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GREENHOUSE GAS CONTRIBUTIONS FROM DEFORESTATION IN BRAZILIAN AMAZONIA

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ABSTRACT

Examination of the often contradictory estimates of the rate and extent of deforestation in Brazilian Amazonia leads to a "best estimate" of the cumulative area of forest cleared through 1988 as 345 X 10^3 km^2 (including old clearings), or 8.2% of the 4 X 10^6 km^2 forested portion of Brazil's 5 X 10^6 km^2 Legal Amazon region. Recent (post-1960) clearing of primary and old secondary forest totaled 268 X 10^3 km^2, or 6.4%. Including clearing in the cerrado increases the total of recent clearing to 460 X 10^3 km^2, or 9.6% of the area originally under forest and cerrado. Forest loss in 1988 was proceeding at 20 X 10^3 km^2/year; inclusion of estimated cerrado loss raises the total to 39 X 10^6 km^2/year, an area almost the size of Holland.

Mean dry weight biomass (above and below ground) is estimated at 211 metric tons (MT)/hectare (ha) for forest areas being cleared in 1988 and 247 MT/ha for the region's forest as a whole (carbon content of biomass is 50%). Pasture biomass averages 10.7 MT/ha. Soil release of carbon (C) from converting forest to pasture is 3.92 MT/ha from the top 20 cm. Were all of the forest and cerrado areas converted to pasture, 51 billion metric tons (gigatons = GT) of C would be released. The annual rate of forest and cerrado loss in 1988 was releasing 270 X 10^6 MT of carbon on conversion to cattle pasture. Considering the quantities of carbon dioxide and methane released--and the relatively greater impact of methane carbon on the greenhouse effect--the release of carbon in these two forms at 1988 clearing rates totals from 262 to 282 million metric tons, depending on assumptions regarding methane release from burning and from termites. This is almost three times the annual carbon release from Brazil's use of fossil fuels, but brings little benefit to the country.

I.) INTRODUCTION

The greenhouse effect is the sum of heat-absorbing actions of various gases emitted from a variety of human activities and natural processes in different parts of the world. Although carbon dioxide emissions from industrialized countries represent the largest single factor, other sources of greenhouse gases, such as tropical deforestation, also make significant contributions. Policies designed to control global warming must be based on an adequate understanding of the nature and magnitude of the gas sources, the cost and effectiveness of possible policy changes, and the benefits that are being derived from activities that now release greenhouse gases. The Brazilian Amazon, with the largest remaining area of tropical forest, is of central importance not only because deforestation in this region contributes a substantial amount of carbon to the atmosphere, but also because controlling deforestation is amply justified from the perspective of Brazil's own interests, independent of the question of global warming. Slowing forest loss is possible because the process of deforestation in Brazil is largely driven by factors that are subject to government decisions. Separate discussions have been published treating deforestation's causes in Brazil (Fearnside, 1987a), its meager benefits (Fearnside, 1985a, 1986a), heavy environmental costs (Fearnside, 1985b, 1988), and irrationality from the perspective of the long-term interests of the country (Fearnside, 1989a,b). Measures that would help slow forest loss in Brazilian Amazonia have been reviewed both from the perspective of what the Brazilian government could do (Fearnside, 1989c) and that of possible contributions from other countries (Fearnside, 1990a). Potential impact on other countries makes Amazonian deforestation a focus of worldwide concern (Fearnside, 1989e).

The present and potential contributions to the greenhouse effect from deforestation in the Brazilian Amazon are uncertain because of the small amount and low reliability of data on several key components in the calculation. Brazilian Amazonia's great size and heterogeneity, combined with the relative paucity of data, make these uncertainties a weak point in global carbon budget calculations.

The present contribution of deforestation is a function of the annual rate at which forests are being cleared, biomass of the forests, partitioning of biomass in above and below ground compartments, carbon content of the vegetation, fraction of above-ground carbon transferred to long-term pools such as charcoal, completeness of burning, reburning practices (including transformations to and from charcoal pools), rate of decomposition of unburned biomass, carbon stocks in replacement vegetation, and carbon stocks in soil under original and replacement vegetations. The ratio of gases released by deforestation affects contribution to the greenhouse effect. Calculation of potential release also requires knowing the total area for each vegetation type present.

All of these quantities are uncertain. The uncertainty of the overall result depends both on the uncertainty of each factor and on the sensitivity of the result to changes in that factor. Many uncertainties have multiplicative effects, rapidly degrading the reliability of the calculated releases (Robinson, 1989). Despite these limitations, it is essential that the best estimate possible be made from the available data. Where measurements are missing for needed quantities, such as the biomass of certain vegetation types, then guesses or assumptions based on similar vegetation elsewhere must be used. Use of such low-reliability values is preferable to extrapolating to the region from the few existing high-reliability biomass measurements: it is better to be approximately right than to be precisely wrong. Despite disagreements and conflicting data on such vital factors as forest biomass and deforestation rates, the conclusion remains inescapable that Amazonian deforestation makes a significant contribution to the greenhouse effect. More fundamental than disagreements about the magnitude of deforestation and biomass is lack of consensus over how the results should be interpreted in terms of policy changes.

II.) DEFORESTATION RATES

Controversy surrounds the existing estimates of the extent and rate of deforestation in Brazilian Amazonia. These controversies are analyzed elsewhere, and a "best estimate" is derived which calculates that 8.2% of the originally forested portion of the Brazilian Amazon had been cleared through 1988 (including old clearings), with new clearing in the forest (virgin + old secondary forest) area expanding at 20 X 10^3 km^2 per year (Fearnside, 1990d).

Much of the literature on the contribution of tropical deforestation to global warming has been based on the deforestation estimates of the Food and Agriculture Organization of the

United Nations (FAO) for 1980 (Lanly, 1982). This survey is both out of date and unlikely to represent the true extent of deforestation even for the period it covers. The information it reports was obtained by a questionnaire sent to the government of each country, rather than from independent monitoring methods such as remote sensing. In the case of Brazil, the task of responding was given to the Superintendency for Development of the Amazon (SUDAM), the agency responsible for subsidizing and promoting large cattle ranches in the region. Much of the information available at the time (reviewed in Fearnside, 1982) is not reflected in the report.

The deforestation estimate adopted here (Fearnside, 1990d) uses as many as possible of the measurements on 1988 LANDSAT-TM images made by Brazil's National Institute of Space Research (INPE) (Brazil, INPE, 1989a,b). In the state of Acre a discrepancy with previous results of the Brazilian Institute for Forestry Development (IBDF), now part of the Brazilian Institute for Environment and Renewable Natural Resources (IBAMA), led to using a projection from 1980 and 1987 data in this state. In the state of Rondônia the absolute value for deforestation was derived from the INPE LANDSAT results, but an unexplained jump relative to LANDSAT data interpreted by IBDF from the previous year (Brazil, IBDF, 1989) led to using an estimate for deforestation rate in this state derived from AVHRR results (Malingreau and Tucker, 1988; J.P. Malingreau, personal communication, 1988; D. Skole, INPA seminar, 1989; see Fearnside, 1990d). In all states the INPE data (Brazil, INPE, 1989a,b) were used to estimate the area originally forested, but the alteration of cerrado (central Brazilian scrub savanna) was estimated using a number of assumptions regarding the proportionality of alteration in different vegetation types, or continuation of previous trends.

By the "best estimate" calculation outlined above, the cleared area in the Legal Amazon totals 353 X 10^3 km^2, 268 X 10^3 km^2 (76%) of which is forest (Table 1). Of the original vegetation cover (Figure 1), 7.4% of the total and 6.4% of the forest had been cleared by 1988. These values do not include "old clearings" (clearings made prior to 1960, which the INPE/Our Nature Program measurements registered as 31,822 km^2 in Pará and 60,724 km^2 in Maranhão). These older secondary forests were not detected in the earlier LANDSAT-MSS studies (see Fearnside, 1982, 1986b) and so cannot be used in the present study for the purpose of establishing trends by comparison with older data. The INPE study's area values for old secondary forest have been included in the biomass and carbon release calculations by considering old secondary forest as a separate vegetation type. The area that has lost its original forest cover, including the old secondary forest area, is an area the size of Finland: 345 X 10^3 km^2, or 8.2% of the original forest area.

The average rate of deforestation can be conservatively estimated by assuming constant rates since the last available satellite measurement of cleared area (Table 2). This procedure underestimates the current rate of deforestation because the calculation averages deforestation over the period between the last two available satellite measurements while all evidence indicates that areas cleared have, in general, been increasing every year. An exception to this trend may be clearing in 1989, mainly due to heavier rains during the dry season than in the two preceeding years. The nearly constant increase in the rate of clearing renders obsolete the many greenhouse effect calculations that have been based on deforestation estimates for 1980 or earlier.

II.) RELEASE OF GREENHOUSE GASES

A.) AVAILABLE ESTIMATES

Calculating the potential contribution of deforestation to the greenhouse effect requires comparison of carbon stocks present before and after clearing. Estimates of potential emissions have been evolving as better information becomes available. An estimate (Fearnside, 1985c) based on a seven-category classification of vegetation by Braga (1979) and biomass for dense forest based on the mean results from existing studies where direct measurements were made concluded that conversion of the Legal Amazon to cattle pasture would release 62 billion metric tons (gigatons = GT) of carbon. The biomass for the "upland dense forest" category used was 361.5 MT/ha dry weight total biomass, including live above-ground (251.7 MT/ha), below-ground (86.3 MT/ha), and litter and dead above-ground biomass (23.6 MT/ha). This biomass value from direct measurements is higher by a factor of two than the 155.1 MT/ha value for total biomass derived by Brown and Lugo (1984) from FAO forest volume surveys for "tropical American undisturbed productive broadleafed forests"--a value that has been used in recent global carbon balance calculations (e.g. Detwiler and Hall, 1988).

The Brown and Lugo (1984) forest volume estimate of 155.1 MT/ha is lower than biomass values derived using the same methodology for 15 of 16 locations for which volume information is given in the FAO reports, making it unlikely that a mean value this low applies to dense forests in Brazilian Amazonia (Fearnside, 1986c). Revising the estimate of Fearnside (1985c), principally by incorporating FAO wood volume information into the dense forest mean and by using values for pasture biomass based on monitoring over an annual cycle at Altamira (Pará) and Ouro Preto do Oeste (Rondônia) (Fearnside, 1989d), yields an estimate of 49.7 GT as the potential release from conversion to cattle pasture (Fearnside, 1987b). The biomass calculations in the present paper yield an intermediate value of 51 GT (Tables 3 and 4).

The 16 locations in the FAO data set have a mean total (above + below ground) biomass of 226.1 MT/ha if calculated using the above-ground volume to biomass conversion factor derived by Lugo and Brown (1984) and the above to below ground ratio measured by Klinge et al. (1975; see Fearnside, 1987b). Brown et al. (1989) have recently derived more reliable volume to biomass conversion factors, raising their estimate for mean above-ground biomass for undisturbed tropical American closed broadleaf forests by 28-47%. The mean above-ground biomass of 169.68 MT/ha (Brown et al., 1989: 898) is equivalent to 222.3 MT/ha total biomass, using the Klinge et al.(1975) conversion factor of 1.31. This is in good agreement with the 226 MT/ha value used here for central Pará (Table 3), where the FAO surveys were concentrated. Both values are probably underestimates: the value used in Table 3 (from Fearnside, 1987b) for having used the lower (and less reliable) volume-to-biomass conversion (from Lugo and Brown, 1984) and the more recent estimate (Brown et al., 1989) for using a weighting scheme by forest type that results in a weighted mean volume lower than that found in 15 of the 16 localities that form the basis of the survey.

B.) LAND USE TRANSFORMATIONS

The cattle pastures that replace forest last only about a decade before they cease to be productive. The vegetation that succeeds cattle pasture has a higher biomass than pasture, thus reducing somewhat the net release of carbon. However, degradation of soil under pasture, combined with rainfall changes expected should the scale of deforestation greatly expand, are likely to make low-biomass dysclimaxes, including grassy formations, the dominant land cover in a deforested Amazon (Fearnside, 1990b).

The rate of deforestation, together with the biomass of forest being cleared, affects the current (as opposed to potential) contribution of deforestation to the greenhouse effect. The rate of clearing was calculated for each state (Table 2) but must also be apportioned between various forest types within each state. This is done by assuming that within each state, each forest type is cleared in proportion to the area in which it occurs.

The areas of different forest types present and the biomass of each forest type are both uncertain quantities. In Table 3, the values listed have been derived from a variety of sources and have varying degrees of uncertainty. The area figures presented in Table 3 have been rounded off after carbon release calculations were made.

The factor most heavily influencing the total biomass present is the dense forest of the state of Amazonas. This has both the largest area and the highest biomass per hectare of any forest type. It also happens to be the unit where the largest number of direct biomass measurements have been made. This area represents approximately 37% of the total potential carbon release from conversion of the Legal Amazon to cattle pasture.

C.) THE FATE OF CARBON STOCKS

1.) Biomass Carbon

Char formed in burning is one way that carbon can be transferred to a long-term pool where it cannot enter the atmosphere. A burn of forest being converted to cattle pasture near Manaus resulted in 2.7% of above-ground carbon being converted to char (Fearnside et al., nd-a). This is substantially lower than the 20% assumed by Seiler and Crutzen (1980) when they identified charcoal formation as a potentially important carbon sink. Using the observed lower rate of charcoal formation would make global carbon cycle models indicate a larger contribution of greenhouse gases from tropical deforestation than has been the case using the higher rates of carbon transfer to long-term pools (e.g. Goudriaan and Ketner, 1984).

The burning behavior of ranchers can alter the amount of carbon passing into a long-term pool as charcoal. Carbon budget calculations generally assume that forest is only burned once and that all unburned biomass subsequently decomposes (e.g. Bogdonoff et al., 1985). This is not the typical pattern in cattle pastures that dominate land use in deforested areas in the Brazilian Amazon. Ranchers reburn pastures at intervals of two to three years to combat invasion of inedible woody vegetation. Logs lying on the ground when these reburnings occur are often burned. Some char formed in earlier burns can be expected to be combusted as well. A typical scenario of three reburnings over a ten-year period would raise the percentage of above-ground C converted to charcoal from 2.6% to 3.6%, given the assumptions outlined in Figure 2 and Table 5, to be discussed later.

The remaining carbon would be released through combustion and decay; the relative importance of each affects the gases released. A one-burn-only scenario would release 27.5% of the preburn above-ground carbon through combustion and 68.9% through decay, whereas the scenario with three reburnings would release 40.6% through combustion and 54.8% through decay. Both combustion and decay release methane, 3.7 times more potent per ton of carbon in provoking the greenhouse effect than is carbon dioxide when the global warming potential over the lifetime of each gas is considered without discounting (Lashof and Ahuja, 1990).

Were a discount rate greater than zero applied, the importance of CH_4 relative to CO_2 would increase (and hence the impact of tropical deforestation relative to fossil fuel emissions). At discount rates of 1%, 2%, 3%, 4%, and 5%, respectively, methane provokes approximately 12, 17, 22, 25, and 28 times more global warming per ton of carbon than does carbon dioxide (Lashof and Ahuja, 1990). An alternative method of giving weight to short-term effects is to consider global warming potential without discounting up to a planning horizon, after which no effects are considered (Arrhenius and Waltz, 1990). Short planning horizons increase the relative impact of methane: considering only the next 30 years rather than the 150 year lifetime of CO_2 raises the relative impact of CH_4 carbon from approximately 4 to 40 times that of CO_2 carbon.

Measurements of emission ratios of CH_4 to CO_2 (expressed as percent volume) indicate values ranging from 0.5 to 2.3% with a geometric mean of 1.1% for samples collected from the ground near burning forest in the Brazilian Amazon (Greenberg et al., 1984) and ranging from 0.3 to 2.0% with a geometric mean of 0.8% when sampled from aircraft (Crutzen et al., 1985: 242). The amount of methane released is heavily dependent on the ratio of smoldering to flaming combustion; smoldering releases substantially more CH_4. Aircraft sampling over fires (mostly from virgin forest clearing) indicates that a substantial fraction of combustion is in smoldering form (Andreae et al., 1988). Logs consumed by reburning of cattle pastures are virtually all burned through smoldering rather than flaming combustion (personal observation).

Termites are the major agent of decay for unburned wood (Uhl and Saldarriaga, nd). No measurement exists of the percentage of felled biomass that is ingested by termites in Amazonian clearings. The region's principal termite specialist can offer no indication more precise than that "most" of the above-ground wood is ingested (Adelmar Bandeira, personal communication, 1990). A value of 75% has therefore been used as a first approximation (midpoint of the 50-100% range). It is assumed that none of the below-ground wood is ingested by termites: a conservative assumption given that termites consume underground biomass in other regions, such as Africa (e.g. Wood et al., 1977).

A lively controversy surrounds the question of how much methane is produced by termites (Collins and Wood, 1984; Fraser et al., 1986; Rasmussen and Khalil, 1983; Zimmerman et al., 1982, 1984). Support for substantial emission potential from termites in deforested areas in the Amazon is provided by high population densities in fields in Pará where forest biomass remains present (Bandeira and Torres, 1985), and high methane emissions from termite mounds near Manaus (Goreau and de Mello, 1987). The billions of metric tons of wood that these insects would devour as Amazonia is deforested cannot help producing substantial contributions of methane regardless of which production rates prove to be correct.

The release of different greenhouse gases can be calculated based on available information from laboratory and field measurements. Low and high methane release scenarios are shown in Tables 6-8, using a range of available values for release from combustion and from termites.

In the low methane scenario, 1550 g CO_2 is released per kg of fuel burned in mixed flaming and smoldering burns (i.e., initial burns) and 1400 g CO_2/kg fuel in smoldering burns (i.e., in reburns) (both values calculated by Kaufman et al., 1990, from Ward, 1986). Mixed combustion produces 5 g CH_4/kg fuel (calculated by Kaufman et al., 1990, from Ward, 1986). Smoldering combustion produces 7 g CH_4/kg fuel (calculated by Kaufman et al., 1990 from Greenberg et al., 1984). The carbon content of the fuel is assumed to be equal to that in the biomass being cleared (50%). Termites in the low methane scenario release 0.2% of the carbon ingested as methane carbon (Seiler et al., 1984 cited by Fraser et al., 1986). The transformations in the low methane scenario are summarized in Figure 3.

In the high methane scenario, mixed and smoldering burns release the same quantities of carbon dioxide as in the low methane scenario. Methane is produced at a rate of 6 g/kg fuel in mixed burns and 11 g/kg fuel in smoldering burns (calculated by Kaufman et al., 1990 from Ward, 1986). Termites release 7.8×10^{-3} molecules of CH_4 per molecule of CO_2 (Goreau and de Mello, 1987), or 7.9 g CH_4 carbon per kg fuel carbon, assuming that all carbon is released either as CO_2 or CH_4. The methane release from termites in the high methane scenario is that measured in termite mound emissions near Manaus--a value only slightly lower than the emissions of the temperate zone species that led Zimmerman et al. (1982) to postulate massive global emissions from termites.

The effect of methane is to raise the impact of net carbon release from Amazonian deforestation by 14 to 18%, depending on whether the low or high methane scenario is used. The effect is slightly lower if gross carbon release is considered--the uptake of carbon by the replacement vegetation in the net release calculation affects only CO_2 since CH_4 does not enter photosynthetic reactions.

Carbon monoxide (CO) is also produced by burning (Tables 6-8). This gas contributes indirectly to the greenhouse effect by impeding natural cleansing processes in the atmosphere that remove a number of greenhouse gases, including methane. Carbon monoxide removes hydroxyl radicals (OH), which react with CH_4 and other gases, including various chlorofluorocarbons (CFCs) that provoke stratospheric ozone depletion, in addition to the greenhouse effect.

For mixed flaming and smoldering combustion in the low release scenario, 120 g CO result per kg of fuel (calculated by Kaufman et al., 1990 from Greenberg et al., 1984), while in the high release scenario the equivalent figure is 150 g (calculated by Kaufman et al., 1990 from Crutzen et al., 1985). Assuming 50% fuel carbon, these values are equivalent to 0.096 and 0.12 kg CO carbon per kg of fuel carbon.

For smoldering combustion in the low release scenario, 220 g CO is released per kg of fuel (Ward, 1986 cited by Kaufman et al., 1990), while in the high release scenario the equivalent figure is 280 g (calculated by Kaufman et al., 1990 from Greenberg et al., 1984 and Ward, 1986). Assuming fuel carbon content as above, these values are equivalent to 0.176 and 0.224 kg CO carbon per kg of fuel carbon, respectively. Complete clearing of the Brazilian Legal Amazon would release 5 to 8 GT of CO (Table 8). The global warming potential of a molecule of CO relative to one of CO_2 is 1.4 without discounting and rises to approximately 7 at an annual discount rate of 5% (Lashof and Ahuja, 1990). As with methane, the more conservative zero discount values have been used in computing CO_2 equivalents (Table 6).

Some carbon is released in other forms, such as nonmethane hydrocarbons (NMHCs) and graphitic carbon (soot). The data available are not sufficiently reliable to calculate emissions of these by difference. The carbon release from forest given in Table 4 corresponds to a gross release from biomass of 105.6 MT/ha, while the equivalent gross carbon release in the form of CO_2, CH_4 and CO totals 103.1 MT/ha (from Table 6). The implied difference of 2.5 MT/ha (2.3%) might be presumed to represent release in other forms, but uncertainties such as the carbon content of fuel used in deriving the gas emission relationships make this number highly uncertain. The implied difference is greater than the releases suggested by emission ratios from laboratory measurements on combustion of temperate-zone forest fuels. Using the ratios of particulates to methane and NMHCs adopted by Kaufman et al. (1990; based on Ward and Hardy, 1984 and Ward, 1986), the low and high methane scenarios imply NMHC releases of 0.29 to 0.39 MT/ha and 0.22 to 0.29 MT/ha for flaming and smoldering combustion, respectively, in forest of average biomass (using the combustion efficiency of 0.275 from Fearnside et al., nd-a; see Figure 2). The comparable releases of total particulates would be 1.47 to 1.97 MT/ha and 0.73 to 0.98 MT/ha; considering 7% of the total particulates to be graphitic carbon (the fraction found over Amazonian fires by Andreae et al., 1988), the releases of graphitic C would be 0.10 to 0.14 MT/ha and 0.05 to non=0.07 MT/ha.

Burning also releases some nitrous oxide (N_2O), which contributes both to the greenhouse effect and to the degradation of stratospheric ozone. A sampling artifact has made measurements prior to 1989 unusable. However, the amounts produced by biomass burning are substantially less than had previously been thought (Crutzen, 1990), so that ignoring the impact of N_20 from fire will not unduly bias the results of the present calculations. A greater bias may be introduced by ignoring the biological production of N_2O in the soil, which may be stimulated by deforestation. N_2O is released from soils in greater quantities in cattle pasture than in forest (observations in the dry season near Manaus by Goreau and de Mello, 1987; see also Goreau and de Mello, 1988). Burning in nontropical environments has been found to stimulate N_2O release from soils (Anderson et al., 1988 cited by Kaufman et al., 1990).

2.) Soil Carbon

Soil carbon in pasture is taken to be that in a profile equivalent to what is compacted from a 20 cm profile in the forest. It would not be fair to compare the amount of carbon (expressed in MT/ha) in the top meter of pasture soil to the top meter in forest soil, since soil under pasture undergoes compaction when exposed to sun, rain, and trampling of cattle. As the pores are crushed and soil bulk density increases, the amount of carbon in the top meter may increase as an artifact of including a greater weight of soil in the profile. The carbon in the top 20 cm of soil decreases from 0.91% to 0.56% by weight (see Fearnside, 1985c), based on soil carbon under forest and 10- and 11-year-old pastures at Paragominas (Pará) sampled by Falesi (1976: 31, 42). Considering the soil density as 0.56 g/cm^3 under forest at Paragominas (Hecht, 1981: 95), the layer compacted from the top 20 cm of forest soil releases 3.92 MT/ha of carbon.

The 3.92 MT/ha release from the top 20 cm of soil represents 38% of the preconversion carbon present in this layer. This is higher than the 20% of presosconversion carbon in the top 40 cm of soil that Detwiler (1986) concluded is released, on average, from conversion to pasture (based on a literature review). The difference is not so great as it might seem: since carbon release is greatest nearest the surface, considering soil to 40 cm would thereby reduce the percentage released. One factor acting to compensate for any overestimation possibly caused by using a higher percentage of soil carbon release is the low bias introduced by having considered only the top 20 cm. If soil to one m depth is considered (the usual practice), then the release would be increased to 9.33 MT/ha. The calculation to one m depth considers that the top 20 cm of soil contains 42% of the carbon in a one m profile (based on samples near Manaus: Fearnside, 1987b). Brown and Lugo (1982: 183) have used a similar relationship to estimate carbon stocks to a depth of one m from samples of the top 20 cm, considering 45% of the carbon in a one m profile to be located in the top 20 cm.

Conversion of all forest and cerrado in the Legal Amazon to cattle pasture would release 1.9 GT of carbon from the top 20 cm of soil-about 4% of the total released from converting the region to pasture. Were the soil considered to a depth of one m, and the assumption made that the proportion of carbon released remains constant with depth, the soil release would be 4.5 GT, or 8% of the total. Considering soil to one m would add 0.014 GT per year to the 0.010 GT release from the top 20 cm, given the 1988 rate and distribution of clearing.

Release of soil carbon would be expected when forest is converted to pasture because soil temperatures increase when forest cover is removed, thus shifting the balance between organic carbon formation and degradation to a lower equilibrium level (Cunningham, 1963; Nye and Greenland, 1960). A number of studies have found lower carbon stocks under pasture than forest (reviewed in Fearnside, 1980). For the same reason, naturally occurring tropical grasslands also have much smaller soil carbon stocks per hectare than do forests (Post et al., 1982). Lugo et al. (1986), however, have found increases in carbon storage in pasture soils in Puerto Rico, especially in drier sites, and suggest that tropical pastures may be a carbon sink. The present study treats soils as a source of carbon when forests are converted to pasture. All carbon released from soils is assumed to be in the form of CO_2.

D.) GLOBAL CONTRIBUTION OF TROPICAL DEFORESTATION

Global carbon emissions from deforestation are uncertain, in part because of the uncertainty associated with Brazil's large contribution to the total. One estimate places the global annual total at 1.67 GT, of which 0.80 GT are ascribed to Brazil (Goldemberg, 1989). The Brazilian contribution of more than double the current estimate of 0.27 GT is probably due to using the AVHRR thermal infra-red burning estimates from 1987 (Setzer et al., 1988) as the rate of deforestation. The global total implies that 0.87 GT of carbon are released annually from non-Brazilian deforestation, and that the global total using the current estimate for Brazil would be 1.14 GT. Brazil's present contribution to the global total from deforestation would be 24%. Assuming a 5 GT/year global release from fossil fuels, deforestation in the Brazilian Amazon contributes 4.4% of the combined total from fossil fuels and deforestation. Using the fossil fuel release as the standard of comparison, as is the usual practice, Brazil's annual rate of deforestation in Amazonia represents 5.4% (Table 9). Using emission estimates for individual gases produces a similar result, since the loss of some carbon in forms not contributing to the greenhouse effect is compensated for by the greater impact of carbon in the form of methane. Using CO_2 equivalent carbon release of 0.259-0.267 GT (for the low and high methane scenarios in Table 6), the contribution represents 5.2-5.3% of the global fossil fuel total.

VI.) DISCUSSION AND CONCLUSIONS

Deforestation in Brazilian Amazonia already makes a significant contribution to the greenhouse effect, and continuation of deforestation trends could lead to an even greater potential contribution to this global problem. Uncertainties concerning clearing rate, biomass, and other factors do not change the basic conclusion regarding the significance of deforestation. This can be seen by examining a series of hypothetical examples (Table 9): were the average biomass of 210.7 MT/ha found to be incorrect, biomass values from other sources would result in contributions that, expressed as percentages of a 5 GT global annual total fossil fuel release, range from 2.8% to 4.6% if only the forest is considered, or 3.3% to 5.1% if the entire Legal Amazon is considered. The conclusion that the effect is significant is therefore quite robust.

Brazil emits 100 X 10^6 MT of carbon annually from burning fossil fuels (Goldemberg, 1989). This contribution to the greenhouse effect is balanced against the benefits of the country's industry and transportation powered by oil and coal, all domestic use of natural gas, etc. In contrast, each year's clearing of forest and cerrado in the Brazilian Amazon is now contributing to the atmosphere 270 X 10^6 MT of carbon--almost three times as much as Brazil's use of fossil fuels (Table 4). The benefits of deforestation, however, are minimal: it leaves in its wake only destroyed rain forests and degraded cattle pastures.

The contrast between costs and benefits of biomass burning and fossil fuel combustion are also tremendous on a percapita basis. Brazil's 140 X 10^6 population emits 714 kg of carbon per person per year from fossil fuels. A single rancher who clears 2,000 ha of forest (with an average biomass of 210.7 MT/ha, see Table 3) is emitting as much carbon as a city of 280,000 people burning fossil fuels (calculation patterned after Brown, 1988). Even a small farmer who clears one hectare per year is releasing 100 MT of carbon, the equivalent of 140 people in Brazil's cities. The gulf between the costs and benefits of deforestation compared to fossil fuel use makes slowing forest loss an obvious place for Brazil to start reducing its contribution to global warming.

Immediate action is needed to reduce emissions of greenhouse gases in order to minimize the global warming that continuation of current trends would provoke. While research and monitoring efforts must be fortified and continued, ample scientific evidence is already in hand to justify strong measures by governments throughout the world. Reducing fossil fuel burning and slowing the rate of tropical deforestation are areas that can be readily identified as targets for such measures. Governments must not wait for the availability of more research results nor for the appearance of observable temperature changes before taking action, or the opportunity will be lost to avert the most damaging impacts of the greenhouse effect.

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FIGURE LEGENDS

Figure 1 - Forest and savanna in the Brazilian Legal Amazon (redrawn from Brazil, INPE, 1989a).

Figure 2 - Carbon transformations in a typical burning sequence. See Table 5 for parameters.

Figure 3 - The fate of biomass carbon and its contribution to the greenhouse effect. The first branch in the diagram summarizes the results of Figure 2.

TABLE 1: ORIGINAL VEGETATION AND BEST ESTIMATE OF AREAS IN THE BRAZILIAN LEGAL AMAZON FROM 1960 THROUG

State	Original v0.036egetation (km^2)(a)				Recently
	Forest	Cerrado	Humid savanna	Total original vegetation	Forest
Acre	152,589	0	0	152,589	8,634
Amapá	99,525	0	42,834	142,359	842
Amazonas	1,562,488	0	5,465	1,567,953	12,837
Maranhão	139,215	121,017	0	260,232	34,140
Mato Grosso	572,669	235,345	72,987(c)	881,001	67,216
Pará	1,180,004	22,276	44,553	1,246,833	91,200
Rondônia	215,259	27,785	0	243,044	30,634
Roraima	173,282	0	51,735	225,017	2,187
Tocantins/ Goiás	100,629	169,282	0	269,911	20,279
Legal Amazon	4,195,660	575,705	217,574	4,988,939	267,969

(Table 1, part 2)

RECENTLY CLEARED
H 1988

cleared area (km^2)		Percent recently cleared		Source
Cerrado(b)	Total	Of forest	Of forest + cerrado	
0	8,634	5.7	5.7	(d)
0	842	0.8	0.8	(e)
0	12,837	0.8	0.8	(e)
20,664	54,803	24.5	21.1	(e)
134,277	201,493	11.7	24.9	(e)
1,722	92,922	7.7	7.7	(e)
989(f)	31,623	14.2	13.0	(e)
0	2,187	1.3	1.3	(e)
34,114	54,393	20.2	20.2	(e)
191,765	459,734	6.4	9.6	

TABLE 1 NOTES:

(a) Original vegetation in accord with the INPE map (Figure 1), with the savanna areas apportioned between humid savanna and cerrado in their approximate proportions in the savanna areas shown for each state. The forest in Tocantins/Goiás has been increased by 68,573 km^2 presumed to have been included in the INPE survey but not in the map of original vegetation. "Forest" includes both "primary (virgin) forest" and "old secondary forests" (from clearings prior to 1960 in Pará and Maranhão). Totals are areas of political units, including water surfaces, as in the INPE and IBDF reports (making the percentages underestimates). The area of Tocantins/Goiás is that used by Brazil, INPE, 1989a,b; it is at variance with the 235,793 km^2 used in previous INPE reports (e.g. Tardin et al., 1980) for the same geographical area.

(b) Cerrado clearing, which was not measured in the INPE study (Brazil, INPE, 1989b), has been estimated assuming that this vegetation type is cleared in the same proportion as the forest within each state, the exceptions of Rondônia (where proportionality is assumed excluding cerrado areas in Amerindian reservations) and Mato Grosso (where data exist for cerrado clearing in the western part of the state in 1983, and the ratio of cerrado to forest clearing observed there is assumed to apply to the entire state through 1988).

(c) Pantanal (Mato Grosso humid savanna) area from IBGE data reproduced in Benchimol (1989: 56). The remainder of the savanna area in Mato Grosso shown in Figure 1 (with correction for state area) is considered cerrado.

(d) Linear projection from the last two years of available satellite data (see Fearnside, 1990c).

(e) Brazil, INPE, 1989b, with corrections for state area and cerrado clearing (see text).

(f) Rondônia cerrado clearing assumes that 6,946 km^2 of cerrado (25% of the 27,785 km^2 of cerrado in the state according to the INPE map) is exposed to clearing. The remainder is in an Amerindian reserve.

TABLE 2: AVERAGE CLEARING RATES IN THE BRAZILIAN LEGAL AM

STATE	Last previous data		
	Year	Source	Clearing total (km
Acre	1987	IBDF, 1988	8,133
Amapá	1978	Tardin *et al*., 1980	171
Amazonas	1978	Tardin *et al*., 1980	1,791
Maranhão	1980	IBDF, 1983a	10,671
Mato Grosso	1980	IBDF, 1982	52,786
Pará	1986	SUDAM/IBDF, 1988	85,203(a)
Rondônia	1987	IBDF, 1989	22,913
Roraima	1981	IBDF, 1983b	1,170
Tocantins/Goiás	1980	IBDF, 1983a	9,120
Legal Amazon			

(Table 2, part 2)

AZON

Clearing total by 1988 (km^2)	Average clearing rate in 1988 (km^2/year ^{2}) Forest	Cerrado	Total
8,634	501	0	501
842	67	0	67
12,837	1,105	0	1,105
54,803	3,437(a)	2,080	5,517
201,493	5,580	13,008	18,588
92,922	3,788	72	3,860
31,623	3,916(b)	126	4,042
2,187	145	0	145
54,393	1,759	2,959	4,718
459,734	20,298	18,245	38,543

TABLE 2 NOTES:

(a) Pará and Maranhão clearing include reclearing in the area of old (pre-1960) secondary forest. Old secondary forest zones total 31,822 km^2 in Pará and 60,724 km^2 in Maranhão; of these an estimated 2,255 km^2 and 2,459 km^2 were cleared by 1986 and 1988 respectively in Pará, and 10,369 km^2 were cleared by 1988 in Maranhão. Estimates in these states for years prior to 1986 had been unable to distinguish the old secondary forest from virgin forest, and the clearing in the old secondary forest region is therefore included without correction. For 1986 and 1988 in Pará and for 1988 in Maranhão the clearing within the old secondary forest area is assumed to have occurred in the same proportion as that in virgin forest.

(b) Rondônia clearing rate assumed to follow the trend from the 1985 to 1987 period shown by AVHRR. Uncorrected deforestation values: 27,658 km^2 by 1985 (Malingreau and Tucker, 1988); 36,900 km^2 by 1987 (Jean-Paul Malingreau, personal communication, 1988); corrected for cerrado and 18% adjustment for pixel size effect (based on comparison made by David Skole, University of New Hampshire, Durham, NH, of 10 m resolution SPOT data with SPOT data degraded to 1.1 km resolution to simulate AVHRR): 24,195 km^2 by 1985 and 32,280 km^2 by 1987.

TABLE 3: APPROXIMATE BIOMASS AND FOREST AREA BY STATE

State	Forest type	Approximate area (km^2 X 10^3)	Approxima Biomass (MT/ha)
Acre	Bamboo	30	20
	Other low biomass	31	209
	Dense	92	418
Amapá	Mangrove	1	200
	Dense	99	354
Amazonas	Flooded	30	216
	Jurua/Purus	400	149
	Western Amazonas	200	119
	Bamboo	30	20
	Other low biomass	226	232
	Dense	677	464
Maranhão	Old secondary	61	100
	Other	78	175
Mato Grosso	Northern	100	143

	Transition	473	83
Pará	Old secondary	32	100
	Central	465	226
	West	249	356
	North	158	354
	Vine/low biomass	277	175
Rondônia	Dense (Samuel)	215	418
Roraima	Montane	26	266
	Other	147	119
Tocantins/ Goiás	Transition	101	83
Legal Amazon	All forests	4,196	247
			211
	<u>Cerrado</u>	576	70.7

(Table 3, part 2)

te	Area source	Biomass source
	W.G. Sombroek, pers. comm. l989	
	(25% of remainder)	
	(75% of remainder)	
	Braga, 1979	guess
	remainder	Jordan and Russell, 1983 for Jari
	guess	Commercial volume 100 m^3/ha W.G. Sombroek, pers. comm., 1989.
	25% of forest on fragile soils (W.G. Sombroek, pers. comm., 1989)	assumed 50% of dense forest
		Mean from four locations around Manaus: Fazenda Dimona (327.7 MT/ha) Fearnside *et al*., nd-a; Fazenda Porto Alegre Fearnside *et al*., nd-a Reserva Ducke and environs (367.5 MT/ha see Fearnside, 1987b, Klinge and Rodrigues, 1974, Reserv Egler (507.5 MT/ha) Klinge *et al*., 1975.
	Brazil, INPE, 1989a,b	guess
		guess based on 144.7 m^3/ha trunk volume for forests in Grande Carajas region Brazil, SEPLAN/CODEBAR/SUDA
	guess	Based on 120 m^3/ha merchant bole found by Jaime Antonio and Edezio Cardoso Carvalho W.G. Sombroek, pers. comm.

guess	Based on 70 m^3/ha merchanta bole found by Jaime Antonio and Edezio Cardoso Carvalho W.G. Sombroek, pers. comm.
Brazil, INPE, 1989a,b	guess
guess	FAO forest volume surveys (mean of 16 localities: see review in Fearnside, 1986c,
guess	Tucurui reservoir area: Cardenas *et al*., 1982.
guess	Jari Project: Jordan and Russell, 1983
guess	Assumed 25% of dense forest
Brazil, INPE, 1989a,b	300 MT/ha above-ground biom for Samuel reservoir: Brown, 1990; Martinelli *et al*., nd
Braga, 1979	Seiler and Crutzen, 1980 fo montane forest in general
remaining forest	Assumed same as western Ama
Assumed all forest reported in Brazil, INPE, 1989a,b	Assumed same as transition forest in Mato Grosso
--------------------------------	---------------------
(mean weighted by area present)	
(mean weighted by clearing rate)	

(Table 3, part 3)

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, 1989.

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TABLE 4: APPROXIMATE CARBON RELEASE FROM CLEARING IN THE BRAZILIAN LEGAL AMAZON

	Carbon release if all converted to pasture (GT)	Carbon re at curren of cleari (GT/year)
Forest biomass	47.3	0.196
Cerrado biomass	1.9	0.059
Soil (top 20 cm)	1.9	0.015
Total	51.0	0.270

(Table 4, part 2)

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TABLE 5: LIST OF PARAMETERS FOR CARBON TRANSFORMATIONS

Parameter	Value	Units	Source
Total biomass	210.67	MT/ha dry weight	Table 2
Carbon content of biomass	0.50	fraction of dry weight	Brown and Lugo, 1984
Above-ground fraction	0.76		Klinge *et al*., 1975
Combustion efficiency in initial burn	0.28	fraction of C released	Fearnside *et al*., nd-a
Char C fraction in initial burn	0.04		Fearnside *et al*., nd-a
Fraction of char on biomass following initial burn	0.89		preliminary data from Fearnside *et al*., nd-b
Exposed to soil char C transfer fraction during first interval	0.30		guess
Fraction surviving decay in first interval	0.41		Calculated from Uhl and Saldarriaga nd (a)
Combustion efficiency in first reburn	0.275	fraction of C released	Assumed equal to initial burn
Fraction converted to char in first reburn	0.027		Assumed equal to initial burn
Char C combustion fraction in first reburn	0.20		guess

Fraction surviving decay in second interval	0.57		Calculated from Uhl and Saldarriaga nd (b)
Combustion efficiency in second reburn	0.28	fraction of C released	Assumed equal to initial burn
Fraction of C converted to char in second reburn	0.04		Assumed equal to initial burn
Fraction of char on biomass after first reburn	0.89		Assumed equal to initial burn
Exposed to soil char C transfer fraction during second interval	0.30		guess
Char C combusted fraction in second reburn	0.20		guess
Fraction of char on biomass after second reburn	0.89		Assumed equal to initial burn
Exposed to soil char C transfer fraction during third interval	0.30		guess
Fraction surviving decay in third interval	0.77		Calculated from Uhl and Saldarriaga, nd (b)
Combustion efficiency in third reburn	0.28	fraction of wood C released	Assumed equal to initial burn
Fraction of C to char in third reburn	0.04		Assumed equal to initial burn
Char C combustion	0.20		guess

fraction in third reburn		
Soil C release from top 20 cm	3.92 MT/ha	Fearnside, 1985c, 1987b
Replacement vegetation biomass	10.67 MT/ha	Fearnside *et al*., nd-c; Fearnside, 1989d

(Table 5, part 2)

Comments
Weighted mean for areas being cleared in 1988
Near Manaus, Amazonas
Near Manaus, Amazonas
Near Manaus, Amazonas

Near Altamira, Pará

First interval = 4 years

Second interval = 3 years

Third interval = 3 years

Pasture: average biomass
throughout year at
Ouro Preto do Oeste, Rondônia

TABLE 5 NOTES:

(a) Uhl and Saldarriaga (nd) report an average of 97.3 MT of above-ground dry weight biomass remaining three to four years after clearing a Venezuelan forest whose original above-ground biomass was believed to be 290 MT/ha based on estimates in the area by Stark and Spratt (1977). Assuming the combustion efficiency (0.275) and charcoal formation fraction (0.027) measured in Brazil (Fearnside *et al*., nd-a), the postburn above-ground biomass exposed to decay in Venezuela would be reduced to 200 MT/ha. Loss to decay over the 3.5-year interval (using the midpoints of the range of site ages) would therefore be 51%. Loss in a four-year interval following the initial burn would be 59%.

(b) Uhl and Saldarriaga (nd) report average biomass as 56 MT/ha for 6 to 7 year-old sites; 45.3 MT/ha for 8 to 10 year old sites, 22.7 MT/ha for 12 to 20 year old sites and 7 MT/ha for 30 to 40 year old sites. Assuming a linear decline in wood mass within each age interval (and using midpoints of age ranges as the limits of the intervals), the loss per year as a percentage of the wood mass at the beginning of each interval would be 14.7% for 0 to 3.5 years, 14.2% for 3.5 to 6.5 years, 7.6% for 6.5 to 9 years, 7.2% for 9 to 16 years and 3.6% for 16 to 35 years. These loss rates have been used to calculate loss values for the intervals used in the present calculation (0 to 4 years, 4 ~to 7 years and 7 to 10 years).

TABLE 6: CARBON RELEASES IN THE BRAZILIAN LEGAL AMAZON[(a)]

LOW METHANE SCENARIO

	Complete clearing of Legal Amazon (GT)			
	Carbon dioxide C	Methane C	Carbon monoxide C	Total C
Forest	45.40	0.19	1.97	47.56
Cerrado	1.73	0.01	0.08	1.82
Total	47.13	0.20	2.05	49.37

HIGH METHANE SCENARIO

	Complete clearing of Legal Amazon			
	Carbon dioxide C	Methane C	Carbon monoxide C	Total C
Forest	45.25	0.39	2.49	48.13
Cerrado	1.72	0.02	0.10	1.84
Total	46.97	0.40	2.59	49.97

(Table 6, part 2)

Annual net release in 1988 (GT/year)				
CO_2 equivalent C	Carbon dioxide	Methane C	Carbon monoxide C	Total C
48.86	0.187	0.001	0.008	0.196
1.88	0.054	0.000	0.002	0.056
50.74	0.241	0.001	0.011	0.253

Annual net release from 1988 clearing rate				
CO_2 equivalent C	Carbon dioxide	Methane C	Carbon monoxide C	Total C
50.18	0.187	0.002	0.010	0.198
1.93	0.055	0.000	0.003	0.058
52.11	0.242	0.002	0.013	0.256

(Table 6, part 3)

	Gross release per hectare (MT C/h for complete clearing of the Lega		
CO_2 equivalent C	CH_4	CO_2	CO
0.202	0.45	113.54	4.71
0.057	0.13	35.35	1.35
0.259			

	Gross release per hectare (MT C/h for complete clearing of the Lega		
CO_2 equivalent C	CH_4	CO_2	CO
0.208	0.92	113.18	5.93
0.059	0.26	35.25	1.70
0.267			

(Table 6, part 4)

a cleared) l Amazon	Gross release per hectare (MT C/ha cleared) for clearing in 1988		
	CH_4	CO_2	CO
	0.38	97.58	4.02
	0.13	35.35	1.35

a cleared) l Amazon	Gross release per hectare (MT C/ha cleared) for clearing in 1988		
	CH_4	CO_2	CO
	0.79	97.27	5.07
	0.26	35.25	1.70

TABLE 6 NOTES:

(a) Net release from biomass and soils. Gross releases would increase CO_2 carbon by 5.34 MT/ha, but would not affect other gases. For the low and high methane scenarios, respectively, gross release of CO_2 equivalent carbon would be 53.58 and 57.54 GT for clearing the Legal Amazon, or 0.283 and 0.341 GT for annual release in 1988.

TABLE 7: GREENHOUSE GAS EMISSIONS FROM DEFORESTATION LEGAL AMAZON (MT/ha)(a)

			CH_4
LOW METHANE SCENARIO			
	FOREST		
		Burning	0.
		Total	0.
	CERRADO		
		Burning	0.
		Total	0.
HIGH METHANE SCENARIO			
	FOREST		
		Burning	0.
		Total	1.
	CERRADO		
		Burning	0.
		Total	0.

(a) Calculated using average biomass for fo

(Table 7, part 2)

OF THE BRAZILIAN

	CO_2	CO
44	115.45	11.77
60	454.16	11.77
12	33.10	3.37
17	141.41	3.37
59	115.45	14.83
23	452.73	14.83
17	33.10	4.25
35	140.99	4.25

rests in the Legal Amazon.

TABLE 8: GREENHOUSE GAS EMISSIONS FROM COMPLETE DEFOR
THE BRAZILIAN LEGAL AMAZON (GT OF GAS)

		CH_4
LOW METHANE SCENARIO		
	FOREST	0.
	CERRADO	0.
	TOTAL	0.
HIGH METHANE SCENARIO		
	FOREST	0.
	CERRADO	0.
	TOTAL	0.

(Table 8, part 2)
ESTATION OF

	CO_2	CO
25	190.55	4.94
01	8.14	0.19
26	198.69	5.13
51	189.95	6.22
15	59.16	1.78
66	249.11	8.01

TABLE 9:

CARBON RELEASE SCENARIOS FROM THE PRESENT RATE OF CLEARING

AMAZON GIVEN DIFFERENT ASSUMPTIONS CONCERNING AVERAGE FOR

Average forest biomass (MT/ha)	Biomass carbon release[a] (MT/ha)	From forest clearin	
		(GT/year)	% of 5 global fuel r
262.6[d]	120.1	0.252	
252.0	115.2	0.242	
225.0	102.9	0.217	
222.5	101.7	0.214	
200.0	91.5	0.194	
174.0	79.6	0.169	
155.1[e]	70.9	0.152	

(Table 9, part 2)

IN THE BRAZILIAN LEGAL

EST BIOMASS

Carbon release		
g(b) GT fossil elease	Total from Legal Amazon(c) (GT/year)	% of 5 GT global fossil fuel release
5.0	0.318	6.4
4.8	0.308	6.2
4.3	0.283	5.7
4.3	0.281	5.6
3.9	0.260	5.2
3.4	0.236	4.7
3.0	0.218	4.4

TABLE 9 NOTES:

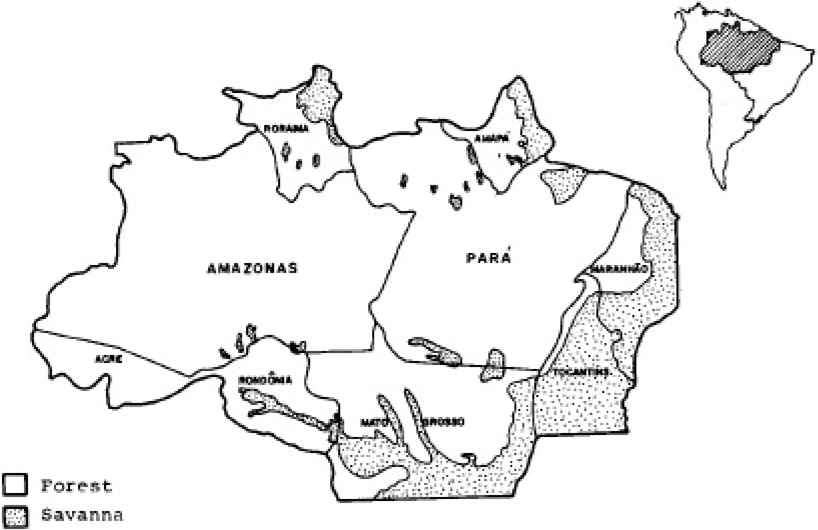
(a) Assumes that the replacement vegetation is cattle pasture (10.67 MT/ha dry weight biomass; see Fearnside, 1987b: 79); carbon content of vegetation 0.50 (after Brown and Lugo, 1982, 1984).

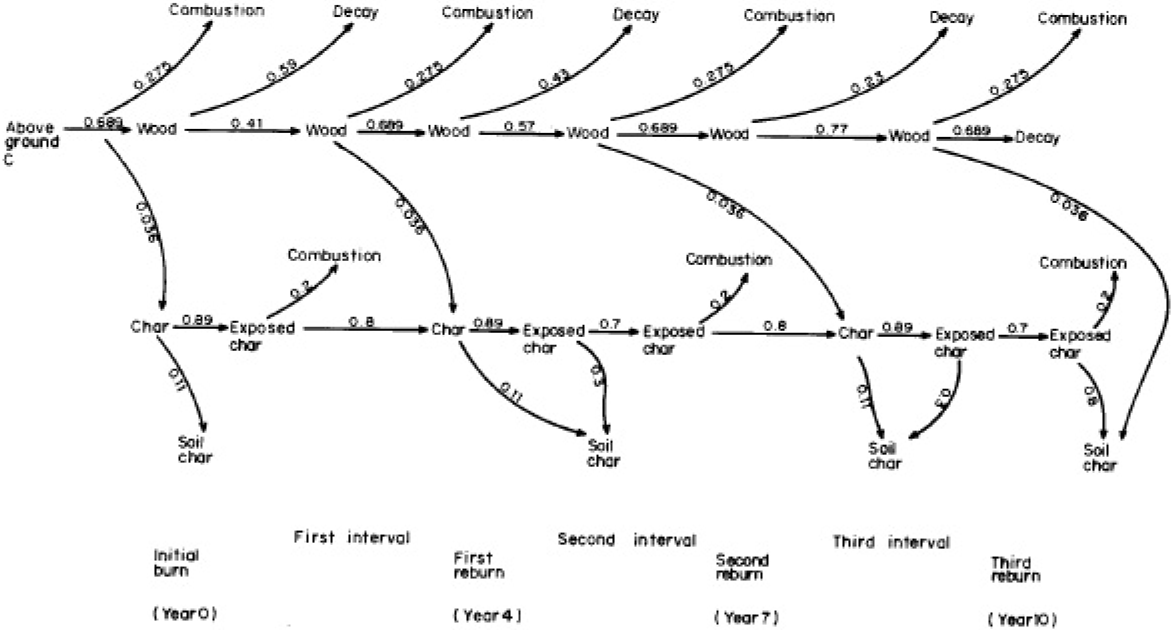
(b) Includes 3.92 MT/ha carbon release from the top 20 cm of soil.

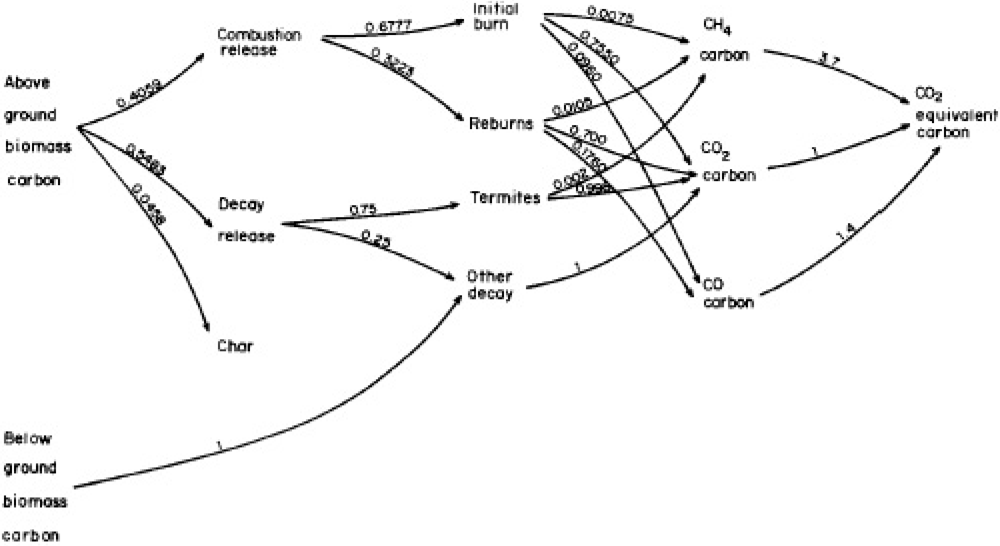
(c) Includes release from *cerrado* (average biomass 70.7 MT/ha) and for soils assumed equal to forest release. *Cerrado* carbon release at current clearing rate is 0.059 GT/year (exclusive of soil release).

(d) Value derived from FAO forest volume estimates and from available direct measurements (Fearnside, 1987b).

(e) Value derived from FAO forest volume estimates for tropical American productive closed broadleaf forests (Brown and Lugo, 1984).


RORAIMA
AMAPÁ
AMAZONAS
PARÁ
MARANHÃO
ACRE
RONDÔNIA
TOCANTINS
MATO
GROSSO
Forest
Savanna


Combustion
Decay
Combustion
Decay
Combustion
Decay
Combustion
0.275
0.59
0.275
0.43
0.275
0.23
0.275
Above ground C
0.689
Wood
0.41
Wood
0.689
Wood
0.57
Wood
0.689
Wood
0.77
Wood
0.689
Decay
0.036
0.036
0.036
0.036
Combustion
Combustion
Combustion
0.2
0.2
0.2
Char
0.89
Exposed char
0.8
Char
0.89
Exposed char
0.7
Exposed char
0.8
Char
0.89
Exposed char
0.7
Exposed char
0.11
0.11
0.3
0.11
0.3
0.8
Soil char
Soil char
Soil char
Soil char
First interval
Second interval
Third interval
Initial burn
(Year 0)
First reburn
(Year 4)
Second reburn
(Year 7)
Third reburn
(Year 10)


Above ground biomass carbon
0.4059
0.5483
0.0458
Combustion release
Decay release
Char
0.6777
0.3223
0.75
0.25
Initial burn
Reburns
Termites
Other decay
0.0075
0.7550
0.0860
0.0105
0.700
0.1750
0.002
0.998
1
CH4 carbon
CO2 carbon
CO carbon
3.7
1
1.4
CO2 equivalent carbon
Below ground biomass carbon
1