2013

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Introduction

The beef industry has defined sustainability as meeting the growing demand for beef by balancing environmental responsibility, economic opportunity, and social diligence. Measuring sustainability is challenging, as the beef supply chain is one of the most complex food systems in the world. As the first and largest research project of this kind, this study represents an innovative approach toward creating a more sustainable beef product. Our objective is to establish a sustainability baseline (including environmental, economic, and social footprints) for the US beef industry by quantifying life cycle inputs and outputs for beef production over time.

Material and methods

To determine the sustainability of beef production, a combination of models were used. The USDA-ARS Integrated Farm System Model (IFSM) was used to simulate environmental and economic footprints from cradle to farm-gate. The socio-eco-efficiency tool (SEEBALANCE®) extends this analysis by determining the environmental, economic, and social impacts of beef from cradle to grave providing a comprehensive assessment of sustainability.

The IFSM is a process-level farm model that simulates crop growth, feed production and use, animal growth, and returning manure nutrients to the land to predict the environmental impacts and economics of agriculture production systems (Rotz *et al.*, 2005). For the current study, relevant information for the US Meat Animal Research Center (USMARC) beef operation was gathered and used to establish model parameters. The USMARC farm, cow-calf and feedlot operations were simulated to evaluate performance, environmental impact and economics.

The environmental impacts and economics of beef production at the USMARC were combined with primary data from the packer, case ready, retail, and consumer segments of the beef value chain for 2005 and 2011 using SEEBALANCE®. The SEEBALANCE® analysis includes environmental, social, and economic considerations as determined by method of life cycle analysis (Kölsh *et al.*, 2008). This approach quantified US beef sustainability considering economic, social and ecological impacts along all segments of the beef value chain.

Results and discussion

Integrated farm system model: USMARC

A 25-year simulation of the USMARC's current production system gave a carbon footprint of 11 kg of CO_2e per kg of live weight sold, which is consistent with other experiments (Johnson *et al.*, 2003; Capper, 2011; Stackhouse-Lawson *et al.*, 2012). The energy required to produce that beef (energy footprint) was 25.9 MJ/kg. The total water required (water footprint) was 21,300 l/kg of live weight sold, and the water footprint excluding that obtained through precipitation was 2,800 l/kg. The simulated total cost of producing their beef was about $2.20/kg of live weight sold, which agreed with USMARC production records.

SEEBALANCE®

Table 1 quantifies the environmental, social and economic considerations of the beef supply chain expressed in 0.45 kg of minimally processed boneless edible consumed beef (UB). Overall, the sustainability of the US beef industry, given the present assumptions, has improved by 7% in 6 yr.

Table 1. Environmental, social and economic sustainability indicators for the beef supply chain.

Sustainability indicators	2005	2011	% change
Economic (expressed per UB[1])			
Consumer price ($)	5.24	5.55	6
Environmental (expressed per UB)			
Energy use (MJ)	521	511.0	-2
Resource consumption (mg $silver_e$)	5.05	4.96	-2
Water consumption (L)	2,418	2,336	-3
Solid waste (kg municipal $waste_e$)	0.19	0.18	-7
Greenhouse gases (kg CO_2e)	23.7	23.6	-1
Photochemical ozone creation potential (g C_2H_4e)	0.026	0.026	0
Acidification potential (g SO_2e)	336	327	-3
Ozone depletion potential (g CFC*e*)	0.013	0.013	0
Water emissions (grey water (l diluted $water_e$)	4,981	4,487	-10
Land use (m^2a)	21.4	20.5	-4
Social (normalized and weighted[2])			
Occupation illnesses and accidents	0.90	0.60	-32
Toxicity potential	1.00	0.84	-16

[1] User benefit (UB) 0.45 kg of minimally processed boneless edible consumed beef.

[2] Social indicators are normalized and weighted based on severity of incident or chemical.

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