Environmental impacts of the Japanese beef-fattening system with different feeding lengths as evaluated by a life-cycle assessment method[1]

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ABSTRACT: The objectives of this study were to evaluate the environmental impacts of a beef-fattening system using the life-cycle assessment (LCA) method and to investigate the effects of feeding length on the LCA results. The functional unit was defined as one animal, and the stages associated with the beef-fattening life cycle, such as feed (concentrate and roughage) production, feed transport, animal management, animal body (i.e., biological activity of cattle), and the treatment of cattle wastes, were included in the system boundary. Our results suggest that enteric or gut CH_4 emissions of cattle were the major source in the impact category of global warming (2,851 kg of CO_2 equivalents), whereas NH_3 emissions from cattle waste were the major source in the impact categories of acidification (35.1 kg of SO_2 equivalents) and eutrophication (6.16 kg of PO_4 equivalents). Feed production also contributed a great deal to all categories. A shorter feeding length resulted in lower environmental impacts in all the environmental impact categories examined in the current study, such as global warming and acidification, although there was a difference in effect of reducing environmental impacts among the categories.

Key Words: Beef Production, Cattle Fattening, Environmental Impact, Feeding Length,
Life-Cycle Assessment, Wagyu

J. Anim. Sci. 2004. 82:2115–2122

Introduction

An increasing environmental consciousness in society requires action by the livestock industry on environmental problems. Methods for evaluating environmental impacts are important for improving problems; however, such methods have not yet been established. In the past, many environmental evaluations conducted for livestock farming focused on one aspect of environmental impact, such as nutrient surplus (de Boer et al., 1997, 2000) or harmful gas emissions (Sommer et al., 2000).

The internationally standardized life-cycle assessment (**LCA**) method is expected to be highly effective for evaluations, and assesses all the relevant environmental impacts at every stage in the life cycle of a product or activity. Recently, several studies have reported that the LCA method was applied to livestock farming (Haas et al., 2001; Berlin, 2002; de Boer, 2003). These studies showed that the LCA method could be applied to livestock farming; however, an evaluation of the environmental impacts of beef fattening by the LCA method have not been reported. In addition to estimation of the environmental impacts of the whole beef-fattening system, identifying activities in the system that contribute most to these impacts should be helpful for improvement of environmental problems.

Japanese Black cattle are fed for a long period in the Japanese beef production system to produce high-quality beef; however, the longer feeding period often causes inefficiency and additional manure excretion. Recently, efforts to improve this situation have begun, and a study aimed at optimizing the feeding length was reported (Ogino et al., 2003). It is not clear, however, how much the environmental load associated with beef fattening is decreased by shortening the feeding length because of physiological changes due to growth.

The objectives of this study were to evaluate the environmental load of the beef-fattening system using the LCA method and to investigate the effects of feeding length on the LCA results.

Materials and Methods

Life-cycle assessment is a method for evaluating the environmental impact associated with a product, process, or activity during its life cycle by identifying and quantitatively or qualitatively describing its require-

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[1] The authors thank M. Mitsumoto and K. Hodate, National Institute of Livestock and Grassland Science, for their scientific advice.

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Received October 21, 2003.
Accepted April 2, 2004.

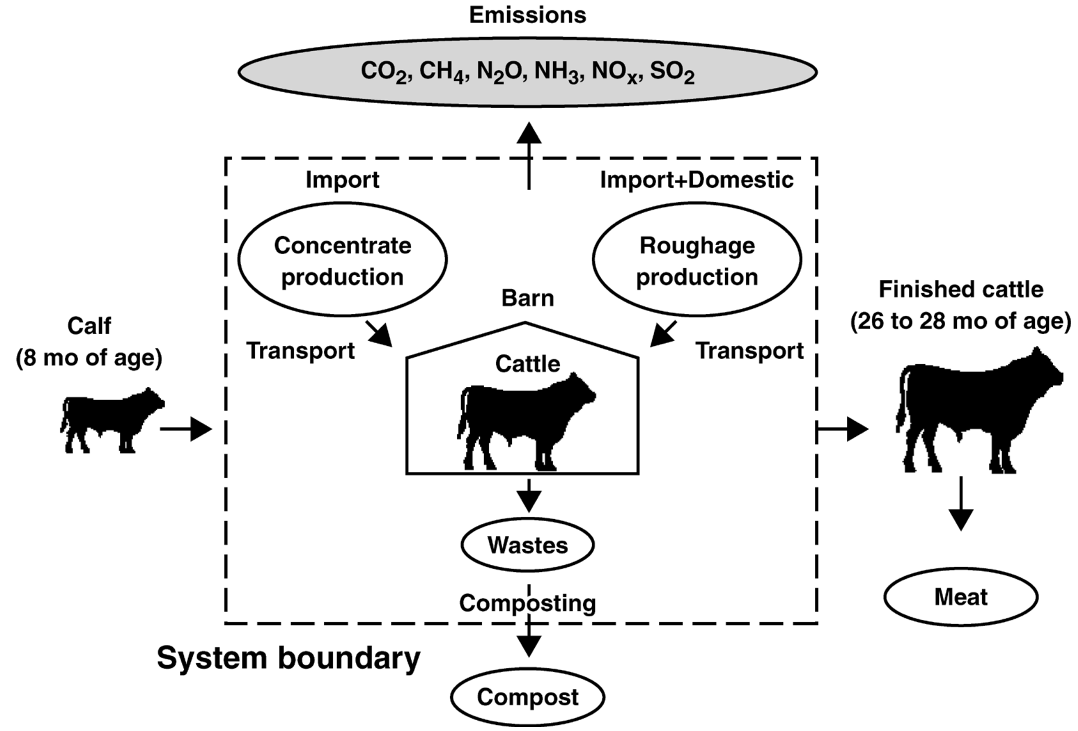

Figure 1. Description of the Japanese beef-fattening system investigated in this life-cycle assessment study.

ments for energy and material and the emissions and waste released to the environment. The life cycle, which not only includes production of the main product but also the processing of raw materials, production of intermediates, their transport, and waste treatment, is taken into account in the assessment. The LCA concept consists of four major steps: 1) goal and scope definition; 2) life-cycle inventory; 3) life-cycle impact assessment; and 4) interpretation. The details of each step are described herein. More information about LCA can be found in ISO 14040-43 (ISO, 1997; 1998; 2000a,b).

Goal and Scope Definition (System Description)

The first component of LCA is the definition of the goal and scope of the analysis, the functional unit, and the system boundaries. The functional unit is a reference to which all other materials (and associated environmental loads) in the LCA are related. Examples of impact categories are global warming, acidification, and eutrophication. In this study, the goal of the analysis was to evaluate the environmental impacts of the Japanese beef-fattening system and to investigate the effects of feeding length on the impacts. The functional unit was defined as one beef animal. The system analyzed in this study is presented in Figure 1. The fattening stage was considered as starting with the purchase of steer calves (8 mo of age) and ending with the marketing of finished steers (26 to 28 mo of age). A growth curve calculated from data on 367 Japanese Black (Wagyu) steers was used to calculate the amounts of N and C excreted into the manure, and a feeding system adopted in the experimental station located in the production region of the cattle was used for cattle diet. The amount and composition of the diets and BW are presented in Tables 1 and 2. The activities in the beef-fattening life

Table 1. Animal age, weight, and quantity of feed used in the life-cycle assessment study[a]

Age, mo	9	10	11	12	13	14	15	16	17	18
Body weight, kg	276	297	320	345	371	398	425	453	481	509
Concentrate, kg/d[b]	4.0	5.0	5.5	6.0	7.0	8.0	8.5	9.0	9.5	9.5
Roughage, kg/d[b]	3.5	3.5	3.5	3.5	3.5	3.0	2.5	2.0	2.0	1.5
Age, mo	19	20	21	22	23	24	25	26	27	28
Body weight, kg	536	563	589	614	637	658	678	695	710	722
Concentrate, kg/d[b]	9.5	9.5	9.5	9.5	9.0	8.5	8.0	7.5	6.5	6.5
Roughage, kg/d[b]	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0

[a] The growth curve was calculated from 367 steers.
[b] As-fed basis.

Table 2. Composition of diets used in the life-cycle assessment study

Item	% of diet[a]	DM, %[a]	CP, %DM	TDN, %DM
Concentrate				
Corn	39.5	86.5	10.2	92.4
Barley	32.0	88.2	13.3	84.0
Wheat bran	23.0	87.0	17.7	72.3
Soybean meal	5.0	88.3	52.2	86.7
Calcium carbonate	0.5	99.0	—	—
Total	100.0	87.3	15.0	84.4
Roughage				
Hay	73.8	85.1	12.8	61.6
Rice straw	26.2	87.8	5.4	42.8
Total	100.0	85.7	11.2	57.7

[a] As-fed basis.

cycle taken into account were feed (concentrate and roughage) production, feed transport, animal management, and the treatment of cattle waste. In Japan, beef cattle waste is treated mainly by composting without forced aeration (Haga, 1999). However, environmental loads of transport of calves from the calf market and of finished steers to the carcass market were excluded. Finished compost was regarded as organic fertilizer and placed out of the system. The environmental loads associated with production of capital goods, such as cattle barn and front loader, were not taken into account.

Life Cycle Inventory

The second major step is to draw up an inventory of all the resources used and all the emissions released into the environment connected with all activities within the system boundary of beef fattening. All the inputs and outputs associated with the beef fattening, such as feed production, feed transport, animal management, animal body (i.e., biological activity of cattle), and waste treatment are shown in Table 3. Data from the literature were used for specific activities for beef fattening, whereas the database of the LCA software JEMAI-LCA (JEMAI, 2000) was used for general activities, such as the production and combustion of fossil fuels and feed transport. Pollutants emitted from feed production were determined as follows:

$$\mathrm{P_A} = \sum_i \mathrm{D}_i \times \left(\sum_j \mathrm{F}_{ij} \times \mathrm{G}_{Aj} + \mathrm{L}_i \times \mathrm{M_A} \right)$$

where $\mathrm{P_A}$ = emission of pollutant A from feed production, g/d; D_i = intake of feed i (kg/d); F_{ij} = consumption of fuel j in production of feed i (MJ/kg of feed); G_{Aj} = emission coefficient of pollutant A from production and combustion of fuel j (g/MJ); $\mathrm{L}i$ = consumption of electricity in production of feed i (kWh/kg of feed); $\mathrm{M_A}$ = emission coefficient of pollutant A from electricity production and consumption (g/kWh); feed i = corn, barley, wheat, soybean, and hay; fuel j = gasoline, diesel, liquefied petroleum gas, and indirect energy.

The weighted average of the coefficient of each fuel, based on the amount of consumption in the United States in 2000 (EIA, 2003), was used as the emission coefficient of pollutant A from indirect energy, which is consumed to produce agricultural materials such as chemical fertilizers or pesticides.

Environmental loads from the feed transport were determined by multiplying unit emission by the product of the feed weight and transport distance. This was defined based on Japanese trade statistics, which report that all concentrates were imported from the United States and 25% of roughage was imported—hay from the United States and rice straw from the People's Republic of China, respectively. The marine transport distances from the United States and China were defined as 18,180 km from New Orleans, LA, to Nagoya, Japan, which includes river freight going down the Mississippi

Table 3. Environmental loads associated with beef fattening and output coefficients

Source	Output coefficient	Reference
Feed production		
Energy use and relevant emissions	See text	Pimental (1980); JEMAI (2000)
NH_3 (from soil)	7.7% (NH_3-N)[a]	Bouwman et al. (1997); Misselbrook et al. (2000)
N_2O (from soil)	0.5% (N_2O-N)[a]	Eichner (1990)
Feed transportation		
Energy use and relevant emissions	See text	JEMAI (2000)
Animal management		
Energy use and relevant emissions	See text	AFFTIS (1997); JEMAI (2000)
NH_3	6.39% (NH_3-N)[b]	Groot Koerkamp et al. (1998)
Animal body		
CH_4 (rumination)	See text	Shibata et al. (1993)
Waste treatment		
CH_4	1.05% (CH_4-C)[c]	Husted et al. (1994)
NH_3	10% (NH_3-N)[d]	Osada et al. (2000)
N_2O	1.13% (N_2O-N)[d]	Osada et al. (2000)

[a] Proportion to nitrogen amount in fertilizer applied.

[b] Proportion to nitrogen amount in manure excreted.

[c] Proportion to carbon amount in manure excreted.

[d] Proportion to nitrogen amount in manure left after subtracting the nitrogen loss in animal management.

River, and 2,070 km from Dalian, China, to Nagoya, respectively; the distances between these cities were based on the JNOA (1990) distance chart. The distances for land transport (trucking) in the United States, China, and Japan were defined as 200, 300, and 210 km, respectively.

Illumination of the cattle barn, feed preparation, and carrying manure out of barn were taken into account as the work associated with animal management, and environmental loads were calculated from quantities of fuel and electricity consumed in the work (AFFTIS, 1997). Enteric or gut CH_4 emission by cattle was calculated from DMI using the following quadratic regression equation reported by Shibata et al. (1993):

$$CH_4 \text{ production, L/d} = -17.766 + 42.793 \times (\text{kg of DMI/d}) - 0.849 \times (\text{kg of DMI/d})^2$$

Nitrogen content in excreted feces and urine (expressed in g/d) was calculated from the percentage of CP and TDN of DM feed, kg of DMI/d, and BW of cattle using the following multiple regression equation reported by Terada et al. (1998):

$$\text{Fecal N} = 7.22 \times \text{DMI} + 2.05 \times \text{CP} - 0.585 \times \text{TDN} + 14.1$$

$$\text{Urine N} = 8.54 \times \text{DMI} + 6.85 \times \text{CP} + 0.123 \times \text{BW} - 131.6$$

Based on these data, energy, CO_2, CH_4, N_2O, NH_3, NOx, and SO_2 were calculated either as resources or as emissions. Emissions of CO_2 from cattle respiration and the composting of their waste were offset by carbon fixation through photosynthesis from the atmosphere into forage crops.

Life-Cycle Impact Assessment

To further interpret the data of the life-cycle inventory, it is necessary to evaluate the environmental impact associated with emissions and resource uses. In impact assessment, the data are interpreted in terms of their environmental impact. The environmental loads (emissions and resource consumptions) are sorted and assigned to specific environmental impact categories in the classification stage. Next comes characterization, where the environmental loads are multiplied by equivalency factors for each specific load and impact category. Thereafter, all weighted environmental loads included in the impact category are added and the result of the environmental impact is obtained.

In this study, the contribution of the beef-fattening system to the following environmental impact categories was examined: global warming, acidification, eutrophication, and energy consumption. The global warming potential, an index for estimating the global warming contribution due to atmospheric emission of greenhouse gases, was computed according to the CO_2-equivalent factors given by IPCC (2001) for CO_2 = 1, CH_4 = 23, and N_2O = 296. These factors are based on a time horizon of 100 yr. To calculate the acidification potential of the different trace gases, the SO_2-equivalent factors for SO_2 = 1, NOx = 0.7, and NH_3 = 1.88 derived from Heijungs et al. (1992) were used. To calculate the eutrophication potential, the PO_4-equivalent factors derived from Heijungs et al. (1992) for NOx = 0.13 and NH_3 = 0.33 were used.

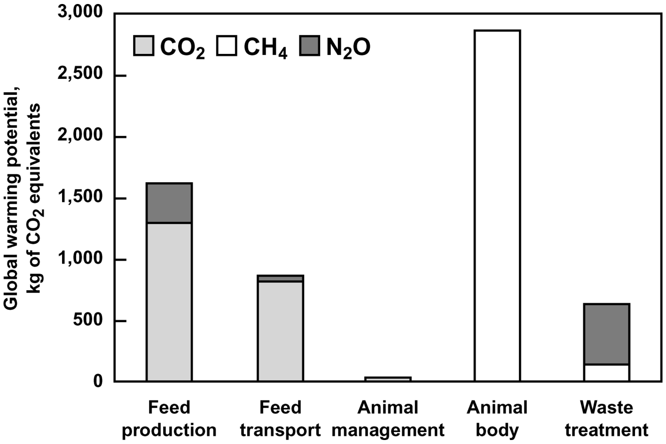

Figure 2. Contribution to global warming of each stage in the beef-fattening life cycle. The functional unit was defined as one animal. To calculate global warming potential, CO_2-equivalent factors with a time horizon of 100 yr were used: 1 for CO_2; 23 for CH_4; and 296 for N_2O.

Normalization and weighting, which are seen as options to further interpret the LCA results, were not conducted in the current study. In normalization, the results of the impact categories from the study are compared with the total impact in the region or country. During weighting, the different environmental impacts are weighted against each other to obtain one figure for the total environmental impact.

Interpretation

In the fourth phase of an LCA, the results of the life-cycle impact assessment are used to identify hot spots and possibilities of decreasing environmental impacts of the system. Results of this phase are described in the Discussion section.

Results

Environmental Impacts of Beef-Fattening System

First, we investigated the effects of each stage in the beef-fattening life cycle on environmental impacts based on the case of feeding cattle until 28 mo of age. The contributions of each stage to global warming are shown in Figure 2. The total contribution to global warming throughout the life cycle was 5,959 kg of CO_2

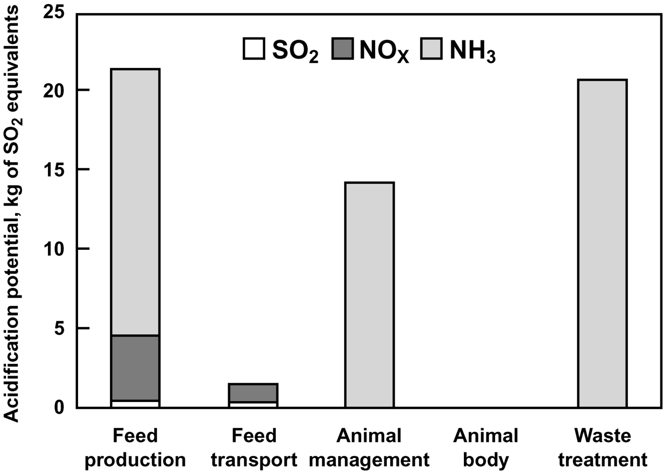

Figure 3. Contribution to acidification of each stage in the beef-fattening life cycle. The functional unit was defined as one animal. To calculate acidification potential, SO_2-equivalent factors were used: 1 for SO_2; 0.7 for NOx; and 1.88 for NH_3.

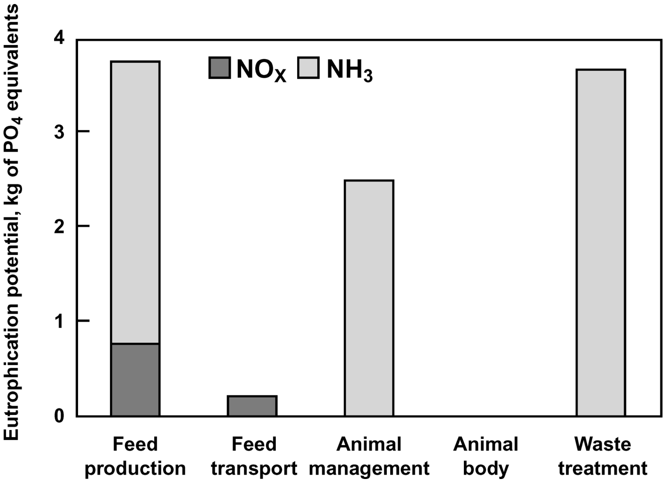

Figure 4. Contribution to eutrophication of each stage in the beef-fattening life cycle. The functional unit was defined as one animal. To calculate eutrophication potential, PO_4-equivalent factors were used: 0.13 for NOx; and 0.33 for NH_3.

equivalents. Enteric or gut CH_4 emission of cattle accounted for 48% of the total contribution. Feed production and feed transport accounted for 27 and 14% of the total contribution, respectively, mainly due to CO_2 emission in both stages. Waste treatment, for which N_2O was a major source (480 kg of CO_2 equivalents), contributed to the same extent as feed transport.

The contributions of each stage to acidification are shown in Figure 3. The total contribution through the life cycle to acidification was 58.1 kg of SO_2 equivalents. The contributions by feed production, waste treatment, and animal management accounted for 37, 36, and 25% of the total contribution, respectively, each mostly due to NH_3 emissions.

The contributions of each stage to eutrophication are shown in Figure 4. The total contribution to eutrophication through the life cycle was 10.1 kg of PO_4 equivalents. This category depended mostly on NH_3 emissions from waste treatment, feed production, and animal management, as in the case of acidification (Figure 3).

The contributions of each stage to energy consumption are shown in Figure 5. The total consumption of energy through the life cycle was 32.8 GJ. Feed production and feed transport accounted for almost all of the energy consumption (64 and 35%, respectively).

Effects of Feeding Length

The effects of the feeding length on each environmental impact category were investigated. A shorter feeding length had fewer environmental impacts in all categories taken into account in this study (Figure 6). Shortening feeding length by 1 mo decreased the environmental impacts of acidification and eutrophication by 4.5%, and decreased the impacts of global warming and energy consumption by 4.1%.

Discussion

Evaluation of Results and Improvement Assessment

This LCA study of the Japanese beef-fattening system showed that the stage of feed production had great environmental impact. This stage contributed most to acidification, eutrophication, and energy consumption and had the largest impact, next to that of animal body, on global warming.

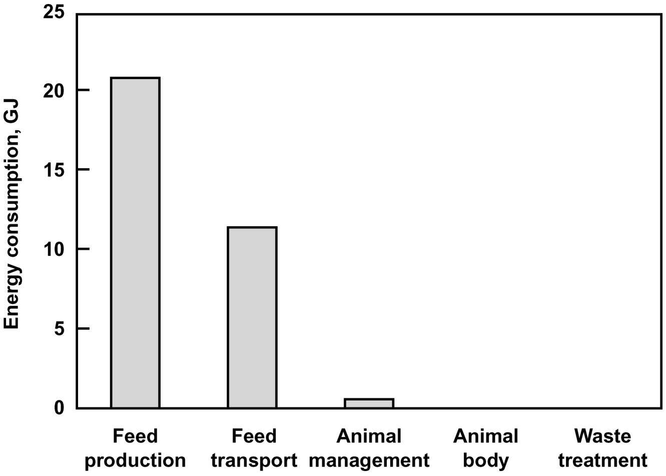

Figure 5. Contribution to energy consumption of each stage in the beef-fattening life cycle. The functional unit was defined as one animal.

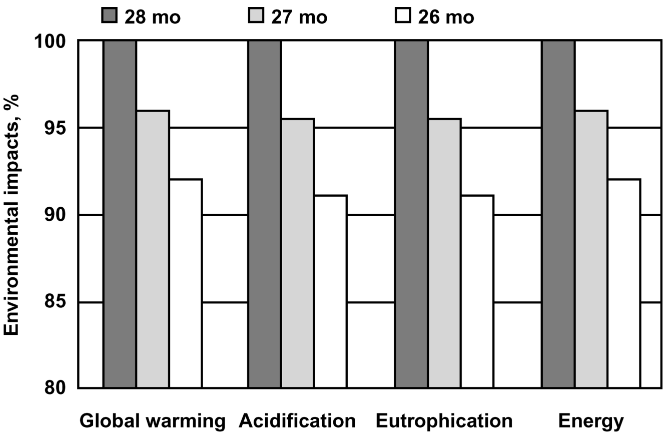

Figure 6. Effects of feeding length on each environmental impact category. The functional unit was defined as one animal. Values for 28 mo are expressed as 100%.

For global warming, the contribution of 5,959 kg of CO_2 equivalents per animal obtained in this study can be converted to 32.3 kg of CO_2 equivalents per kilogram of beef gained during fattening based on the retail beef yield percentage of 40%. Subak (1999) reported that the contribution of beef production in the U.S. feedlot system, including the calf stage, was 16.3 kg of CO_2 equivalents per kilogram of beef gained during feeding based on a 12.9-mo feeding period and assuming that birth weight is 50 kg. The Subak (1999) value was based on the higher beef yield percentage of 54%, although it is unclear whether it was carcass beef percent or retail beef percent. However, the contribution of the U.S. feedlot system is 22.0 kg of CO_2 equivalents per kilogram of beef gained during feeding even if the beef yield percentage is 40%. The contribution of the Japanese beef-fattening system to global warming analyzed in this study was therefore larger than that of the U.S. feedlot system, which seemed to be due to the much longer feeding length of the Japanese system.

Enteric or gut CH_4 emission of cattle was the most important source in the category of global warming described above. Recently, it was reported that CH_4 emission from ruminating cattle could be reduced by strategies based on dietary control (Benchaar et al., 2001; DeRamus et al., 2003); hence, decreasing CH_4 production in the rumen using these techniques can decrease its impact on global warming. For waste treatment, Fukumoto et al. (2003) reported that the pile scale of swine manure compost changed the emission rate of greenhouse gases, and a similar result is considered to be obtained for cattle manure. Utilization of this effect can decrease the contribution of waste treatment to the global warming category, although the stage of waste treatment did not have a very large impact. Furthermore, Osada et al. (2000) reported that forced aeration during the process of manure composting reduced emissions of both greenhouse gases, CH_4 and N_2O. However, they also reported that the technique increased NH_3 emissions from the composting process. In other words, forced aeration causes a trade-off between contributions to global warming and acidification or eutrophication, and it was therefore not very effective in cattle waste treatment for decreasing the total environmental impacts.

Ammonia was a major pollutant in the categories of acidification and eutrophication, as shown in Figures 3 and 4. The NH_3 emissions from animal management (i.e., from the cattle barn) were derived from fresh cattle manure before removal from the barn. Ammonia was also emitted from cattle manure in the stage of waste treatment, although NH_3 emissions from soil in the feed production stage were mainly derived from the chemical fertilizer applied there. Therefore, many of the sources of acidification during beef fattening were generated from cattle wastes. Biofiltration is effective in preventing NH_3 emissions from cattle barns and compost plants (Hartung et al., 2001; Sheridan et al., 2002). However, biofiltration systems have been uncommon among Japanese beef farms because of the additional costs in building and maintaining such facilities.

The stages of feed production and feed transport were dominant contributors to energy consumption, and it was proved that most of the energy was consumed before the feed reached the cattle's mouth. Furthermore, the feed production consumed more energy than the feed transport, despite the long transport distance from the United States to Japan. The reasons for this seem to be smaller environmental loads for marine transport per unit of traffic volume, especially in the case of using large bulk carriers rather than other transportation modes.

For roughage in feed production and feed transport, environmental loads from production and transport of rice straw were included in the system based on the definition that commercially distributed roughage was purchased. In Japan, while there are often many rice farms neighboring beef-fattening farms, a shortage of manpower prevents collection of rice straw from the paddy fields after the harvest. These beef-fattening farms have to buy commercially distributed rice straw, despite a cost of ¥40 to 50/kg. However, considering the wide production of rice in Japan, if rice straw were collected from neighboring rice farms in exchange for compost, environmental loads of rice straw as a by-product of rice production could be excluded from the system. This would serve to decrease the environmental impacts of the beef-fattening life cycle by 1.9 to 3.1% and 0.6 to 1.0% for the feed production and feed transport stages, respectively.

Effects of Feeding Length

Shortening feeding length by 1 mo decreased environmental impacts in all the categories examined in the current study as described above. Furthermore, a shorter feeding length had slightly greater effects on reducing environmental impacts in the categories of acidification and eutrophication (4.5% decrease) than in those of global warming or energy consumption (4.1% decrease). This difference seems to be caused by the physiological characteristics of beef cattle in the last 6 mo of fattening. Ammonia emissions from cattle waste were a major source of acidification and eutrophication (Figures 3 and 4). The levels of these emissions were mainly due to the amount of N excreted into the cattle manure. In contrast, enteric or gut CH_4 emission and the energy consumed in the stages of feed production and feed transport were major sources of global warming and energy consumption, respectively (Figures 2 and 5). The quantities of this emission and the energy use were mainly due to the feed intake of cattle, which increases until 17 mo of age in response to the growth of cattle and declines to 65% of the maximum in the last 6 mo of fattening. However, the N level excreted into the manure does not decrease greatly (81% of the maximum) because the growth rate of cattle also decreases, followed by decrease of N utilization in organs such as the skeletal muscles, which have a protein content of 70 to 80% (DM basis).

Although a longer feeding length makes cattle heavier, causing an increase in beef yield (Table 1), the shorter feeding length (by 2 mo) had a smaller environmental impact per unit weight of beef. For example, the contributions to global warming per kilogram of beef in the case of feeding cattle until 28 and 26 mo of age were 20.6 and 19.7 kg of CO_2 equivalents, respectively. Defining the functional unit as 1 kg of beef provides an answer for this problem. However, all systems, including cow-calf management, slaughtering of cattle, and beef distribution, would have to be included in the system boundary to investigate the total environmental impacts of beef production. Therefore, to focus on the beef-fattening system, this definition was not adopted in this study. The total environmental impacts of beef production including such systems should be investigated in further research.

Efforts for decreasing environmental impacts have been started in the livestock industry. The results that show the present environmental impacts of beef fattening will be an index for quantifying effects of environmentally sound beef production systems developed in the future.

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