

Evaluation of beef sustainability in conventional, organic, and mixed crop-beef supply chains

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ABSTRACT

Demand for sustainable meat with balance between environmental, economic and social (EES) aspects has increased recently. Brazil has promoted production of a wider variety of beef products and European Union is one of the target markets for Brazilian organic beef. This study aims to evaluate the EES performance of conventional and organic beef production. Accordingly, global warming, land occupation, energy consumption, operating profit and animal welfare were evaluated for different systems. Relevant indicators were measured using different methods, such as life cycle assessment, operating profit analysis, price volatility analysis, and qualitative scoring. Results confirmed a higher impact of organic beef production on global warming and land use due to animals' longer grazing period. Animal welfare, however, scored slightly higher for the organic beef production systems. Organic beef showed a slightly higher profitability, but its economic sustainability is constrained by technical barriers and higher transaction costs.

Keywords: Organic, conventional, mixed crop-beef, life cycle assessment

1. Introduction

The last decade has witnessed an increasing demand for meat that has been produced in a sustainable way, i.e., meat that provides a better balance between environmental, economic, and social (EES) aspects. The sustainability needs improving agricultural production systems which requires the promotion of farm practices that provide high-quality, affordable food in sufficient quantity while ensuring appropriate economic returns and minimizing negative environmental effects (Pelletier et al. 2008). Some countries, such as Brazil, have promoted the production of a wider variety of beef products to give consumers more choices. Essentially Brazil is producing two types of beef, i.e., organic and conventional. Conventional beef is produced either in specialized beef farm or mixed¹ crop-beef farm. Mixed crop-beef farming is an agricultural system in which a farmer conducts crops and livestock farming practice together. Mixed crop-beef developers can greatly improve the productivity of a beef system by improving carrying capacity and providing higher quality pasture. Organic beef is a type of farming in which it is not allowed to use synthetic inputs such as medicines, fertilizers, and genetically modified organisms (Chander et al. 2011). The aim of beef organic farming is to establish a method for avoiding environmental problems and promoting the quality and safety of beef (Nardone et al. 2004). Although currently mixed crop-beef and organic system cover a small share of the total beef production in Brazil, experts in beef production perceive these two systems as potential for future beef production in Brazil. However, there is limited knowledge regarding sustainability performance of the different beef production systems. A number of studies evaluated environmental aspects of beef production (Beauchemin et al. 2010; Casey and Holden 2006; Cederberg and Stadig 2003; Dick et al. 2014; Nguyen et al. 2010; Ogino et al. 2007; Pelletier et al. 2010; Rös et al. 2013; Roy et al. 2012; Stewart et al. 2009). Nevertheless, none of these studies focused on the three dimensions of sustainability simultaneously. Hence, an assessment of the EES performance of conventional and organic beef systems in Brazil should give insight into the sustainability consequences of these two production systems. Therefore, the objective of this study is to evaluate the EES performance of the conventional (based on specialized and mixed crop-beef farming) and organic beef production systems in Brazil.

2. Methods

2.1. Description of the systems

EES issues relevant for soybean production systems were listed in a study that performed by Pashaei Kamali et al. (2014). We limited the evaluation to some key EES issues for beef production due to data restriction,

¹ In this study mixed farm refers to On-farm mixing which enables the recycling of resources generated on a single farm.

methodological feasibility, and geographical relevancy of issues. Four EES issues were selected: Global warming, land occupation, primary energy use, profitability and animal welfare. Data for the conventional production systems were derived from Embrapa² cooperative data base which is aggregated farm data for two biomes in Brazil (Cerrado and Pampa) and represent average contemporary Brazilian conditions in these biomes. Comparable, broadly representative data were not available for mixed crop-beef and organic system in Brazil. Hypothetical mixed crop-beef and organic models were therefore designed to capable comparability with the conventional systems while reflecting key similarities and differences from conventional production technologies. The scenario model for the mixed crop-beef and organic beef were defined based on Brazilian expert opinion and broad trends identified through a literature review of comparative inputs in conventional (specialized and mixed crop-beef) and organic beef production systems. The simulated production unit used in this study for all systems consisted of a herd starting with originally 608 cows, 36 bulls.

2.1.1. Specialized beef system

The normal production system in Brazil is to produce animals under pasture condition. A small amount of animals (6.7% of slaughtered animals), in 2008 were fed in feedlots for a short period (Ferraz and Felício 2010; Somwaru and Valdes 2004). Therefore, in this study EES performance were calculated on a whole-herd basis in one year for grass-finishing systems, where the animals are able to continuously graze on the natural pasture throughout the year with little or no supplementation. Housing is not utilized in Brazilian beef production system, hence all manure is assumed to be deposited directly to pasture. The description of specialized beef system was based on representative beef production system in two biomes (Cerrado and Pampa). Main characteristics of specialized beef system are presented in (Table 1).

2.1.2. Scenario 1: Mixed crop-beef system

In the mixed crop-beef systems, livestock and crops are produced within a coordinated framework. In this system cattle graze in pasture-crop land, thus contributing to the relatively short beef production period. Crop-livestock systems that are spatially and temporally mixed can occur through various combinations of the following: (i) rotations of grain crops with perennial pastures; (ii) short rotations of grain crops with annual or short-season pastures; and (iii) utilization of grain crop residues for livestock grazing (Sulc and Tracy 2007). The mixed crop-beef model in this study was the third one. The crop was considered to be sold and assumed to be leguminous crops which increase the nitrogen of the soil and helps pasture improvement as well as reduce farm costs. The sold legumes were not included in this analysis, but the quantity of resources used for producing the crops were corrected in the computations. The herd evolution was performed using a method similar to that in the specialized beef system; with a starting point of same number of cattle. Main assumptions of mixed crop-beef system are presented in Table 1.

2.1.3. Scenario 2: Organic beef system

Organic animal husbandry is defined as a system of livestock production that promotes the use of organic and biodegradable inputs from the ecosystem in terms of animal nutrition, animal health, animal housing and breeding. It deliberately avoids the use of synthetic inputs such as drugs, feed additives and genetically engineered breeding inputs. In general, organic beef in Brazil comes from cattle raised in pastures for the majority of their lives. Unlike traditional or conventional systems of production, organic production systems are governed by a set of standards that must be strictly followed by producers. Main assumption and characteristics of organic system was presented in Table 1. There seem to be no fundamental differences between the specialized and organic cattle nutrition in Brazil since both of them are pasture base.

² Embrapa: Brazilian Enterprise for Agricultural Research

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Table 1: Main characteristics assumed for different farming practices and basic assumption for each systems

Description	Farming practices				
	Conventional beef	Mixed crop-beef	Reference/sources	Organic	Reference/sources
Pasture (ha) ^a	1600	1600	Assumed similar to base scenario	1600	Assumed similar to base scenario
Composition pasture type	Native pasture	Native pasture with Leguminous	(Cederberg and Mattsson 2000; Dick et al. 2014)	Native pasture	
Phosphorous fertilizer (kg/ha/yr ^c)	-	60 ^b	(Embrapa soja, 2012)	-	-
Potassium fertilizer (kg/ha/yr)	-	76	(Embrapa soja, 2012)	-	-
Lime (kg/ha/yr)	-	400	(Embrapa soja, 2012)	-	-
Replacement rate (%)	20	12.5	(Dick et al. 2014)	20	Expert opinion
Age of first calving (month)	30	24	Expert opinion	32	Expert opinion
Calving rate	70	75	(Rearte and Pordomingo 2014)	70	(Rearte and Pordomingo 2014)
Stocking rate (AU/ha) ^d	1	1.6	(Oliveira et al. 2006)	0.8	(Oliveira et al. 2006)
Calf Mortality rate (%)	6	4	(Oliveira et al. 2006)	10	Expert opinion
Manure management	Pasture deposition	Pasture deposition	(Dick et al. 2014)	Pasture deposition	(Dick et al. 2014)
Total number of slaughtered cattle (yr)	731	796	-	640	-
Average age of slathering (months)	40	26	(Oliveira et al. 2006)	44	Expert opinion
Average weight of slaughter for female (kg) ^e	475	500	(Oliveira et al. 2006)& expert opinion	450	(Casey and Holden 2006)
Average weight of slaughter for male	475	520	Corrected based on (Dick et al. 2014)	472	(Casey and Holden 2006; Dick et al. 2014)
Number of labour (person.ha ⁻¹ .yr ⁻¹)	3	6 ^e	Expert opinion	3	Expert opinion
Manure handling	Pasture	Pasture	(Dick et al. 2014)	Pasture	(Dick et al. 2014)
Crop farm in mixed crop-beef farm	-	Soybean	Expert opinion	-	-
Prices					
Selling price of cattle to slaughtered house (R\$/@) ^g	90	90	90	90	(IBGE-SIDRA 2012)
Price premium (%)	-	-	-	30	Expert opinion
Salary of labour (R\$/hr ^h)	1.14	1.14	Embrapa	1.14	(IBGE 2012)

- a. ha: hectare
- b. Part p fertilizers were provided by manure
- c. Yr: year
- d. AU: Animal unit
- e. Kg: Kilogram
- f. Labour working for both cattle and crop farm
- g. Selling price in farm gate is for 15 kg of cattle weight
- h. R\$: Brazilian Real
- i. hr: hour

2.2. Environmental performance

2.2.1. Global warming

The environmental impact of beef production systems was evaluated by life cycle assessment (LCA). LCA is a method that evaluates the environmental impacts along the entire life cycle of a product (Guinée 2002). LCA relates the environmental impacts of the defined production system to the functional unit (FU) (Guinée et al., 2002), which is the main product of the analyzed system in quantitative terms, and defined here as one kilogram of live weight. The system boundary is cradle-to-farm gate (Figure 1). The animal population of systems was estimated from the simulation of herd evolution as recommended by (IPCC et al. 2006). The LCA began when the initial animals were weaned, continued through the meat production cycles, and ended when the initial cows and bulls were fully replaced (Dick et al. 2014). To estimate greenhouse gases (GHGs) in beef production in different systems, the following GHGs sources were included: (1) on-farm methane (CH₄) emissions from cattle and manure, (2) on-farm nitrous oxide (N₂O) emissions from manure and soils, (3) off-farm N₂O emissions from Nitrogen (N) leaching, run-off and volatilization (indirect N₂O emissions), (4) carbon dioxide (CO₂) emissions from on-Farm energy use (e.g., fuel and electricity). Animal housing is not common in Brazilian cattle system, so the energy use related to housing was not considered. Emission related to production of medicines and vaccines were excluded in this study due to lack of data.

To assess the impact of a production system on global warming (GW), we quantified emissions of CO₂, CH₄ and N₂O. Emission of CO₂, CH₄, and N₂O were summed based on their equivalence factors in terms of CO₂-equivalents (100-year time horizon): 1 for CO₂, 25 for CH₄, and 298 for N₂O (IPCC et al. 2006). Emissions were subsequently summed based on their equivalence factor in terms of CO₂. For this study, impacts were calculated on a whole-herd basis for each class of cattle separately and per kg of live weight (LW) produced in each system. For the cow-calf system and grass-finishing systems modelled, housing is not utilized hence all manure is assumed to be deposited directly to pasture.

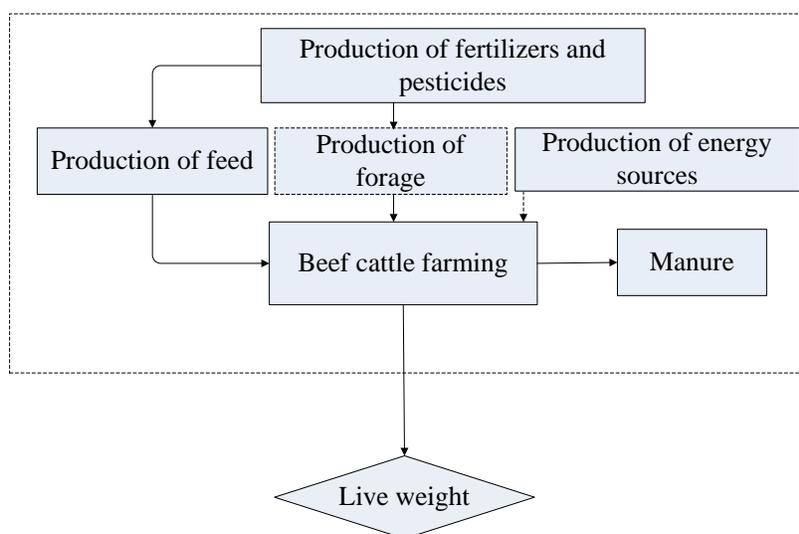


Figure 1: System boundary

Tier II method were applied for calculating enteric methane emissions due to the sensitivity of emissions to diet composition and the relative importance of CH₄ emissions to total GHG emissions in beef production (Pelletier et al. 2010). The enteric methane fermentation was quantified based on gross energy intake (GEI) of the cattle, which was calculated based on animal requirements and feed energy values. Daily net energy requirements for cattle in each stage of production were estimated from energy expenditures for maintenance, activity, growth, pregnancy, lactation and work as appropriate. The gross energy (GE) intake required to meet

energy requirements was then estimated taking into account the energy density of the diet (Dick et al. 2014). Enteric CH₄ emission was calculated from gross energy intake using the CH₄ conversion factors (Y_m) for each diet. Methane emissions from manure management were calculated following IPCC (2006) Tiers I. Tier I method was applied for manure management given the trivial methane emissions associated with solid manure management, which is common to all systems modelled (Pelletier et al. 2010). Nitrogen excretion estimates were used to calculate direct N₂O emission, ammonia and N₂O emissions from manure management and indirect N₂O emissions from nitrate leaching following (IPCC et al. 2006) emission factors.

The physical occupation of land areas was measured as the area (m². yr⁻¹) used for production of one kg of beef during one year. In calculations related to land occupation it was considered. For this study, we considered land for animal grazing (pasture). Primary energy use for producing beef was estimated based on total energy consumption in each phase. The energy required to produce beef included the energy used to produce farm inputs including transports (i.e., seed, fertilizers and agrochemicals) and energy use for field operation (fuel and electricity to operate agricultural field equipment). The energy required for buildings and agricultural machinery was ignored due to the lack of data and its small contribution to the total emissions (Pradhan et al. 2008). The primary energy use was calculated as the mass (kg) of material multiplied by its energy (MJ/kg).

2.2.2. Economic performance

To explore economic performance, profitability was evaluated. Operating profit was selected as an indicator for profitability, and was quantified as total revenue minus operating costs minus depreciation (Hillier et al. 2010). Operating costs are costs related to vaccination, medicines such as fertilizers, antibiotics, ear tags, fuel, electricity, repair, maintenance, operating interest, insurance, hired labor and transportation. Operating profit was quantified by revenue minus operating cost minus depreciation. Total operating costs is an indicator of the relative success of operations in terms of their ability to meet short-term financial obligations (McBride and Greene 2009).

2.2.3. Social performance

Animal Welfare focuses on beef cattle production including on-farm management of beef cattle. Animal welfare was evaluated based on main principles of welfare quality (assessment protocol for cattle). Four main principles are identified by this protocol: (P₁) good feeding, (P₂) good housing, (P₃) good health, and (P₄) appropriate behavior. The last one is out of the scope of this study due to lack of data. Regarding principle (1), (2), and (3), a number of welfare criteria were defined based on the aforementioned protocol for farm, transportation, and slaughtering. We defined eight welfare criteria for the farm level: (C₁) absence of prolonged hunger, (C₂) absence of prolonged thirst, (C₃) comfort around resting, (C₄) thermal comfort, (C₅) ease of movement, (C₆) absence of injuries, (C₇) absence of disease, and (C₈) absence of pain induced by management procedures (Welfare Quality 2009). The survey was carried out from April 2013 to January 2014 in Brazil. An invitation to complete an online questionnaire was distributed by email to the personal networks of SALSA³ members. The questions were structured as closed-end questions and referred to eight welfare criteria for beef cattle farms. Respondents were asked to assign importance to each issue, using a five-point Likert scale, where 1 represented the “worst” or the poorest situation, 2 represented “worse” situation 3 represented “neutral” situation (neither bad nor good), 4 represented “good” situation and 5 represented the “best” situation (no more improvement is needed). Finally, an overall performance score is computed as the average over all indicators scores.

3. Results and discussion

Results from previous beef production studies showed large variability in terms of sustainability performance. The methods applied in these studies (e.g., system definition and characterization factors) were

³ Knowledge-based Sustainable Value-added food chains: innovative tools for monitoring ethical, environmental and Socio-economic impacts and implementing EU-Latin America shared strategies.

different, which likely contributed to the variability in the results. However, the results of environmental evaluation of beef production obtained in this study fall within the range of values from previous studies. Total emission was low for specialized and mixed crop beef production compared to the organic and specialized beef production (Table 2). This conclusion is consistent with previous research, which has shown that higher quality diets and increased growth rates, reduce cattle CH₄ and manure N₂O emissions, both of which are key contributors to life cycle emissions (Dick et al. 2014). Short days at grass and high productivity of the mixed crop-beef system are the main reasons for low emission. In the mixed crop beef production, crop residues (fibrous by-products) resulting from the cultivation of cereals and oil plants were the major source of nutrients for beef cattle and caused higher yields and better quality of the beef. The difference between the different beef production is due to the lower quality of the forage consumed by the animals in the specialized and organic compared with the mixed crop-beef and is based on the differences in dry matter (DM) intake/animal/day, the Y_m, the digestibility, and the pasture use efficiency related to the time required to produce 1 kg live weight (Dick et al. 2014; Pelletier et al. 2010). Legumes in mixed crop-beef farms act as cover crops and green manures preventing soil degradation (Dick et al. 2014). Another benefit for incorporating legumes crops into pasture is the significant amount of available N added to the farm through dinitrogen fixation (Sulc and Tracy 2007).

Beef production in Brazil does not differ dramatically between organic and conventional systems. A few differences between these two systems were distinguished, for instance using antibiotics and medicines in conventional beef system which is not allowed in organic system. In this study organic beef had the highest GHGs emission since in this system cattle have the longest days at grass, lowest stocking rate, highest mortality rate and lightest animals sold for slaughtering. The aforementioned factors in organic system cause slightly higher GHGs emission compared to conventional system. Although this result has contradiction with other studies (Casey and Holden 2006), however, the difference easily can be explained by differences in feedlot or grain based finishing versus pasture based finishing (this study). Organic beef usually produced for quality rather than weight (Casey and Holden 2006), therefore the moderately high GHGs emission arises because of the lower weight per animal.

The land occupation for organic farm was higher (53.1) compared to conventional system (Table 2). Higher land occupation in organic system can be explained by a lower total production of slaughtered cattle (due to high mortality rate and high grazing period). Organic beef production system is commonly associated with lower productivity in comparison with conventional production system (Casey and Holden 2006; Nardone et al. 2004). This study also confirmed that there is difference between organic and conventional beef system productivity. Therefore, the main challenge for organic production system to improve overall sustainability is to increase productivity without negative impact on the environment (Nardone et al. 2004). A number of research experiments have shown that under carefully controlled management and better performance conditions organic production system has the potential to achieve comparable output with those in conventional one. The lowest land occupation was in mixed crop-beef farm (38.6) due to high productivity in this farming practice (Dick et al. 2014). Regarding energy specialized and organic beef use less energy compared to specialized crop-beef beef production (Table 2). The result of land occupation in this study is in similar to the studies performed by Pelletier et al. (2010) for intensive pasture finishing beef cattle. For specialized and organic beef production there was not any energy related to feed production, fertilizer production and transportation of feed and fertilizers. However, for mixed crop-beef system due to having crop production in the farm part of energy use was allocated to beef production system. Indeed energy use in this study is much less than the other studies which had feedlot or grain based finishing system (Nguyen et al. 2010; Pelletier et al. 2010). Hence, we could compare this study only with limited number of studies which had pasture based systems (Cederberg et al. 2009).

Despite the interest in organic beef production due to some environmental and human safety reasons, there is a little information concerning the relative costs and returns of organic beef production. Although our study showed that organic production has higher production cost compared to the conventional beef production, however, the operating profit per kg live weight was highest for organic beef, followed by mixed crop beef, and specialized beef. Without organic price premiums, the average annual profits of the conventional production system were higher than the organic production system. (Azadi and Ho 2010; Fernandez and Woodward 1999). Higher cost of organic beef is related to veterinary cost, certification cost, long staying of animal in farm and low productivity. Mixed crop-beef systems is resulted in higher livestock carrying capacity and more consistent farm profitability compared with conventional system (Sulc and Tracy 2007). Lowering input levels increase

productivity, and maintaining or increasing profitability. Crop residues represent a vast feed resource available to livestock producers that can effectively reduce feed costs. According to (Sulc and Tracy 2007) in southern Brazil, research and experiences on commercial farms have demonstrated that mixed crop–livestock grazing systems can improve net returns eightfold over the traditional extensive stocker grazing systems and 1.5-fold over soybean grain production systems. Grazing winter cover crops (such as soybean) did not reduce subsequent grain yield when animal stocking was managed (Sulc and Tracy 2007). Animal welfare score of the organic system was slightly higher (4.5) than the score of the other farms. Animal welfare is a basic principle of organic production, and organic beef cattle farmers and managers have a more explicit responsibility for the health, welfare, and treatment of the animals. Organic farms are obliged to obey certifications and standards, which are proposed for organic beef production. The mixed crop beef system had a slightly lower average score (4.2) than the organic farm. The specialized beef system had the lowest animal welfare score (3.98).

Table 2: Environmental and economic performance of beef cattle production in different farming practice

Impact	Unit	Conventional beef	Mixed crop-cattle beef	Organic beef
Global Warming potential	kg CO ₂ eq.	16	14.2	15.7
Primary energy use	MJ eq.	13	12	13.7
Land occupation	m ² x year	41.4	38.6	53.1
Operating profit	US \$	2.91	3.1	4.3

The management of small ruminant organic farming is fundamentally based on the choice of an appropriate forage system and on good knowledge of climatic and animal production system. Furthermore, prices of organic beef might have great variability, immature nature of the organic market (McBride and Greene 2009). Organic beef cattle productivity are is subject to disease, weather and other factors, which mean that the output stay rather volatile also in the future and may present particular risks and ways of managing risks (Van Bueren et al. 2002). Additional risks of producing organic beef, such as production, marketing and policy risks may cause differences in farmers’ risk attitudes. For a risk-neutral farmer it is optimal to produce organic beef; however, for a risk-averse farmer it is only optimal to produce organic products if policy incentives are applied, or if the market for the organic beef becomes more stable.

4. Conclusion

The potential environment impacts of 1 kg live weigh beef produced in different beef production systems in Brazil were shown to differ considerably. (Hanson et al. 2004). Different features of systems contribute to EES performance of each system. The production period of the beef and the quality and production of the pastures determine the GWP, land occupation, energy use and profitability. Concerning product quality, there is little evidence for a system-related effect on product quality due to the production method. It is concluded that the benefits of the basic standards are primarily related to environmentally friendly production and to the animal welfare issue while the issues of animal health and product quality are more influenced by the specific farm management than by the production method. There is evidence to support the assumption that organic livestock farming creates stronger demands on the qualification of the farm management, including the higher risk of failure. As a consequence, quality assurance programs should be established to ensure that the high demands of the consumers are fulfilled. (Sundrum 2001). Alterations in diet composition and animal husbandry practices in mixed crop-beef and organic systems have been proposed as a means of reducing negative environmental impacts and improving economic performance of beef farms (Beauchemin et al. 2008; Eckard et al. 2010; Johnson and Johnson 1995; Martin et al. 2010). We hypothesize such systems will be economically competitive and less environmentally harmful than the specialized beef system. However, for this to become reality it needs to invest in research and training for establishment of management systems adapted to environment and sociological context. Moreover, crop–beef farming systems by producing of different products can provide additional marketing opportunities beyond the conventional commodity markets

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