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Estimating greenhouse gas emissions from cattle raising in Brazil

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Abstract The study estimated, for the first time, the greenhouse gas emissions associated with cattle raising in Brazil, focusing on the period from 2003 to 2008 and the three principal sources: 1) portion of deforestation resulting in pasture establishment and subsequent burning of felled vegetation; 2) pasture burning; and 3) bovine enteric fermentation. Deforestation for pasture establishment was only considered for the Amazon and Cerrado. Emissions from pasture burning and enteric fermentation were accounted for the entire country. The consolidated emissions estimate lies between approximately 813 Mt CO_2eq in 2008 (smallest value) and approximately 1,090 Mt CO_2eq in 2003 (greatest value). The total emissions associated with Amazon cattle ranching ranged from 499 to 775 Mt CO_2eq, that of the Cerrado from 229 to 231 Mt CO_2eq, and that of the rest of the country between 84 and 87 Mt CO_2eq. The full set of emissions originating from cattle raising is responsible for approximately half of all Brazilian emissions (estimated to be approximately 1,055 Mt CO_2eq in 2005), even without considering cattle related sources not explicitly estimated in this study, such as energy use for transport and refrigeration along the beef and derivatives supply chain. The potential for reduction of greenhouse gas emissions offered by the

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Brazilian cattle industry is very high and might constitute Brazil's most important opportunity for emissions mitigation. The study offers a series of policy recommendations for mitigation that can be implemented by public and private administrators at a low cost relative to other greenhouse gas reduction options.

1 Introduction

Brazil has the largest commercial beef cattle herd in the world (over 170 million head in 2006; IBGE 2009). Over the past decade, beef cattle production has rapidly expanded in Brazil owing to an expansion in exports, accounting for 20.4 % of total production from 2001 to 2010. The value of beef exports in 2010 amounted to US$ 4.8 billion while domestic consumption has, remained stable at an average of 37.1 kg capita^{-1} yr^{-1} through 2010 (CNPC 2011).

The dairy herd averaging 21 million cows in 2006, produced 20 billion liters of milk annually (IBGE 2009), nearly all destined toward domestic consumption. Other important products originate from both the Brazilian beef and dairy industries, including raw leather hides as well as manufactured leather products, approaching export revenues of $2 billion yr^{-1} (CIBC 2009) and $1.8 billion (ABICALÇADOS 2009), respectively.

According to the census data (Fig. 1), the Brazilian cattle herd has grown steadily, but this growth has been regionally differentiated. While the historically settled regions (South, Southeast, Northeast) have stabilized or even declined in absolute herd size, herds in the North (Amazon) and Center-West (Cerrado) regions have grown rapidly.[1] This differential growth pattern can be traced to the expansion of cropland onto former pastures in the southern regions, with displacement of cattle herds to other regions.

Recent exploratory studies on the cattle industry in Brazil raised some important concerns regarding the environmental impacts of the sector, as well as the role of public credit policies and incentives toward the cattle industry, in relation to emissions of greenhouse gases (Smeraldi and May 2008, 2009; Greenpeace 2009). Scientific research has raised similar concerns regarding the relationship between pasture expansion and climate change. The conversion of native vegetation to pasture causes substantial changes in biogeochemical processes (Reiners et al. 1994). The effects initiate in the use of burning to open native forest areas and install pastures. Artaxo et al. (2005) showed the following effects from biomass clearing and burning and associated gas emissions to the atmosphere: a) decrease in the size of the cloud condensation nuclei affecting mechanisms and efficiency of rainfall formation; b) increase of ozone concentration, at lower troposphere, to values considered phytotoxic, especially in sites heavily impacted by fire; c) changes in radiation balance with losses of photosynthetic active radiation at the surface up to 70 %. However, to date no studies have presented, in an integrated way, the emissions related to deforestation, burning, pasture maintenance and enteric fermentation.

Our objective was to estimate what part of land cover and land use change emissions can be attributed to cattle ranching, particularly in the Amazon and Cerrado biomes of Brazil, in the period from 2003 to 2008. These estimates include the greenhouse gas (GHG) emissions associated with: i. deforestation and subsequent biomass burning, ii. burning for pasture maintenance (CH_4 and N_2O), and iii. enteric fermentation and wastes from cattle (CH_4 and N_2O). Some policy recommendations for decision-makers are discussed.

[1] Geographic macroregions are not congruent with biome boundaries, but provide a rough approximation of the area in respective biomes.

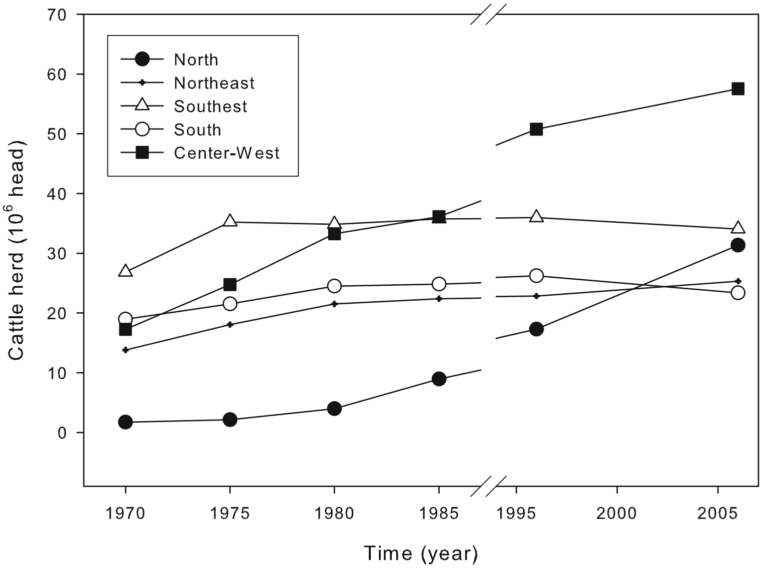

Fig. 1 Growth in the Brazilian cattle herd, by region: 1970–2006 (IBGE 2009)

2 Material and methods

2.1 Area occupied by pastures in Brazilian biomes

In this study, the area of cultivated pastures in Brazilian biomes was estimated using those areas mapped by the PROBIO project (Conservation and Sustainable Use of Brazilian Biological Diversity—PROBIO (PROBIO 2004)), based on the segmentation, classification and visual interpretation of 2002, high resolution Landsat (http://landsat.gsfc.nasa.gov/) images (Fig. 2).

According to PROBIO, the pasture area in the Cerrado by 2002 had reached 546,250.9 km^2, which amounted to 26.8 % of the biome area and 36.8 % of the total pasture area in Brazil, while in the Amazon, the area of cultivated pasture was 245,808.2 km^2 representing 5.9 % of the total biome area and 16.5 % of the total pasture area in Brazil. The sum of pasture areas in both biomes represents 53.3 % of the pasture area in Brazil (Table 1).

The Amazon forest is the only Brazilian biome that is systematically monitored by remote sensing (through the Program for Satellite Monitoring of the Brazilian Amazon Forest—PRODES) to estimate the annual rates of deforestation (INPE 2009).

The estimate of area occupied by pasture in the Amazon obtained by this study from PROBIO is substantially lower than that estimated by PRODES. This discrepancy is due to the fact that only the “Ap class” (pasture in the PROBIO map) was considered for the Amazon in order to maintain consistency with pasture estimates for the other biomes (in particular with the Cerrado, where pastures are clearly distinguished from agriculture). However, using PROBIO 2002 data (Fig. 3), the classification on pastures, cropland and cropland/pasture shows that farming and grazing areas in the Amazon are spatially closely related and mostly continuous. According to data from PROBIO, the cropland/pasture combination occupies about 97,000 km^2. When the area of pasture and those under deforestation process are added, this corresponds to a total of approximately 450,000 km^2. PRODES data indicate about 600,000 km^2 of cleared area in the Amazon up to 2008, from

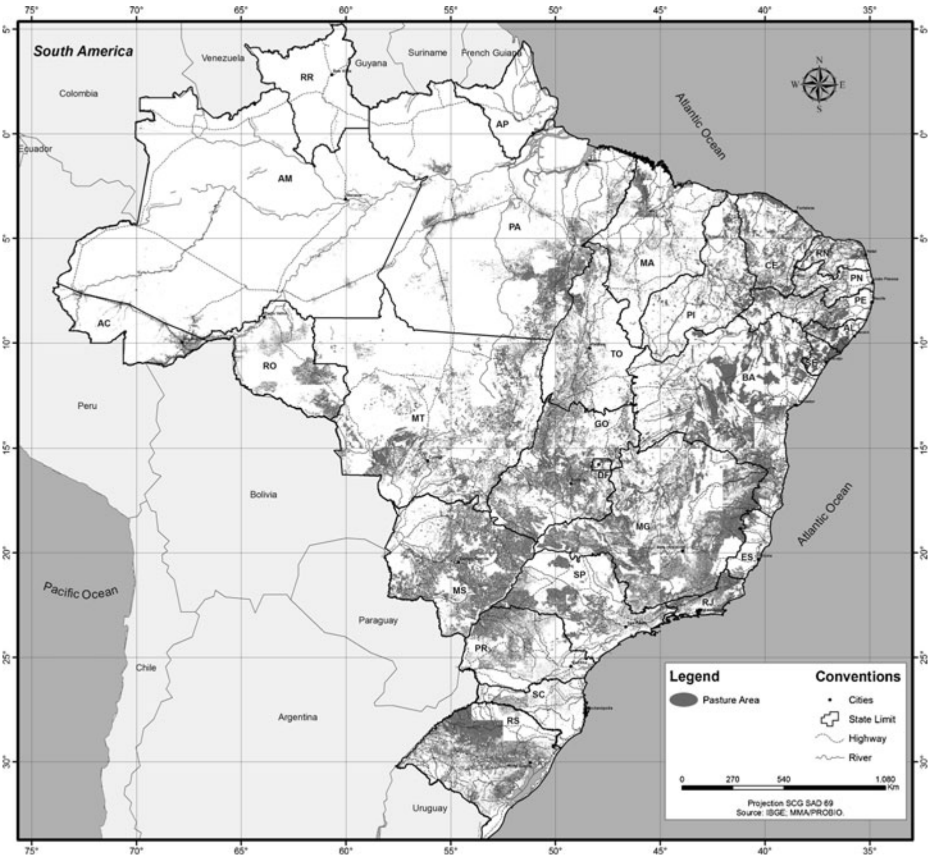

Fig. 2 Area distribution of cultivated pastures in Brazil (source: PROBIO 2004)

which, between 70 % and 80 %, as shown in census data, are comprised of grassland, resulting in total pasture area ranging between 420,000 and 480,000 km^2. Therefore, the two sources can be seen to be roughly similar in their estimates.

Table 1 Area of cultivated pasture in Brazilian biomes (PROBIO data)

Biomes	Total area (km^2)	Area of pasture (km^2)	Pasture/Biome (%)	Pasture Biome/Pasture Brazil (%)
Amazon (tropical rainforest)	4,199,043.4	245,808.2	5.9	16.5
Caatinga (tropical scrubland)	827,954.2	293,756.4	35.5	19.8
Cerrado (tropical savanna)	2,040,065.5	546,250.9	26.8	36.8
Atlantic Forest (tropical-subtropical moist forest)	1,117,861.6	286,295.7	25.6	19.3
Pampa (subtropical grasslands)	165,813.3	96,735.1	58.3	6.5
Pantanal (seasonal flooded grasslands)	151,180.8	16,517.8	10.9	1.1
Brazil	8,501,918.8	1,485,364.1	–	–

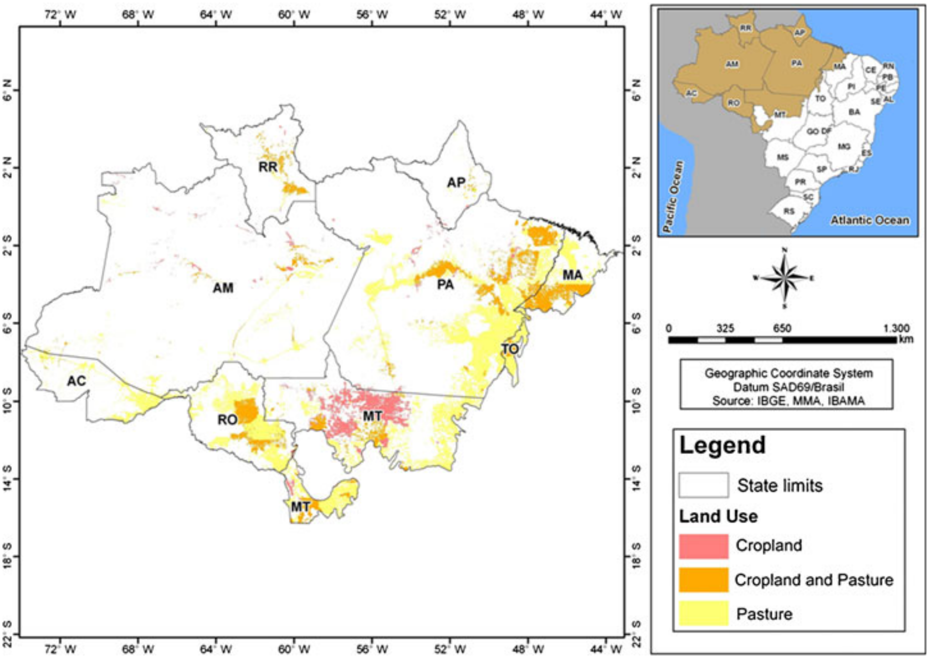

Fig. 3 Distribution of pastures, agriculture and pastures/agriculture for the Amazon according to PROBIO (2004)

2.2 Extension of burned pastures in Brazil

The extent of the burned area was mapped using the product MCD45A1 (MODIS collection 5, http://modis.gsfc.nasa.gov/), which generates, pixel by pixel, information on the burned area with monthly frequency and spatial resolution of 500 m. Basically, the algorithm detects, in short time series, rapid changes in daily surface reflectance (BRDF) (MODIS bands 2 and 5; Terra and Aqua data), thus mapping the spatial extent of recent fires, excluding fires from previous years (Roy et al. 2005; Boschetti et al. 2007). For this study, specifically, only the most confidently detected pixels were utilized (Boschetti et al. 2009).

Considering the entire country during the 2002–2008 period (at monthly frequency), 1365 MCD45A1 tiles were acquired and processed according to the flowchart shown in Fig. 4.

2.3 Estimate of emissions of GHG and other trace gases and aerosol particles from burning associated with pastureland establishment and maintenance in Brazil

An estimate for biomass burning emissions of specific chemicals (CO_2, CH_4 and N_2O) is obtainable by taking the product of the volume of biomass burned and an emission factor (fraction of mass of each compound emitted per mass of fuel burned, on a dry mass basis). The estimation of the biomass burned can be accomplished using the above-ground biomass density, the combustion factor (the fraction of the fuel load actually combusted) and the burned area. Carbon dioxide (CO_2) emissions were considered in GHG emissions estimate from pasture establishment (replacement of natural vegetation by grasses), but not from fire used for pasture maintenance (for this only other gas species were considered). A thorough review of measured biomass burning emission factors was presented by Andreae and Merlet (2001) and Longo et al. (2009).

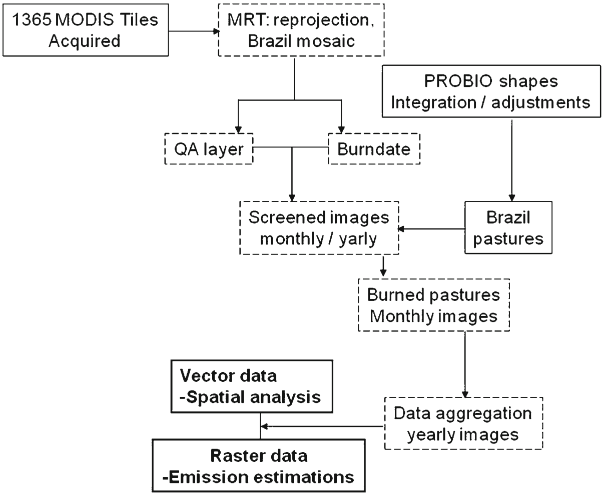

Fig. 4 Flowchart depicting the organization, processing, and analysis of the MCD45A1 product over the pasture sites in Brazil

For this study, a literature survey was conducted to estimate the values for above-ground pasture biomass in different states of Brazil. The mean value for different ecosystems and for grass species in Brazil is 5 Mg ha^{-1}, while for the Cerrado and Amazon states this figure decreases to 4.1 and 3.5 Mg ha^{-1}, respectively. Pastures are usually subjected to maintenance burns every 2–3 years for 10–20 years (Guild et al. 1998) before they are abandoned or converted to other uses. Since cattle ranching expansion is one of the main drivers of deforestation in Amazonia (Becker 2001, 2004; Margulis 2004; Escada et al. 2005; Américo et al. 2010), and pasture is the main land cover inside deforested areas, according to the two most recent agricultural censuses (IBGE 2009), pasture burning is the prevalent type of fire in Amazonia on an area basis.

2.4 Estimates of GHG emissions from new pasture areas in the Amazon and Cerrado between 2003 and 2008

In order to estimate emissions related to cattle ranching from deforestation and burning as described above, we combined detailed annual deforestation maps produced by the National Institute for Space Research (INPE) with 2006 agricultural census data (The Brazilian Institute of Geography and Statistics—IBGE), using a spatially explicit approach proposed by Aguiar (2006) and Espindola et al. (2012).[2] In the absence of other annual land use change maps available for the whole region, this approach provides a fair estimate of the amount and location of new pasture areas across the Legal Amazon (Fig. 5). Additionally, it includes aspects of intra-regional heterogeneity in the model (Loarie et al. 2009), both in terms of land use change process (Becker 2004; Aguiar et al. 2007; Almeida et al. 2010) and biomass present in different vegetation types distributed over the region (Saatchi et al. 2007). This last aspect influences directly the amount of gases released when the forest is destroyed.

The emission model applied in this study refers to the models developed by INPE (Aguiar et al. 2009, Technical Report) and Aguiar et al. (submitted) to estimate deforestation emissions in Amazonia, including the relative contribution of new pasture establishment.

[2] Municipality based census data provides information on the relative percentage of pasture areas in relation to other agricultural land uses. Assuming the sum of these land uses cover the deforested area, we distribute these percentages over the deforested areas in each municipality.

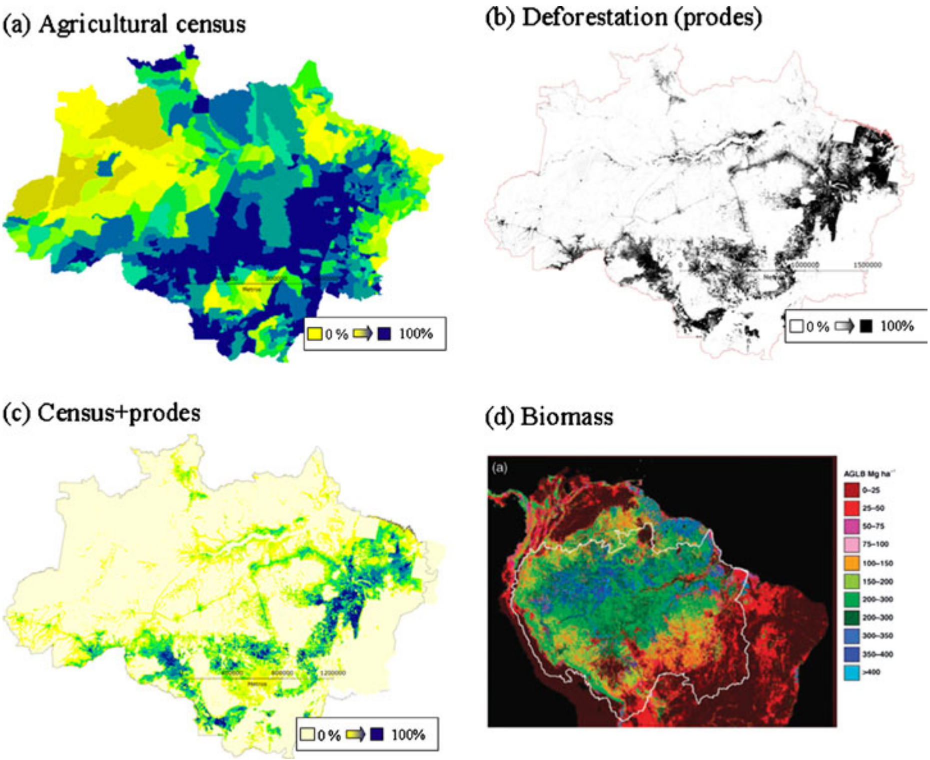

Fig. 5 Spatial information used to compute deforestation emissions related to pasture establishment in Amazonia: **a** Percentage of pasture area in 5×5 km^2 cells according to 2007 Agricultural Census (source: IBGE 2009); **b** Percentage of deforested areas in 5×5 km^2 cells (INPE 2009); **c** Percentage of pasture areas in 5×5 km^2 cells combining 2007 deforestation and 2006 agricultural census information (source: this study); **d** Biomass map (source: Saatchi et al. 2007)

It combines the new deforested areas for pasture and forest biomass using spatially explicit information derived from Saatchi et al. (2007), at 5×5 km^2 resolution. The model considers a broad dynamic of deforestation processes, including timber exploitation, fire, above and below ground biomass decay, and secondary products decay—as elemental carbon (C) and wood products (Aguiar et al. submitted). The deforestation dynamic and pasture implementation considered by Aguiar et al. (submitted) propose that the first fire consumes 50 % of the biomass, and the remaining C is emitted to the atmosphere in the following years.

Cerrado landscape comprises a mosaic of open grasslands to woodlands depending on the co-existence and density of woody and herbaceous strata. Among the savanna formations, the cerrado sensu stricto is the most extensive vegetation type, occupying about 70 % of the region and is characterized by a canopy cover ranging from 20 % to 60 %. Most surveys of biomass were conducted in areas of cerrado sensu stricto. In this study, we used biomass values estimated by Ottmar et al. (2001) since they considered the different components of total biomass, sites in different locations and presented a range of variation within each vegetation type. The native Cerrado, generally lower in C stocks than the humid forest, has larger stock in the belowground biomass in the different physiognomies, especially in grasslands due to the dense root systems of grasses. The ratio belowground biomass/living aboveground biomass defined by Castro and Kauffman (1998) for open cerrado (2.6) was used. These authors report that 70 % of root biomass is concentrated in the first 30 cm of soil. Due to the smaller number of studies on belowground biomass and methodological differences between them, alternately, we calculated the total biomass with a conservative ratio of belowground biomass/living aboveground biomass (1.5). We used the value of 0.47 to convert biomass to C according to Intergovernmental Panel on Climate Change (IPCC 2006) guidelines for national inventories.

2.5 Estimate of emissions from enteric fermentation and wastes

To calculate emissions distribution in pastures among biomes, an estimate of the area in pasture in each biome was obtained for each Brazilian state. The proportional distribution of pastures x biomes in each state was then used as a basis for allocating cattle head and animal-related emissions of CH_4 and N_2O. The latter emissions estimates were generated state-by-state using a model expressing herd and nutritional composition developed by the Brazilian Enterprise for Agricultural Research (Embrapa), for a reference scenario, for the 2006–2008 period.

The Embrapa model takes into account the structure of cattle herds including animals of different age cohorts, males and females, lactation characteristics, and differential use of supplemental feed rations as a proportion of the national herd. These dimensions are used to simulate emissions of CH_4 from enteric digestion and N_2O emissions associated with manure decomposition for each state's cattle herd (using the IBGE Annual Municipal Livestock estimates of total herd size), in accordance with IPCC emission factors as adjusted for Brazilian conditions (additional data are given in online resource 1).

3 Results

3.1 Extension of burned pastures in Brazil

For the period from 2003 to 2008, the year 2007 showed the largest area burned, for both the major land cover types in Brazil and pasture areas; 170,120 km^2 and 18,804 km^2, respectively (Fig. 6). Among biomes, and for all years considered, the Cerrado, followed by the Amazon, had the greatest extent of burned areas, both in relation to their total areas, as well as for areas converted to pasture (Fig. 7 and Table 2).

3.2 Emissions of GHG (except CO_2), trace gases and aerosol particles from burning associated with pastureland establishment and maintenance in Brazil

The biomass burned annually associated with forest and Cerrado conversion to pastureland and its annual maintenance contributes significantly to the atmospheric loading of pollutants in Brazil. It is important to report the emission of aerosol particles, other GHG and trace gases which contribute to the formation of ozone in the troposphere and strongly affect the oxidizing power of the atmosphere, cloud dynamics and microphysics, and C uptake by the forest. In addition to water vapor and CO_2, biomass burning is a major source of other compounds such as carbon monoxide (CO), volatile organic compounds, nitrogen oxides (NO_x), hydrocarbons (CH_4 and NHMC) and organic halogen compounds (Andreae and Merlet 2001). In the presence of abundant solar radiation and high concentrations of NO_x, the oxidation of CO and hydrocarbons results in ozone (O_3) formation. Undoubtedly, biomass burning emissions have a strong impact on the tropospheric and stratospheric

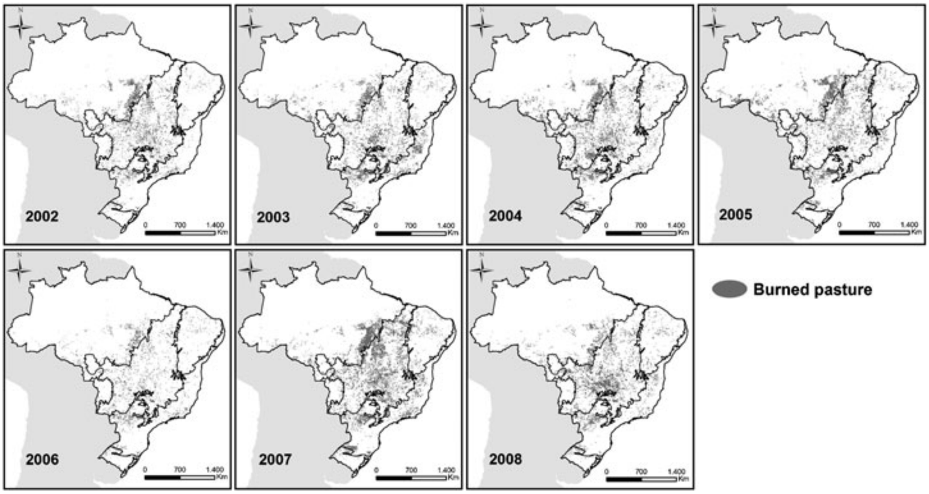

Fig. 6 Distribution of burned pasture areas (2002–2008), in relation to Brazilian biomes

chemical composition and is an important agent of weather and climate change. Therefore, the estimation of the amounts injected into the atmosphere is a relevant issue.

Cerrado fires events rapidly consume the above-ground biomass (Coutinho 1990; Ward et al. 1992; Kauffman et al. 1994; Andrade et al. 1999). Residual smoldering combustion normally accounts for about 10 % of fuel consumption (Bertschi et al. 2003). Deforestation fires feature much greater total aboveground biomass than Cerrado fires: e.g. 288 (n=1), 402 (n=1), 265 (n=1), 349±21 (n=7), and 292 (n=1) ton ha^{-1}, respectively, as reported by Carvalho et al. (1998, 2001); Fearnside et al. (1993); Guild et al. (1998); and Ward et al. (1992). Although the majority (80–90 %) of the fire emissions derives from deforestation in the Amazon and Cerrado, pasture maintenance also contributes significantly to the bulk

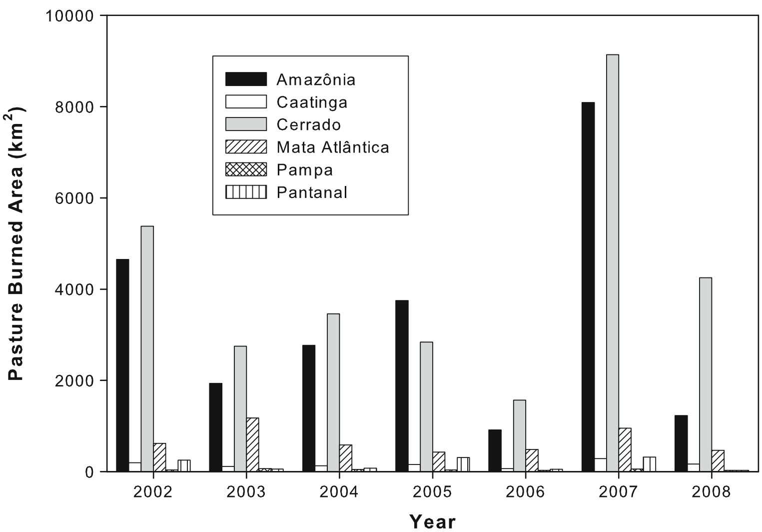

Fig. 7 Extension of burned pastures (2002–2008) in relation to the Brazilian biomes

Table 2 Burned area in Brazil (for all land cover types and pastures) for the 2002–2008 period

Year	Burned Pasture (km^2)	Total Burned Area (km^2)
2002	11,122	81,320
2003	6,172	48,258
2004	7,209	68,798
2005	7,600	78,109
2006	3,518	38,047
2007	18,804	170,120
2008	6,201	57,667

emission. Pasture fires are intermediate in total aboveground biomass and fuel characteristics between Cerrado and Amazon forest deforestation fires, because residual wood debris from the first deforestation fire on the site usually persists for many years. Table 3 summarize the emissions from vegetation fires associated with pastureland conversion and maintenance in the Amazon and Cerrado biomes (pastures established after 2002) between 2003 and 2008, respectively. Emissions from the Amazon fires contribute to the total with 50 % for N_2O and NO_x, 70 % for CO, CH_4, NHMC and aerosols and 80 % for CO_2.

Table 4 presents the emissions of CO_2eq (Mt) between 2003 and 2008 from burning for pasture maintenance related to pastures established up to 2002 (data from PROBIO, 2004) for all Brazilian biomes. The total amounted emitted during the period is 3.4 Mt CO_2 eq and burning of pastures in the Amazon and Cerrado represent 86.8 % of this value (1.26 and 1.69 Mt CO2eq, respectively). The emission of CO_2eq related to burning of pastures in all other Brazilian biome was 0.45 Mt. Deforestation rates for the other biomes associated with pastures between 2003 and 2008 are not yet available.

Table 3 Emissions (Mt) of GHG and other important trace gases and aerosol particles from fire activities associated with cattle in the Amazonia and Cerrado (deforestation+burning and pasture maintenance) between 2003 and 2008

Year	Biome	CO_2	CH_4	N_2O	CO	NMHC	NO_x	PM2.5	PM10
2003	Amazonia	581	1.02	0.022	18.1	1.34	0.289	2.458	3.086
	Cerrado	121	0.380	0.021	8.438	0.454	0.241	1.024	1.394
2004	Amazonia	651	1.27	0.028	22.1	1.64	0.341	3.006	3.165
	Cerrado	121	0.381	0.021	8.466	0.455	0.242	1.026	1.397
2005	Amazonia	626	1.08	0.022	19.4	1.42	0.286	2.622	3.292
	Cerrado	121	0.381	0.021	8.480	0.456	0.243	1.027	1.399
2006	Amazonia	580	0.97	0.020	17.5	1.28	0.259	2.359	2.967
	Cerrado	121	0.377	0.021	8.365	0.450	0.238	1.018	1.384
2007	Amazonia	525	0.62	0.011	12.27	0.88	0.177	1.633	2.061
	Cerrado	121	0.392	0.022	8.790	0.473	0.254	1.051	1.441
2008	Amazonia	481	0.66	0.011	12.82	0.93	0.183	1.711	2.157
	Cerrado	121	0.380	0.021	8.439	0.454	0.241	1.024	1.394
Total	Amazonia	3444	5.6	0.113	102.2	7.49	1.506	13.79	16.73
	Cerrado	726	2.29	0.127	50.98	2.742	1.459	6.171	8.408

Includes only pastures installed between 2003 and 2008

Table 4 Emissions of CO_2eq (Mt) from burning, between 2003 and 2008, for pasture maintenance related to pasture installed until 2002 (data from PROBIO) for all Brazilian biomes

Biome	2003	2004	2005	2006	2007	2008	Total
Amazon	0.16	0.20	0.25	0.09	0.47	0.10	1.26
Cerrado	0.23	0.25	0.19	0.15	0.53	0.34	1.69
Caatinga	0.01	0.01	0.01	0.01	0.02	0.01	0.07
Atlantic Forest	0.10	0.04	0.03	0.05	0.06	0.04	0.31
Pampa	0.01	0.00	0.00	0.00	0.00	0.00	0.02
Pantanal	0.00	0.01	0.02	0.01	0.02	0.00	0.06
Total	0.50	0.50	0.50	0.30	1.10	0.50	3.40
Sum biomes without Amazon and Cerrado	0.12	0.06	0.06	0.06	0.10	0.05	0.45

3.3 Estimates of GHG from new pasture areas in the Amazon and Cerrado between 2003 and 2008

Deforestation rates in Amazonia (INPE 2009) show a reduction trend in the past 4 years, although the total deforested area in the 2003–2008 period was still high, close to 110,000 km^2. Table 5 presents the total and new pasture areas computed for 2003 to 2008 combining PRODES spatial data[3] and census data according to the methodology described by Aguiar (2006). As these results show, even with the decrease of deforestation rates from 2005 onwards, there is a tendency for pasture to increase its relative importance as the primary activity responsible for replacing the native vegetation.

Accumulated deforestation emission values related to pasture establishment from 2003 to 2008 were roughly 3450 Mt CO_2eq or 575 Mt/year (considering CO_2, CH_4 and N_2O), Table 3. As observed with the deforestation and pasture area information, shown in Table 2, the contribution of pasture to land use change related emissions in the Amazon is substantial, accounting for more than 75 %, and increasing up to 80 % in 2008, which indicates that this new deforestation is taking place in municipalities in which cattle ranching prevails.

For the Cerrado biome, The Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) indicated a cumulative deforestation of 85,074.87 km^2 from 2003 to 2008, or 14,179.14 km^2 annually. Thus, the total deforested area in the Cerrado is currently 975,636 km^2 or 47.91 % of the total area of the biome.

Deforestation rates in the Cerrado varied during the past 15 years. The mean annual deforestation rate from 1994 to 2008 was 16,380 km^2/year (total deforested area of 229,332 km^2). However, in the 1994–2002 period, the rate was 18,031 km^2/year and decreased to 14,179 km^2/year between 2002 and 2008.

As deforestation data for 2008 have not yet been released by land use category, we estimated the increase of pasture area in the Cerrado biome for the 2003–2008 period as all deforestation detected up to1km from any previous PROBIO pasture polygon. Based on this approach, the pasture area increase, from 2003 to 2008, was about 48,000 km^2; i.e. nearly 56.5 % of all new clearings in the Cerrado were directly related to the expansion of cattle ranching. Thus, by 2008, the Cerrado biome was estimated to have had a total of approximately 594,251 km^2 of cultivated pastures.

[3] There is a difference in the numbers computed this way and the official rate, which is computed using a specific formula to account for the time scaling in the year (see INPE 2009 for details). In our current models, we use directly the spatially derived information, disregarding the official rate computation approach.

Table 5 Estimated emissions from deforestation attributed to pasture establishment in Amazon (combining deforestation and census information)

Year	New pasture areas		Emissions		
	New pasture areas—Prodes increment+census 2006 (km^2)	% new pasture/new deforestation (%)	Total emission related to the deforestation process (MtonCO_2eq)	Pasture related emission[a] (MtonCO_2 eq)	% pasture/ deforestation emission (%)
2003	18,981	76 %	849.0	628.0	74 %
2004	22,409	75 %	934.0	701.0	75 %
2005	20,058	76 %	878.0	685.0	78 %
2006	18,761	79 %	783.0	610.0	78 %
2007	8,346	80 %	695.0	556.0	80 %
2008	9,256	80 %	632.0	506.0	80 %

[a] Fraction of the total emission related to the deforestation process

Values of C in total biomass (above and below ground) varied in a range between 33.6 and 45.4 tC/ha (range 26 %). Thus, between 2003 and 2008, the emissions from deforestation and burning (including CH_4 and N_2O emissions) of Cerrado areas resulted in the emission of 1449.4 Mt CO_2eq. Of this total, the conversion to pastures corresponds to 818.9 Mt CO_2 eq (or a mean of 136.5 Mt CO_2 eq/year).

3.4 GHG emissions from cattle

The vast majority of cattle in Brazil are pastured on grass land dominated by exotic grasses (*Brachiaria* spp.). Emissions of GHG from enteric fermentation related to the cattle herd present in the Cerrado and the Amazon (according to IBGE annual livestock estimates) correspond to approximately 39 % and 24 % of the emissions from the total Brazilian herd, respectively (Table 6). In the case of the Amazon, the annual emissions from enteric fermentation correspond to 13 % of the emissions from deforestation and burning while in the Cerrado this percentage increases to 68 %. Most of these emissions can be attributed to enteric methane rather than to N_2O, since waste materials are widely dispersed on extensive range land.

4 Discussion

Pasture is highly concentrated on large ranches some of which are vertically integrated with a globally important meatpacking industry (Table 7), but despite this concentration, pasture management is extensive at low stocking rates even on the largest ranches. Only a small proportion of cattle are raised in feedlots, though there is an increasing trend toward feedlot production (over 4 million head in 2006), particularly by large slaughterhouses at the end of the growth cycle. Emissions related to feedlots, including the production of grain are still insignificant, since most animals spend just the last 3 months of their growth cycle in a feedlot. Some pasture-fed cattle are raised on pasture while supplemented with grains. Of those beef cattle farms with more than 50 head of cattle (534,630 ranches, constituting over 70 % of the national herd), only 20,864 (4 %) raise cattle in confinement, although 166,126 (31 %) use some form of supplemental rations (IBGE 2009) (Tables 6, 8).

Table 6 Emissions (total and relative values) of GHG from enteric fermentation in Cerrado, Amazon and other Brazilian biomes

		Emissions from cattle ranching (Mt CO_2eq^a)—Reference Scenario		
		2006	2007	2008
Cerrado	Total	94.1 (39.4 %)	91.9 (39.4 %)	92.2 (39.4 %)
	CH_4	88.8	86.7	87.0
	N_2O	5.3	5.2	5.2
Amazonia	Total	57.7 (24.2 %)	57.2 (24.5 %)	57.4 (24.5 %)
	CH_4	54.4	54.0	54.2
	N_2O	3.3	3.2	3.2
Other biomes	Total	87.2 (36.4 %)	84.3 (36.1 %)	84.3 (36.1 %)
	CH_4	82.3	79.5	79.5
	N_2O	4.9	4.8	4.8
Total Brazil		239.0	233.4	233.9

[a] Global Potencial Warming: $N_2O=310$; $CH_4=21$

Cattle ranching intensification can reduce pasture area needed for the same beef output, thus affecting deforestation rates. The mixture with grains or other forages can improve digestibility of rations and help to mitigate enteric methane emissions. At the same time, however, the production of the necessary feed grain can result in an increase of GHG emissions through higher inputs of reactive nitrogen.

4.1 Other sources of GHG from cattle ranching

Besides indirect emissions from feed production, other important sources of GHG derived from land use for cattle ranching and production systems associated were not quantified in this study. These include those emissions associated with use of inputs (such as fertilizers), energy and transportation. However, as almost all the Brazilian production systems are low input, levels of emissions associated with these inputs are very low. In a life cycle analysis of the Brazilian beef sector, Cederberg et al. (2009) found that petrol-related inputs plus transportation-related emissions to export to Europe would total only about 3 % of the emissions directly related to production (CH_4 emissions from enteric fermentation plus N_2O emissions related to animal wastes). Although Brazil applies 678,000 t of nitrogen fertilizer to grain crops annually, chiefly corn and soybeans, of which about 40 % are destined to livestock rations (FAO 2006), the proportion of associated emissions due to cattle production

Table 7 Number of cattle farms and cattle herd by pasture size. Source: IBGE (2009)

Pasture size	Number of cattle farms	Percent, %	Number of Cattle	Percent, %
No pasture	477,183	17.9	7,796,346	4.5
<50 ha	1,793,771	67.1	41,048,063	23.9
50–200 ha	276,494	10.3	32,782,449	19.1
200–500 ha	77,307	2.9	25,362,991	14.8
>500 ha	48,421	1.8	64,623,488	37.7

Table 8 Total GHG emissions in CO_2 eq (Mt) emissions between 2003 and 2008

Biome	Process	2003	2004	2005	2006	2007	2008
Amazon	Total Deforestation + burning (Deforestation related to pasture + burning)	971.0 (718.0)	951.0 (715.0)	872.0 (680.0)	559.0 (438.0)	532.0 (423.0)	552.0 (442.0)
	Animal emissions				57.7	57.2	57.4
	Emissions from burning of pastures (until 2002)	0.16	0.20	0.25	0.09	0.47	0.10
Cerrado	Total Deforestation + burning (Deforestation related to pasture + burning)	241.6 (136.5)	241.6 (136.5)	241.6 (136.5)	241.6 (136.5)	241.6 (136.5)	241.6 (136.5)
	Animal emissions				94.1	91.9	92.2
	Emissions from burning of pastures (until 2002)	0.23	0.25	0.19	0.15	0.53	0.34
Other biomes	Animal emissions				87.2	84.3	84.3
	Emissions from burning of pastures (until 2002)	0.12	0.06	0.06	0.06	0.10	0.05

is considerably lower than that for other livestock, particularly swine and poultry, as cattle in Brazil are mainly raised on grass.

Despite the enormous scale of pasture expansion in Brazil, there is still no clear understanding of the direction of the resulting changes in soil C stocks. For the Amazon region, Fearnside and Barbosa (1998) reported that conversion of Amazon forest to pasture can produce a net soil C sink (well managed pasture) or a net C source (overgrazed pasture), depending on management. Neill and Davidson (1999) observed that conversion of forest to pasture in the Amazon occurs on a variety of soils and in regions that differ in the amount and timing of precipitation. The sequence leading to pasture development also differs. Some pastures are created by planting grasses directly into forest slash, while others are created after 1 or 2 years of annual cropping or after a cropping and fallow sequence. The choice of grass species and practice of interplanting with legumes also differ. These factors can influence whether a pasture soil will become source or sink of carbon. Once established, pasture management by stocking rate, burning frequency, effectiveness of weed control, fertilizing or disking may also affect soil C balance (Neill and Davidson 1999).

The soil compartment is the largest component of C in Cerrado ecosystems. Studies have shown that the period of time since conversion has a significant effect on C stocks and fluxes in the Cerrado, which is related to how the converted systems are managed. In general, soil C stocks up to 100 cm depth, under different Cerrado vegetation covers and soil types, range from ~97 to 210 MgC ha^{-1} (Bustamante et al. 2006) with C content increasing with clay content. Well-managed cultivated pastures may provide enough organic C to maintain or even increase native C contents (Roscoe et al. 2001) due to high ecosystem gas exchange rates (Santos et al. 2004). However, at least half of the pastures in the Cerrado are in different stages of degradation due to poor management (Oliveira et al. 2004) with C inputs too low to sustain the high soil C storage under native Cerrado. Therefore, the potential of soil C sequestration under pastures lies heavily on the recovery of degraded pastures. For example, in Rondônia and Mato Grosso states, soil stocks decrease by about 0.28 Mg C ha^{-1} yr^{-1} in degraded pastures and increase up to 0.72 Mg C ha^{-1} yr^{-1} under improved management (Maia et al. 2009).

It has been estimated that 50 % to 80 % of pastures in the Amazon and Cerrado are degraded, as indicated by the dominance of invading species, common occurrence of termite hills, loss of soil fertility, and decrease in biomass (Serrão et al. 1993; Vieira and Kichel 1995; Barcellos 1996; Perón and Evangelista 2004). Thus, adoption of improved management practices would significantly reverse the soil C loss.

4.2 Policy recomendations

Findings of this study strengthen the perception of how Brazil's cattle industry provide an unparallel opportunity for mitigation of GHG emissions. A general consensus has emerged from recent multi-stakeholder dialogues such as those convened by Amigos da Terra-Amazônia Brasileira and other organizations (International Workshop on Solutions for Deforestation and GHG Emissions Caused by the Expansion of Cattle Ranching, Acre and São Paulo, August, 2009), as well as the Leather Working Group, with the participation of large companies and NGOs (LWG 2009–2011) and the Working Group on Sustainable Beef (GTPS 2011), that with concerted action it is possible to promote both the rehabilitation of degraded land and the spatial intensification of livestock activities, with higher land productivity. The key challenge is how to avoid that the much needed measures to increase productivity do not end up generating increased pressure towards further spatial expansion, as well as displacement of less capital-intensive, smallholder ranching.

There is also consensus on the fact that policy measures to this end should be coordinated, and mutually supportive, between public and private sectors, with harmonization of credit and procurement policies.

Finally, it became progressively clear that most of investments needed to this end would also contribute to increase the economic return of the activity as well as promote job generation, thereby resulting in economic, social and environmental benefits.

Some priority action areas to effectively address the sources of emissions described in this report are identified in the considerations listed below.

1. Mitigation potentials in the Brazilian cattle industry are significant and do not imply cutting back on current production. Actually, they can be compatible with a moderate increase in production. According to the data presented in this study, key mitigation sources should include reduction of deforestation and regeneration of secondary forest, reduction in enteric fermentation, recuperation of degraded pasture and soils and elimination of fire in pasture management.
2. Substantial investment in quality of pasture and related technologies such as, among others, rotational grazing or introduction of legume pasture, is essential to all forms of mitigation: it is a necessary condition, albeit not sufficient alone, for concentrating current cattle herd in a smaller area, reducing pressure for new spatial expansion, regenerating forests, recovering degraded pasture, improving the diet of animals among others.

   Several technologies with potential for mitigation of GHG emissions need further research and development. This would include the development of grass and legume species with lower emission potential, additives (e.g., ionophores), propionate precursors and vaccines. Therefore, there should be a major effort of Brazilian and international research funding agencies towards research on mitigation of GHG emissions from livestock.

3. Methane emissions by enteric fermentation can be reduced significantly as a result of increased productivity, including genetic improvement in the herd, use of supplemental rations and provision of mineral salt, which allow for faster fattening and higher survival rates resulting in a much shorter average lifespan in relation to current standards of extensive ranching.
4. Measures to increase organization and transparency throughout the supply and trade chains would facilitate the adoption of selective remuneration, instead of flat criteria, essential to stimulate and reward investments on the part of ranchers. Also, the role of retail is critical, since it is the segment where the largest part of the value is added: adoption of consistent procurement policies that include rewards for sustainable sourcing as well as for quality of beef and leather can have a significant impact.
5. However, it is important that procurement policies are based on transparent criteria that duly target improving the GHG balance of products, not just on negative criteria of exclusion, such as simple black lists. In addition, procurement policies should be backed by traceability and by independent, third-party verification or certification.
6. The financial sector should harmonize its policies towards ranchers and towards meatpackers, so as to facilitate the establishment of low C trade chains. The financial sector might benefit as a result of bundling and underwriting resulting carbon credits in official or voluntary markets. Carbon benefits should be focused on improving price conditions at the farmgate and not only at slaughterhouses.
7. Establishment of industrial capacity (large meatpacking plants) needs to be subject to proper zoning on both territorial and biophysical criteria, since it was a key driver towards uncontrolled and unprecedented expansion of the ranching activity in the central part of the past decade. Slaughter capacity expansion should be conditioned upon commensurate productivity improvements. This is a critical government function, not just because zoning regulation implies public policy intervention but also because most of the financing for this segment comes from state development banks. The systematic monitoring, through remote sensing and periodic census data, of the pasture areas, for both assessing its spatial distribution and productivity/cattle occupation, as well as for detecting, at early stages, ongoing degradation processes is also a crucial aspect of the government's functions.
8. Another key challenge for public policy is related to reducing the expectation of impunity arising from the practices of occupation of public land as well as environmental crimes: lack of enforcement in these areas enables speculative and destructive occupation to outcompete investments in recuperation of degraded land, reforestation associated with intensification and establishment of long-term pasture management on existing production units. There are clear links between such impunity, rampant land speculation and forest degradation, particularly in the Amazon.
9. Since ranching is usually more closely associated with the opening of frontiers, being displaced by more intensive uses of land, it is important that public policies consider the leakage of ranching when implementing their sectoral policies towards other activities that—depending on market conditions—can generate pressure for land. Integrated crop-livestock systems should be promoted as an alternative.
10. On the international level, it becomes clear that the establishment of a broad, sustainable and long-term approach for Reduction in Emissions from Deforestation and Forest Degradation (REDD-plus), including all the forms of forest C (avoided deforestation, conservation of forest stocks and forest and pasture regeneration), could substantially favor the transition needed to a low C livestock sector in Brazil (and in other countries). Its role should be seen as catalytic in relation to good practices and national programs, rather than an outright solution.

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