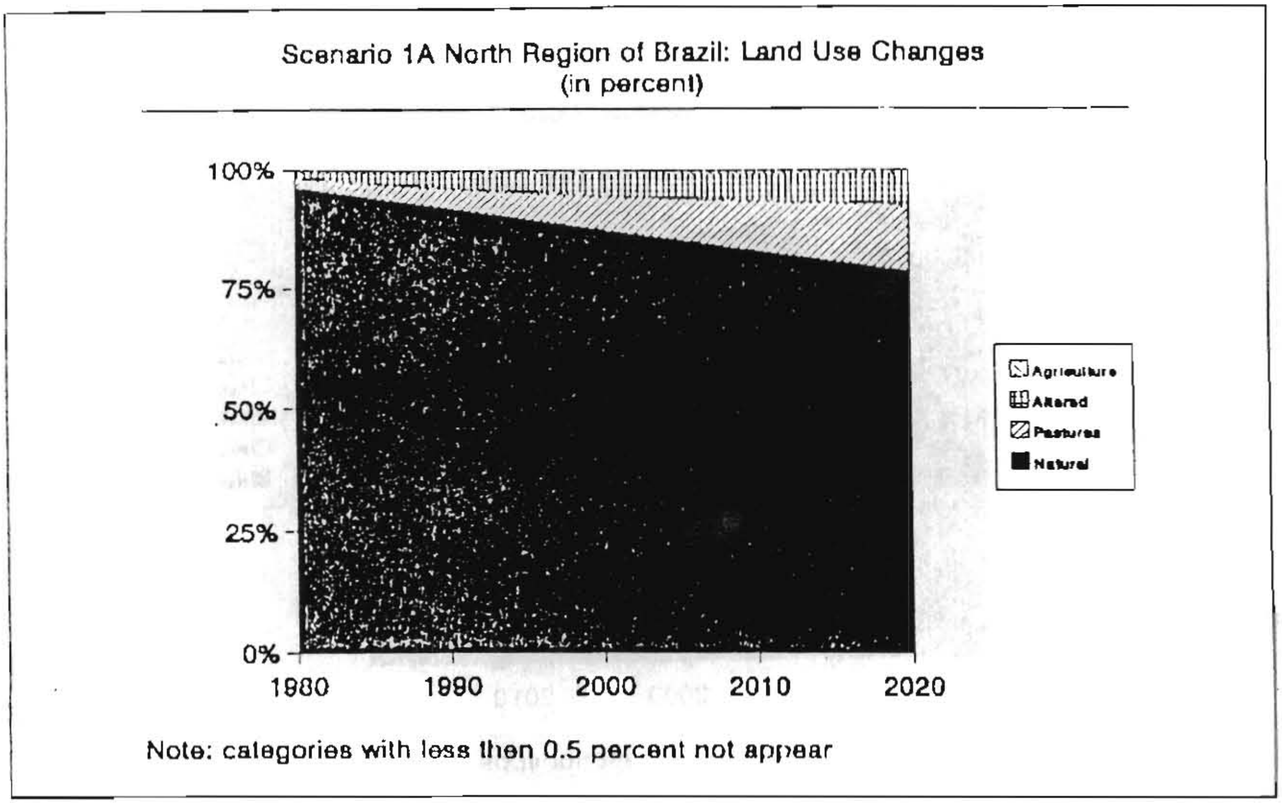


Scenario 2A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.5	306.4	294.5	284.9
Urban	0.1	0.2	0.3	0.4	0.5
Plantations	0.15	0.2	0.3	0.35	0.4
Pastures	7.8	15.3	24.6	33.5	42.4
Agriculture	2	2.6	3.2	4.7	5.7
Altered	4.35	11.2	15.2	16.6	16.2
Wasteland	0	0	0	0	0

Scenario 2A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	17.2	28.5	42
Logs (10^6 m^3)	19.8	24	27	29	30
Fruits (10^6 T)		TO BE ADDED			

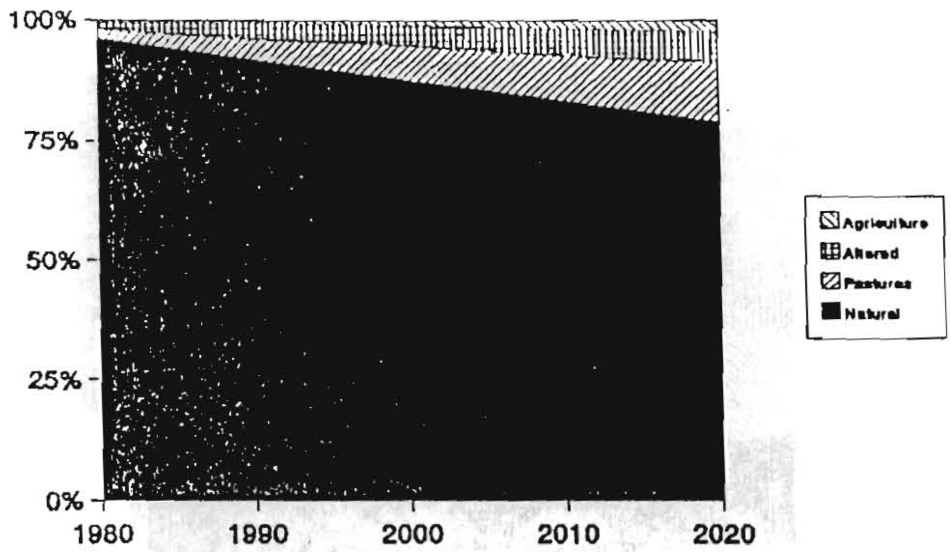


Scenario 1A North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.4	305.1	289.6	274.5
Urban	0.1	0.2	0.3	0.4	0.5
Plantations	0.15	0.19	0.22	0.26	0.29
Pastures	7.8	15.5	25.5	36.7	48.5
Agriculture	2	2.4	2.6	2.8	3
Altered	4.35	11.2	15.9	18.6	23.1
Wasteland	0	0	0	0	0

Scenario 1A North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)		TO BE ADDED			
Cattle (10^6 head)	4	9	15.3	23.8	34
Logs (10^6 m^3)	19.8	24	31	39	48
Fruits (10^6 T)		TO BE ADDED			

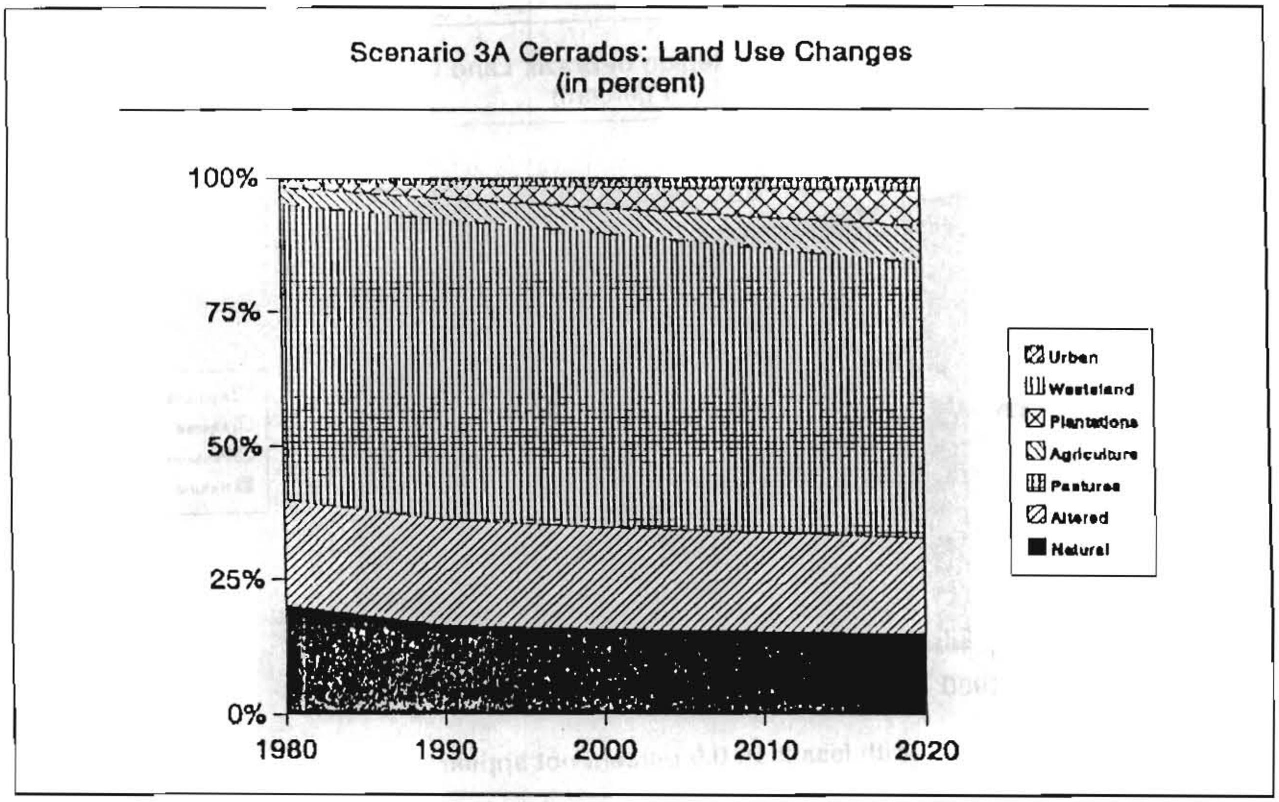


Scenario 1B North Region of Brazil: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	335.8	320.5	305.1	289.6	274.5
Urban	0.1	0.2	0.3	0.4	0.5
Plantations	0.15	0.2	0.33	0.5	0.74
Pastures	7.8	15.5	25.5	34.1	43.5
Agriculture	2	2.6	4	6.7	8.5
Altered	4.35	11	14.7	18.6	22.1
Wasteland	0	0	0	0	0

Scenario 1B North Region of Brazil: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)			TO BE ADDED		
Cattle (10^6 head)	4	9	20	36	54
Logs (10^6 m^3)	19.8	24	40	51	63
Fruits (10^6 T)			TO BE ADDED		

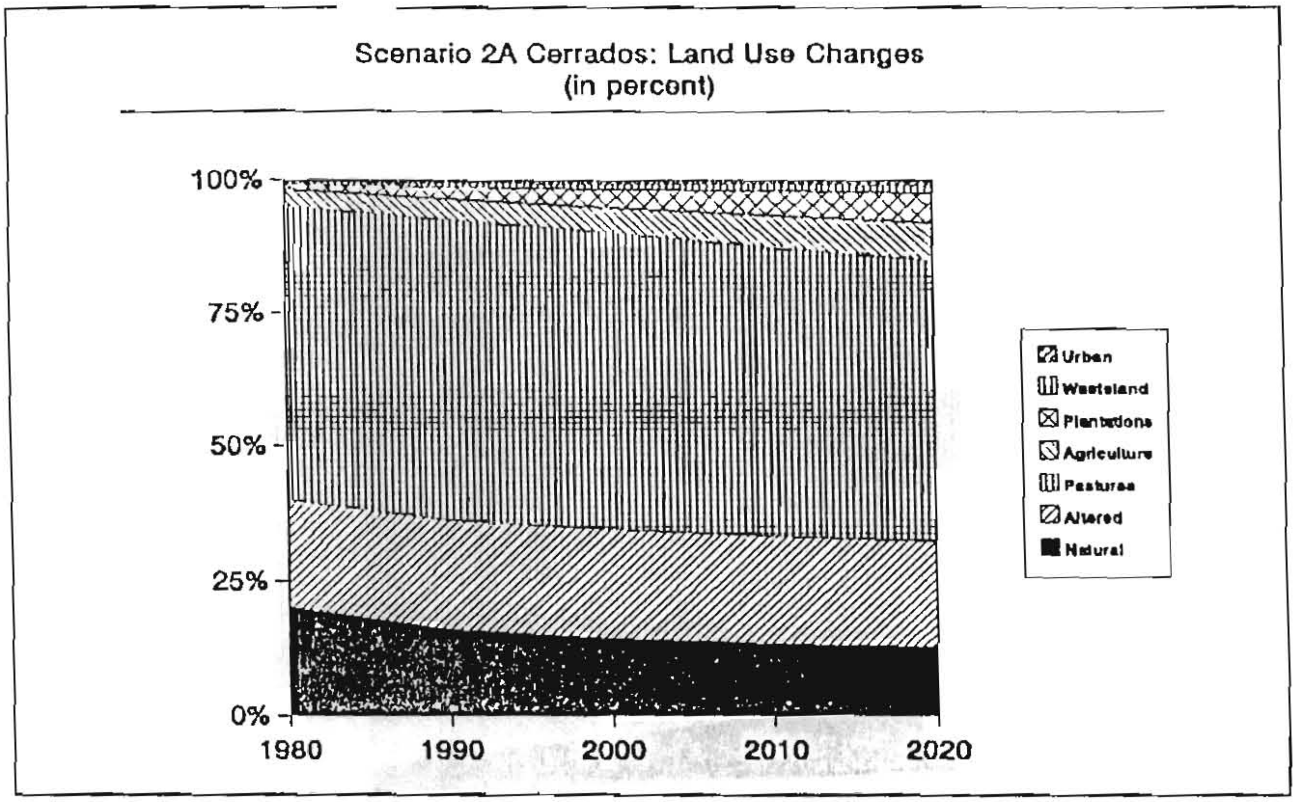


Scenario 3A Cerrados: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	31	25.5	24.1	23.5	23
Urban	0.65	0.9	1.1	1.4	1.6
Plantations	1.5	3.9	6.1	8.3	10.3
Pastures	85.5	86.8	84.8	81.9	79.3
Planted Pastures	26.5	33	39.5	46	52.5
Agriculture	5	6.2	7.4	9.1	10.8
Altered	30.7	30.7	30	28.9	27.7
Wasteland	0.65	1	1.5	1.9	2.3

Scenario 3A Cerrados: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)	6.2	9.1	12.5	17.3	23.1
Cattle (10^6 head)	31.7	42	50	57	64
Fuelwood and Charcoal (10^6 m^3)	37.3	42	52	62	72



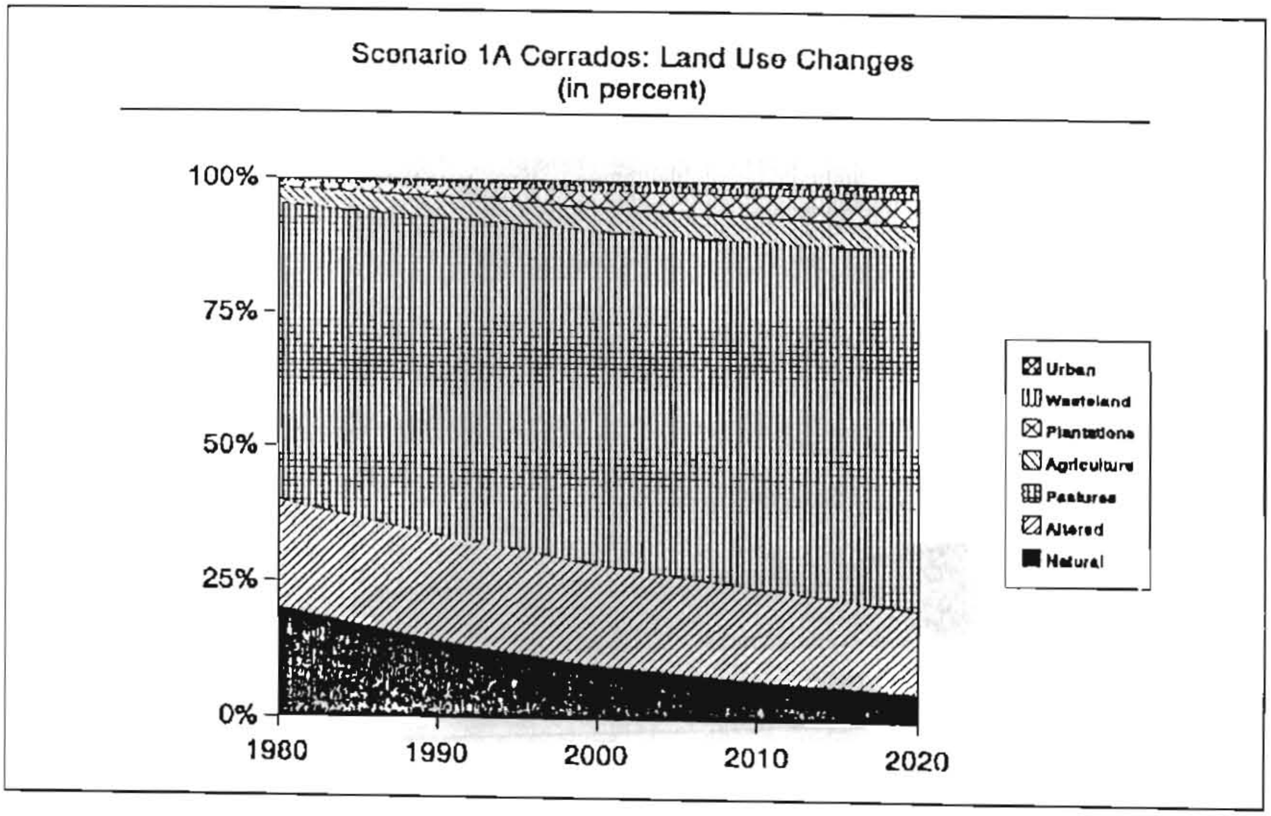
Scenario 2A Cerrados: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	31	24.5	21.9	20.4	19.5
Urban	0.65	0.9	1.1	1.4	1.6
Plantations	1.5	3.5	5.3	7	8.7
Pastures	85.5	87.3	86.1	83.7	81.3
Planted Pastures	26.5	33.5	40.5	47.5	54.5
Agriculture	5	6.2	7.5	9.5	11.2
Altered	30.7	31.6	31.6	31.1	30.4
Wasteland	0.65	1	1.5	1.9	2.3

Scenario 2A Cerrados: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)	6.2	8.8	12	16.9	21.3
Cattle (10^6 head)	31.7	42	51	59	66
Fuelwood and Charcoal (10^6 m^3)	37.3	42	47	52	57

Run of Land Use Models



Scenario 1A Cerrados: Land Use Changes
(millions of hectares)

	1980	1990	2000	2010	2020
Natural	31	21.7	15.6	11.6	8.8
Urban	0.65	0.95	1.3	1.6	1.8
Plantations	1.5	3.3	4.9	6.5	8
Pastures	85.5	92	96.9	100.4	102.7
Planted Pastures	26.5	33	39.5	46	52.5
Agriculture	5	5.95	6.6	7	7.3
Altered	30.7	30.1	28.2	26.1	24.2
Wasteland	0.65	1	1.5	1.8	2.2

Scenario 1A Cerrados: Production Changes

	1980	1990	2000	2010	2020
Grain (10^6 T)	6.2	8.1	9.9	11.6	14.1
Cattle (10^6 head)	31.7	42	53	64	74
Fuelwood and Charcoal (10^6 m^3)	37.3	42	46	50	54