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Energy Analysis and Measurement of the Greenhouse Gas Emissions of Livestock Systems. A Comparison of Different Livestock Systems in the Eastern Brazilian Amazon

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Abstract

This paper introduces an assessment method based on the Planet method (2002). It aims to measure the energy inputs and outputs, their conversion efficiencies and the greenhouse gas (GHG) emissions in agricultural systems at the farm level. The method was applied to compare smallholder mixed dairy-beef livestock systems (SM) with two extensive and highly technical beef breeding-fattening (BB) and fattening (BF) systems, in the Eastern part of the Brazilian Amazon. It appears that SM farms are the lowest-level input system (13 koe ha^{-1} of pasture); therefore, they do not require substantial amounts of fossil-energy to produce the outputs. The BF system is the highest level inputs user (60 koe ha^{-1} of pasture). No significant difference was found for the BB system when compared to the BF and SM systems (38 koe ha^{-1} of pasture). In regards to the energy outputs, the SM system had the lowest production per hectare of pasture (30 koe ha^{-1} of pasture), while the BB system had an intermediate amount of energy production (68 koe ha^{-1} of pasture), and the BF system had the highest production (129 koe ha^{-1} of pasture). The only output from the BB and BF systems is beef, while the SM system produces beef obtained from the sale of male calves to the BF farms and also dairy products on the local market (essentially cheese). No significant difference was found between the three systems in terms of energy efficiency (average of 2.3). Finally, the GHG emissions were the highest for the BF system (7814 kg CO_2 ha^{-1} of pasture), intermediate for the BB system (2619 kg of CO_2 ha^{-1} of pasture), and the lowest for the SM system (1702 kg of CO_2 ha^{-1} of pasture). The major source of emissions differed for the three systems - burning practices for the SM farms; enteric fermentation for the BB farms; and the purchase of calves and burning practices for two-thirds and one-third of the BF farms, respectively. The energy inputs and outputs and GHG emissions expressed per ton of live weight produced were compared between the BB and the BF systems. No significant differences were found for the four indicators. According to other analyses, the three systems studied are low-level fossil energy users.

Keywords: Energy analysis; Greenhouse gas emissions; Livestock systems; Brazilian Amazon

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1. Introduction

Agriculture, particularly livestock farming systems, has become a primary societal challenge concerning environmental impacts from human activities. The publication of the report “Livestock’s Long Shadow” (Steinfeld et al., 2006), released by the FAO in 2006, emphasized the role of livestock in the environmental issues, making it responsible for 18% of the greenhouse gas (GHG) emissions of anthropomorphic origin. Livestock production is also accused to be a poor converter of energy and to be a major consumer of fossil energy for the production, transport, storage and feed processing. Brazil has the largest herd in the world, with 212 million cattle, and it is the number one beef exporter (IBGE, 2016) and represents 11.5% of the total GHG emissions from global livestock(Bustamante et al., 2012; Gerber et al.,2013).In Brazil, 19% of the national GHG emissions are due to livestock(Clerc et al., 2012), and it is the second country, after Indonesia, in terms of GHG emissions caused by land-use change, which represents 57% of the national emissions (Barreto and Silva, 2009). To limit the environmental impacts from livestock production, the Brazilian government promised to reduce its GHG emissions from 39% to 36% by 2020 (National Plan of Climate Change, 2007).

The Brazilian Northern region owns 20% of the national cattle herd, and it is the second center of beef production after the Center West region, composed of the Goiás, Mato Grosso and Mato Grosso do Sulstates (IBGE, 2016). Between 1990 and 2010, the Amazonian cattle population increased by 80%, which represented the highest rate in Brazil during this period (Miragaya, 2013). Actually, 75% of the deforested areas are dedicated to pasture (Barreto and Silva, 2009) and Amazonian livestock production is often criticized due to its low level of productivity because of its extensive systems. No study has been done to compare the diversity of these systems from an environmental point of view (Steinfeld et al., 2006) and little data are available to estimate the energy efficiency and the GHG emissions of livestock systems in the Amazon region. However, in the context of zero deforestation and of expansion of agriculture, livestock production in tropical areas, is facing a double challenge - on one hand it is facing a need in the increase of production, while on the other hand, it is facing the necessity of decreasing its environmental impacts.
This paper aims to compare different pasture-based livestock systems: the smallholder mixed dairy-beef livestock system based essentially on self-consumption, with two extensive and highly technical beef livestock systems (beef breeding-fattening system and beef fattening system) in terms of energy indicators, energy efficiency and GHG emissions, at the farm level, in the Eastern part of the Brazilian Amazon.

2. Materials and methods

2.1. Initial method of energetic analysis

The method used to calculate the energy balance and GHG emissions was based on the Planet method (2002), updated by Ges'tim (Gac et al., 2010) and Dia 'Terre (ADEME, 2011). The principle of life-cycle assessment was used, where each farm was considered as a closed system. The direct and indirect emissions of all the inputs used (since their manufacture) by the production process were considered as inputs of the system. Electricity, fuels, and gas were considered as direct energy. Indirect energy was represented by the indirect inputs of crops (fertilizers, phytosanitary products, irrigation water, seeds, etc.), herd (concentrates, fodder, veterinary fees, salts and minerals, drinking water, etc.), and the equipment and farm buildings (Bordet et al., 2010).The outputs of the system were the animal products (live animals and dairy products).Several indicators are calculated by the model: the energy outputs and inputs (kilogram oil equivalent - koe), and the energy efficiency corresponding to the relationship between energy outputs and inputs. Direct and indirect emissions of GHG were calculated, without taking into account the potential sinks of carbon from pasture and forest present on the farm. Livestock systems produce three main greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Direct emissions correspond to the CH_4 releasing from enteric fermentation from the ruminants; the N_2O from manure management; and theCO_2 from the fuel and electricity consumption and the burning practices. There is no off-set from the carbon sequestration coming from the growing pasture. Indirect emissions correspond to the use of fertilizers, phytosanitary products, animal foods, seeds, animal purchase, equipment and farm buildings (Bordet et al., 2010).The model converts CH_4 and N_2O into a CO_2 equivalent (IPCC, 2006) according their power of global warming(Meinshausen et al., 2009).All of the indicators were expressed per hectare of pasture.

This allows the comparison of different production systems and different areas. The model also gives the indicators per ton of live weight which allowed to make the comparison of the indicators per ton of live weight produced between the BB and BF systems.

2.2. Application of the model in Amazonian farms

The data were collected during three years between 2011 and 2014, through a questionnaire in order to get the quantities of inputs used and outputs produced on an average year on each farm. In the Amazonian context, the inputs corresponded to electricity and fuel as direct inputs and animal purchase, animal food, fertilizers, installation and equipment as indirect inputs. The outputs were the animal products (beef, milk and/or cheese) and the calf purchase. Twenty-two (22) farms, located at the Eastern Brazilian Amazon region, which are representative of the area as described by Poccard-Chapuis et al. (2005), were studied. Among these farms, two groups of farms were identified: Ten (10) low mechanized smallholder mixed dairy-beef farms (SM) producing essentially for local consumption and sell the surpluses of milk in the form of cheese at the local scale and the male calves to the beef fattening farms. These farms employ mainly family workforce. Twelve (12) extensive and highly technical farms which produce beef for the national or international markets and employ mainly hired laborers. In this group, two different livestock systems were described; six (6) beef breeding and fattening farms (BB) and six (6) beef fattening farms (BF). The two groups were separated for this study because the categories of inputs used for each group were different.

The size of the total area of the BF farms was 1.3 times larger than the BB farms, and the pastures and herd of the BF farms were also 1.3 times larger than the BB farms. The size of the total area of SM farms was, respectively, 66.4 and 38.5 times smaller than BF and BB farms, with the size of the pastures 48.1 and 37 times smaller, and the size of the herd was 62.3 and 46.6 times smaller. Legal reserves and permanent protection areas represent 55% of the total area of the SM farms, 53% of the BB farms, and only 40% for the BF farms. According to the Brazilian forestry code (Lei Nº12.651, de 25 de Maio, 2012), a minimum of 50% of legal reserve and permanent protection area have to remain on the farm. The main characteristics of the three livestock systems are presented in Table 1.

Table 1. System description, Beef Breeding-Fattening System (BB), Beef Fattening System (BF), Smallholder Mixed System (SM)

	Average			Minimum			Maximum			Standard deviation		
Livestock system	BB	BF	SM	BB	BF	SM	BB	BF	SM	BB	BF	SM
Farm area (ha)	2156	3719	56	785	500	25	5163	6950	100	1594	2623	25
Pasture area (ha)	1146	1490	31	500	425	12	2700	3250	49	814	1091	13
Head	1583	2117	34	700	700	18	3400	5000	68	970	1581	17
Animal charge (TLU ha^{-1})	1.7	2.1	-	1.3	1.1	-	2.2	4.5	-	0.4	1.2	-
Crops area (ha)	3.5	0.0	0.1	0.0	0.0	0.0	11.0	0.0	0.7	5.4	0.0	0.2
Number of hired laborers	7.8	10.2	0.1	3.0	3.0	0.0	10.0	17.0	1.0	2.8	5.3	0.3

TLU =Tropical Livestock Units

2.3. Adaptation to the Amazonian context

The technical practices, the energy coefficients of inputs and outputs, were adapted to the context of the Amazon region, in a new software called ALGEBRA, developed by the “French agricultural research for development” (Cirad) and Agro Paristech, with the cooperation of the Embrapa Amazônia Oriental. The enteric emission factors used were obtained from case studies from southern Brazil (Braz Pereira et al., 2002; Lima et al., 2007). In the absence of Brazilian emission coefficients for the direct emissions of N_2O from tropical soils, they were estimated from the literature existing for tropical regions worldwide and international study values of Ges'tim (2010) and Dia'terre (2011).Some items were added to the balance spreadsheet in comparison to the Planet method (2002), including GHG emissions by the use of fire to burn forest areas or to manage pastures. In this case, the simplified methodology "Tier 1" of the IPCC(2006) was applied, using coefficients and data specific to Amazon region (Fearnside, 1997). Thus, for CO_2 destocking, the first year, with biomass air and litter, was estimated at 179 t CO_2 ha^{-1} for primary rainforest (39% burnt of 290 t DM ha^{-1}) and12.2 t CO_2 ha^{-1} for grass cover (94.6% burnt of 8 t DM yield ha^{-1}).Emissions from the use of fire for deforestation were amortized over 20 years (IPCC, 2006).

The mechanisms of CO_2 destocking by ground biomass after deforestation and from that stored in the pastures were not taken into account because of their complexity, their high variability, and the absence of references in this area study (Clerc et al., 2012).

2.4. Statistical analysis

The data were analyzed with the mixed model procedure (SAS. 2013. SASOnlineDoc® 9.1.3. in SAS Inc., Cary, NC, USA). The univariate procedure of SAS was used to test for normal distribution of the data. The data were analyzed as a completely randomized design, with farm system as a fixed effect. Differences among means were tested using LSMEANS with the PDIFF option (SAS 2016), with significance declared if p-value ≤ 0.05.Six variables were analyzed to compare the three production systems: the total energy outputs and inputs, the direct and indirect energy inputs (koe ha^{-1} of pasture), the energy efficiency (no unit) and the emissions of GHGs (kg of CO_2 eq ha^{-1} of pasture). To compare the BB and BF systems, the following indicators were used: total energy inputs and outputs (koe t^{-1} of live weight produced) and the GHG emissions (kg of CO_2 eq t^{-1} of live weight produced).

3. Results

3.1. Energy results

The BF system produces 1.9 times more energy per hectare than the BB system, and this energy corresponds to the quantity of meat produced. The smallholder mixed system produces less than half as much energy per hectare as the BB system and 4 times less than the BF system. The SM farms have a low productivity because they use few inputs. However, the consumption of energy per hectare is more than 4.6 times lower for the SM farms than the BF farms. No difference was found between the BB system and the BF and SM systems (Table 2).In absolute terms, the consumption of energy from the use of fertilizers for pasture was twice as high for the BF system (15 koe ha^{-1}) than for the BB system (8 koe ha^{-1}). The energy from the purchase of food supplementation was 1.4 times higher for the BB system (10 koe ha^{-1}) than for the BF system (7koe ha^{-1}), as a consequence of the volume of food used for the calves in the BB farms. The BF system is the highest input intensity user compared to the BB system, with the highest source of energy input coming from the purchase of calves (28% of the total inputs).The SM system is a low input system, where the energy inputs come mainly from the farm buildings (Table 2).No significant difference was found concerning the energy efficiency. The three systems are efficient in the sense that the level of outputs produced is higher than the level of inputs used for the production. The two extensive systems are more productive than the SM system, although the SM farms appear to be more efficient (Table 2).

3.2. GHG emissions

The GHG emissions were significantly higher for the BF system (7814 kg CO_2 eqha^{-1} of pasture). No significant difference was found between the SM system and the BB system, although the GHG emissions of the BB system were 1.5 higher compared to the SM system (2619 and 1702 kg CO_2 eq$ha^{-1}$of pasture, respectively). The BF system emits3and 4.6 times more CO_2 than the BB and SM systems, respectively(Table 2).The main source of emissions was different for the three systems. For the BB system, the enteric fermentation of the animals (CH_4) was the first source of emissions which represented an average of 90% of the GH emissions. The BF system had two main sources of GHGs. For two thirds of the BF farms, the most important source came from the purchase of calves representing an average of 49% of their emissions. One third of the farms used fire in the last 20 years since the date of the interview. As example, one specifically interviewed in 2011 burnt 2210 ha in 1992, which still represents 75% of its GHG emissions in 2011. Finally, 80% of the SM farms used burning practices for pasture management. Burning represented an average of 71% of the emissions of GHGs (CO_2) for these farms. The burning practices occurred in the last 3 years on an average of 16 ha (29% of the total area) in these farms. The remaining 20% of SMfarms, without fire practice, had the smallest emission rates of all the analyzed farms (respectively, 41% of N_20 from manure management and 61% of CO_2 from the purchase of cows).

Table 2. Energy outputs and inputs (koe$ha^{-1}$of pasture), energy efficiency and GHG emissions (kg CO_2eq ha^{-1} of pasture) at the farm level for the three livestock systems

	BB	BF	SM	P-value[a]
Energy outputs	68b	129a	30c	***
Energy inputs	38ab	60a	13b	**
Direct energy inputs	14a	16a	3b	**
Indirect energy inputs	24ab	44a	10b	**
Energy efficiency	2	2	3	ns
GHG emissions	2619b	7814a	1702b	***

[a] ns = P >0.05, *P <0.05, **P <0.01, ***P <0.001; Beef Breeding-Fattening System (BB), Beef Fattening System (BF), Smallholder Mixed system (SM). a, b and c values are significantly different for the indicated P-value.

3.2.Comparison of BB and BF systems per ton of live weight produced

Table 3. Energy outputs and inputs (koet^{-1}live weight) and GHG emissions (kg CO_2 ept^{-1}live weight) at the farm level for the BB and BF systems

	BB	BF	p-value[a]
Energy outputs	338	321	ns
Energy inputs	198	145	ns
GHG emissions	14249	19716	ns

[a] ns = P>0.05, Beef Breeding-Fattening System (BB), Beef Fattening System (BF)

No significant difference between the BB and the BF systems was found when expressing the indicators per ton of live weight produced. It is favorable for extensive systems to express the indicators per hectare instead of ton of live weight produced as the consumption of energy and the GHG emissions are lower.

4. Discussion

4.1. Differentiated management of the herd and the pastures between the three livestock systems

Concerning the BB and BF systems, all the studied farms have a precise management of the herd under pasture feeding. They all apply rotational grazing, with accurate stocking rate and duration of animals in the pastures according to each season. Each farm has their own technical assistance. Of the BB and BF farms, seven farms use concentrate supplementation for the animals either during the dry season or for the last months of fattening, included in the GHG emissions. Except for one farm, which burnt 42 ha of pasture in 2014, burning practices are no longer used and pastures management is totally mechanized. The BF system has a higher inputs level compared to the BB system. More fertilizers, veterinary products, and supplementation are used. Additionally, it produces more meat per hectare as all the animals are destined for slaughter and the replacement rate is higher, unlike the BB system where a large part of the herd is comprised of breeding animals. The milk production per cow in the SM farms is low (620 L per year) compared to the national average (1525 L per cow per year) (IBGE, 2014). Technical assistance is rare and corresponds to three of the SM farms analyzed. Eight farms do not use concentrate supplementation, and the remaining two farms supply it only during the dry season. Eight farms use burning practices to manage the pastures, not one had precise management of the herd under pastures. Only two farms had precise management of the herd in the pastures, and they use concentrate supplementation during the dry season and apply manual or mechanized management of the pasture without burning practices.

4.2. Ecological intensification of the practices

In order to prevent deforestation and increase the production per unit of surface, more and more practices shift towards to an intensification of land use. One farm from the BB systems appliessil vopastoral practices(trees shrubs and grasses) and consortium of legumes forages with different species of grass pastures. This farm obtainedthe highest energy output among the BB system (111 koe ha^{-1} of pasture) and the highest energy efficiency among the BB and BF systems (3.9). Finally, the GHG emissions were higher than the average (3183 kg eq^{CO2} ha^{-1}); however, 98% of these emissions came from enteric fermentation of the animal. The farm does not use chemical lfertilizers and carries out the maintenance of the pastures by using dolomite lime and natural phosphorus. Mineral salt is used throughout the year and are balanced according to each animal category.

According to Smith(2007), the salvo pastoral system allows the highest carbon sequestration in comparison with conventional pastures because of the presence of trees. In addition, to mitigate the GHG emissions, this system increases the productivity (Albrecht and Kandji, 2003) and recovers degraded pastures (Steinfeld et al., 2006; Dias-Filho, 2006).Indeed, the silvopastoral system increases the fertility of soils through a better recycling of nutrients by the roots of the trees, which carry the elements and water deeper into the soil, and through the decomposition of organic matter carried by leaves at the surface of the soil. (Dias- Filho, 2006; Albrecht and Kandji, 2003).

Moreover, the trees increase the climate humidity rate and provide shade for animals. Finally, legume trees fix nitrogen of the atmosphere through the association of their roots with nitrogen-fixing bacteria, increasing pasture yields (Dias-Filho, 2006) while improving the diet of the ruminants, making it richer in proteins. There are also data reporting positive aspects of biodiversity, such as species richness (fungus)to improve the control on Deo is flavopictaStal which is the most damaging insect to tropical grass.

4.3. Carbon sequestration

The model does not take into account the carbon sequestration from pasture biomass. However, this carbon sequestration appears to be one of the most important factors in reducing the environmental impact of livestock systems. Thirty percent of the world carbon was stored in the pastures. Lal et al. (2004) showed that the sequestration potential at the earth level could reach 0.3 billion tons per year of organic carbon, which corresponds to an offset of 4% of the total GHG emissions. Tropical pastures have twice the capacity for carbon storage of temperate pastures. Globally, the extensive management of pastures increases the capacity carbon storage (Blanc et al., 2009). After deforestation, the pool of carbon declines suddenly; however, through appropriate pasture management, the reserve can be recovered and even surpass the carbon storage of forest soil after 88 years (Cerri et al., 2004).

4.4. Comparison with other livestock production systems

Energy analysis and measurement of the GHG emissions of agricultural systems are scarce in the literature, especially for tropical livestock systems. Vigne et al. (2013)compared four dairy systems using the Planet and Dia'terre methods: one low-level inputs system in South Mali (SoM), one high-level inputs system in Reunion Island (RI) and two intermediate-level inputs systems in metropolitan France (Poitou Charente (PC) and Bretagne (BR) regions). All these systems have forage and crop production. The results differed from our results. The energy inputs and outputs of the RI system are68 and 12 times higher, respectively, than the BF system (the two highest inputs level systems of the two studies). The energy inputs and outputs of SoM system are2 and 11 times higher, respectively, than the SM system (the two lowest inputs level systems of the two studies). The four systems are dairy systems and forage production is compulsory. The comparison with our systems is difficult, as the level of inputs and outputs differ. However, these results show that when the level of inputs used is higher, the efficiency is lower. The energy efficiency of low-level fossil energy inputs systems (such as SoM systems) appears to be higher than high-level inputs systems. In such systems, the most important input is the human labor. For specialized and extensive systems, such as the BB and BF systems analyzed in the Amazon region, the level of outputs and inputs is low. Indeed, because of the availability of huge areas for pastures, they do not use massive food supplementation and fertilizers and do not intensify the practices concerning pasture management. However, the pressure to stop deforestation will lead to an intensification of such practices, but the challenge is to lead towards an ecological intensification of practices to limit the use of fossil energy.

5. Conclusion

The BF system has the highest inputs level use compared to the BB and SM systems. The BF system has the highest outputs level and the SM has the lowest one. The BF system emits the highest rate of GHG emissions and the SM the lowest. For future studies, it is necessary to measure the storage of carbon in the pasture, which could represent an important offset of GHG emissions according to appropriate pasture management. The BB, BF and SM systems are providing animal products of quality, which represents an important source of protein for many people. The use of fossil fuel, chemicals, and animal food is low compared to more intensive systems.

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