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Environmental impacts of extensive and intensive beef production systems in Thailand evaluated by life cycle assessment

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Abstract

Beef production is rapidly increasing and is accordingly becoming intensified in Southeast Asia, and the changes in beef production systems could contribute to large changes in the environmental impacts, taking into account the emission intensity of beef production. Here we assessed and compared the environmental impacts of extensive and intensive beef production systems in northeastern Thailand, using life cycle assessment (LCA). The extensive system was based on grazing and forage from grassland, and the intensive system houses cattle in the fattening phase and uses purchased concentrate feed as well as home-grown forage. An LCA model was developed based on data collected by site investigations of beef farms as well as literature and LCA databases. The processes associated with the beef-farming life cycle, i.e., animal management including biological activities of the cattle, grassland management, purchased feed production, and waste treatment were included within the LCA system boundary. The functional unit was defined as 1 kg of liveweight of marketed beef cattle. The environmental impacts of the extensive and intensive beef production systems were 14.0 and 10.6 kg CO_2 equivalents for climate change, 3.5 and 11.3 MJ for energy consumption, 47.4 and 61.8 g SO_2 equivalents for acidification, and 30.4 and 33.9 g PO_4^{3-} equivalents for eutrophication, respectively. These impacts except for eutrophication were significantly different ($P<0.05$) between the two systems. The enteric CH_4 emissions were the largest sources for climate change, and the manure-related emissions were the largest sources for acidification and eutrophication. In the intensive system, the purchased feed contributed a great deal to energy consumption and to some extent to other impact categories. Our results suggested that the ongoing intensification of beef production in Thailand reduces GHG emissions while increasing impacts on energy consumption and acidification. These results

provide helpful information to develop a strategy to balance the increasing productivity with the environmental sustainability of beef production in developing countries.

Keywords: beef farming, greenhouse gas, intensification, LCA, Southeast Asia

1. Introduction

Beef production has been increasing worldwide, and Southeast Asia is one of the regions that have the largest increase rate of beef production in the last decade (FAO, 2013). The number of beef cattle in Thailand has been increasing, and there are presently 9.1 million cattle in the country (DLD, 2008). While cattle used to be utilized as a draft animal together with the swamp buffalo, most of the cattle in Thailand are now used for beef production with the exception of a small number of dairy cattle (Lambertz et al., 2012). An extensive beef production system based on grazing and with low inputs of materials and labor was once the predominant system in Thailand as in South American and other Asian countries (Na-Chiangmai, 2002; Modernel et al., 2013).

However, in response to the increasing demand for beef, especially high-quality beef, an intensive beef production system that uses concentrate feed and houses the cattle has begun to prevail in Thailand, although the proportion of the intensive system to the total beef production is less than 10% at the moment (FAO, 2013; JETRO, 2013). Changes in the beef production system will affect greenhouse gas (GHG) emissions and other environmental impacts of beef production through an increase in material inputs, improvements of productivity, and more; however, the details of the impact of the changes have not been established.

The GHG emissions from developing and emerging countries have been increasing and now account for more than one half of global GHG emissions (IPCC, 2014); thus, the need to reduce GHG emissions in both developing and developed countries is high. Compared to developed countries, the GHG emissions from the agricultural sector in developing countries comprise a larger proportion of the national GHG emissions, further highlighting the necessity of reducing GHG emissions. Livestock production accounts for 14% of the global GHG emissions (Gerber et al., 2013) and for approx. 64% of global anthropogenic ammonia (NH_3) emission (Galloway et al., 2004; Steinfeld et al., 2006), which contributes to acidification. It has been also indicated that livestock production is a significant source of eutrophication (Steinfeld et al., 2006). Concerted efforts are thus needed to reduce these figures, particularly in the countries where livestock production is growing rapidly. It is important to first evaluate the effects of changes in beef production systems on the environmental impacts in those countries before considering mitigation options for GHG emissions and other environmental impacts.

The life cycle assessment (LCA) method is suitable for environmental evaluations (ISO, 2006) and has been used to evaluate the environmental impacts of beef production. However, most of the existing studies were of beef production systems in developed countries such as the United States (Pelletier et al., 2010; Lupo et al., 2013), Canada (Beauchemin et al., 2010), the European Union (Nguyen et al., 2010), France (Nguyen et al., 2012), Ireland (Casey and Holden, 2006), the United Kingdom (Edwards-Jones et al., 2009), Australia (Peters et al., 2010), and Japan (Ogino et al., 2004; 2007a). A very limited number of studies in emerging or developing countries have been reported, and all of them were conducted in South American countries (Cederberg et al., 2011; Modernel et al., 2013; Ruviaro et al., 2014). According to these LCA studies, the environmental impacts per kg-liveweight (LW) of beef production taking into account cow-calf production ranged from 8.6 to 47.6 kg of CO_2 equivalent (CO_2e) for climate change without carbon sequestration or land use effects, from 11.6 to 67.7 megajoule (MJ) for energy consumption, from 95 to 180 g of SO_2 equivalent (SO_2e) for acidification, and from 19 to 142 g of PO_4^{3-} equivalent (PO_4e) for eutrophication. The differences among the reported environmental impacts seemed to depend on the feed, farming system, productivity, and climate, as well as assumptions and emission factors used.

The objective of the present study was to evaluate and compare the environmental impacts of extensive and intensive beef production systems in Thailand using LCA.

2. Materials and Methods

2.1. System Description

The first step of LCA is the definition of the goal and scope of the analysis, the functional unit (FU), and the system boundaries. Here, the goal of our analysis was to evaluate and compare the environmental impacts of two types of Thai beef production systems: an extensive system (EXT) and an intensive system (INT).

The northeastern region of Thailand is the production area of beef cattle, where 54% of the beef cattle in Thailand are maintained (DLD, 2008). We thus conducted site investigations of beef farms using the EXT system or the INT system in the Khon Kaen, Sakon Nakhon, and Nakhon Phanom provinces in the northeastern region to collect data about the number of cattle marketed, the age and weight of the marketed cattle, the consumption of fuel, electricity, and agricultural materials, and the amounts of feed used. The investigated farms were four EXT farms, and two cow-calf, three backgrounding, and six fattening farms of the INT system. The annual mean temperature and annual precipitation of Khon Kaen (16°26'N, 102°50'E), a city located in the center of the region, are 27.4°C and 1296 mm/yr, respectively (NOAA, 2012).

Table 1 provides a summary of the EXT and INT farms investigated in this study. The average number of cattle per farm is slightly larger in the INT system compared to the EXT system. The INT farms had larger slaughter weights but a shorter feeding period compared to the EXT farms on average. The grassland area of the EXT system seemed small considering that no purchased feed was used, and this was considered to be compensated by the use of rice straw from surrounding paddy fields as well as native grass from the roadsides and contour hedgerows (Na-Chiangmai, 2002; Wanapat et al., 2007). Cattle manure is deposited directly on grassland for grazed cattle, and it is stored and applied to grassland for housed cattle.

An outline of the systems analyzed is presented in Figure 1. The EXT system was based on grazing and forage from grassland and did not use purchased feeds. Seeded pastures based on guinea grass (*Panicum maximum*) and ruzi grass (*Brachiaria ruziziensis*) were used in the EXT system. Rice straw from surrounding paddy fields was also used in the dry season. The ratio of forages were assumed to be 40% guinea grass, 27% ruzi grass, and 33% rice straw based on the site investigations. Fencing was not used in grazing management because the EXT beef farms were small scale (as shown in Table 1), and cattle can be easily managed by a farmer without the use of fencing. In the EXT system, there is no subsystem unlike the INT system, and all cattle were simply grazed in the same manner. This is partly because EXT farmers raise cattle as an asset or savings (Na-Chiangmai, 2002), and cattle are shipped for not only expected expenditures but unexpected expenditures such as health costs and ceremonies (Lambertz et al., 2012). The cattle used in the EXT system were mainly crossbreds of Thai native × Brahman.

The INT system consisted of three subsystems: cow-calf (~12 mo), backgrounding (~24 mo), and fattening (24 mo~), and the subsystems are usually conducted at different farms. The environmental impacts per beef animal in each subsystem were calculated, and the sum of the values for all subsystems was considered to be the environmental impacts of the INT cattle. The fattening subsystem houses the cattle and uses purchased concentrate feeds and locally produced agricultural byproducts such as molasses as well as forage. The composition of the purchased concentrate feeds was found to be 41% cassava, 30.8% palm kernel meal, 12.3% rice bran, 12.3% soybean meal, 3.1% molasses, and 0.5% urea, with 13% crude protein (CP) and metabolizable energy (ME) of 12 MJ/kg. The cow-calf subsystem of the INT system is based on grazing and is similar to the EXT system. The characteristics of the backgrounding subsystem are in between those of the cow-calf and fattening subsystems; it uses a small amount of the purchased concentrate feed. The environmental loads of cow rearing for calf production were included in the analysis.

A cow was considered to produce five calves in the INT system on the basis of the production situation in the region. The breeding cows in the INT system were the same breed as the EXT cattle (Thai native × Brahman crossbreds) and were raised in almost the same way as the EXT cattle. They were therefore assumed to have the same environmental load as that of the EXT cattle. The cattle used in the INT system were Thai native × Brahman × Charolais crossbreds (Thai native × Brahman crossbred cows were sired by Charolais), and the breeding cows were more Brahman than Thai native. No EXT or INT farms had breeding bulls; 75% of the calves were produced by artificial insemination (AI) and 25% were produced by rented bulls in the EXT system, and 100% of the calves were produced by AI in the INT system. Thus, their environmental loads were not taken into account.

The FU is a reference to which all other materials (and also the associated environmental loads) in the LCA are related. The FU was defined as 1 kg-LW of a marketed beef animal. The slaughter weight of cattle was different between the two beef production systems due to the different feeds and breeds of cattle (Table 1), and the dressing percentage was unknown for the investigated cattle. The FU was therefore not defined as one beef animal or 1 kg-carcass weight in this study. The impact categories investigated herein were climate change, energy consumption, acidification, and eutrophication. The environmental loads associated with the production of capital goods such as cattle barns and agricultural machines for concentrate feed production were not taken into account (Baumann and Tillman, 2004).

2.2. Life Cycle Inventory

An LCA model was developed on a monthly basis to evaluate the environmental impacts of the two Thai beef production systems. The data collection for the model was based on the site investigations, published studies, and LCA software databases.

For the EXT system, since it is very difficult to directly measure feed intakes of grazed cattle — which are necessary to calculate the enteric methane (CH_4) emissions from cattle and nitrous oxide (N_2O) emissions from cattle manure — we estimated the growth curves of cattle on the basis of data about the body weights and ages of the cattle obtained by our site investigations. In the estimation of growth curves, Brody's growth curve (Brody, 1945), which has often been used for cattle (Hirooka et al., 1998; Oishi et al., 2013), were fitted to the data on weight and age using the NLIN procedure of the SAS software (SAS, 1990), whereas the growth of calf (~12 mo) was assumed to be linear due to the youth of these cattle. The birth weights of the female and male calves were determined to be 23 and 26 kg, respectively, based on Intaratham et al. (2008) and Browning et al. (1995). The estimated growth curves were as follows:

$$W = 13.09 \times T + 23 \quad \text{(for a female EXT calf, ~12 mo)} \tag{1}$$

$$W = 14.34 \times T + 26 \quad \text{(for a male EXT calf, ~12 mo)} \tag{2}$$

$$W = 567.3 - 479.5 \times \exp(-0.0177T) \quad (R^2 = 0.84) \quad \text{(for an EXT cow, 12 mo~)} \tag{3}$$

$$W = 556.8 - 524.6 \times \exp(-0.0316T) \quad (R^2 = 0.59) \quad \text{(for an EXT bull, 12 mo~)} \tag{4}$$

where W is kg of body weight and T is months of age.

Metabolizable energy intakes (MJ/d) were calculated at each month of age from the body weight (W, kg) and average daily gain (ADG, kg/d) of the cattle based on the estimated growth curves using the following regression equations for Thai native (Eq. 5) and Brahman (Eq. 6) cattle suggested in the Nutrient Requirements of Beef Cattle in the Indochinese Peninsula edited by the Working Committee of Thai Feeding Standard for Ruminant (WTSR) (WTSR, 2010), and we used the average of the two as a metabolizable energy intake of Thai native × Brahman crossbreds.

$$\text{ME intake} = 31.37\text{ADG} + 0.4836W^{0.75} \tag{5}$$

$$\text{ME intake} = 22.67\text{ADG} + 0.48619W^{0.75} \tag{6}$$

The gross energy (GE) intakes (MJ/d) were calculated from the ME intakes and the GE/ME ratio of the feed. The ME contents of each feed ingredient were taken from WTSR (2010), and the GE contents (MJ/kg) of the dry matter (DM) feed were calculated from the percentages of CP, ether extracts (EE), nitrogen-free extracts (NFE), and crude fiber (CF) of the DM feed using the following equation (NARO, 2010).

$$\text{GE content} = (5.67 \times \text{CP} + 9.68 \times \text{EE} + 4.25 \times \text{NFE} + 4.9 \times \text{CF}) \times 4.184/100 \tag{7}$$

The enteric CH_4 emissions (L/d) were calculated using the following equation based on a number of studies that have measured enteric CH_4 emissions under the conditions in Thailand (Chaokaur, 2011).

$$\text{Enteric } CH_4 = 1.26 \times (\text{GE intake}) + 45.1 \tag{8}$$

For calves under 6 months of age in both the INT and EXT systems, however, the CH_4 emissions were calculated as a function of weeks of age, taking into account the immaturity of rumen digestion, using the following regression equation reported by Sekine et al. (1986).

$$\text{Enteric } CH_4 = 3.4 \times (\text{week of age}) - 1.2 \tag{9}$$

The CH_4 emissions from manure management were calculated on the basis of the Intergovernmental Panel on Climate change (IPCC) methodology (IPCC, 2006) from the parameters shown in Table 2 and the percentage of digestible energy (DE) of the feed taken from the WTSR (2010) and, if no data were available from the WTSR, from NARO (NARO, 2010). The N_2O emissions from manure management were calculated on the basis of the IPCC methodology (IPCC, 2006) from nitrogen excretion, which is the difference between nitrogen intake and retention, and the N_2O emission factors. The CP intakes of the EXT cattle were calculated from the ME intakes and the CP/ME ratio of the feed, and they were converted into the nitrogen intakes by dividing by 6.25. The ME and CP contents were taken from the WTSR (2010). The nitrogen retentions were calculated from body weight and weight gain of cattle. The N_2O emission factors are shown in Table 2.

For the INT system, the calf-backgrounding and fattening subsystems are very different in terms of cattle feed and housing; therefore, we fit different growth curves for the calf-backgrounding and fattening subsystems. The growth of calf-backgrounding cattle was assumed to be linear due to the youth of these cattle, and Brody's curve was fitted for the fattening cattle considering their maturity. The birth weight of each INT calf was assumed to be 30 kg. The estimated growth curves were as follows:

$$W = 15.417 \times T + 30 \quad \text{(for calf and backgrounding in INT)} \quad (10)$$

$$W = 751.2 - 4254.7 \times \exp(-0.1038T) \quad (R^2 = 0.93) \quad \text{(for fattening in INT)} \quad (11)$$

where W is kg of body weight and T is months of age.

For the calf-backgrounding subsystem of the INT system, we calculated the ME intakes using Eq. (6), because the cattle used in the INT system were Thai native × Brahman × Charolais crossbreds containing more Charolais and Brahman than Thai native, and the characteristics of cattle such as ADG are closer to those of Brahman than to those of Thai native. The GE intakes and enteric CH_4 emissions were calculated as described for the EXT system. For the INT fattening subsystem, the GE intakes were calculated based on the feed intakes obtained by the site investigations and the GE content of feed ingredients calculated as described above. The CH_4 emissions (kg/d) were calculated using the IPCC equation (IPCC, 2006) (Eq. 12) from the GE intakes and the methane conversion factor Ym shown in Table 2, because the GE intake at the latter fattening stage is over the range covered by Chaokaur's equation, which we used for the EXT system.

$$\text{Enteric } CH_4 = (\text{GE intake}) \times Ym / 55.65 \quad (12)$$

For the calf-backgrounding subsystem, the CP intakes (kg/d) were calculated using the following equation for Brahman crossbreds suggested in the WTSR, because the cattle used in the INT system were Thai native × Brahman × Charolais crossbreds containing more Charolais and Brahman than Thai native as described above, and “Brahman crossbred” in the WTSR means crossbreds of Brahman and European breed cattle such as Charolais (Tangjitwattanachai and Sommart, 2009).

$$\text{CP intake} = 0.59\text{ADG} + 0.00547W^{0.75} \quad (13)$$

The CP intakes were calculated using this equation whereas the ME intakes and the

CP/ME ratio of the feed were used for the EXT system. This is because the CP intakes were larger using this equation than when the ME intakes and the CP/ME ratio were used for the calf-backgrounding subsystem of INT, whereas for the EXT system the CP intakes were larger using the ME intakes and the CP/ME ratio. In other words, the CP intake calculated using the ME intake and CP/ME ratio of the feed is insufficient for growth of cattle in the INT calf-backgrounding subsystem. The CP intakes, used for calculating nitrogen excretion, were thus conservatively estimated for both the EXT and INT systems.

For the INT fattening subsystem, the CP intakes were calculated based on the feed intakes obtained by the site investigations and the CP content of feed taken from the WTSR. The N_2O emissions from manure management were calculated as described for the EXT system using the CP intakes and the emission factors shown in Table 2. The CH_4 and NH_3 emissions from manure management were also calculated as described for the EXT system using the parameters and emission factors shown in Table 2.

To calculate the pollutant emissions from the production and combustion of fossil fuels, the consumption of electricity, the production of materials, and transport, we used the Thai National Life Cycle Inventory Database (TLCID) (MTEC, 2012), and if data for materials were lacking in the database, we used the database of the LCA software MiLCA (JEMAI, 2012). The inventory data for grass seed production were taken from the Ecoinvent database (Ecoinvent Center, 2007).

We calculated the energy consumptions of the processes in each system using the amounts of fuel and electricity consumption determined in the calculation of GHG emissions. For the TLCID data, we determined the energy consumption by multiplying the GHG emissions by the average energy consumption per kg of CO_2 emission based on the national energy consumption and CO_2 emission in Thailand (CDIAC, 2011).

The acid and eutrophication pollutant emissions involved in fuel and electricity consumption were calculated using their GHG emissions and the ratio of acid and eutrophication pollutants to GHG emissions taken from the MiLCA database. The average energy mix in Thailand was determined based on the national consumption of each fuel, and the acid and eutrophication pollutant emissions involved in the production and use of agricultural materials were calculated using their GHG emissions and the ratio of acid and eutrophication pollutants to GHG emissions of the average energy mix taken from the MiLCA database.

We calculated the NH_3 emissions from manure management, manure applied to grassland, and chemical fertilizer application using the nitrogen excretion, the amount of nitrogen in applied manure, and the amount of nitrogen in applied chemical fertilizer, respectively, using the emission factors shown in Table 2. The nitrate (NO_3) emissions from manure applied to grassland and chemical fertilizer application were calculated using the amounts of nitrogen in applied manure and chemical fertilizer, respectively, using the emission factor of 30% only during the rainy season (IPCC, 2006). Phosphorus (P) emissions were calculated using the P emission model which calculates P emissions due to leaching, run-off, and erosion (Nemecek and Kägi, 2007). The P leaching was 0.06 kg-P/yr/ha-grassland. The P run-off was calculated using the average quantities of P run-off of 0.15 (extensive) and 0.25 (intensive) kg-P/yr/ha-grassland and the amounts of P applied to grasslands as manure or chemical fertilizer. Cattle P excretion was calculated as the difference between P intake and retention; the P intakes were calculated from the feed intakes and the P contents taken from the WTSR (2010), and the P retentions were calculated from weight gain of cattle and cattle body P concentration of 0.8% (ARC, 1980). The P erosion was calculated as described by Nguyen et al. (2012).

We used several published reports to determine pollutant emissions from the production and transport of purchased concentrate ingredients that are unavailable in the TLCID such as cassava (Nguyen et al., 2007a), palm kernel meal (Schmidt, 2007; Ecoinvent Center, 2007), soybean meal (Mosnier et al., 2011), and molasses (Nguyen et al., 2007b; Nguyen and Gheewala, 2008).

The emissions of CO_2 from cattle respiration and the degradation of cattle manure were assumed to be offset by carbon fixation from the atmosphere into forage through photosynthesis. The GHG emissions from land use and land use change (LULUC) were not taken into account in the present study.

2.3. Impact assessment

We examined the contributions of the two beef production systems in relation to the environmental impact categories of climate change, acidification, eutrophication, and primary energy consumption. First, the data of the life cycle inventory were interpreted in terms of their environmental impact. The environmental loads were sorted and assigned to specific environmental impact categories, then multiplied by equivalency factors for each specific load and impact category. Thereafter, all of the weighted environmental loads included in the impact category were added, and the environmental impact was obtained. We computed the global warming potential (GWP), an index for estimating the climate change contribution due to the atmospheric emission of GHGs, according to the CO_2-equivalent factors defined by the IPCC (2007): CO_2, 1; CH_4, 25; and N_2O, 298. These factors were set based on a time horizon of 100 years. To calculate the acidification potential (AP) of the different trace gases, we used the SO_2-equivalent factors for SO_2 and $SO_X = 1$, NO_2 and $NO_X = 0.7$, and $NH_3 = 1.88$ derived from Heijungs et al. (1992). To calculate the eutrophication potential (EP) of the different pollutants, we used the PO_4^{3-}-equivalent factors for NO_2 and NO_X = 0.13, NH_3 = 0.33, NO_3 = 0.1, and P = 3.06 derived from Heijungs et al. (1992).

2.4. Statistical analyses

We calculated the GHG emissions from, energy consumption, the AP, and the EP of each EXT and INT farm using the LCA model developed. For the INT system, the averages of the cow-calf farms and the backgrounding farms were calculated first, and then the environmental impacts of the total INT system were calculated for each fattening farm. We analyzed the environmental impacts of the EXT and INT systems by Welch's t-test using R version 3.0.3 (R-Development-Core-Team, 2014). P-values < 0.05 were considered significant.

3. Results

The GHG emissions from the two beef production systems in Thailand are shown in Figure 2. The average GHG emissions from the EXT and INT farms were 14.0 and 10.6 kg CO_2e/kg-LW, respectively. The INT farms had significantly (25%) lower GHG emissions than the EXT farms. The enteric CH_4 emissions were the largest GHG sources, accounting for 77% of the total for the EXT system and 65% of the total for the INT system, followed by the GHG emissions from manure management in both systems. The GHG emissions derived from purchased feed contributed to the total GHG emissions to some extent in the INT farms; however, the INT farms had much lower enteric CH_4 emissions and GHG emissions related to manure and thus lower total GHG emissions compared to the EXT farms. The GHG emissions derived from utilities and agricultural materials such as chemical fertilizer were very small in both beef production systems.

Figure 3 shows the energy consumption of the two beef production systems. The average energy consumption of the EXT and INT farms were 3.5 and 11.3 MJ/kg-LW, respectively. In contrast to the GHG emissions, the energy consumption of the INT farms was significantly and much larger than that of the EXT farms. The energy consumed at the beef farms for utilities and in relation to agricultural materials was not very large in both systems, and thus the energy consumption derived from purchased feed (9.6 MJ/kg-LW) caused the difference between the EXT and INT systems. A large variation of energy consumption was observed among the four EXT farms.

The average AP of the EXT and INT farms were 47.4 and 61.8 g SO_2e/kg-LW, respectively, and the average AP of the INT farms was also significantly larger than that of the EXT farms (Fig. 4). The NH_3 emissions from cattle manure were the largest sources of acidification in both systems, representing 93% of the total for the EXT system and 84% of the total for the INT system. The acid pollutants derived from purchased feed also contributed to acidification in the INT farms, accounting for 14% of the total AP of the INT farms.

Figure 5 shows the EP of the two beef production systems. The average EP of the EXT and INT farms were 30.4 and 33.9 g PO_4e/kg-LW, respectively; however, there was no significant difference between them. The NH_3 and NO_3 emissions from cattle manure were the largest sources of eutrophication in both systems, representing 70% of the total for the EXT system and 56% of the total for the INT system. The second largest sources were the on-farm P emission for the EXT farms and the purchased feed for the INT farms.

4. Discussion

4.1. Comparison of the two beef production systems

Our evaluation of the EXT and INT beef production systems using the LCA revealed that the INT system differs from the EXT system in its environmental impacts among the categories investigated here. With respect to climate change, the INT farms had additional GHG emissions derived from purchased feed; however, the INT farms had much lower enteric CH_4 emissions and manure-related GHG emissions per kg-LW and thereby lower total GHG emissions than the EXT farms (Fig. 2). The average slaughter age and slaughter weight were 36 months and 653 kg for the INT farms, compared to 59 months and 421 kg for the EXT farms (Table 1). The shorter feeding period and larger cattle weight of the INT farms therefore seemed to lead to the lower enteric CH_4 and manure N_2O emissions per kg-LW of the INT farms. It has also been reported that improving productivity reduces the GHG emissions per kg-LW in beef production systems (Peters et al., 2010; Pelletier et al, 2010) and cow-calf systems (Becoña et al., 2014).

In contrast to the case of climate change, the INT farms showed larger contributions to energy consumption and acidification despite the improved productivity. The on-farm energy consumption was smaller for the INT farms compared to the EXT farms; however, the energy consumption involved in the purchased feed was much larger and thus the total energy consumption was larger for the INT farms than for the EXT farms (Fig. 3). The smaller on-farm energy consumption per kg-LW for the INT farms might be because of the small on-farm energy consumption of the INT farms due to smaller grassland per animal compared to the EXT farms and the higher productivity of the INT farms. Moreover, very large on-farm energy consumption was observed in one of the EXT farms. The extensive system was a very low-input system based on grazing using only a small amount of fertilizer and fuels as a whole, and thus the energy consumption involved in the purchased feed production and transport resulted in the much larger energy consumption of the INT farms compared to the EXT farms.

Regarding acidification, the INT farms also had a larger AP than the EXT farms due to the acid pollutant emissions derived from purchased feed and the higher NH_3 emissions from manure (Fig. 4). The increase of nitrogen excretion due to the use of the purchased feed (concentrate) was offset by the increased weight gain of the cattle, and the nitrogen excretion per kg-LW was lower for the INT farms (0.19 kgN/kg-LW) compared to the EXT farms (0.24 kgN/kg-LW). However, the NH_3 emission factors related to manure were larger for the INT system due to housing and manure storage, and thus the NH_3 emissions from manure in the INT farms were higher, which was reflected by the larger AP of the INT farms.

The EXT and INT farms showed no significant difference in their impacts on eutrophication (Fig. 5). The INT farms had higher NH_3 emissions from manure as described above and the additional emissions involved in purchased feed. However, the increase of NO_3 emissions from manure were completely offset by the increased weight gain of the cattle, and the on-farm P emission was higher for the EXT system due to the larger grassland areas used and the smaller weight gain of the cattle in the EXT farms. These negative and positive effects of the INT system appeared to result in no significant difference between the two systems.

Our findings revealed that the ongoing intensification in beef production in Thailand reduces GHG emissions while increasing impacts on energy consumption and acidification. The existence of both environmental advantages and disadvantages for intensification in beef production was also observed in a study by Modernal et al. (2013), in which a feedlot system had lower GHG emissions but higher impacts on other impact categories such as energy consumption and nutrient balances compared to a grazing system. In contrast, Capper (2011) reported that a beef production system with better productivity had lower GHG emissions and smaller energy consumption in a comparison of beef production systems at present and 30 years ago. The reason for this difference among studies might be that the intensification of extensive systems has both positive and negative environmental effects, whereas increasing the productivity of a system that is already intensive to some extent improves all environmental impacts. The different effects of intensification on environmental impacts among impact categories indicate the need to evaluate multiple impact categories in conducting an LCA of beef production systems.

By 2050, the global population is expected to total more than nine billion people, and the future global food demand is expected to increase by some 70% (Turral et al., 2008). To meet this demand, it is essential to increase the productivity of foods including beef, but this should be accomplished in an environmentally sustainable manner, as by sustainable intensification (Garnett et al., 2013). The environmental impacts involved in purchased concentrate feed accounted for a certain proportion in all of the impact categories investigated. In the present study we found that the calculated GHG emission, energy consumption, acidification potential, and eutrophication potential per kg of purchased concentrate feed were 321 g CO_2e, 2.38 MJ, 2.09 g SO_2e, and 2.25 g PO_4e, respectively. To mitigate impacts on energy consumption and acidification, one of the options is the use of locally available agri-food residues/co-products that are nutritionally comparable to concentrate feed such as, in the case of Thailand, cassava pulp (Chen et al., 2010). Reductions of energy consumption as well as GHG emissions have been reported for the use of agri-food residues/co-products as animal feeds (Ogino et al., 2007b; 2012; Elferink et al., 2008).

We observed large differences in the feeding periods and slaughter weights between the EXT and INT systems, and they were strongly affected by the difference of cattle breed used as well as the difference of feeding regime. The Thai native × Brahman crossbred is more suitable for extensive production conditions (especially in the dry season when forage tends to be insufficient), and European breeds such as Charolais have higher weight gains in intensive production conditions. The selection of inadequate breeds could result in higher environmental impacts per unit amount of product due to decreased farm productivity. It is therefore important to consider the change of production systems in terms of not only the feeding regime but also the cattle breed to reduce environmental impacts.

Regarding the sensitivity of our LCA results, the enteric CH_4 emissions dominated the total GHG emissions from both of the beef production systems, and thus the methodology used for the calculation of enteric CH_4 emissions could affect the results. The country-specific equation was used in this study; however, using the general IPCC (2006) methodology instead did not greatly affect the results for the GHG emissions (13.1 kg CO_2e/kg-LW for the EXT farms and 10.4 kg CO_2e/kg-LW for the INT farms). It is meaningful to discuss the effects of an alternative FU on the results (Gonzalez-Garcia et al., 2013). The FU was defined as 1 kg-LW of cattle and environmental impacts were compared per kg-LW in the present study, since the dressing percentage was unknown for the investigated cattle. Waritthitham et al. (2010) reported dressing percentages of 56.2% for Thai native × Brahman crossbred and 58.1% for Thai native × Charolais crossbred cattle. The comparison based on carcass weight would therefore be slightly advantageous for the INT system, although the effect of the choice of FU was not very large.

The GHG emissions from LULUC were not taken into account in the present study, although they were included in some LCA studies on beef production systems (Cederberg et al, 2011; Nguyen et al, 2010). This is because the amount of GHG emissions from LULUC is still unclear, particularly for carbon sequestration in grasslands. Some groups have reported the accumulation of soil carbon in grasslands for a long period under certain conditions (Liebig et al., 2010; Sanderman et al., 2013). In contrast, Smith (2014) suggested it is untenable that grasslands act as a perpetual carbon sink on the basis of soil surveys, long-term measurements, and mass balance calculations.

The results of the present study showed the difference of environmental impacts between the EXT and INT beef production systems. Hence their economic performances were compared on the basis of information obtained from the site investigations, statistics, and governmental information. The costs and sales per head of the EXT and INT systems in 2011 were 400 and 950 Thai baht (THB, 1 THB = 0.031 USD) for AI cost, 5,920 and 2,390 THB for chemical fertilizer cost, 200 and 170 THB for grass seed cost, 0 and 28,970 THB for purchased feed cost, and 20,550 and 53,160 THB for cattle sales, respectively. Of the EXT and INT systems, the calculated profits per head were 14,030 and 20,680 THB, and the profits per head per year were 3,090 and 6,840 THB, respectively; thus, the INT system is more profitable than the EXT system. However, it should be noted that the EXT system has much less costs for beef production, which is advantageous to smallholder farms.

4.2. Environmental impacts of beef production systems

The results of several LCAs of beef production have been reported, and a comparison of environmental impacts per kg-LW of beef production systems are shown in Table 3. Only the research results that evaluated beef production systems taking into account the cow-calf production and that reported the GHG emissions without LULUC were included in the table for a comparison with the results of the present study. A large variation in the environmental impacts was observed among the studies, depending on the feed, farming system, and productivity. Different assumptions, emission factors, and characterization factors were also applied in these different studies. In particular, the newer IPCC CO_2-equivalent factors to compute the GWP have a higher characterization factor for CH_4, and thereby the more recent studies are likely to have resulted in higher GHG emissions, because the enteric CH_4 is usually the largest source of GHG emissions in beef production. A precise comparison is thus difficult; however, many of the present results are fairly consistent with the previously reported values.

GHG emissions were evaluated in all of the studies cited, and most of the reported values and the present values were in the range from 10 to 20 kg CO_2e. The GHG emissions exceeding 40 kg CO_2e appeared to be due to extensive production using native pasture in a study by Ruviaro et al. (2014) and to large N_2O emission from organic soils in a UK study (Edwards-Jones et al., 2009). The energy consumption of INT farms in the present study is comparable to the results of an Australian study (Peters et al., 2010), whereas that of the present EXT farms is the smallest among the studies, a result which appears to be attributable to the very low-input production based on grazing. The larger energy consumption in the Japanese studies (Ogino et al., 2004; 2007a) is likely to be caused by the fact that most of the feeds used are imported from distant countries such as the United States. Only a small number of the studies reported the impacts on acidification and eutrophication. The present results for acidification are smaller than the previously reported values. Larger acidification potentials reported by Lupo et al. (2013) appeared to be due to the higher manure NH_3 emission factors used. The present results for eutrophication are between the results of the U.S. study (Lupo et al., 2013) and the French study (Nguyen et al., 2012). Much larger values were obtained by another U.S. study (Pelletier et al., 2010), and the higher values were indicated to be due to a higher nitrogen leaching factor and their double counting for manure nutrient leaching (Lupo et al., 2013).

The present study revealed that the ongoing intensification of beef production in Thailand has environmental advantages and disadvantages. Improving productivity is essential for helping foster global food security; however, the improvements must be implemented in an environmentally sustainable manner. Efforts to increase the environmental sustainability of beef production while improving productivity are needed.

5. Conclusions

The results of our LCA of two beef production systems in Thailand suggest that the intensive system differed from the extensive system in its environmental impacts per kg-LW of cattle among the categories investigated. The intensive system had lower GHG emissions but larger impacts on energy consumption and acidification compared to the extensive system. No significant difference in the impact on eutrophication was observed between the two systems. These results provide helpful information on the effects of the ongoing intensification of beef production on the environment, and they will contribute to the development of strategies to balance the increasing productivity with the environmental sustainability of beef production in developing countries.

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Table 1. Summary of the extensive and intensive beef farms studied.

	Extensive	Intensive
No. of cattle per farm	9.8 (2.8)	12.2 (8.1)[ab]
Average shipping age, mo	59.0 (5.3)	36.3 (1.4)
Average shipping weight, kg	421.1 (13.4)	653.3 (55.4)
Average daily gain, kg/d	0.22	0.56
Breed	Thai native × Brahman crossbred	Thai native × Brahman × Charolais crossbred
Grazing/Housing	Grazing (daytime)	Grazing/Housing
Diet	Grass (grazed), rice straw	Purchased concentrate (see text for details), molasses, grass, rice straw
Purchased feed, kg/head/d[c]	–	6.8[a]
Area of grassland per farm, ha	0.68	0.45[a]
Synthetic N fertilizer use, kgN/ha/yr	17.0	36.7
Synthetic P fertilizer use, kgP_2O_5/ha/yr	6.2	0
Synthetic K fertilizer use, kgK_2O/ha/yr	3.1	0
Manure management	Directly deposited onto grassland	Solid storage and applied to grassland

Values in parentheses are standard deviations.

[a] Fattening farms

[b] The average numbers of cattle per farm for cow-calf and backgrounding farms of the intensive system were 9.5 and 13.3, respectively.

[c] Purchased concentrate and by-products (molasses and rice bran)

Table 2. Emission factors and parameters used in the present Thai beef LCA model.

Source/parameter	EXT	Ref.	INT (fattening)[a]	Ref.
Enteric CH_4 emission				
Equation	see the text	Chaokaur (2011)	see the text	IPCC (2006)
Ym	–		6.5%	IPCC (2006)
CH_4 emission from manure management				
MCF[b]	2.0%	IPCC (2006)	5.0%	IPCC (2006)
Bo	0.1	IPCC (2006)	0.1	IPCC (2006)
N_2O emission from manure management				
direct N_2O EF during manure treatment	–		0.5%	IPCC (2006)
indirect N_2O EF during manure treatment	–		0.45%	IPCC (2006)
direct N_2O EF from manure applied to grassland	2.0%[c]	IPCC (2006)	1.0%	IPCC (2006)
indirect N_2O EF from manure applied to grassland[d]	0.29%[c]	IPCC (2006)	0.29%	IPCC (2006)
N_2O emission from synthetic fertilizer application				
direct N_2O EF	1.0%	IPCC (2006)	1.0%	IPCC (2006)
indirect N_2O EF[d]	0.19%	IPCC (2006)	0.19%	IPCC (2006)
NH_3 emission				
EF from manure during housing/storage	–		12.0%	Payraudeau et al. (2007)
EF from manure applied to grassland	8.0%[c]	Payraudeau et al. (2007)	7.0%	Bouwman et al. (2002)
EF from synthetic fertilizer application	7.0%	Bouwman et al. (2002)	7.0%	Bouwman et al. (2002)

EXT, extensive system; INT, intensive system; Ym, methane conversion factor for enteric CH_4 emission; MCF, methane conversion factor for manure management; Bo, maximum methane producing capacity; EF, emission factor.

[a] The same EFs and parameters as for EXT were used for the calf-backgrounding subsystem unless noted.

[b] Based on the annual temperature of 27.4°C in Khon Kaen, Thailand.

[c] Values for grazing (emissions before and after manure application are included).

[d] Leaching and runoff were taken into account only during the rainy season (5 months)

Table 3. Comparison of environmental impacts of beef production systems taking into account cow-calf production without LULUC or carbon sequestration.

System	Country	GWP, kg CO_2e	Energy, MJ	AP, g SO_2e	EP, g PO_4e	Dressing percentage[a]	Ref
		---------------- per kg-LW ----------------					
Intensive, grain-finished	Thailand	10.6	11.3	62	34		This study
Extensive, pasture	Thailand	14.0	3.5	47	30		This study
Intensive (similar to feedlot)	Japan	14.6	67.7	136	24		Ogino et al. 2007
Feedlot	US	14.8	38.2		104		Pelletier et al. 2010
Backgrounding/feedlot	US	16.2	45.0		119		Pelletier et al. 2010
Pasture	US	19.2	48.4		142		Pelletier et al. 2010
Backgrounding/feedlot	US	12.7		180	22	55.0%	Lupo et al. 2013
Grass-fed	US	17.6		165	19	55.0%	Lupo et al. 2013
Backgrounding/feedlot	Canada	13.0					Beauchemin et al. 2010
Conventional	Ireland	13.0					Casey and Holden, 2006
Agri-environmental scheme	Ireland	12.2					Casey and Holden, 2006
Organic	Ireland	11.1					Casey and Holden, 2006
Conventional	UK	15.5					Edwards-Jones et al. 2009
Extensive	UK	47.6					Edwards-Jones et al. 2009
Conventional, suckler cow-calf	EU	11.4	33.7	120	94	57%	Nguyen et al. 2010
Conventional (mean)	France	15.6	39.2	96	55	56.5%	Nguyen et al. 2012
Feedlot (grain-finished)	Australia	8.7	12.8			57.5%	Peters et al. 2010
Pasture and organic	Australia	10.4	11.6			57.5%	Peters et al. 2010
Pasture	Brazil	15.4				55%	Cederberg et al. 2012
Pasture: natural grass	Brazil	42.6					Ruviaro et al. 2014
Pasture: cultivated ryegrass & sorghum	Brazil	18.3					Ruviaro et al. 2014

LULUC, land use and land use change; GWP, global warming potential; AP, acidification potential; EP, eutrophication potential; LW, liveweight

[a] Environmental impacts were converted from per kg-carcass weight (CW) to per kg-LW using the listed dressing percentages when expressed per kg-CW in the references.

Figure captions

Fig. 1. Description of the extensive (EXT) and intensive (INT) beef production systems investigated. *Bull is not for breeding.

Fig. 2. Greenhouse gas (GHG) emissions from beef production systems in Thailand. LW, liveweight; GHG, greenhouse gas. Error bars: standard errors. Values with different superscripts differ significantly ($P<0.05$).

Fig. 3. Energy consumption of beef production systems in Thailand. Error bars: standard errors. Values with different superscripts differ significantly ($P<0.05$).

Fig. 4. Impacts on acidification of beef production systems in Thailand. Error bars: standard errors. Values with different superscripts differ significantly ($P<0.05$).

Fig. 5. Impacts on eutrophication of beef production systems in Thailand. Error bars: standard errors. NS: no significant difference ($P>0.05$).

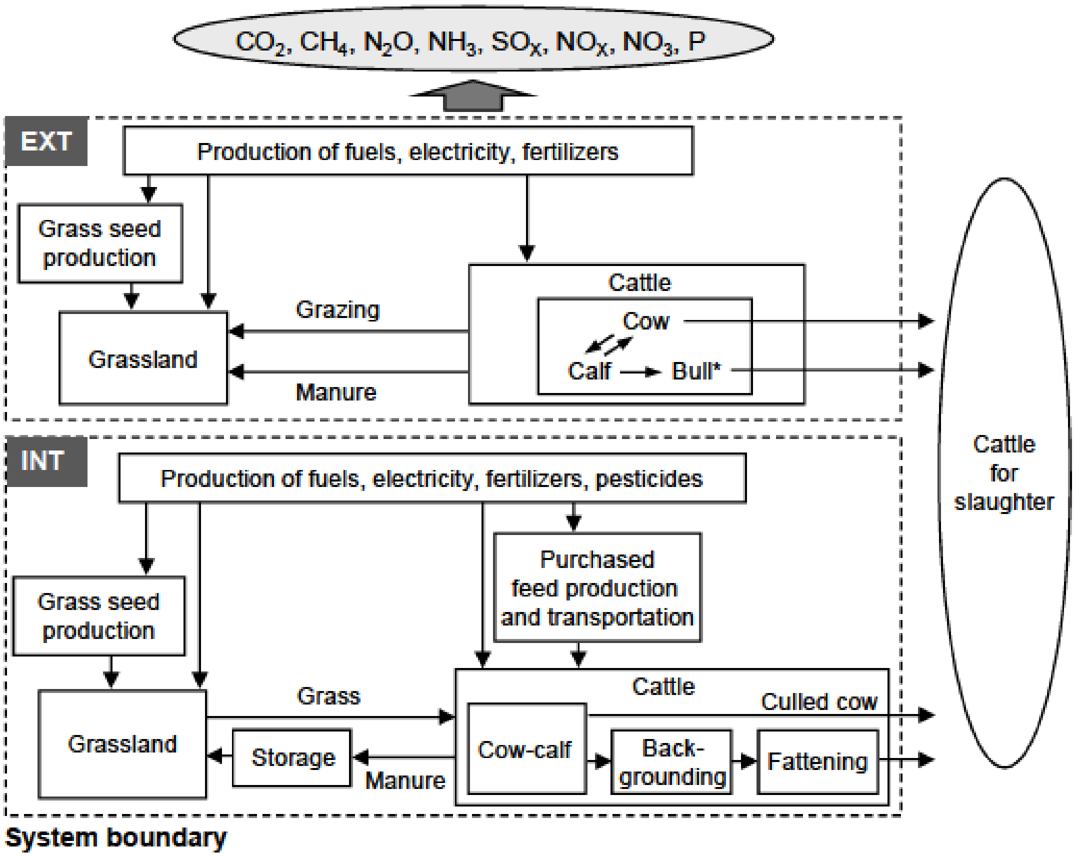

Fig. 1 Ogino et al.

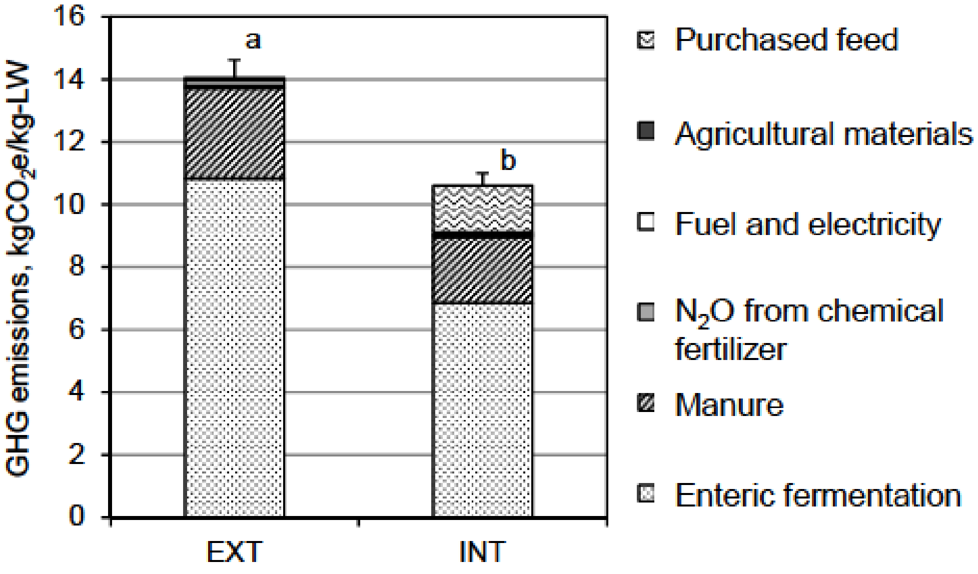

Fig. 2 Ogino et al.

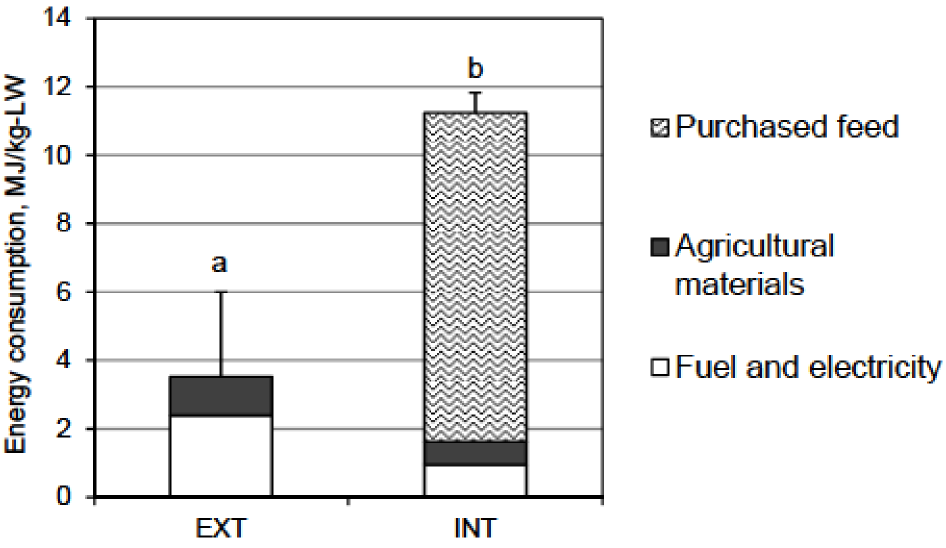

Fig. 3 Ogino et al.

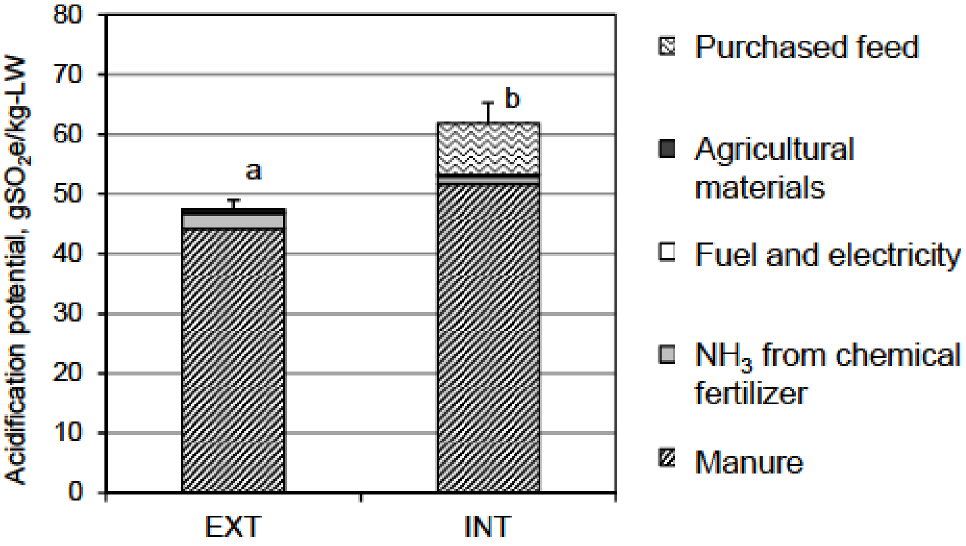

Fig. 4 Ogino et al.

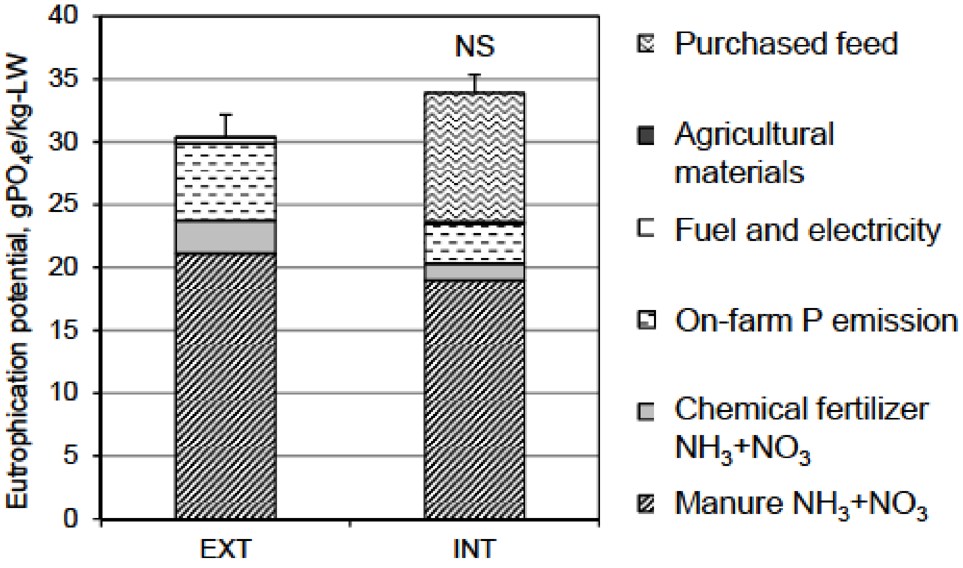

Fig. 5 Ogino et al.