Agricultural Systems 143 (2016) 86–96

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Impact of the intensification of beef production in Brazil on greenhouse gas emissions and land use

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A R T I C L E I N F O

Article history:
Received 17 April 2015
Received in revised form 30 November 2015
Accepted 15 December 2015
Available online xxxx

Keywords:
Beef production
Brachiaria spp.
Brazil
Forage legume
Greenhouse gas emissions
Life-cycle analysis

A B S T R A C T

Brazil has the largest herd of beef cattle in the world, estimated at approximately 200 million animals. Production is predominantly pasture-based and low input and hence time to slaughter is long, which promotes high methane (CH_4) emissions per kg of product. The objective of this study was to investigate the impact of increasing animal productivity using fertilizers, forage legumes, supplements and concentrates, on the emissions of greenhouse gases (GHGs) in five scenarios for beef production in Brazil. A life cycle analysis (LCA) approach, from birth of calves to mature animals ready for slaughter at the farm gate, was utilized using Tier 2 methodologies of the IPCC and the results expressed in equivalents of carbon dioxide (CO_2eq) per kg of carcass produced. Fossil CO_2 emitted in the production of supplements, feeds and fertilizers was included using standard LCA techniques. The first four scenarios were based solely on cattle production on pasture, ranging from degraded *Brachiaria* pastures, through to a mixed legume/*Brachiaria* pasture and improved N-fertilized pastures of Guinea grass (*Panicum maximum*). Scenario 5 was the most intensive and was also based on an N-fertilized Guinea grass pasture, but with a 75-day finishing period in confinement with total mixed ration (TMR). Across the scenarios from 1 to 5 the increase in digestibility promoted a reduction in the forage intake per unit of animal weight gain and a concomitant reduction in CH_4 emissions. For the estimation of nitrous oxide (N_2O) emissions from animal excreta, emission factors from a study in the Cerrado region were utilized which postulated lower emission from dung than from urine and much lower emissions in the long dry season in this region. The greatest impact of intensification of the beef production systems was a 7-fold reduction of the area necessary for production from 320 to 45 m^2/kg carcass. Carcass production increased from 43 to 65 Mg per herd across the scenarios from 1 to 5, and total emissions per kg carcass were estimated to be reduced from 58.3 to 29.4 kg CO_2eq/kg carcass. Even though animal weight gain was lower in the mixed grass-legume scenario (3) than for the N-fertilized Guinea grass pastures (scenarios 4 and 5) GHG emissions per kg carcass were similar as the legume N_2 fixation input had no fossil-fuel cost. A large source of uncertainty for the construction of such LCAs was the lack of data for enteric CH_4 emissions from cattle grazing tropical forages.

1. Introduction

The recent report from the Brazilian government (MCTI, 2013) showed a reduction of 76% in greenhouse gas (GHG) emissions from the land use change and forestry (LULUCF) sector from 2005 to 2010, which was mainly attributable to the decrease in deforestation in Amazonia. In 2005, the LULUCF sector constituted 57% of all of Brazil's anthropogenic GHG emissions and with this decrease in deforestation, the total national emissions fell by 38% from 2032 Tg to 1247 Tg carbon dioxide equivalents (CO_2eq) in 2010. One consequence of this is that the agricultural sector, which represented 20% of all emissions in 2005, in the 2010 inventory now constitutes more than 35% of all emissions, of which over half (56%) are estimated to come from enteric methane (CH_4) and a further 18% from direct and indirect emissions of nitrous oxide (N_2O) from animal excreta deposited on pastures.

Over 94% of cattle in Brazil are raised for beef production and intensification is thought to lead to a reduction in the time to slaughter, pasture area and GHG emissions per kg of product (Berndt and Tomkins, 2013). According to the most recent statistics, 90% of beef cattle are raised and finished on pasture (ANUALPEC, 2015; Pedreira et al., 2015). In tropical regions, most production is on unfertilized pastures of grasses of African origin, mainly *Brachiaria* spp. Large responses in animal live weight gain (LWG) can be obtained with applications of

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http://dx.doi.org/10.1016/j.agsy.2015.12.007
0308-521X/

nitrogen (N) and phosphorus (P) fertilizer or with the introduction of forage legumes (Euclides Filho et al., 2002; Andrade et al., 2012). The manufacture of fertilizers, especially N, requires significant fossil fuel inputs and hence increases the overall GHG emissions of the production systems. However, it can be expected that these emissions will be more than compensated for by the reduction in the time taken to fatten the cattle, such that there will be an overall reduction in GHG emissions per kg product (Thornton and Herrero, 2010; Crosson et al., 2011). The same may also apply to the extra N_2O emissions resulting from N fertilizer additions and those emissions related to feed and supplement production. Supplying N via N_2-fixing legumes instead of applying N fertilizer eliminates entirely the fossil CO_2 emissions associated with fertilizer manufacture and N_2O emissions from legumes may be lower than from N-fertilized swards (Jensen et al., 2012).

Attention has been given by some authors to the potential of *Brachiaria* pastures to accumulate soil carbon (Bustamante et al., 2012; Assad et al., 2013) and the evidence indicates that more productive pastures will accumulate more soil C than degraded pastures (Braz et al., 2013). This sink for atmospheric CO_2 is finite, site dependent, and will asymptotically approach a new steady state after some years (Johnston et al., 2009). As we feel that there are insufficient data available at present to allocate factors of CO_2 mitigation to this phenomenon in the different scenarios, it is not considered in this study.

The objective of this study was to investigate the impact of increasing pasture productivity using fertilizers, forage legumes, supplements and concentrates, on the emissions of GHGs per kg of product in 5 different scenarios using published emission factors (EFs) from the Intergovernmental Panel on Climate Change (IPCC) and available Brazilian data.

2. Material and methods

2.1. Estimation of GHG emissions

Within the overall strategy for this study a life cycle analysis (LCA) approach was adopted, covering the full cycle of the whole herd from birth of the calves to mature animals ready for slaughter at the farm gate. However, unlike full LCA studies where all environmental impacts of activities are evaluated, in this study only GHG emissions were accounted for. The GHG emissions were expressed as a function of the unit mass (kg) of carcass weight. This kind of analysis is often known as a “carbon footprint”.

The comparison of the GHG emissions from each scenario was made using Tier 2 methodologies of the IPCC (2006) and for fossil CO_2 used in the production process standard life cycle analyses. The basic data on herd composition, animal characteristics and performance and pasture productivity were sourced from the available Brazilian literature. The GHGs accounted for were:

a. CH_4 from enteric fermentation and from cattle dung;
b. N_2O emissions from dung and urine deposited in the pasture or in confinement sheds and N_2O from fertilizer applications in the field; and
c. GHGs (principally fossil CO_2) emitted in the production, manufacture and transport of animal feeds, fuels, fertilizers, pesticides and other agrochemicals and in the manufacture of the equipment and machinery used in the production systems.

The GHG emissions from the construction of farm buildings and machinery and the production of veterinary products and pesticides were not included in the study. This was the case for other GHG life cycle studies on Brazilian beef as it is assumed that such emissions are almost insignificant (Cederberg et al., 2009; Evans and Williams, 2009; Dick et al., 2015; Ruviaro et al., 2015). For the same reason in this and other studies, emissions associated with production of seeds were not accounted for.

To compare each of the 5 scenarios (Table 1) on an equal basis, the emissions were calculated from herds based on 400 reproducing females in each case with 16 bulls (Table 3), which is typical herd for the Cerrado region (Euclides Filho, 2000). The basic information on the animal performance indicators for each scenario, displayed in Table 2, was taken from a wide range of Brazilian literature, which is cited in the footnotes to this Table. These data include digestibility of the acquired forage in the different phases of animal growth, characteristics and fertility indices of the cows in the herd, carcass yields and weights. The numbers and carcass weights of each category of animals slaughtered (replaced cows, and finisher males and females) are listed in Table 4.

Total GHG emissions were estimated in CO_2eq using the global warming potential (GWP) conversion factors of 25 and 298 for CH_4 and N_2O, respectively (Forster et al., 2007) and the results expressed as CO_2eq per kg carcass weight (CW) which is equivalent to a fraction of between 0.48 and 0.54 of total animal live weight at slaughter (see Supplementary Information – SS01).

For full transparency the calculations of all emissions and ancillary data are presented in the spreadsheet SS01 provided in the Supplementary Information.

2.1.1. Enteric CH_4 emissions

Enteric CH_4 emissions were calculated using the standard IPCC Tier 2 methodology based on gross energy requirements and digestible energy in feeds (IPCC, 2006). This methodology requires the live weight of adult male and female animals, and the LW and daily LWG of all other categories of younger animals as displayed in Tables 2 and 3. In addition, the digestibility and protein content of the consumed forage/ration is required (Table 2). Using the procedures described in the IPCC manual (Chapter 10, IPCC, 2006) the total gross energy of each category of animal was calculated and it was assumed that the proportion of the gross energy intake converted into CH_4 (the Ym value) was 6.5% for all scenarios except for the finishing stage of scenario 5 when the cattle were receiving concentrate and the Ym was assumed to be 3% (Johnson and Johnson, 1995). The total CH_4 production of the whole herd was calculated using the proportion of days in the year that each animal category was in the field or feedlot, the number of each category of animals that subsequently yielded the total annual CH_4 production of the herd (Table 3).

2.1.2. CH_4 emissions from dung

The CH_4 emissions from the dung were determined from the total fecal production from the estimated forage intake and the digestibility. Forage intake (dry matter— DM) of each category of animal was calculated from the metabolic weight of the animal ($LW^{0.75}$) and the digestibility of the consumed forage. The values for digestibility used in the different scenarios are displayed in Table 2 and the live weights of each category of animal in Table 3. We used the equation 10.23 from the methodology (IPCC, 2006) to calculate the CH_4 emissions factor from dung and equation 10.24 to calculate volatile solids (VS) production for equation 10.24. This is fully described in the Supplementary information Spreadsheet SS1.

2.1.3. N_2O emissions from bovine excreta

For the estimation of N_2O emissions from dung and urine, firstly the total N intake was calculated from the protein content (6.25 × N concentration) of the forage/ration (Table 2) and from the DM intake, calculated as for the estimation of CH_4 emissions from dung. The total N excreted was assumed to be the N intake minus N accumulated in the animal carcass (2.5% of LWG – Scholefield et al., 1991) and N exported in milk in the case of lactating cows. Recently some estimates have been made of N_2O emissions from dung and urine in Brazil. As the majority of beef production in Brazil is on poorly managed pastures (as in scenarios 1 and 2), the protein content in the acquired diet is low and the proportion of N deposited in the dung can often be equal to or