A doctoral dissertation

Study on the Integrated Evaluation of Environmental Impacts Resulting from the Agricultural and Livestock Industries

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Chapter 1 Introduction

1.1 Problems of Modern Agriculture

Many traditional agricultural activities have been managed sustainably using local resources to sustain the environment as well as human life in terms of food production. However, both developed and developing countries face environmental problems resulting from agricultural activities aiming to solve the problems of food shortages due to pressures of increasing population (Kada 1998). Significant environmental problems were principally due to agricultural activities during the modernization of agriculture in developed countries which commonly employed fossil fueled agricultural machinery and excessive inputs of mineral fertilizer, pesticides and herbicides. High inputs led to increased crop yields although it negatively affected the biological ecosystem as well as biodiversity. This kind of mass production also produced the problem of livestock manure management. The separation of animal and crop production to create an efficient production system led to the massive waste of livestock manure. As a consequence, eutrophication resulting from nitrogen accumulation, not only due to mineral fertilizer but also from livestock manure, has been a significant problem in the neighboring environment of agricultural industries. Furthermore, emissions of greenhouse gasses (GHGs) from agricultural activities have been noted as an important global environmental problem in recent years (Shiyomi 1996). The CH_4 from enteric fermentation, livestock manure management, composting and paddy rice fields, and the N_2O from fertilizer application, livestock manure management and composting are major agricultural emitters of GHGs, although the rate of CO_2 emissions is relatively low compared to other industries. On the other hand, there are different kinds of environmental problems in many developing countries. A characteristic of agricultural activities in developing countries is to expand agricultural land using low inputs in order to increase food production, which contrasts with many developed countries that try to increase productivity using high inputs. Therefore, land degradation resulting from unsustainable land use, the utilization of marginal land, as well as deforestation, are significant environmental issues in developing countries. However, the situation in some developing countries has been changing due to economic growth. In those countries, big scale intensive farming is combined with traditional small scale farming. Thus, the situation of developing countries in terms of environmental impacts from agricultural activities is diverse and in flux. However, the environmental impacts due to agricultural activities has rarely been investigated and monitored.

These environmental problems create direct negative impacts to human life. Especially in areas where agricultural activities are conducted near to human settlements. Moreover, this environmental degradation leads to low food productivity. The UNDP warned of this situation and established the Sustainable Development Goals (SDGs) which identify 17 goals. In particular, goal 2: “End hunger, achieve food security, improve nutrition, and promote sustainable agriculture”; and goal 13, “Take urgent action to combat climate change and its impacts”; share the same objectives as this study. In recent years global warming and nitrogen balance are significant topics in terms of environmental impacts due to agricultural activities, therefore I would like to discuss these in more detail.

1.2 Global warming

Agricultural activities contribute both positively and negatively to global warming. In the agricultural sector in recent years, the GHG emissions from agricultural activities are perceived as an important global environmental problem (Shiyomi 1996). However, the study revealed global warming from the agricultural sector to be less when compared to other industries, even though environmental impacts such as the contamination of underground water due to the excessive use of agrochemicals for pest and weed control, as well as excessive fertilizer application have been well studied. CH_4 from enteric fermentation, livestock manure management, composting and paddy rice fields, and N_2O from fertilizer application, livestock manure management and composting, are major agricultural GHG emitters, although the rate of CO_2 emissions is relatively low compared to other industries. GHG emissions from agriculture in Japan were 2.6% (33.2 million tons CO_2-eq) in Japanese fiscal year (JFY) 2017 (GIO 2019). The major GHG emissions in Japan are predominately from CO_2 at 92.0%, CH_4 2.3%, and N_2O 1.6%. The content of CH_4 emissions was dominated by agricultural activities, such as 41% from paddy fields, and 22% from enteric fermentation. The content of N_2O emissions was also dominated by agricultural activities, such as 26% from agricultural land (including emissions from mineral fertilizer application), and 19% from livestock manure management. GHGs from agricultural activities is considerably important because the rate of global warming is accelerated because CH_4 and N_2O are respectively 25 and 298 times more potent than CO_2, although the rate of CO_2 emissions in agriculture is low compared to other industries. Thus, the agricultural industry must also take countermeasures to reduce GHG emissions.

As a consequence of global warming, agriculture will be significantly impacted in terms of production because agriculture depends very much on climatic conditions. Some areas have already experienced reductions in yields due to droughts, floods, pests and diseases, etc.. For example, the incidence of pests and diseases have led to the reduction of production quality in Japan. Moreover, increasingly heavy rains, the battering of strong typhoons, growing incidents of heatstrokes and infections, and damage to ecosystems such as coral bleaching, have considerable negative effects to humans and the environment as a result of global warming in Japan (Ministry of the Environment 2018).

On the other hand, agriculture contributes positively as a source of carbon absorption because agricultural activities assist plant creation which require CO_2 as an important substance for respiration. Forests and pastures in particular are well known as important CO_2 absorption sources. Moreover, carbon fixation in soil by the use of organic fertilizer contributes to the reduction of carbon emissions into the air. Therefore, it is important to consider the agricultural system from the perspective of not only reducing GHG emissions, but also increasing the absorption of GHGs.

1.3 Nitrogen balance

Nitrogen is a substance known to have both positive and negative effects on the environment. This all-important agricultural substance negatively affects humans and the environment in the case of excessive use (Rockström *et al.* 2009). Nitrogen is a key nutrient, vital for the survival of humans and all other living organisms. However, the excessive application of nitrogen causes excess nitrate concentrations in drinking water, food, and feed, which is poisonous to livestock as well as humans (Bruning-Fann and Kaneene 1993). The excessive application of nitrogen also affects biodiversity of closed water systems by increasing the eutrophication load, and contributes to global warming by increasing N_2O emissions from farmlands.

Nitrogen was never excessive in agriculture until the development of the Haber-Bosch process to produce synthetic nitrogen fertilizer. Crop productivity increased dramatically from the use of this mineral fertilizer. At the same time, animal production also increased due to increased feed availability. In spite of increased livestock manure, it was not effectively used in food production because nitrogen fertilizer was readily available. The nitrogen in mineral fertilizer is released into the environment by leaching because of the low efficiency of using nitrogen fertilizer due to poor management (Oenema 2006). As a result, the global nitrogen cycle has been dramatically altered even more than the global carbon cycle (Galloway *et al.*

2008, Fowler *et al.* 2013). The SDGs also indicated the importance of nitrogen balance and established an index to monitor the balance for sustainable food production (UNDP, 2018). This was based on the study by Planetary Boundaries which indicated that nitrogen circulation is already at a high-risk level (Rockström *et al.* 2009).

In Japan for example, the unbalance of nitrogen circulation by the high rate of imported feed used in animal production is a characteristic which contributes to nitrogen accumulation. The high rate of imported concentrated feed used in animal production means importing nitrogen from overseas, however livestock manure with high nitrogen content is never taken out of Japan. As a consequence, imported nitrogen accumulates in Japan and leads to leaching and contamination of the surrounding environment, especially underground water. Using imported feed from distant overseas countries also leads to the high consumption of fossil fuels.

It is also possible to identify excessive nitrogen levels in some developing countries in rapid growth, although the problems of nitrogen are more common in developed countries. Low input grazing is a common animal production system in many developing countries, so nitrogen accumulation tends not to occur. However, the increase of both crop and animal production to meet population growth is occurring in many countries. It is important to also investigate and monitor the situation of developing countries.

The EU has already established regulations to directly control the application of nitrogen as fertilizer in agriculture. However, there is no specific regulation to control nitrogen application in Japan. Only agrochemicals such as pesticides and herbicides are legally controlled. Two acts were legislated to promote environmentally sustainable agriculture in Japan. For example, the sustainable agriculture act in 1999 in which “eco-farmers” who use less agrochemicals and more composting to prepare land, obtain benefits in terms of financial and tax incentives. And the agricultural environment benchmarks in 2005 in which farmers commit to using environmentally sustainable agricultural practices by following fertilizer application standards described in prefectural guidelines. In spite of not being legally binding, the agricultural subsidies are available only to farmers who follow these guidelines. In the case of livestock manure management, it is legally controlled in order to prevent inappropriate management, such as piling manure in fields.

Nitrate content regulations for foods have not yet been established in Japan, although the EU has had nitrate content reference values for vegetables, baby food and cereals since 1997. According to the FAO and WHO, the allowable intake of nitrate is 5 mg/kg of human body weight/day. The concentration of nitrate and nitrite in underground water has been monitored as an important environmental standard since 1999 in Japan because high concentrations were observed over a wide area. However, the nitrate and nitrite concentration in many monitoring areas is still over environmental standards, which is the highest rate when compared to other substances.

1.4 Characteristics of animal production and crop production

Animal production contributes significantly to environmental impacts from agricultural activities. For example, animal production contributes more than half of GHG emissions from agricultural activities. Particularly noteworthy are CH_4 from enteric fermentation, livestock management and composting, and N_2O from livestock manure management and composting (de Vries and de Boer 2010). Furthermore, animal production using the dry-lot feeding system in Japan relies on imported feed, which is based on long distance transportation using fossil fuels. This greatly contributes to CO_2 emissions. The utilization of imported feed unbalances substance circulation. As a consequence, the accumulation of nitrogen in livestock manure contaminates the surrounding streams and leads to eutrophication. Thus, the management of livestock manure is extremely important in both the reduction of GHG emissions and nitrogen balance.

Livestock manure management was not an important issue before feed and crop production was separated from animal production in order to seek the high productivity of mass production. Moreover, in places adopting the low density grazing system, this problem rarely occurs and pasture is positively evaluated as a CO_2 absorption source. However, desertification by overgrazing is one of the most important issues facing many developing countries. For example, grazing is permitted on steep slopes in the Andean region of Ecuador which causes a high rate of erosion. There is a benefit that land unsuitable for crop production is used for animal production. However, the utilization of this kind of marginal land easily leads to environmental problems such as erosion.

Comparing paddy rice fields, the types of environmental impacts from its associated activities is quite different from animal production. The paddy rice field is well known as a sustainable crop production system. It is proven that rice cultivation in paddies has existed for thousands of years without crop rotation. This is because water protects soil from land degradation. However, rice paddies are one of the highest sources of CH_4 emissions. Although the midterm drying during rice cultivation is promoted in order to minimize CH_4 emissions from paddies, this method requires more intensive labor. In spite of the negative effect of paddies on GHG emissions, paddies also provide habitat for many endemic animals, especially waterfowl. Because they have existed for thousands of years, paddies provide a unique ecosystem for endemic species. Therefore, a measure to maintain water the whole year in paddies has also been adopted to protect the valuable endemic ecosystem. Thus, paddies have multiple functions including the prevention of landslides, floods and erosion. Moreover, paddy rice cultivation has the unique characteristic that nitrogen application is not required when compared to other crops because paddies provide minerals and nitrogen. Also, rice itself does not require much nitrogen because over-application negatively affects the taste and can cause the plant to topple before harvest. This contributes to the nationwide trend of having low total nitrogen use on the whole because paddies occupy the majority of agricultural land in Japan. However, vegetable and tea production require large amounts of nitrogen as fertilizer.

1.5 Environmental Impact Assessment

To promote sustainable production, the collection of information and the monitoring and evaluation of environmental impacts are required to convince people with hard data. The Environmental Impact Assessment (EIA) method, called Life Cycle Assessment (LCA), has been utilized to quantitatively assess environmental impacts. The LCA considers the whole process of production from cradle to grave. That is, the environmental impacts from production, transportation, and the use of materials up to final disposal are calculated and assessed. LCA is utilized effectively in the industrial sector to produce environmentally friendly products. In addition, there is an integrated method to compare the level of environmental impacts. The method to calculate damage, called the Life cycle Impact assessment Method based on Endpoint modeling 2 (LIME2) by Itsubo and Inaba (2010), provides an integrated estimation in order to determine the total amount of economic damage. The integrated results of LIME2 make it possible to compare the environmental impacts of products by economic value in Japanese currency (yen). It is common in business situations to compare costs and benefits. LIME2 also contributes to compare costs and benefits by calculating the cost of external environmental damage. This promotes the consideration and mitigation of environmental damages in terms of management and product development in a business situation.

As agriculture is one of the biggest industries in terms of nitrogen use, understanding the nitrogen level is very important. Although LCA provides more detailed environmental impacts considering the whole production system, in many cases it is difficult to collect detailed information due to data limitations. On the other hand, it is relatively easier to quantify the results using an indicator called Nutrient Balance

(NB) (Mu *et al.* 2017). The method called the Nutrient Monitoring model (NUTMON model) (Smaling and Fresco 1993) is the most frequently used tool for calculating soil nutrient balance and flows (Cobo *et al.* 2010). This method, based on inputs and outputs, totals them to calculate nitrogen balance. Inputs usually consist of mineral fertilizer, organic fertilizer (livestock manure), atmospheric deposition, biological nitrogen fixation and sedimentation. Outputs usually consist of harvested product, removed crop residues, gaseous losses, leaching and erosion. Furthermore, the Organization for Economic Co-operation and Development (OECD) defines nitrogen use efficiency (NUE) as the ratio between the amount of nitrogen fertilizer a crop removes from the field, and the amount of nitrogen fertilizer that is applied. The negative impacts of agricultural nitrogen are generally caused by a decrease of NUE in most regions of the world (Erisman *et al.* 2018).

1.6 Objective of this study

Agriculture has changed dramatically to consider not only productivity but to also consider environmental impacts. Therefore, the assessment of environmental impacts of agricultural activities is required in order to promote sustainable agricultural production (Hirooka *et al.* 2009). This study focused on the whole agricultural production system including animal production, which greatly impacts the environment, and analyzed integrated environmental impacts from hotspots and nationwide in order to contribute to adaptations for sustainable agricultural production by considering the current situation. There are many studies focusing on the farm situation or crop and animal production systems. This study will focus on the integrated evaluation of the agricultural environment from farm, to region, and to the country. A feature of this study is that it targets: 1) comprehensive agricultural production including animal production; 2) the whole process of the agricultural production system using the LCA method; 3) the case study of a developing country; and 4) nitrogen as an important agricultural substance. This study is based on cases in Japan. Ecuador, located in Latin America where 50% of the world's nutrient depleted soils are found (Tan *et al.* 2005), was also included as a case study of a developing country.

In Chapter 2, the environmental impacts of dairy production including different types of self-supplying feed production systems were evaluated by the LCA method according to "Agricultural Production Technology Systems" (APTS) created by Hokkaido and Iwate Prefectures in Japan. Four types of self-supplying feed production in Hokkaido, and two types of self-supplying feed production in Iwate, were analyzed according to three types of fertilizer application, respectively. These results were included in environmental impact assessments of dairy production consisting of four types of production systems in Hokkaido and 2 types in Iwate. The global warming load (GWL), acidification load (AL) and eutrophication load (EL) were evaluated as environmental impacts. Furthermore, LIME2 was used for integrated estimations in order to find the total cost of economic damage. In Chapter 3, the nitrogen balance per agricultural activity, including livestock production, was estimated based on the soil surface balance of farmland in Japan. The balance included nitrogen inputs such as “mineral fertilizer”, “livestock manure”, “atmospheric deposition” and “biological nitrogen fixation”; and nitrogen outputs included “crop products” and “gaseous losses”. Furthermore, the results were shown using the geographical information system (GIS) to visualize the differences of nitrogen inputs, outputs and balance according to municipality. In Chapter 4, targeted Ecuadorian agricultural activities including livestock production reveals the nitrogen balance of the whole country as well as each region. The nitrogen balance was estimated based on the soil surface balance of farmland. The balance included nitrogen inputs such as “mineral fertilizer”, “livestock manure by dry lot feeding”, “atmospheric deposition” and “biological nitrogen fixation”; and included nitrogen outputs such as “crop products”, “livestock products by grazing” and “gaseous losses”. These results were also visualized using GIS to analyze the differences of nitrogen inputs, outputs and balance according to municipality. Finally in Chapter 5, an overall discussion was developed based on the results of Chapter 2 to 4 and statistical data from FAO to compare world trends. Moreover, countermeasures were proposed based on this study.

Chapter 2 Comparison of Environmental Impacts among Various Dairy Production Systems in Japan

2.1 Introduction

Greenhouse gas (GHG) emissions due to agricultural activities in Japanese fiscal year (JFY) 2017 was equivalent to 33.2 million tons CO_2, which was 2.6% of total GHG emissions in Japan (GIO 2019). Global warming load (GWL) is a significant problem and the main sources related to livestock production are CH_4 emissions from enteric fermentation and livestock manure composting, and N_2O emissions from livestock manure composting (de Vries and de Boer 2010). An important characteristic of the livestock production system in Japan is that livestock production relies very much on imported feeds based on long distance transportation. This causes an unsustainable material circulation, which contributes to GWL, acidification load (AL) and eutrophication load (EL).

Life Cycle Assessment (LCA) has been utilized to estimate the environmental impact of the whole production system (Inaba 2005). The LCA method estimates environmental impact quantitatively by calculating environmental loads from material production up to product disposal. LCA is well utilized in the agricultural sector, especially in livestock production which greatly contributes to environmental problems. There are several studies that used the LCA method to estimate the environmental impacts of dairy production, such as Cederberg and Mattsson (2000), Haas *et al*. (2001), de Boer (2003) and Thomassen *et al*. (2008). Furthermore, Hospido *et al*. (2003), Ogino *et al*. (2008) and Basset-Mens *et al*. (2009) endeavored to compare feeding systems; Arsenault *et al*. (2009), Casey and Holden (2005a) and Masuda *et al*. (2005) studied low inputs and intensity systems; and Casey and Holden (2005b) and Thoma *et al*.（2013）focused on the allocation of environmental impacts. Tsuiki *et al*. (2009) focused on yearly changes and Flysjö *et al*. (2012) conducted integrated estimations of dairy and meat production. Flysjö *et al*. (2011) and O’Brien *et al*. (2012) endeavored to compare grazing and dry lot feeding production systems using the LCA method. There are many studies using LCA with individual data sets to estimate environmental impacts in dairy production, however, there is no study using generalized data such as “Agricultural Production Technology Systems” (APTS) which presents several production systems according to feeding types and different production scales. It is very important to consider production scale because the size change relates to the efficiency of machinery and facility use, which significantly influences environmental impact (Tsuiki and Harada 1997). It is also important to consider the environmental impacts according to fertilizer application types in feed production because the low rate of self-supplying feed is a significant characteristic of animal production in Japan. Therefore, this study is based on the hypothesis that “there are differences in the environmental impacts dependent on the scale of dairy production and fertilizer application types in dairy production including feed production”. The environmental impacts of dairy production including feed production systems were evaluated using the LCA method according to the APTS created in Hokkaido (Hokkaido government 2005) and Iwate Prefectures (Iwate prefecture 2005). Furthermore, LIME2 (Life cycle Impact assessment Method based on Endpoint modeling 2) by Itsubo and Inaba (2010) was used for integrated estimations to determine total economic damage.

2.2 Materials and Methods

2.2.1 Production systems

Data on self-supplying feed and dairy production systems from the APTS created in Hokkaido (Hokkaido government 2005) and Iwate Prefectures (Iwate prefecture 2005) was used to estimate environmental loads. Four types of self-supplying feed production were analyzed: “hay cutting two times annually”; “low moisture herbage roll silage cutting three times annually”; “grazing pasture” and “maize silage” in Hokkaido; and two types of self-supplying feed production such as “herbage roll silage cutting three times annually” and “maize silage” in Iwate. The estimated yields of self-supplying feed production by APTS are shown in Table 2.1. Moreover, three types of fertilizer application were analyzed: “chemical fertilizer application”, “compost application” and “slurry application” as shown in Table 2.2. Only compost application was assumed in the case of Iwate Prefecture. The amount of fertilizer application was estimated based on “pasture and feed production usage guidelines” (Iwate Prefecture 2009) in the case of Iwate Prefecture. The area of self-supplying feed production for each dairy production scale estimated by APTS are shown in Table 2.3. The area of self-supplying feed production per production scale in Hokkaido was larger than that of Iwate.

These results were included in environmental impact assessments of dairy production consisting of four types: 40, 60, 100 and 400 head scale in Hokkaido; and two types: 40 and 100 head scale in Iwate. The amount of annual feed and milk production in dairy production systems per head scale is shown in Table 2.4. The dairy production system in Hokkaido used the free stall method in the case of more than 60 head scale, and tethering mixed with grazing in the case of 40 head scale. In the case of Iwate, the free stall method for 100 head scale and tethering for 40 head scale was adopted.

2.2.2 Evaluation scope and functional unit

The evaluation scope in this study of dairy production including feed production is shown in Figure 2.1. All content described in Figure 2.1 was included as evaluated scope. Machinery and facilities were included in the evaluation scope in order to evaluate differences in production scale. The amount of environmental load from the manufacture of compost and slurry application in self-supplying feed production was excluded because livestock manure from dairy production was utilized in self-supplying feed production as compost and slurry.

The functional unit of self-supplying feed production is one kg of total digestible nutrients (TDN) and that of dairy production is 1,000 kg of produced milk (4% milk fat; the amount of milk production in Iwate Prefecture was revised from 3.8% milk fat, the standard value of Iwate Prefecture). The EL per reductive agricultural land (ha), which includes grazing and self-supplying feed production land, was also calculated because EL produces a negative impact on the neighboring environment in the short term.

2.2.3 Inventory analysis

The sources of inventory data for each environmental impact factor are listed in Table 2.5. The amount of fossil fuel consumption on the farm was estimated from the time used and fuel consumption rate of facilities and machines. The emission factors for fuel consumption were 2,619 gCO_2/L light oil, 6.34 gSO_2/L light oil, 18.3 g NO_x/L light oil (National institute for Agro-Environmental Sciences 2003). Some machinery not described in APTS was defined from similar machinery according to the “Value Guide of Agricultural Machinery 2009” (Institute of Agricultural Machinery industry investigation 2009). The value was divided by service life to calculate annual value and divided by the self-supplying feed production area (ha). The value of some machinery commonly used among many types of self-supplying feed production and pasture renovation were calculated by time utilized. The data of facilities, service life and environmental impacts per facility value by Nansai and Moriguchi (2012) was used to calculate environmental impacts by constructing a bunker silo for silage making. The inventory of formula feed by Tsuiki *et al*. (2009b) was utilized to evaluate formula feed production and transportation. The composition of formula feed was 40% maize, 30% barley, 16% wheat bran, 6% soybean meal, 6% rice bran, 1%

Calcium carbonate and 1% salt. The inventory of each material in the formula feed was estimated according to the “LCA Practicing Editors Committee” (1998). The CO_2 emissions factor for chemical fertilizer production was 5.9 gCO_2/yen (National Institute for Agro-Environmental Sciences 2003). The CH_4 emissions by enteric fermentation was calculated using the formula from Shibata *et al.* (1993) in the case of whole dairy cattle, including calves.

$$CH_4\ (g) = (-17.766+42.793\times DMI-0.849\times DMI^2)\times 16/22.4$$

DMI represents Daily Matter Intake per day per head. Milk for the calf was not included in the calculation.

2.2.4 Environmental impact assessment

GWL, AL and EL were evaluated as environmental impacts. The amount of CO_2, CH_4 and N_2O emissions were estimated as causal substances of GWL. Each substance was equalized at the same contribution rate to global warming as CO_2: CH_4: N_2O =1:25:298 (IPCC 2007). The CO_2 absorption by plant photosynthesis was not included in the calculation and based on carbon neutral. The amount of SO_2, NO_x and NH_3 emissions were estimated as causal substances of AL. Each substance was equalized to SO_2: NO_x: NH_3=1:0.7:1.88 (Inaba 2005). The amount of NO_3^- and NH_3 emissions were estimated as causal substances of EL. Each substance was equalized to PO_4^{3-}: NO_3^-: NH_3=1:0.1:0.35. The NO_3^- was calculated from the nitrogen balance according to the “farm gate” (Heijungs *et al.* 1992). This study did not include PO_4^{3-} in EL because it rarely reaches excessive levels in underground water in Japan due to the easy fixation of PO_4^{3-} in acid soils.

The results were also evaluated by the method called LIME2 which combines all environmental impacts into an integrated result of the environmental economic damage. LIME2 is a method to assess life cycle environmental impacts considering Japan's environmental conditions. This method integrates all results of the quantitative amount of environmental impacts of substances into the yen equivalent in order to calculate the cost of environmental damage. The amount of emissions of each substance in environmental load was multiplied by integrating factors of LIME2 (Itsubo and Inaba 2010, Table 2.6).

Table 2.1 Estimated yields of self-supplying feed production by APTS

Region	Type of self-supplying feed production	DM yield (kg/ha)	TDN yield (kg/ha)
Hokkaido	Hay cutting two times annually	7,830	4,860
	Low moisture herbage roll silage cutting three times annually	7,830	4,860
	Grazing pasture	7,830	4,860
	Maize Silage	13,610	9,750
Iwate	Herbage roll silage cutting three times annually	9,750	6,211
	Maize silage	15,600	11,170

[1] DM represents Dry Matter and TDN represents Total Digestible Nutrients

[2] Estimated yield of TDN = Dry weight of stems and leaves × 0.582 + Dry weight of female panicles × 0.850 (Nakui 1984)

Table 2.2 Estimated amounts of fertilizer applied to fields of self-supplying feed production by APTS

Region	Type of fertilizer application	Type of self-supplying feed production	Amount of fertilizer applied to meadow				Amount of fertilizer applied to pasture during renovation		
			Chemical fertilizer (kg/ha)	Compost (kg/ha)	Urine (kg/ha)	Slurry (kg/ha)	Chemical fertilizer (kg/ha)	Compost (kg/ha)	Slurry (kg/ha)
Hokkaido	Chemical fertilizer	Hay	900	-	-	-	400	50,000	-
		Low moisture herbage roll silage	900	-	-	-	400	50,000	-
		Grazing pasture	600	-	-	-	400	50,000	-
		Maize silage	1,000						
	Compost	Hay	300	40,000	5,000	-	400	50,000	-
		Low moisture herbage roll silage	450	20,000	5,000	-	400	50,000	-
		Grazing pasture	450	20,000	-	-	400	50,000	-
		Maize silage	500	50,000					
	Slurry	Hay	300	-	-	30,000	400	-	40,000
		Low moisture herbage roll silage	450	-	-	20,000	400	-	40,000
		Grazing pasture	450	-	-	10,000	400	-	40,000
		Maize silage	500			50,000			
Iwate	Compost	herbage roll silage	800	30,000			114	50,000	
		Maize silage	1,000	30,000					

[1] Composition of chemical fertilizers; $N-P_2O_5-K_2O$: 20-10-20 for pastures in Hokkaido and Iwate, $N-P_2O_5-K_2O$: 15-27-20 for Maize silage in Hokkaido, $N-P_2O_5-K_2O$: 10-12-10 for Maize silage in Iwate, $N-P_2O_5-K_2O$: 4-20-8 for basal fertilizer application in Hokkaido, $N-P_2O_5-K_2O$: 14-28-14 for basal fertilizer application in Iwate

[2] Nitrogen content in compost is 0.60％ and in slurry and urine 0.35% in Hokkaido (Hokkaido government 2010) Nitrogen content in compost is 0.57% in Iwate (Iwate prefecture 2009)

Table 2.3 Estimated area of self-supplying feed production by APTS

Region	Production type	Meadow (ha)		Grazing	Pasture renovation (ha)			For Feed	Total
		Hay	Silage	(ha)	Hay	Silage	Grazing	Maize	(ha)
Hokkaido	40 head scale	-	37.0	16.0	-	4.2	1.8	-	59.0
	60 head scale	14.0	37.0	-	2.2	5.8	-	9.0	68.0
	100 head scale	-	71.0	-	-	9.0	-	22.0	102.0
	400 head scale	-	285.0	-	-	37.0	-	86.0	408.0
Iwate	40 head scale	-	15.0	-	-	1.5	-	2.5	19.0
	100 head scale	-	25.0	-	-	2.5	-	5.0	32.5

[1] Due to data limitations, pasture renovation in Iwate was calculated as once per ten years and the area as one-tenth of feed production area.

Table 2.4 Estimated amount of annual feeding and milk production by APTS

Region	Production type	Amount of milk production (kg)	Amount of feed（kgDM/total head/year）				
			Hay	Grazing pasture	Herbage silage	Maize silage	Formula feed
Hokkaido	40 head scale	352,000	-	66,473	214,877	-	74,605
	60 head scale	528,000	80,955	-	213,101	115,920	128,503
	100 head scale	880,000	-	-	411,308	265,720	212,069
	400 head scale	3,520,000	-	-	1,650,134	1,060,325	809,713
Iwate	40 head scale	360,000	-	-	225,000	36,652	117,815
	100 head scale	900,000	-	-	375,000	73,304	311,031

[1] 4% milk fat in Hokkaido and 3.8% milk fat in Iwate.

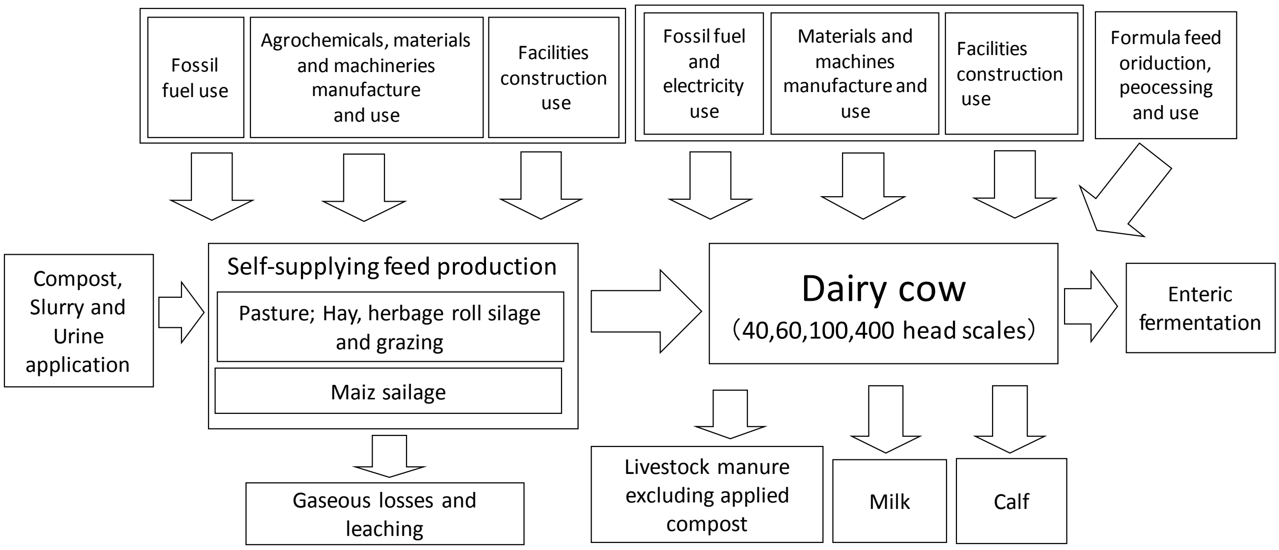


Figure 2.1 Scope of environmental impact assessments in feed and dairy production

Table 2.5 Source of inventory data in feed and dairy production

Contents of production	References
Fossil fuels and electricity	National institute for Agro-Environmental Sciences 2003
Materials	Nansai *et al.* 2002, Nansai and Moriguchi 2012, National Institute for Agro-Environmental Sciences 2003, Pre Consultants 2003
Agricultural machinery	Nansai *et al.* 2002, Nansai and Moriguchi 2012
Facilities	Nansai *et al.* 2002, Nansai and Moriguchi 2012
Formula feed	Tsuiki *et al.* 2009b
Chemical fertilizer production	National Institute for Agro-Environmental Sciences 2003
Emissions during composting and after compost application	IGES 2006, Osada *et al.* 2000, Ministry of Agriculture, Forestry and Fisheries of Japan 2012, Tsuiki *et al.* 2009, Haga 2002, GIO 2016
Enteric fermentation	Shibata *et al.* 1993

[1] Emission factors of composting: 0.00052 gCH_4/g organic, 0.0025 gN_2O-N/gN, 0.2 kgNH_3/kgN
slurry production: 0.0305 gCH_4/g organic, 0.002 gN_2O-N/gN, 0.2 kgNH_3/kgN
after fertilizer application: 0.01 kgNH_3/kgN
after slurry application: 0.121 kgNH_3/kgN.

Table 2.6 Integrated factors of LIME2 for each substance

Environmental load	Substance	Factor (yen/kg)
GWL	CO_2	2.33
	CH_4	61.9
	N_2O	738
AL	SO_2	120
	NO_x	95.7
	NH_3	736
EL	NO_3^-	18.6
	NH_3	67.9

2.3 Results and discussion

2.3.1 Results of environmental impact analysis

The results of the environmental impact analysis in self-supplying feed production are shown in Figure 2.2 to 2.4. GWL in self-supplying feed production was 252 to 1,001 gCO_2-eq./kgTDN, and was highest in slurry type (Figure 2.2). AL was 1.5 to 27.5 gSO_2-eq./kgTDN, and was highest in compost and slurry types (Figure 2.3). EL was -0.95 to 21.1 gPO_4^{3-}-eq./kgTDN, and was highest in compost type (Figure 2.4). All results show a significant difference in compost and slurry types compared to chemical fertilizer type in self-supplying feed production. Excess use of compost and slurry will cause significant environmental impacts, although the utilization of compost with the appropriate management of livestock manure contributes to a reduction of chemical fertilizer use and soil improvement. Therefore, the appropriate amount of fertilizer application is required, especially for organic fertilizers such as compost and slurry, for each feed production field. Excess fertilizer application not only produces these environmental impacts but can also cause the increase of potassium and nitrate content in pasture (Kawamura and Ishii 2015). A high content of potassium produces grass tetany and a high content of nitrate produces nitrate poisoning.

The results of environmental impact analysis in dairy production including feed production are shown in Figure 2.5 to 2.8. GWL was 1,096 to 1,446 kgCO_2-eq./1000kg milk, and was highest in slurry type even though CH_4 by enteric fermentation from dairy production was added (Figure 2.5). AL was 15.1 to 34.5 kgSO_2-eq. /1000kg milk (Figure 2.6). Chemical fertilizer type was higher in AL of dairy production, although compost and slurry types were higher in self-supplying feed production itself. This is because livestock manure is not used effectively in chemical fertilizer type. EL was 3.2 to 6.8 kgPO_4^{3-}-eq./1000 kg milk. The compost type was highest, except in 40 head scale and the same as self-supplying feed production in EL, even though the chemical fertilizer type which could not utilize livestock manure effectively was higher compared to self-supplying feed production itself (Figure 2.7). The EL in slurry type was lower and the same as the result of self-supplying feed production. The results showed a significant trend that larger production scale decreases environmental impacts in all GWL, AL and EL of dairy production. The reason for this is that a larger feed production scale is more effective in machinery use, as is a larger dairy production scale. For example, the tethering method adopted by 40 head scale has the characteristic of requiring high labor for feeding and milking, and was high in environmental impacts from material manufacture. Although AL of feed production in Iwate was not so high (Figure 2.3), the AL of dairy production in Iwate was significantly high (Figure 2.6). This is also because of the high management costs in Iwate. Therefore, adopting effective dairy production methods such as the free-stall method, will contribute to the reduction of environmental impacts.

The contents of environmental loads shown in Figure 2.9 to 2.11 indicate which process contributes to environmental impacts in dairy production. Enteric fermentation contributed most to GWL. Composting was highest in contributing to AL, however, the self-supplying feed production also had high amounts especially in the case of the compost type in Hokkaido. The environmental load from materials was highest in the case of Iwate due to production costs which tend to be higher than that of Hokkaido. Composting had the highest EL rate, especially the chemical fertilizer type. Interestingly, the compost type which uses livestock manure from dairy production as compost in self-supplying feed production tends to be a high rate in self-supplying feed production.

2.3.2 Results of integrated assessments, environmental impacts, and economic analysis

The results of LIME2 averaged all production scales to show the differences of each fertilizer type are shown in Figure 2.12. The amount of damage from environmental impacts in dairy production was from 7,750 to 10,550 yen/1,000kg milk, and was highest in NH_3 of AL. One of the reasons for NH_3 to be highest is that the LIME2 integrated factor of NH_3 is relatively higher than other substances. Comparing fertilizer types, the amount of damage was highest in chemical fertilizer type and lowest in slurry type. This is because the chemical fertilizer type did not utilize livestock manure as compost in feed production, thus the environmental loads from livestock manure accumulated. On the other hand, the amount of damage from NH_3 of AL was low in the case of compost and slurry types because livestock manure was utilized effectively as compost.

The results of LIME2 averaged all fertilizer application types to show the differences between each production scale are shown in Figure 2.13. The amount of damage from environmental loads in dairy farming was from 8,279 to 10,546yen/1,000kg milk, and was highest in NH_3 of AL, the same result as for fertilizer type. Therefore, the reduction of NH_3 will greatly contribute to minimize environmental economic damages. Comparing production scales, the amount of damage was higher when production scale was smaller. This trend is the same in Figures 5 to 7 even though the result is produced by multiplying the integrated factor. As previously described, larger production scales have the potential to produce efficiently with less environmental loads when calculations are based on the amount of produced milk.

The average amount of damage from environmental loads made up 16 % of annual profit which reduced feed, materials, management and settlement costs from yearly sales of milk in dairy production. It is not suitable to simply compare profit and the cost of damage because this cost is not only the responsibility of dairy farmers, however, this point of view will assist to consider the sustainability of production by thinking in both economic and environmental terms.

2.3.3 Comparing Hokkaido and Iwate

The GWL of Iwate was higher than that of Hokkaido in the case of self-supplying feed production. This is because N_2O emissions from composting and gaseous loss from soil were higher. Moreover, more types of agricultural machinery were used and fossil fuel consumption was higher in Iwate, even though machinery was utilized efficiently in Hokkaido, especially in larger production scales. Therefore, the improvement of fossil fuel efficiency by utilizing appropriate machinery for the production scale will contribute to reducing environmental impacts. The AL and EL in Hokkaido were higher than that of Iwate in self-supplying feed production. The reason for this is that the nitrogen and organic content of compost were different in terms of calculating the environmental loads of composting. In Hokkaido livestock manure was divided into excrement and urine, or slurry was divided into solid and liquid for composting, however in Iwate livestock manure was not divided.

In comparing dairy production in Hokkaido and Iwate, there was no differences between them in the case of GWL. The AL of Iwate was higher than Hokkaido because the amount of environmental load from materials was higher in Iwate. The EL of Hokkaido was higher than Iwate due to the higher EL of self-supplying feed production.

2.3.4 Comparison to previous studies

There are a few environmental impact assessment studies in feed production. The results of the environmental impact assessments by Tsuiki *et al.* (2009b) in terms of herbage silage production revealed GWL to be 944 kgCO_2-eq./tTDN, the AL was 8.2 kgSO_2-eq. /tTDN and EL was 10.0 kgPO_4^{3-}-eq. /tTDN. By comparison, the AL and EL of this study were on average higher than that of Tsuiki *et al.* (2009), although the GWL was lower. The results of Masuda and Yamamoto (2013) were lower than those of this study, especially CO_2 emissions which were significantly lower. This is because the manufacture of agricultural machinery was not included in the assessment. The results of Van der Werf *et al.* (2005) in terms of maize production, were lower than those of this study, however, the results were higher when their functional units were adjusted to one ton of raw grass weight.

There are many studies using LCA to assess environmental impacts in terms of dairy production. The results of this study were approximately the same as previous studies, however value comparisons are not always appropriate because each study set different evaluation scopes and the percentage of milk fat, etc. (de Boer 2003，Basset-Mens *et al.* 2009). In previous studies the GWL of dairy production was approximately 689 to 1,300 gCO_2-eq./kg milk (Cederberg and Mattsson 2000, Haas *et al*. 2001, de Boer 2003, Hospido *et al*. 2003, Casey and Holden 2005b, Masuda *et al*. 2005). The AL was approximately 3.5 to 22.0gSO_2-eq./kg milk (Cederberg and Mattsson 2000, Haas *et al*. 2001, de Boer 2003, Masuda *et al*. 2005). The EL was approximately 2.8 to 28.8 gPO_4^{3-}-eq./kg milk (Haas *et al*. 2001, de Boer 2003, Hospido *et al*. 2003, Masuda *et al*. 2005). The rate of CH_4 from enteric fermentation in the GWL of this study was 30 to 40%, which was the highest in GWL. This rate was similar to the previous study by Ogino *et al*. (2008) which indicated approximately 36%.

This study revealed that organic fertilizer application itself, such as compost and slurry in self-supplying feed production, greatly contributes to environmental impacts. However, the utilization of organic fertilizer will have lower environmental impacts considering dairy production including feed production as a whole. This is because the utilization of organic fertilizer uses livestock manure efficiently. This means that organic fertilizer application itself is not always environmentally friendly, hence the application of organic fertilizer must be done carefully in terms of amount and timing since it is very difficult to estimate the effects of organic fertilizer. There is the tendency to over-apply organic fertilizer due to difficulties of estimating its effects, as well as its image of being eco-friendly. Previous studies mention the importance of fertilizer application. Casey and Holden (2005b) and Flysjö *et al*. (2011) described the significant environmental impact by nitrogen fertilizer application following enteric fermentation. Thoma *et al*. (2013) indicated that feed production, enteric fermentation, and manure management had high environmental impacts. Furthermore, there are many studies comparing the environmental impacts of organic and conventional farming especially in Europe (Cederberg and Mattsson 2000, Haas *et al*. 2001, de Boer 2003, Thomassen *et al*. 2008), which concluded that organic farming produced lower environmental impacts than conventional farming. From another point of view, the GWL will be lower by considering soil carbon accumulation in the environmental load of organic fertilizer. Therefore, the results of environmental impact assessments in the case of organic fertilizer will also depend on the method used in the analysis. However, it is very obvious that the efficient use of livestock manure as organic fertilizer in feed production from the perspective of material circulation is required, as well as considering the amount and timing of its application.

Previous studies also indicated that an efficient production system and improved quantities of milk contributed to the reduction of environmental impacts (Casey and Holden 2005a, Tsuiki *et al*. 2009a, Hirooka *et al*. 2009, Audsley and Wilkinson 2014, Veysset *et al*. 2014), however it is not appropriate to simply compare the results by production scales because in this study each production scale has a different feeding system. On the other hand, there are studies indicating that grazing and organic dairy farming, which are generally of lower efficiency in production quantities, produce less environmental impacts (Cederberg and Mattsson 2000, Masuda *et al*. 2005, Thomassen *et al*. 2008, Basset-Mens *et al*. 2009, Arsenault *et al*. 2009, O'Brien *et al*. 2012). Therefore, an efficient production system is one that considers the density of the feeding system, the amount of imported formula feed input, and the amount of labor required, which does not always mean a conventional massive scale dairy production system by dry-lot feeding. In particular, imported formula feed contributes to environmental impacts not only in its production, but also in transportation and processing which negatively contribute to the environment in terms of CO_2 emissions by fossil fuel use. Therefore, it is very important to reduce the rate of imported formula feed use in dairy production. Many previous studies also indicated high environmental impacts of using formula feed (Haas *et al*. 2001，de Boer 2003，Van der Werf *et al*. 2005, Casey and Holden 2005a，Thomassen *et al*. 2008, Arsenault *et al*. 2009, Hirooka *et al*. 2009, O'Brien *et al*. 2012, Tsutsumi *et al*. 2014). Furthermore, efficient farm management, sharing the use of agricultural machinery and adopting a less labor intensive feeding system, such as the free stall method, will contribute to the reduction of environmental impacts.

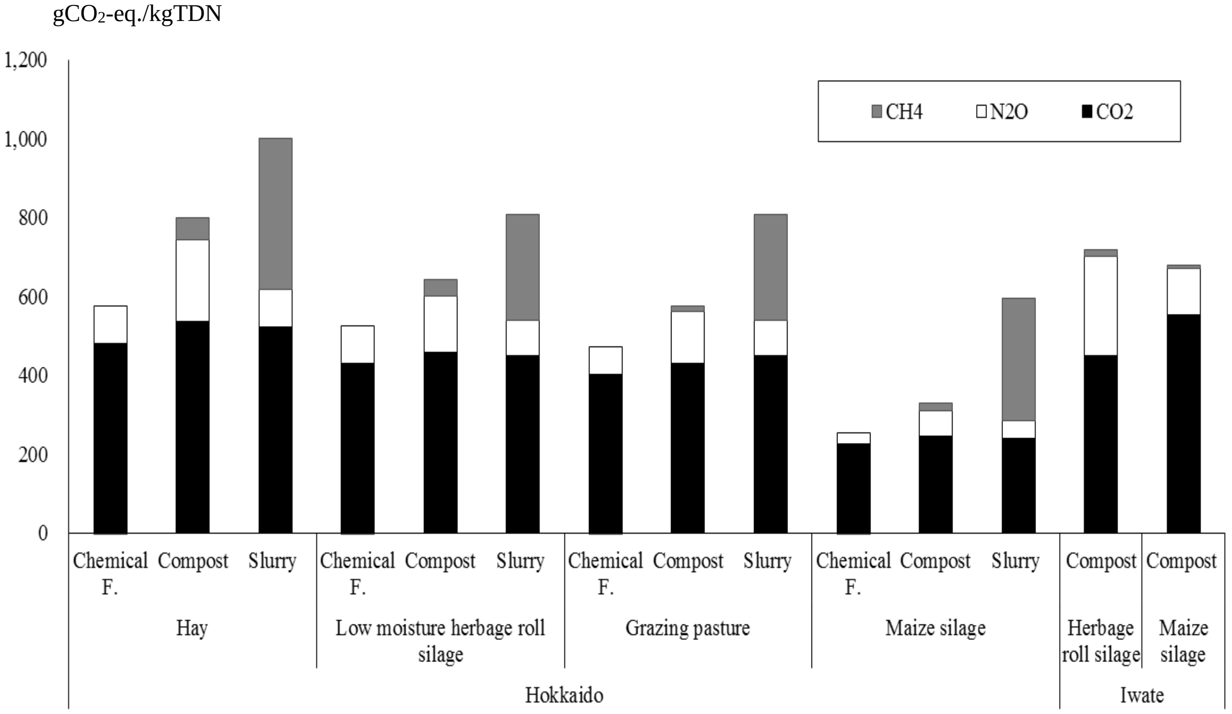


Figure 2.2 GWL in self-supplying feed production

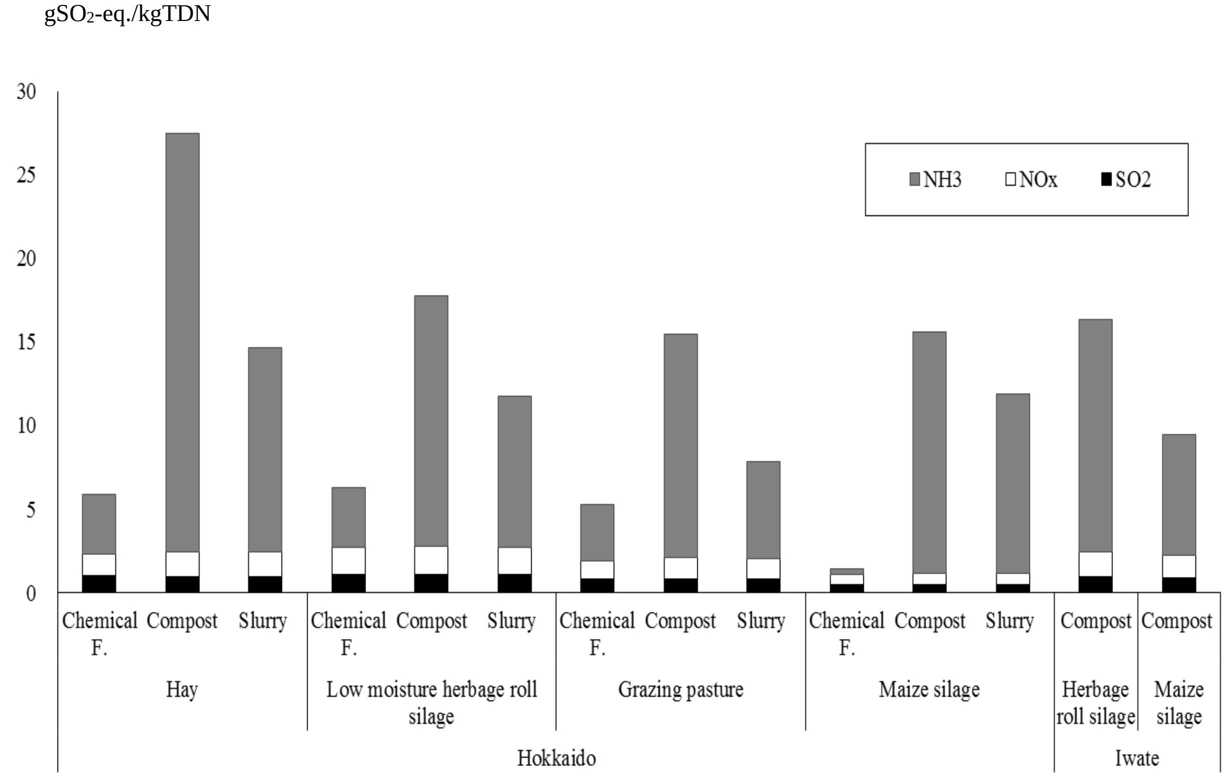


Figure 2.3 AL in self-supplying feed production

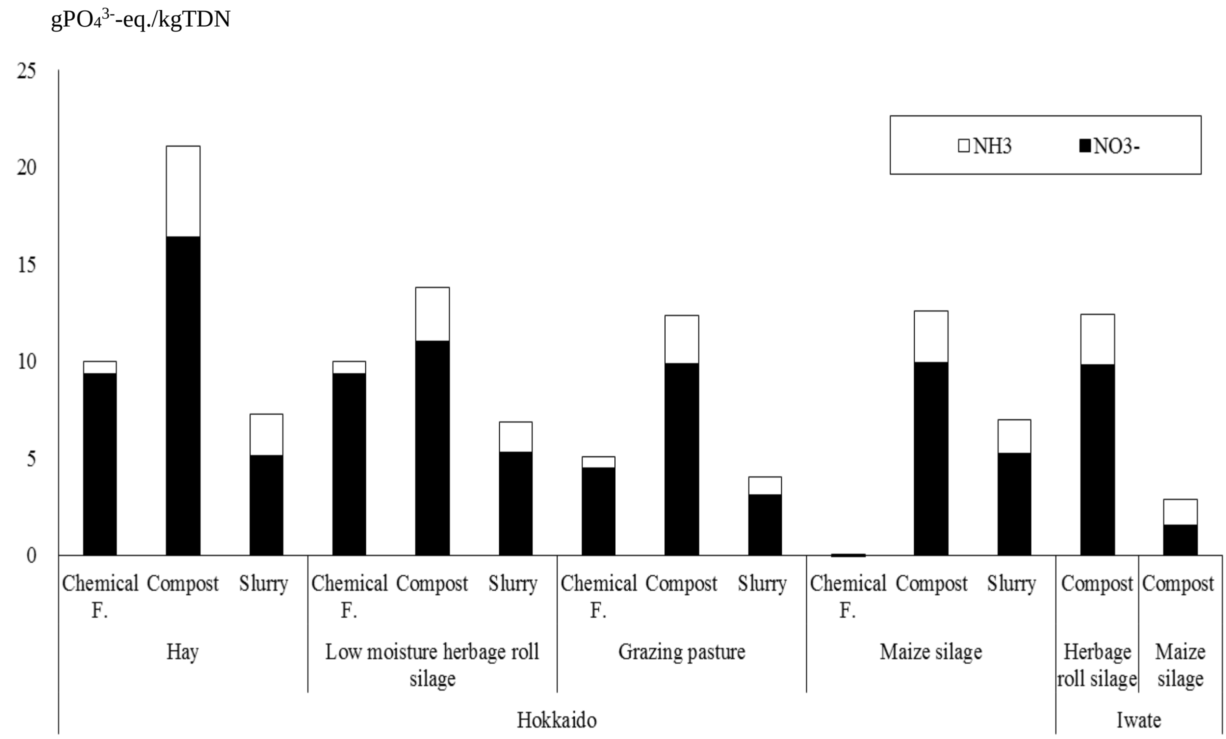


Figure 2.4 EL in self-supplying feed production

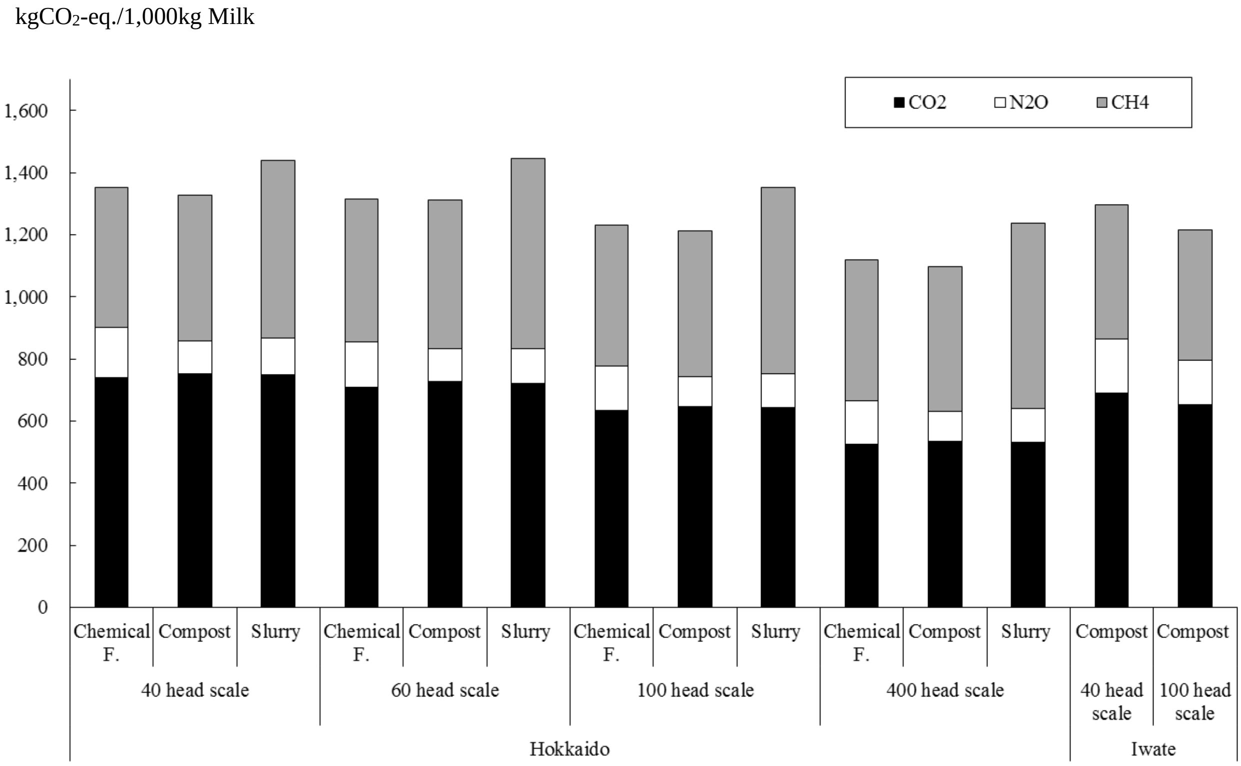


Figure 2.5 GWL in dairy production

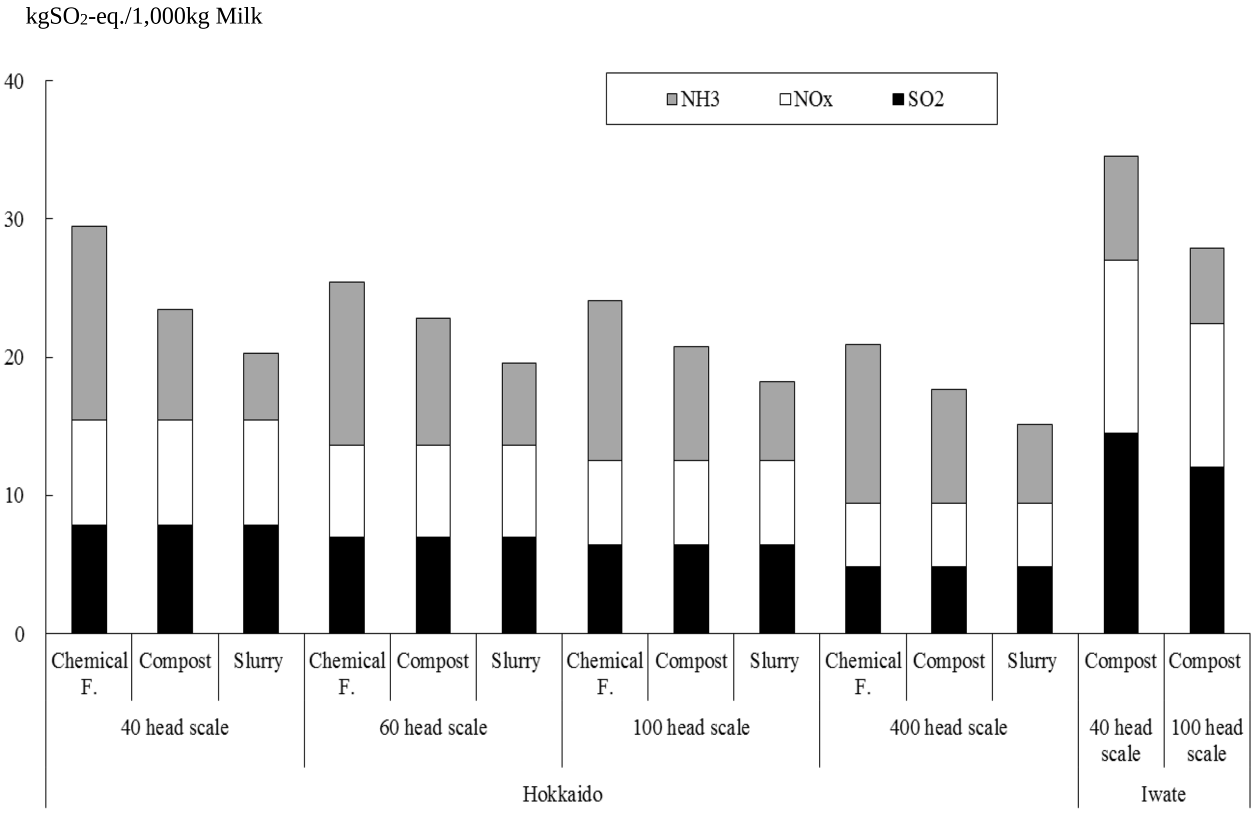


Figure 2.6 AL in dairy production

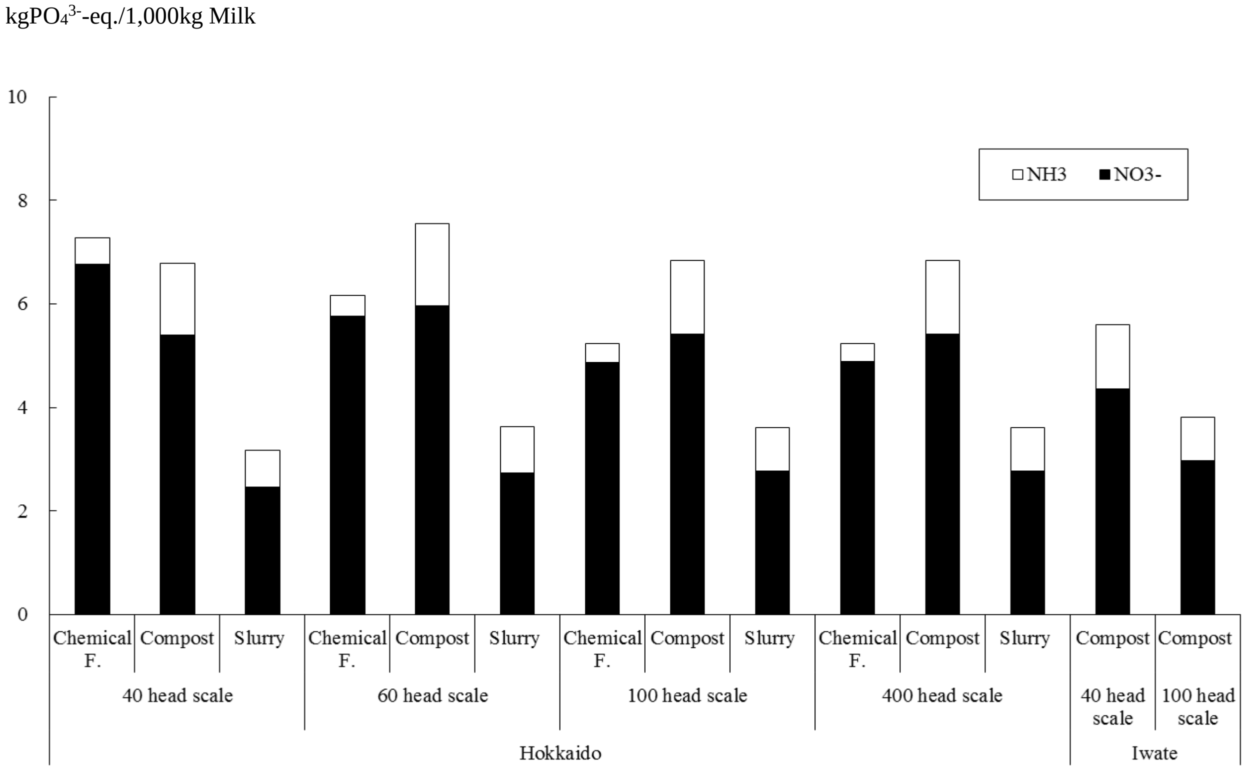


Figure 2.7 EL in dairy production

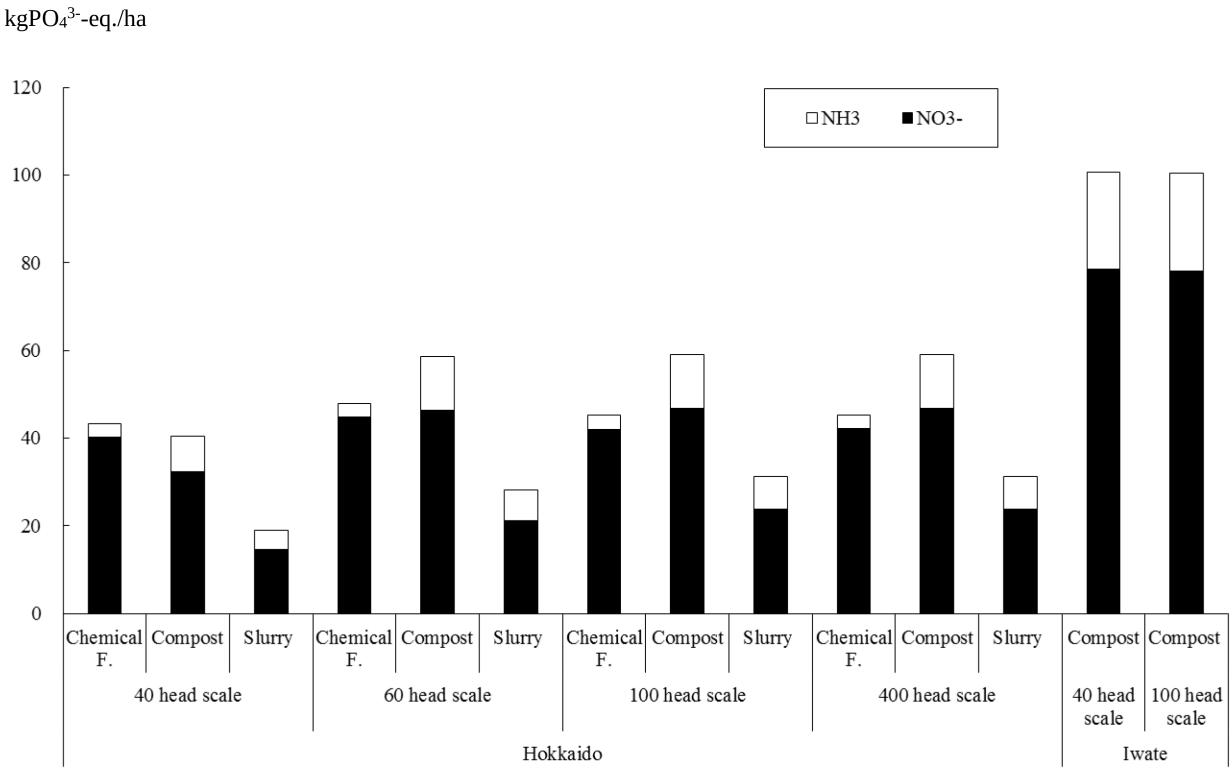


Figure 2.8 EL in dairy production per area

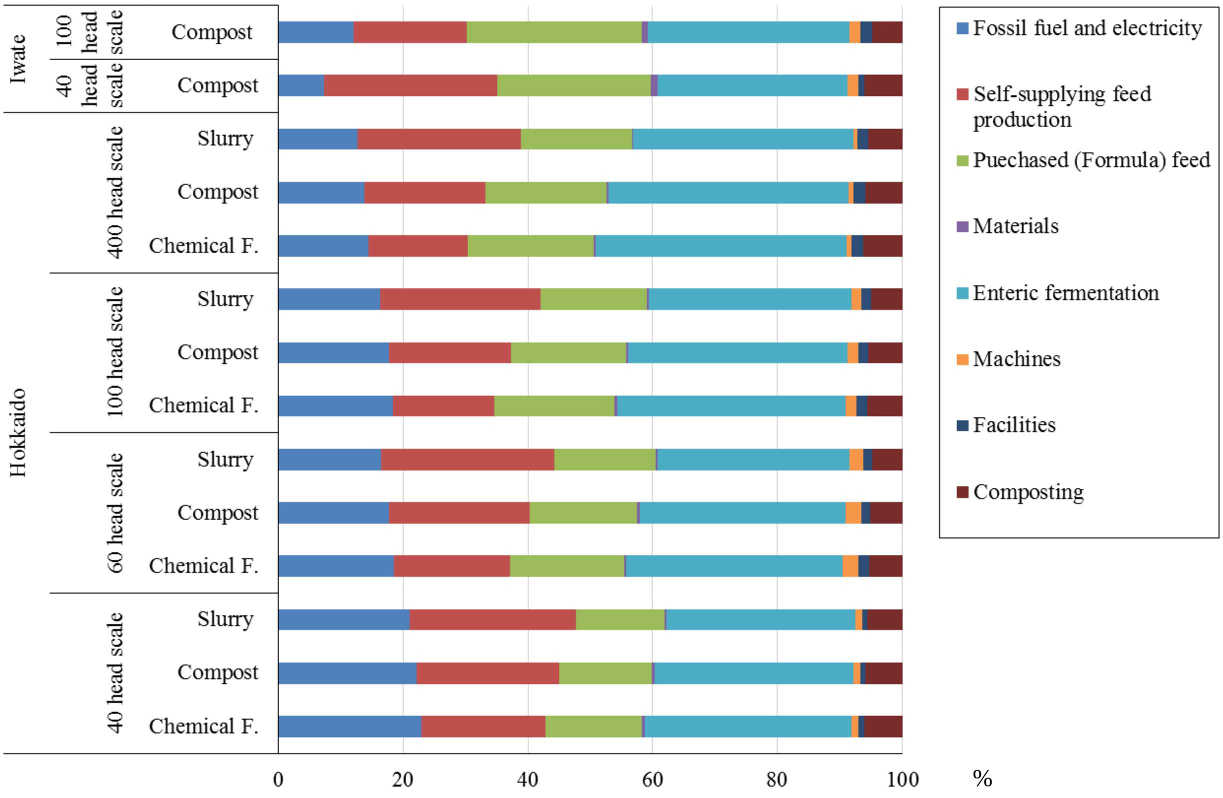


Figure 2.9 Content of GWL in dairy production including feed production

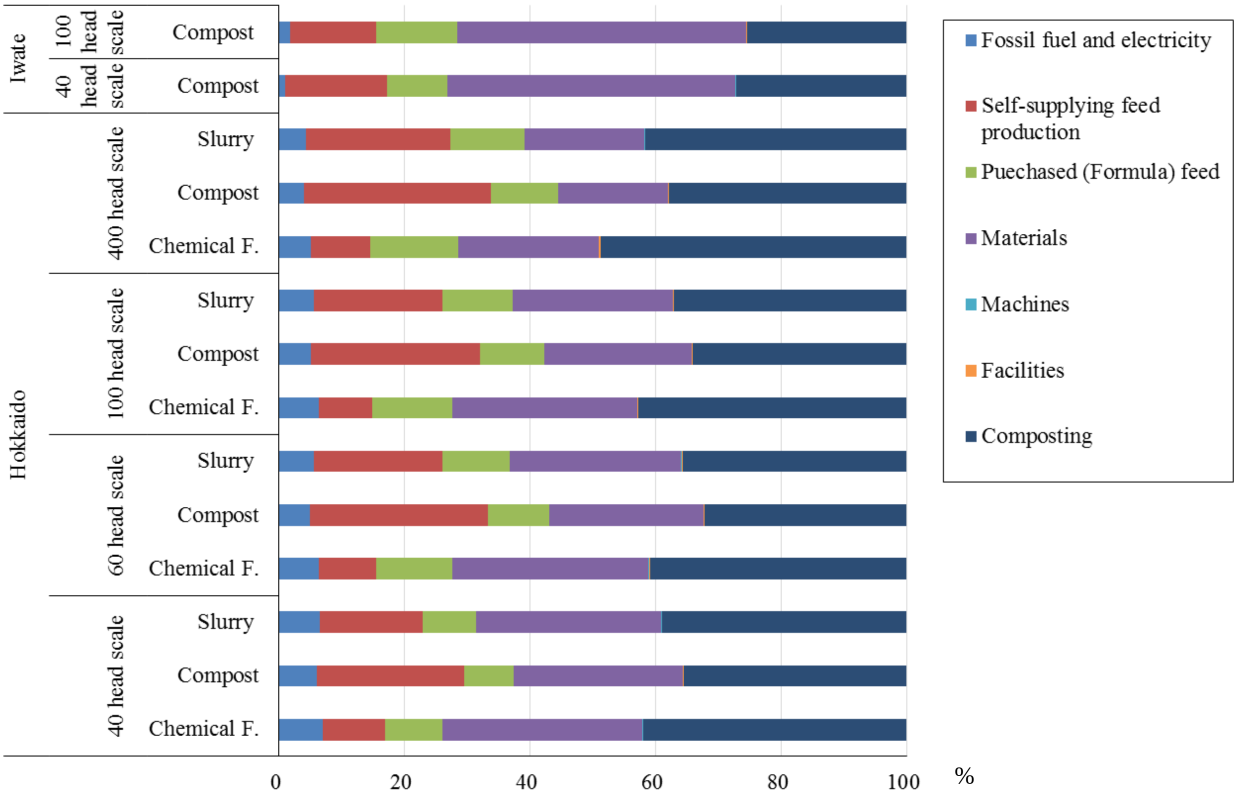


Figure 2.10 Content of AL in dairy production including feed production

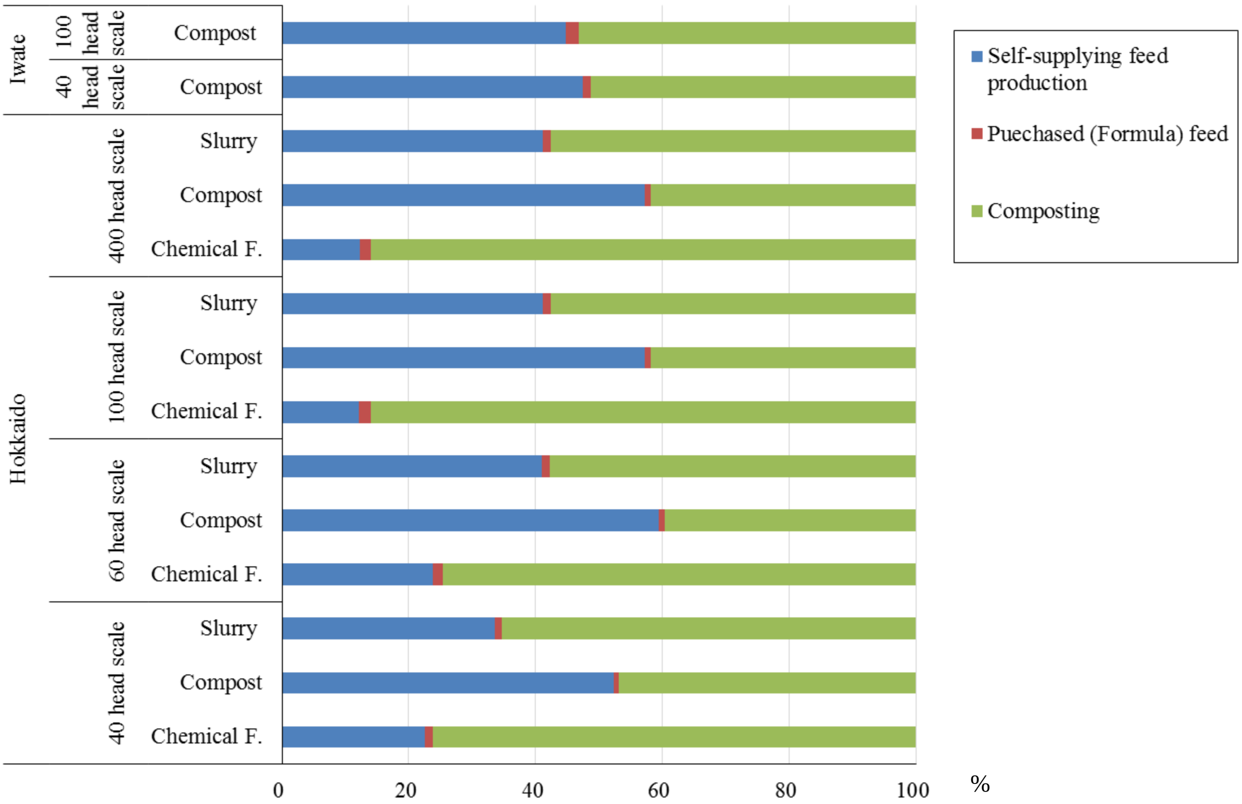


Figure 2.11 Content of EL in dairy production including feed production

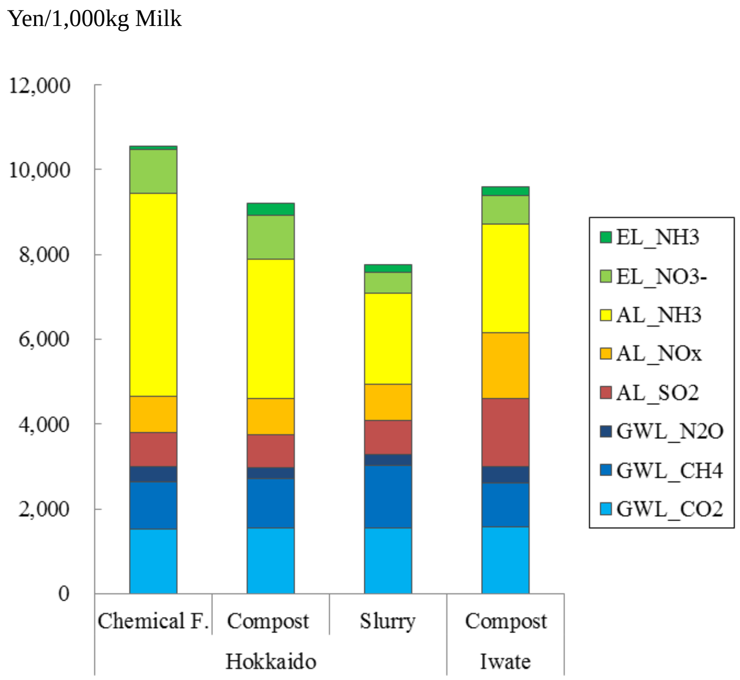


Figure 2.12 Results of LIME2 by fertilizer type in dairy production

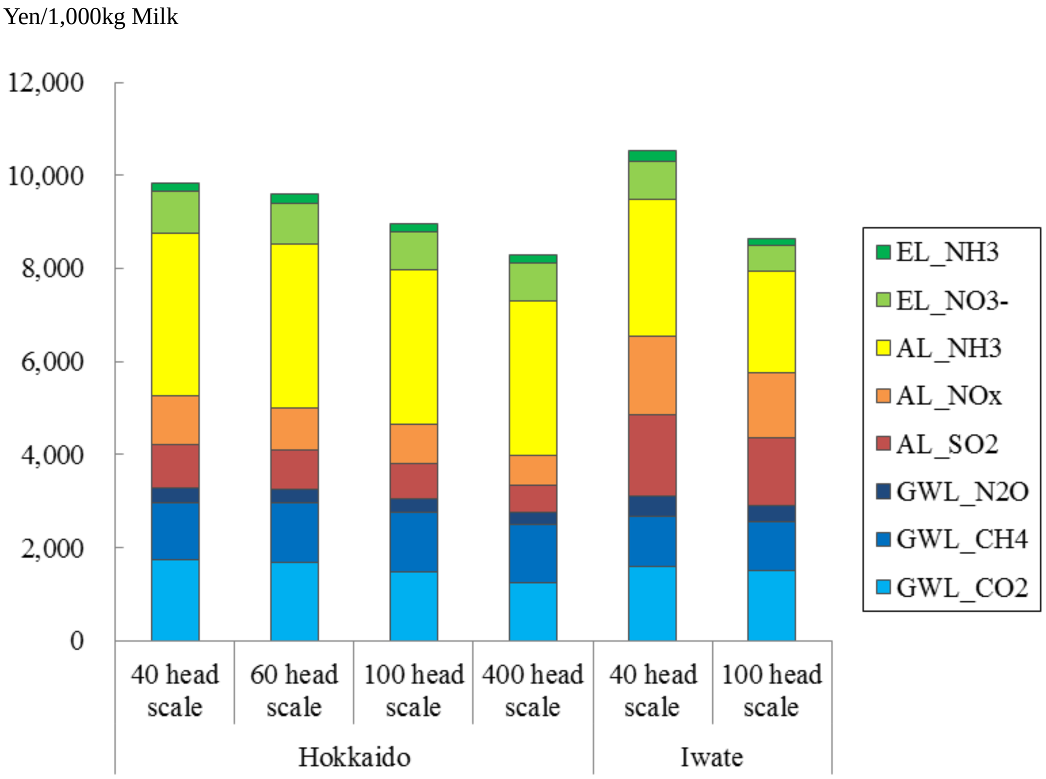


Figure 2.13 Results of LIME2 by production scale in dairy production

2.4 Conclusions

The results show that the environmental impact of dairy production was lower in the types using organic fertilizer, even though the impact of organic fertilizer use was higher in the case of self-supplying feed production. This is because the utilization of organic fertilizer in self-supplying feed production contributes to efficient livestock manure management. Moreover, large scale production systems had a lower environmental impact due to efficient production, especially in terms of machinery. The AL was higher in Iwate and EL was higher in Hokkaido, while there was no significant difference to GWL in dairy production. The LIME2 results of integrated environmental impacts show that the AL from NH_3 contributed the most to economic damage. As a consequence, the results suggest that selecting organic fertilizer in self-supplying feed production in order to contribute to utilizing animal manure, and the efficient use of machinery for effective production systems, will contribute to reducing the environmental impact of dairy production. This study limited environmental impact loads to GWL, AL and EL in the analysis. Future study will require the inclusion of biodiversity, animal welfare and agricultural rural scenery into environmental impact assessments to obtain an integrated analysis. Moreover, future studies should also consider environmental conservation, organic farming, grazing and integrated agriculture with livestock. Case studies from developing countries will also greatly contribute to influence policy making in order to promote environmentally friendly agricultural production systems, which unfortunately is not yet common on a global scale.

2.5 Summary

In recent years, it is required to establish environmentally friendly agricultural production systems. In this study, the environmental impacts of dairy production including different types of self-supplying feed production systems were evaluated using the Life Cycle Assessment (LCA) method according to "Agricultural Production Technology Systems" (APTS) created by Hokkaido and Iwate Prefectures. Four types of self-supplying feed production (hay cutting two times annually, low moisture herbage roll silage cutting three times annually, grazing pasture and maize silage) in Hokkaido and two types of self-supplying feed production (herbage roll silage cutting three times annually and maize silage) in Iwate, were analyzed according to three types of fertilizer application (chemical fertilizer, compost and slurry respectively).

These results were included in environmental impact assessments of dairy production consisting of four types (40, 60, 100 and 400 head scale) of production systems in Hokkaido and 2 types (40 and 100 head scale) in Iwate. The global warming load (GWL), acidification load (AL) and eutrophication load (EL) were evaluated. The results show that the environmental impact of dairy production was lower in the types of organic fertilizer use, even though the impact of organic fertilizer use itself was higher in the case of self-supplying feed production. The AL was higher in Iwate and EL was higher in Hokkaido, while there was no significant difference in the GWL. Large scale production systems had a lower environmental impact. The results of integrated environmental impacts using LIME2 (Life cycle Impact assessment Method based on Endpoint modeling 2) show that the AL from NH_3 contributed the most to economic damage. As a consequence, the results suggest that the selection of organic fertilizer in self-supplying feed production in order to contribute to utilizing livestock manure, and the efficient use of machinery for effective production systems, will contribute to reducing the environmental impact in dairy production including feed production.

Chapter 3 The Nitrogen Balance from Agricultural Activities including Livestock Production in Japan

3.1 Introduction

Japan has the third highest nitrogen balance among OECD countries, following Korea and the Netherlands (OECD 2015). Nitrogen has been applied excessively to vegetables and tea in Japan (Mishima *et al*. 2010b). The high nitrogen balance has significant effects on underground water. Examining the situation of underground water in Japan, levels of nitrate and nitrite were highest at 3.6%, which exceeded environmental standards of underground water quality in JFY2016 (Ministry of the Environment 2018). Even though the sustainable agricultural production act was introduced in 2004 in order to reduce environmental problems due to agricultural activities, there are no specific regulations to control nitrogen balance. On the other hand, the Netherlands for example, has the “Mineral accounting system” which charges for excessive fertilizer application (Fukushima 2006).

The high rate of imported feed in livestock production also contributes to the high rate of nitrogen accumulation from livestock manure in Japan. Dry-lot feeding systems based on imported feeds is common in both dairy and beef production, with the rate of grazing being only 22% in dairy production and 19% in beef production (MAFF 2018a). The rate of imported feed in concentrated form was 88% in livestock production in 2012 (MAFF 2014). Pig and poultry production consume less feed, however the rate of concentrated feed consumed is almost 100%. This imported feed accumulates as livestock manure with high nitrogen content in Japan.

There are many previous studies considering nitrogen balance in Japan. Mishima *et al.* (2013) investigated nutrient balance by surveying the topsoil of seven crop groups on several soils from 1979 to 2003, and reported that nitrogen was well controlled. In fact the amount of chemical fertilizer decreased from 1985 to 2005, especially in rice cultivation, although yields remain stable (Mishima and Kohyama 2010a). On the other hand, the utilization rate of manure as compost has actually decreased from 76% in 1985 to only 57% in 2005 (Mishima *et al.*, 2009). According to a previous study (Mishima *et al.* 2013), it seems that the nitrogen balance has markedly improved because yields have remained stable even though the amount of both chemical fertilizer and manure application have decreased. However, there are no studies of nitrogen balance which consider each municipality by region nationwide. The monitoring of nitrogen balance by calculating the amount of nitrogen inputs and outputs nationwide will be essential to provide basic information for sustainable agriculture.

In this study, the nitrogen balance of agricultural activities including livestock production was estimated in Japan. Furthermore, the results were shown using the geographical information system (GIS) to visualize the differences of nitrogen inputs, outputs and balance according to municipality.

3.2 Methods

The nitrogen balance was calculated based on the soil surface balance of farmland (van Beek *et al.* 2003). “Mineral fertilizer”, “livestock manure”, “atmospheric deposition” and “biological nitrogen fixation” were considered as nitrogen inputs. “Crop products and forage”, and “gaseous losses” were considered as nitrogen outputs (Figure 3.1). The nitrogen balance was analyzed by summing up inputs and outputs. Grazing was not included in total nitrogen balance because the rate of grazing in Japan is low and conducted only in specific seasons, such as summer, and it is difficult to precisely estimate the amount ingested while grazing. Leaching was not included in this study due to difficulties of monitoring nitrogen flow because the rainfall rate is quite high in Japan. Erosion was also not included because there are not many cases of erosion in Japan.

The data of each municipality was based on the latest completed version of the “crop survey” by MAFF in 2006 (MAFF 2006, Table 3.1). The amount of mineral fertilizer application in 2010 estimated by MAFF was divided equally according to the agricultural area of each municipality. The amount of nitrogen input from livestock manure was estimated using the coefficient of nitrogen in livestock manure by Tsuiki and Harada (1997). The amount of nitrogen from atmospheric deposition and biological nitrogen fixation by leguminous crops and grasses was estimated using the method of de Koning *et al.* (1997).

The amount of nitrogen output from crop production was calculated by the amount of crop shipped multiplied by the protein content indicated in Japan's standard food composition table (METX 2015) and divided by 6.25 (Tsuiki *et al.* 1990). The crops included in this study is shown in Table 3.1. Nitrogen output by grazing was not included in the nitrogen balance, however the approximate rate of nitrogen was analyzed by region. A half yield of forage production in each municipality was multiplied by grazing area to obtain the approximate nitrogen output rate from grazing. The amount of nitrogen from gaseous losses was estimated using the method of FAO (2004).

Inputs and outputs of nitrogen were summed to analyze nitrogen balance. Furthermore, each result of nitrogen input and output and nitrogen balance was analyzed using QGIS in order to focus on the differences among regions. Details of the results are shown by municipality on the map in order to analyze the characteristics among regions (Figure 3.2). To compare results the region was divided into "Hokkaido" and "other regions" because the livestock production system in Hokkaido is quite different from other areas. Finally, the SPSS correlation was used to analyze which factor contributes most to nitrogen balance.

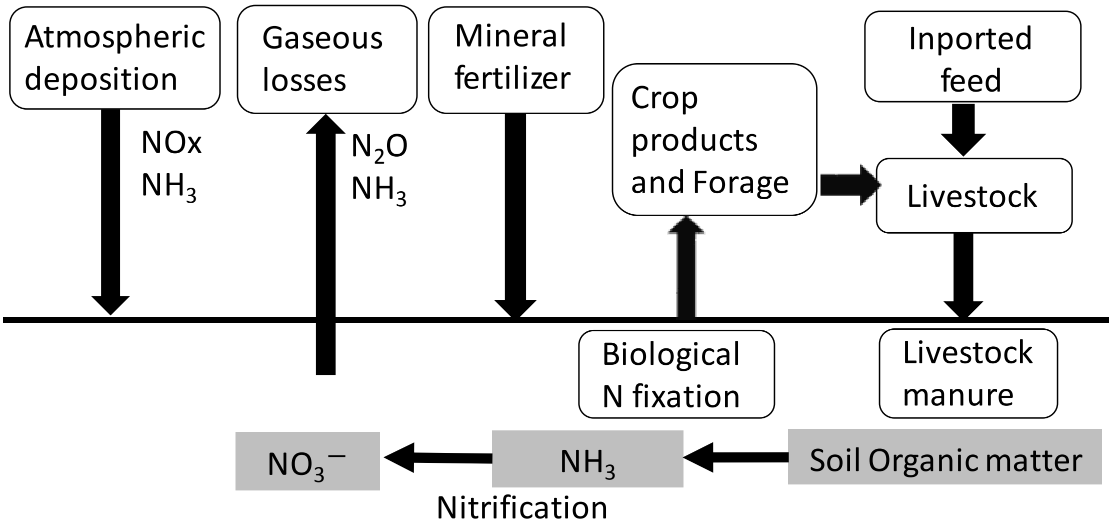
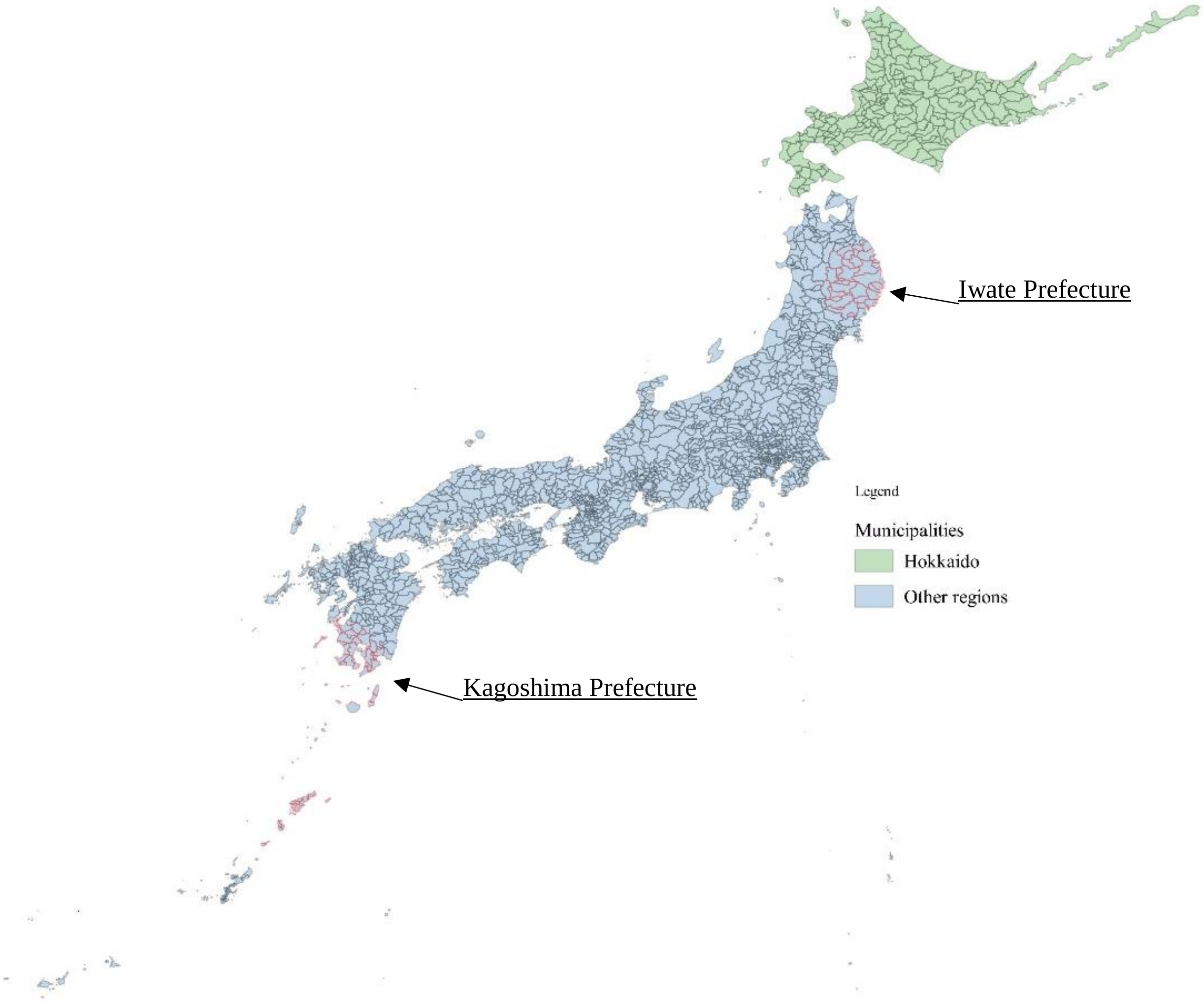


Figure 3.1 Nitrogen flow and the estimated scope in this study

Table 3.1 Data for nitrogen balance calculation (MAFF 2006)

Agricultural area
Cultivated land (upland and paddy field) Orchard Pasture
Crops
Paddy rice, Upland rice, Wheat, Barley, Soy, Azuki bean, Green beans, Peanuts, Sweet potatoes, Buckwheat, Cucumbers, Pumpkins, Eggplants, Tomatoes, Green peppers, Sweet corn, Kidney beans, Cowpeas, Broad beans, Edamame (green soya), Daikon radish, Radish, Carrots, Burdock, Lotus root, Potatoes, Taro, Yams, Chinese cabbage, Komatsuna leaves, Cabbage, Green pak choi, Spinach, Giant butterbur (fuki), Japanese honeywort, Crown daisy, Celery, Asparagus, Cauliflower, Broccoli, Lettuce, Welsh onion, Chinese chive, Onion, Garlic, Strawberry, Melon, Watermelon, Mandarin, Oranges, Apple, Pears, Persimmon, Japanese loquat, Peach, Plums, Cherry, Japanese apricot, Grape, Chestnuts, Pine apple, Kiwi fruit, Ginger, Tea, Rush, Elephant foot, Sugar cane, Tobacco, Sugar beet, Soiling maiz, Sorgo, Herbage, Soiling oats.
Livestock
Cattle (milk and meat) Pigs Poultry (eggs and meat)



Iwate Prefecture

Kagoshima Prefecture

Figure 3.2 Regions and municipalities in Japan

3.3 Results and discussion

The results show that the average nitrogen balance nationwide per agricultural land was positive 132.9 kgN/ha annually. In detail, average inputs for each municipality were 93.0, 89.5, 5.8, and 0.1 kgN/ha from mineral fertilizer, livestock manure, atmospheric deposition and biological nitrogen fixation, respectively. In the case of outputs, 31.8 and 23.8 kgN/ha from crop production and gaseous losses, respectively. Overall, mineral fertilizer and livestock manure inputs contributed significantly to excessive nitrogen. Compared by region, the nitrogen balance in Hokkaido was lower than other regions, and the nitrogen from livestock manure was significantly high in other regions (Figure 3.3). Following beef production, the farming of pig and poultry also contributed to the nitrogen input from livestock manure in other regions even though the rate of pig and poultry farming was lower in Hokkaido (Figure 3.4). Almost all feed for pig and poultry is imported concentrated feed, which means that livestock manure is not used as compost on these farms. This situation tends to produce considerable environmental problems in specific hotspots. On the other hand, the rate of dairy production in livestock manure was highest in Hokkaido. Dairy production in Hokkaido has a relatively higher rate of self-supplying feed production when compared to other regions, which means that livestock manure is used as compost on these farms.

The results of GIS show differences in nitrogen balance for each municipality (Figure 3.5). The nitrogen balance was higher in municipalities located in the northern parts of Iwate Prefecture and Kagoshima Prefecture. The results of livestock manure inputs also show the same trend as indicated in Figure 3.5 (Figure 3.6), which means the nitrogen from livestock manure contributed significantly in terms of regional differences. In detail, the nitrogen from dairy and poultry production in the northern part of Iwate Prefecture, and beef production and pig farming in Kagoshima Prefecture, contribute to excess nitrogen (Figure 3.7-3.10). Moreover, mountainous areas were higher in nitrogen input from livestock manure. In the case of nitrogen output by crop production, northern coastal areas bordering the Japanese sea known for paddy rice cultivation have higher nitrogen output (Figure 3.11). The nitrogen output from intake by grazing was higher in Hokkaido and the northern part of Tohoku region, even though the nitrogen rate of grazing in outputs was relatively lower (see appendix). From the nitrogen rate of both figures and GIS maps, it is clear that the nitrogen from livestock manure contributed significantly to total nitrogen balance. The correlation analysis using non-parametric (Spearman) tests also suggested a strong positive relationship ($r= 0.883$, $p<0.001$, $n=1805$) between nitrogen balance and nitrogen from livestock manure (see appendix). The OECD (2001) also reported that the intensification of livestock farming, rather than the increase of chemical fertilizer use, contributed to increased nitrogen in OECD countries. Therefore, improving and monitoring livestock manure management will be essential in terms of considering nitrogen accumulation and contamination. Livestock production of less density with higher rates of self-supplying feed like Hokkaido, are able to circulate nitrogen on farms by applying the compost processed from livestock manure in order to avoid nitrogen accumulation in specific areas with intensive livestock production. Grazing also contributes to nitrogen circulation on farms even though in other regions a major production system, dry lot feeding with higher density and more grazing, are found only in Hokkaido and the northeastern part of Tohoku region. If it is difficult to increase the rate of self-supplying feed and grazing due to land limitation issues, the utilization of compost from livestock manure along the northern coastline bordering the Japanese Sea, which has intensive crop production, will assist the sustainable nitrogen balance of the country as a whole to prevent nitrogen accumulation hotspots in areas with intensive livestock production.

Compared to a previous study, Mishima *et al.* (2013) investigated the actual nitrogen balance of each soil in five times per crops. The nitrogen balance in this previous study indicated an approximate average of 200 kgN/ha/year, except for tea. The chemical fertilizer application rate for tea was quite high at approximately 700 kgN/ha/year, though the amount of chemical fertilizer applied was divided equally among agricultural land areas in this study. Mishima *et al.* (2013) concluded that the nitrogen balance was well controlled. On the other hand, another study concluded that the nitrogen balance would not cause environmental problems if less than 100 kgN /ha/year (OECD 2001). The nitrogen balance was positive 132.2 kgN/ha in this study, however, it is difficult to define whether the value obtained actually causes environmental damage. The nitrogen content may be lower due to leaching by the high rainfall in Japan. Therefore, a future study with integrated analysis and monitoring is required to obtain precise results of nitrogen balance.

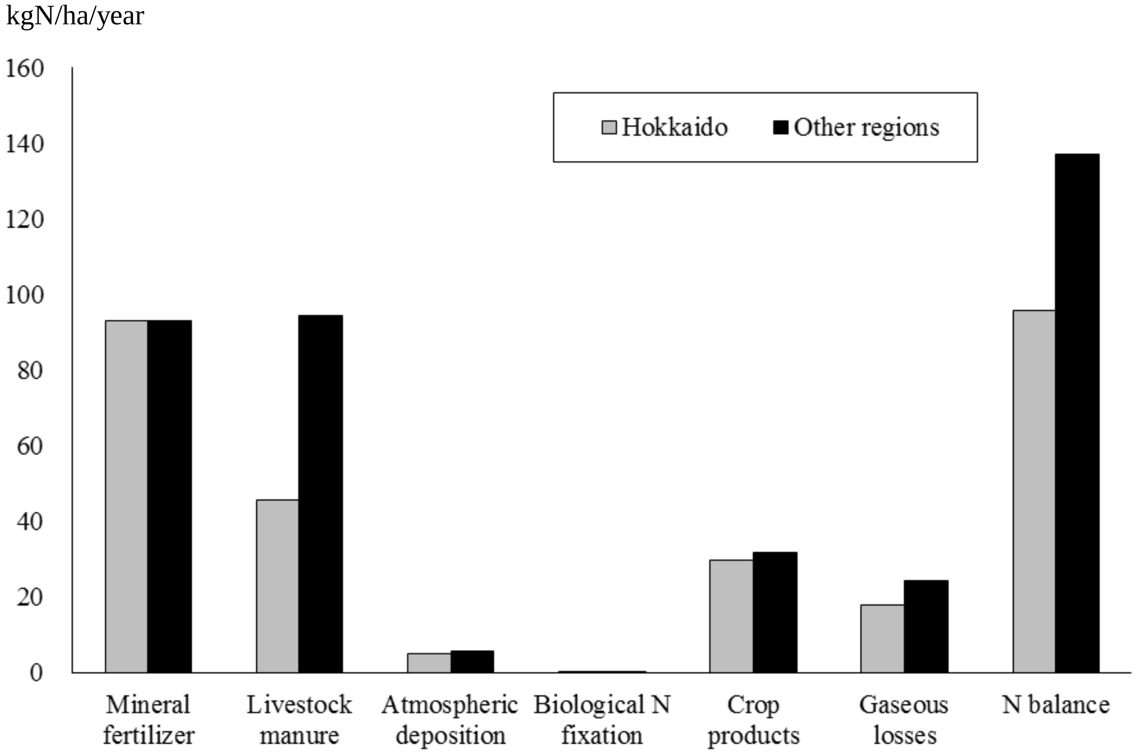


Figure 3.3 Detail of nitrogen inputs, outputs and balance by region

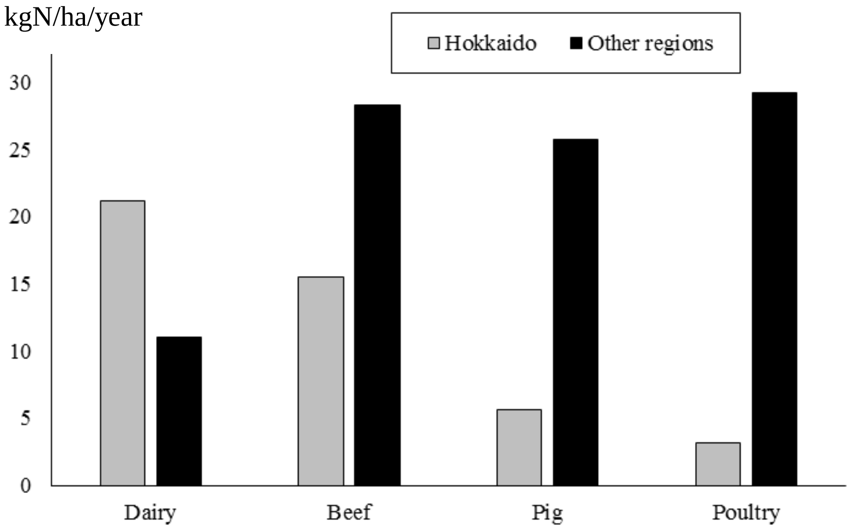


Figure 3.4 Nitrogen input from livestock manure between regions

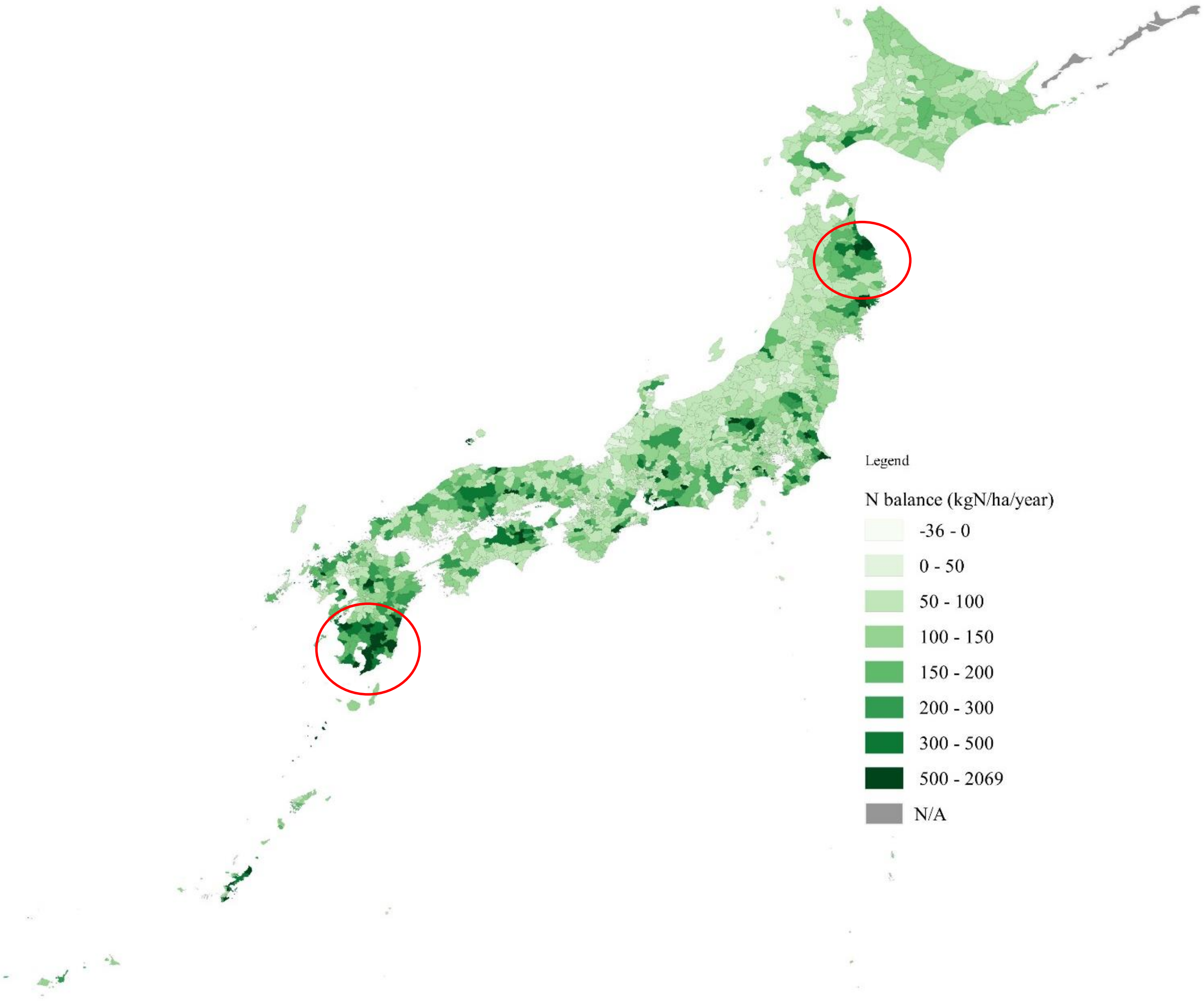


Figure 3.5 Total nitrogen balance in Japan

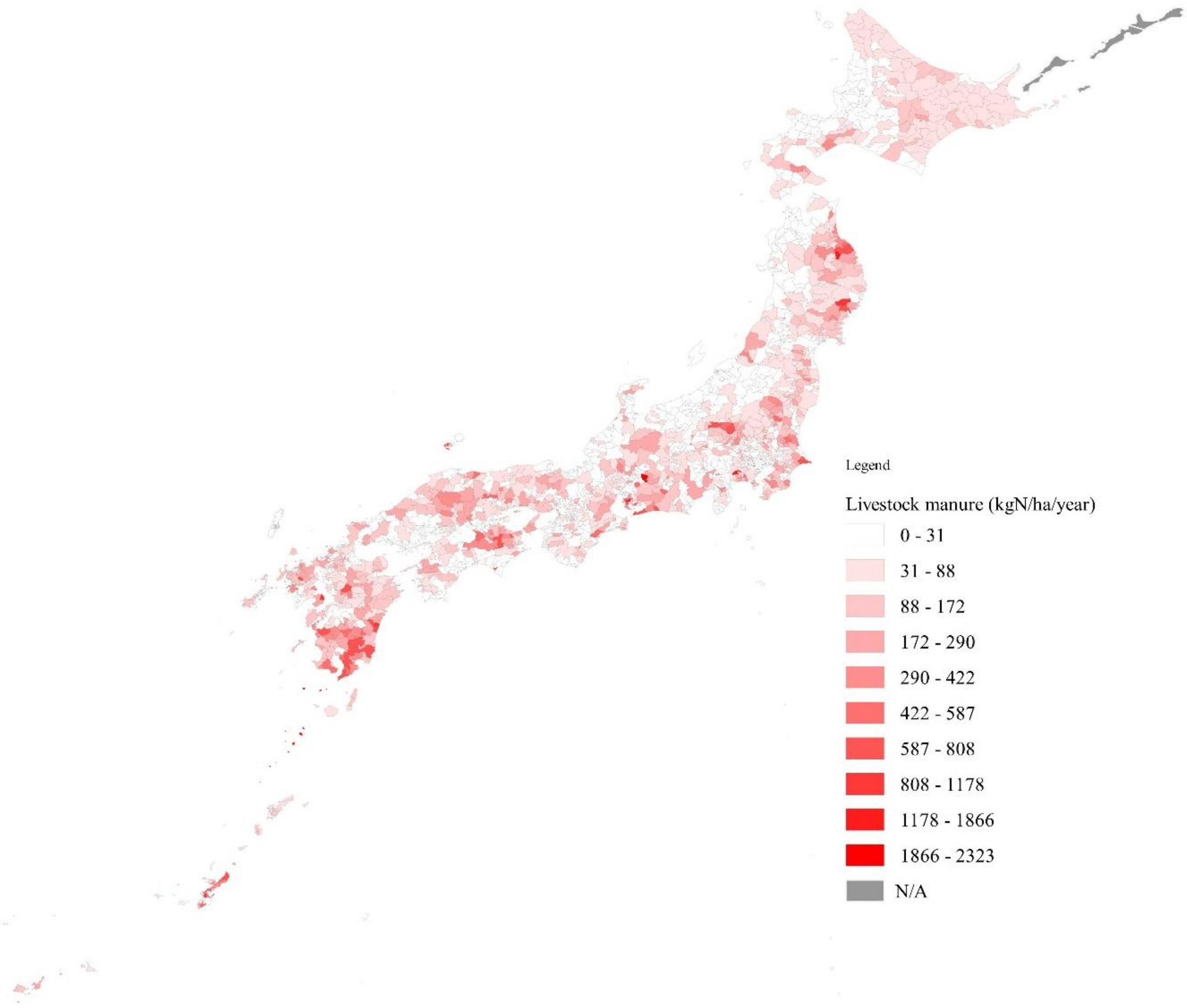


Figure 3.6 Nitrogen input from livestock manure (total)

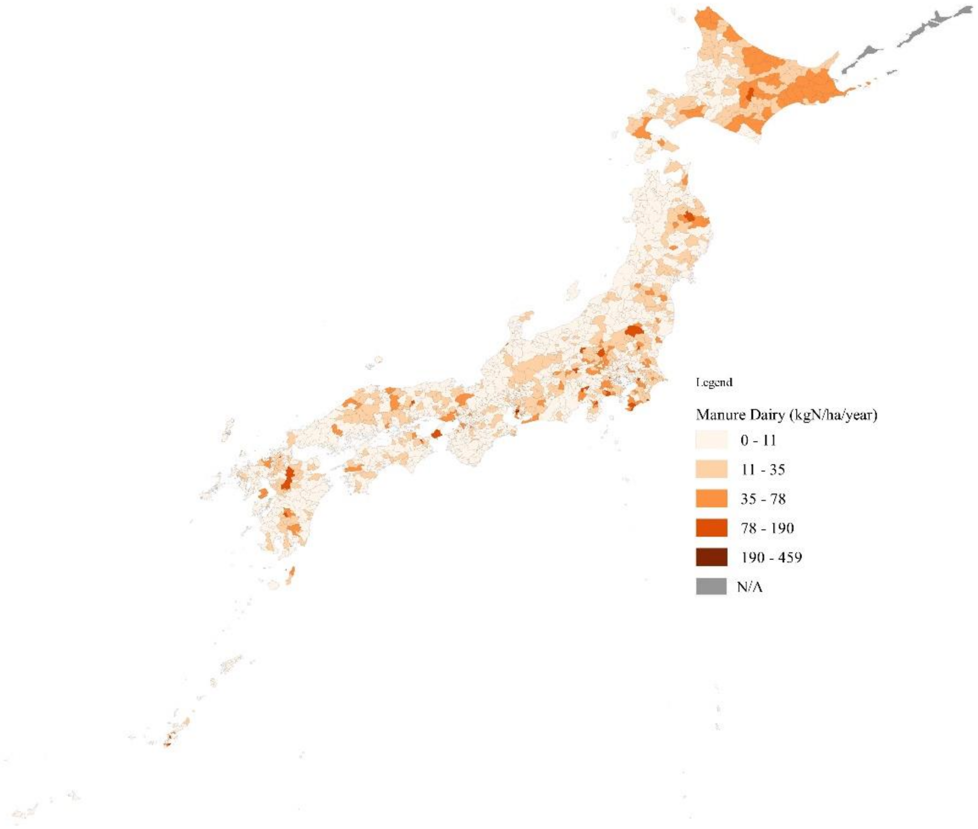


Figure 3.7 Nitrogen input from dairy production (livestock manure)

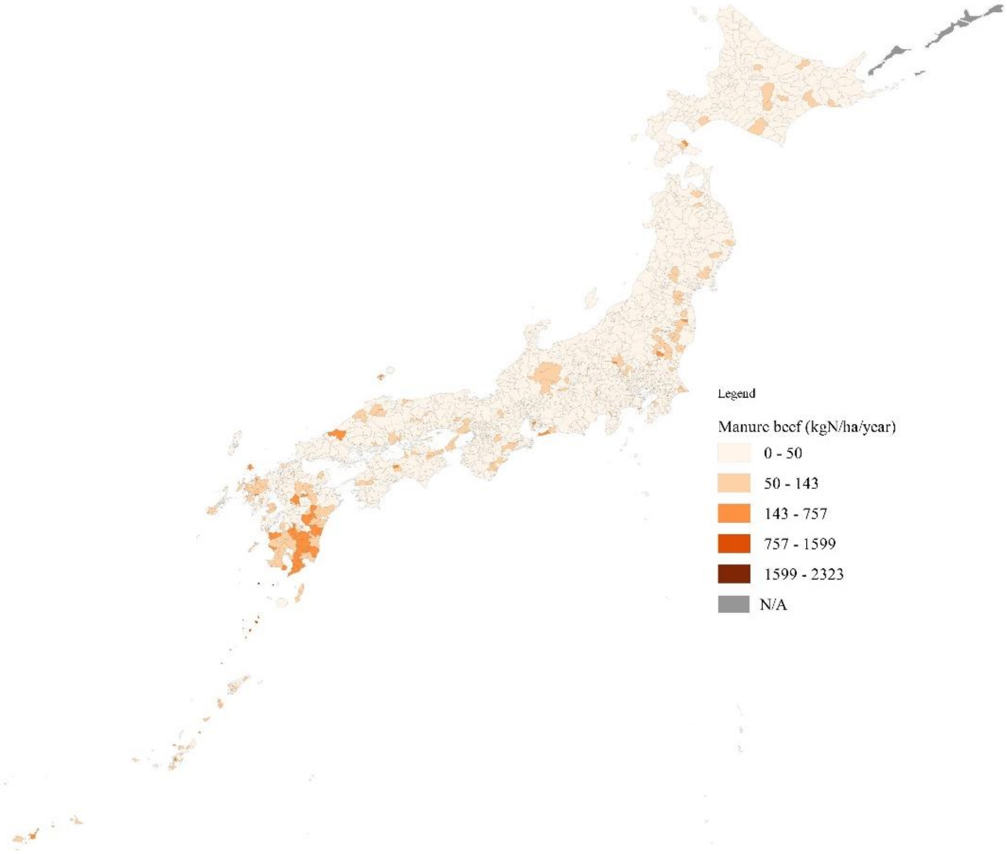


Figure 3.8 Nitrogen input from beef production (livestock manure)

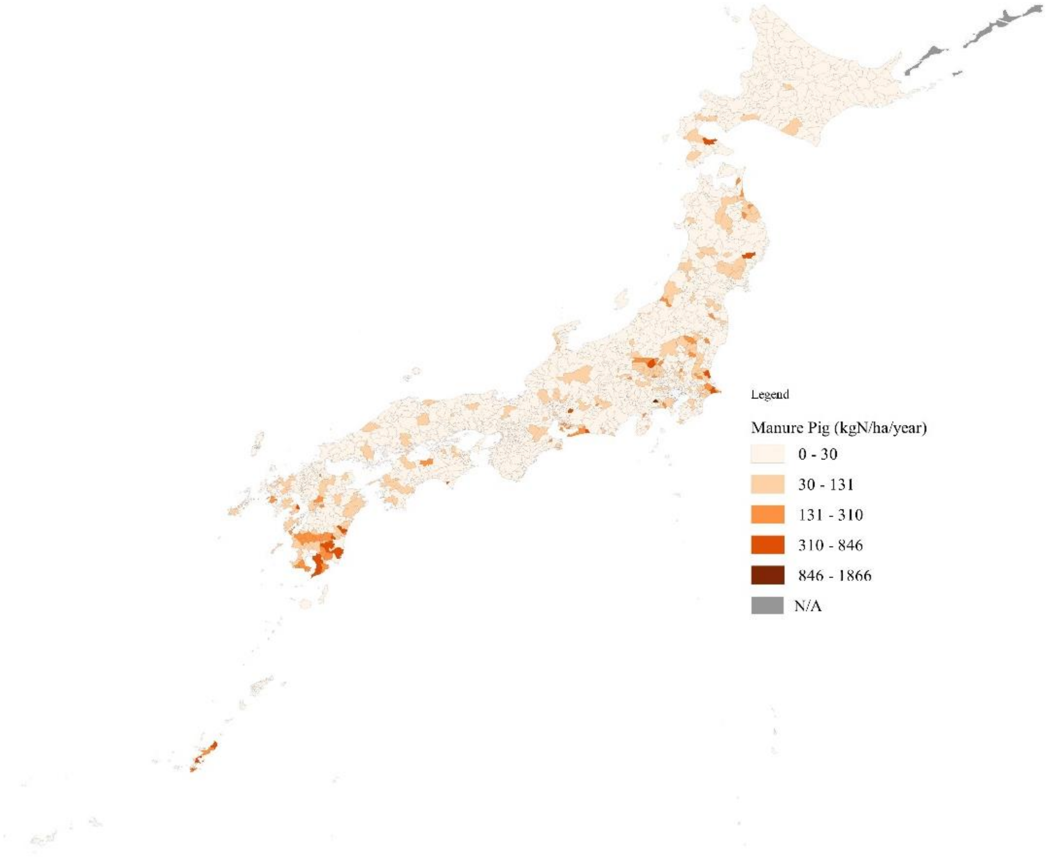


Figure 3.9 Nitrogen input from pig farming (livestock manure)

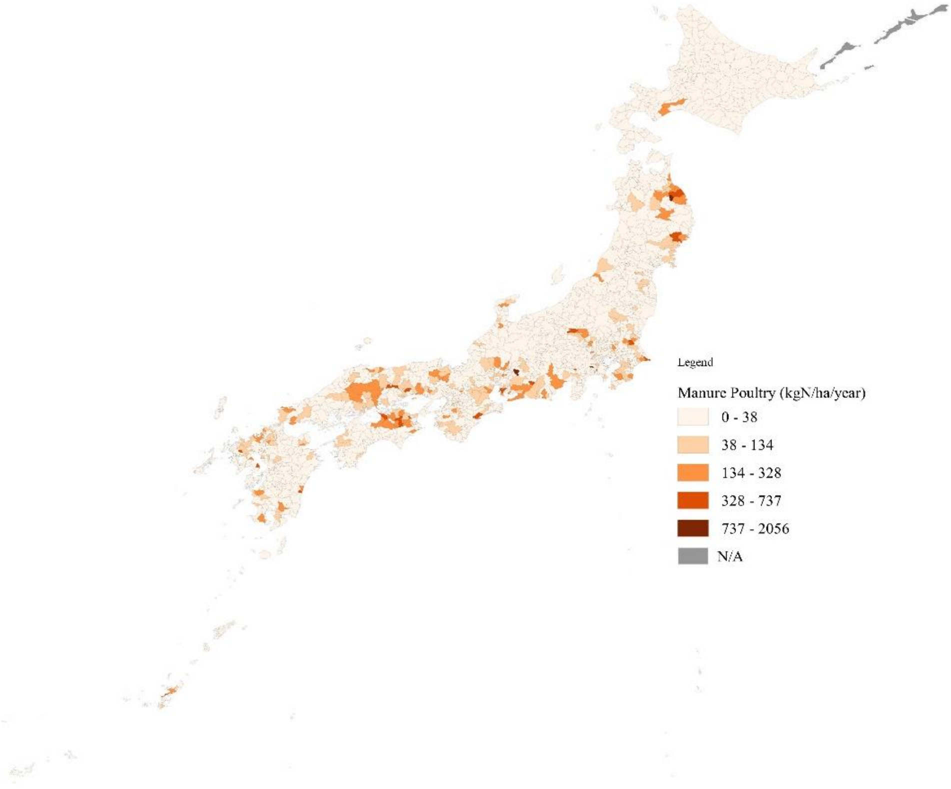


Figure 3.10 Nitrogen input from poultry (livestock manure)

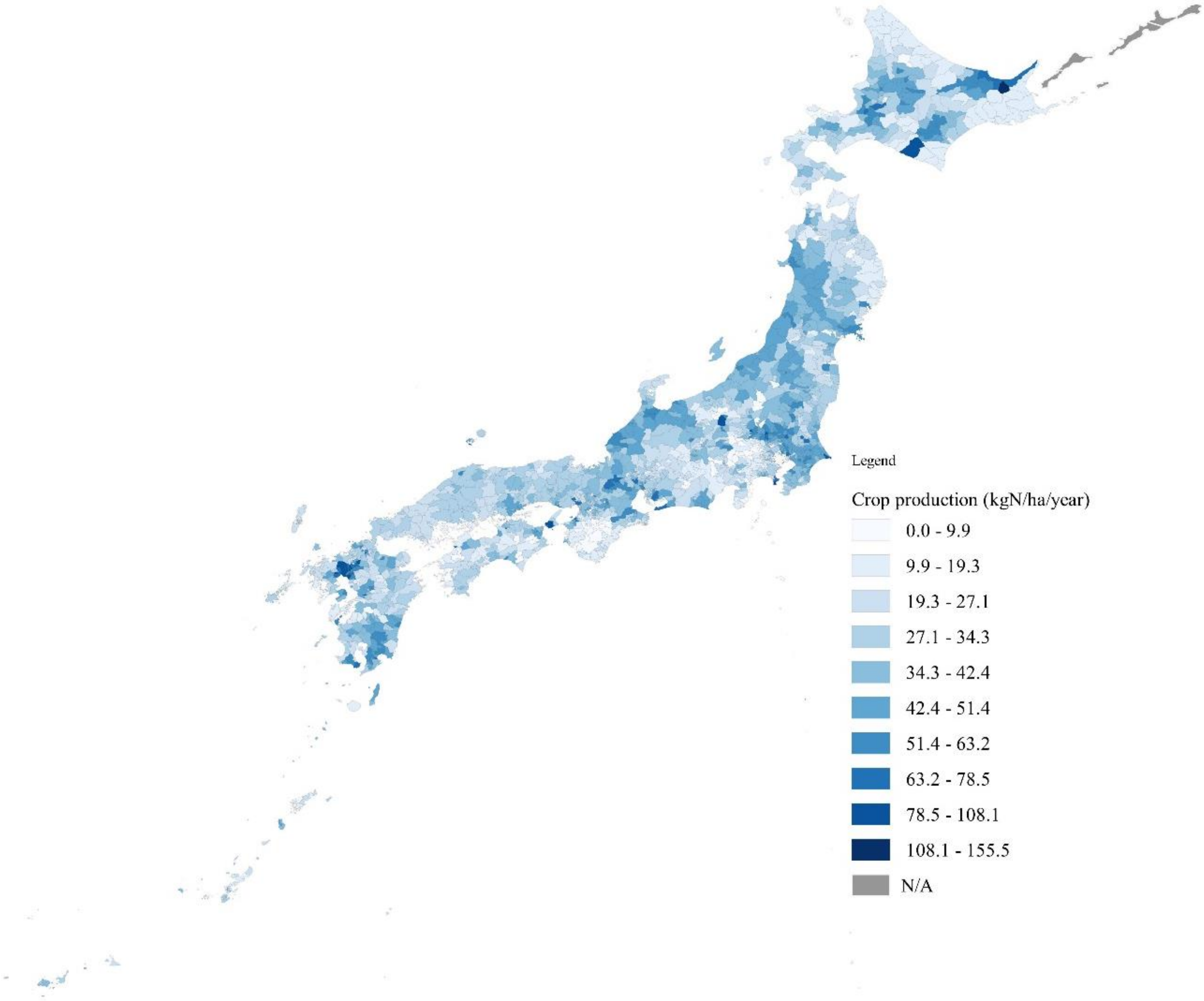


Figure 3.11 Nitrogen output from crop products

3.4 Conclusions

The results showed that average nitrogen balance in Japan per agricultural land was positive 132.9 kgN/ha annually. Notably, mineral fertilizer application and livestock manure greatly contribute to a positive nitrogen balance. Comparing regions, the nitrogen balance in Hokkaido was lower than other regions and the nitrogen from livestock manure was significantly high in other regions. The nitrogen balance was significantly positive in the northern parts of Iwate Prefecture and Kagoshima Prefecture. Looking closely, dairy and poultry production in the northern part of Iwate Prefecture, and beef production and pig farming in Kagoshima Prefecture, contribute excessive nitrogen. In the case of nitrogen output by crop production, northern coastal areas bordering the Japanese Sea known for paddy rice cultivation exhibit higher nitrogen output. Therefore, improving and monitoring livestock manure management will be essential in terms of considering nitrogen accumulation and contamination. The increase of self-supplying feed and grazing contribute to nitrogen circulation on farms towards sustainable production. If it is difficult to increase the rate of self-supplying feed and grazing due to land limitation issues, the utilization of compost from livestock manure in areas of intensive crop production will assist the nitrogen balance of the country as a whole to counteract nitrogen accumulation in hotspots with intensive livestock production. Compared to a previous study, the results obtained in this study were relatively lower. It is difficult to define whether the values calculated in this study are actually sustainable or not due to analysis limitations and instable nitrogen flows.

3.5 Summary

Japan has the third highest nitrogen balance among OECD countries. However, there are no specific regulations controlling the nitrogen balance in agricultural activities. The excessive use of nitrogen in vegetable and tea production and the high rate of imported feed in livestock production contribute to the high rate of nitrogen accumulation in Japan. There are many studies investigating nitrogen balance, however there are no studies of nitrogen balance which considers specific areas by region nationwide. In this study, the nitrogen balance per agricultural activity, including livestock production, was estimated based on the soil surface balance of farmland in Japan. The balance included nitrogen inputs such as “mineral fertilizer”, “livestock manure”, “atmospheric deposition” and “biological nitrogen fixation”; and included nitrogen outputs such as “crop products” and “gaseous losses”. Furthermore, the results were shown using GIS to visualize the differences of nitrogen inputs, outputs and balance according to municipality. The nitrogen balance of all farmland in Japan was estimated to be positive 132.9 kgN/ha annually. Notably, mineral fertilizer application and livestock manure greatly contribute to a positive nitrogen balance. The nitrogen balance was significantly positive in the northern part of Iwate Prefecture and Kagoshima Prefecture with intensive livestock production, and less in northern coastal areas bordering the Japanese Sea widely known for paddy rice cultivation. Therefore, improving and monitoring livestock manure management will be essential in terms of considering nitrogen accumulation and contamination. The increase of self-supplying feed and grazing on farms contribute to nitrogen circulation for sustainable production. If it is difficult to increase the rate of self-supplying feed and grazing due to land limitation issues, the utilization of compost from livestock manure in areas of intensive crop production will assist the nitrogen balance of the country as a whole to prevent nitrogen accumulation in specific areas with intensive livestock production.

Chapter 4 Nitrogen Balance from Agricultural Activities including Livestock Production in Ecuador

4.1 Introduction

It is possible to identify excessive nitrogen levels in some developing countries in rapid growth, though the problems of nitrogen are commonly identified in developed countries. The Republic of Ecuador is located in South America where many countries are growing rapidly and its economic level is relatively higher compared to other developing countries. Agriculture is the main industry in Ecuador and the agricultural system is diverse. Although most farms in Ecuador are small scale and conducting low input farming, big scale intensive farming is increasing (MAG 2018). Regulations to control nitrogen balance do not exist at present in Ecuador. In some other countries in Latin America, such as in Argentina, regulations to control nitrate content of agricultural products have already been enacted. So in the near future, regulations regarding nitrogen balance will also be implemented in Ecuador. There are some previous studies such as the study of nitrogen balance targeting specific areas of Ecuador (Bahr *et al.* 2014, Bahr *et al.* 2015）and targeting some crops and agricultural production, excluding livestock production, nationwide (de Koning *et al.* 1997, Priess *et al.* 2001). However, there are no studies of nitrogen balance which considers all agricultural production, including livestock production. Moreover, it is significantly important to consider the environmental impact in terms of agricultural activities including livestock production because agriculture is a major industry in Ecuador.

In this study, the nitrogen balance per agricultural activity including livestock production was estimated in Ecuador in order to contribute to the understanding of the current situation from the regional to the nationwide level, as well as to contribute to policy making with regard to controlling nitrogen balance. Furthermore, the results were shown using GIS to visualize the differences of nitrogen inputs, outputs and balance according to region.

4.2 Methods

The nitrogen balance was calculated based on the soil surface balance of farmland (van Beek *et al.* 2003). “Mineral fertilizer”, “livestock manure by drylot feeding”, “atmospheric deposition” and “biological nitrogen fixation” were considered as nitrogen inputs. “Crop products”, “livestock products by grazing” and “gaseous losses” were considered as nitrogen outputs (Figure 4.1). The nitrogen balance was analyzed by summing up inputs and outputs. Erosion was not included to this study due to unavailability of slope angle and soil type data.

The amount of fertilizer application in 2015 in Ecuador by FAO (FAO 2018) was divided equally according to the agricultural area of each municipality consisting of permanent and temporary crops and cultivated grass land (Table 4.1). The data of agricultural area was taken from the census conducted by the Ecuadorian Ministry of Agriculture and Livestock (MAG) in 2000 (MAG 2018, hereafter, census 2000). The amount of fertilizer application in Ecuador has been gradually increasing up to 177,976 tons in 2015 (Figure 4.2). The amount of nitrogen input from livestock manure was estimated by a coefficient of nitrogen in livestock manure by the IPCC (2006) using statistical data of each livestock head by municipality from the census 2000 (MAG 2018). The livestock included in this study are shown in table 4.1. The nitrogen amounts from atmospheric deposition and biological nitrogen fixation by leguminous crops and grasses were estimated using the method of de Koning *et al.* (1997).

The amount of nitrogen output from crop production was calculated by the amount shipped of each crop multiplied by the protein content indicated in the standard food composition table in Japan and U.S.A. (METX 2015, USDA 2018) and divided by 6.25 (Tsuiki *et al.* 1990). The crops included in this study are shown in table 4.1. The amount of nitrogen output from livestock production was estimated using the method of Tsuiki *et al.* (1990) for cattle and sheep meat production. The amount of nitrogen output from other meat products and dairy products was estimated by the same method as crop production. In the case of grazing, the nitrogen output from livestock products was evaluated. On the other hand, in the case of livestock production by drylot feeding, the nitrogen input from livestock manure and the nitrogen output from feed production was evaluated. This was based on that domestically produced feed was used for livestock production by drylot feeding due to low amounts of forage imports according to FAO statistical data (FAO 2018). The amount of nitrogen from gaseous losses was estimated by using the method of FAO (2004).

Finally, inputs and outputs of nitrogen amount were summed to analyze nitrogen balance. In the case of census data by the Ecuadorian government (MAG 2018), the latest completed version was in 2000. Therefore the trend in recent years, from 2000, was confirmed by FAO statistical data such as agricultural area, crop production and number of livestock as the trend has not changed much since 2000.

Furthermore, each result of nitrogen inputs and outputs and nitrogen balance was analyzed using GIS due to focusing on the differences between regions. Details of the results were shown on the Ecuadorian map by municipality in order to analyze the characteristics among the “Coastal”, “Andean” and “Amazon” regions (Figure 4.3). The precipitation amount utilized to calculate “atmospheric deposition”, “biological nitrogen fixation” and “gaseous losses” came from an Ecuadorian governmental organization called INAMHI (National institute of Meteorology and Hydrology 2018, Figure 4.4). Finally, the correlation was used by SPSS to analyze which factor contribute to nitrogen balance most.

Table 4.1 Data for nitrogen balance calculation (MAG 2018)

Agricultural area
Permanent crops
Temporary crops
Cultivated grassland*
Natural Grassland
Paramos (natural alpine grasslands)
Crops
[Permanent crops]
Abaca, Achiote, Araza, Plantain, Borojo, Cocoa, Coffee, Chonta, Lemon, Mango, Passion fruit, Orange, Naranjilla, Straw stems, African palm, Palmito, Black pepper, Pineapple, Banana, Tamarillo, Tomato tree, Avocado, Babaco, Custard apple, Prune, Peach, Granadilla, Guava, Mandarin, Apple, Blackberry, Pear, Papaya, Sapote, Sugar cane, Prickly pear, Soursop, Star apple, Rubber, Coconut, Tagua, Grapefruit, Plum, Asparagus, Cashew, Grape, Cabuya, Lima, Tea, Cardamom, Macadamia, Pitahaya.
[Temporary crops]
Garlic, Sesame, Artichoke, Cotton, Anise, Rice, Dry and fresh vetch*, Oats, Badea, Broccoli, Sweet potato, Barley, White and red onion, Rye, Chocho*, Cilantro, Cabbage, Cauliflower, Dry and fresh kidney beans*, Garbanzo*, Dry and fresh broad beans*, Higuerilla, Lettuce, Lentil*, Flaxseed, Hard dry and Soft corn, Malanga, Peanut, Ullucus, Melon, Turnip, Oca, Potato, Chinese Potato, Gherkin, Pepper, Quinoa, Radish, Beet, Watermelon, Soy, Tobacco, Tomato, Wheat, Green beans*, Yucca, Zambo, Yellow Carrot, Pumpkin.
Livestock
Cattle (milk and meat), Drylot feeding and Grazing.
Pigs, Drylot feeding.
Sheep (wool and meat), Grazing.
Poultry (eggs, chicken, turkey, etc.), Drylot feeding and Grazing.
Rabbits, Grazing.
Guinea pigs, Grazing.

[1] The crops marked * were included to calculate Biological nitrogen fixation.

[2] Livestock raised by small scale farmers was classified as grazing.

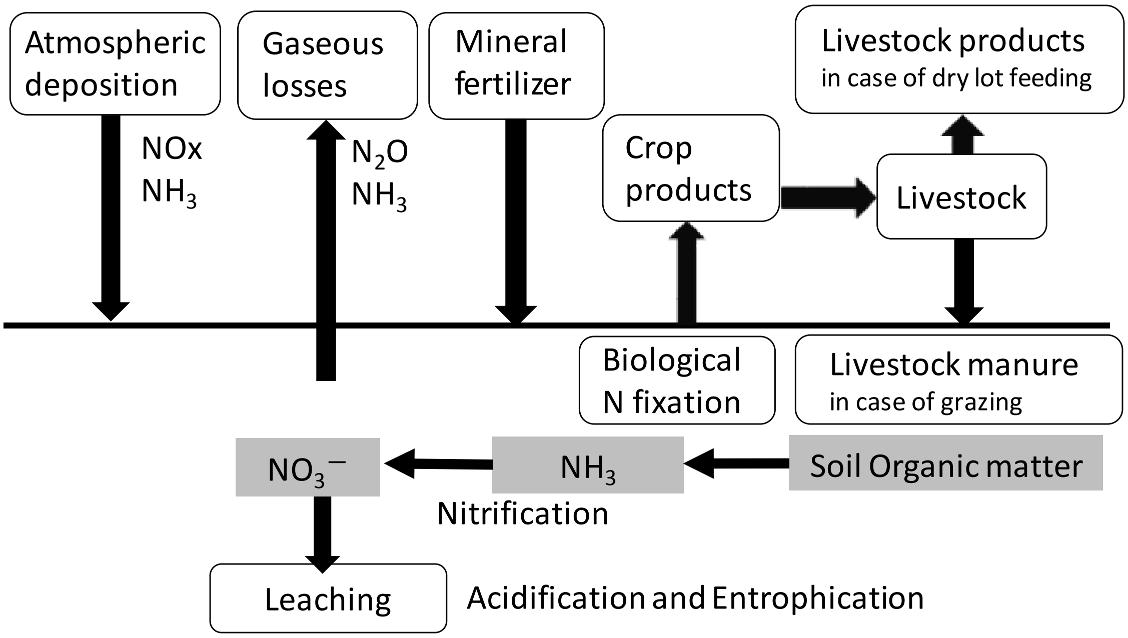


Figure 4.1 Nitrogen flow and the estimated scope in this study

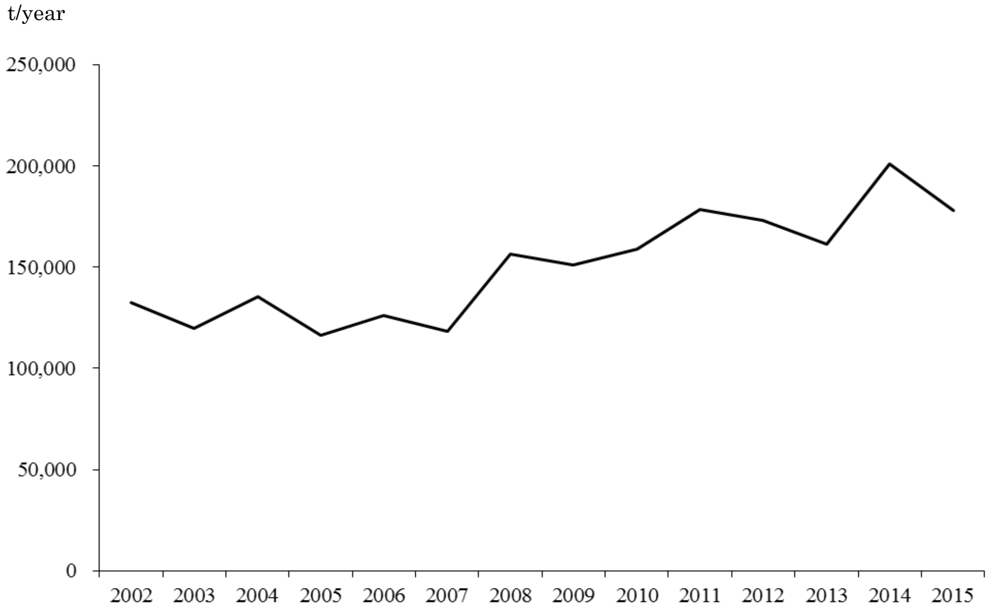
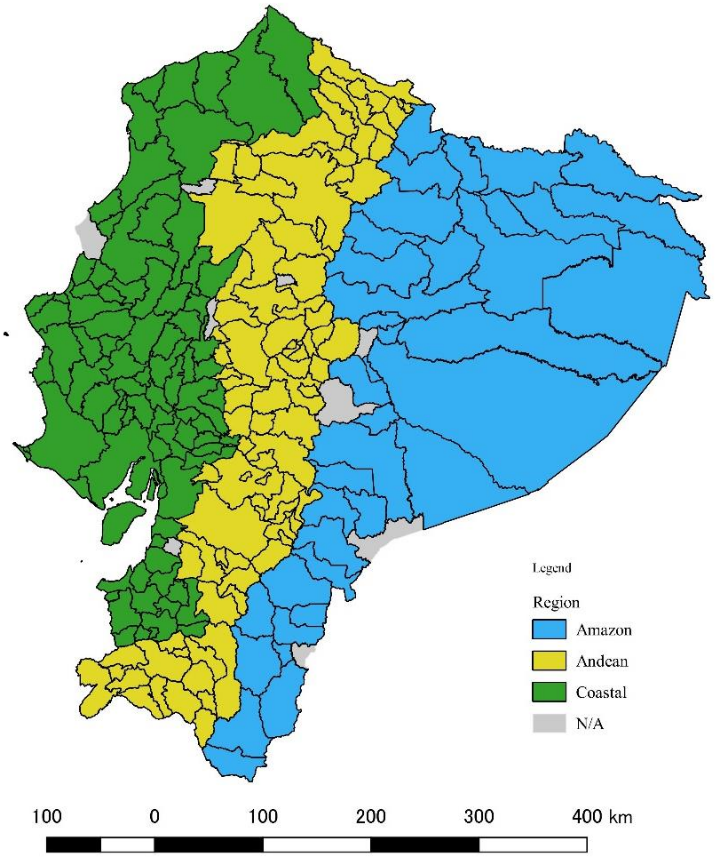


Figure 4.2 Amount of N fertilizer application in Ecuador (FAO, 2018)



[1] Galapagos Islands were not included in this study.

Figure 4.3. Regions and municipalities in Ecuador

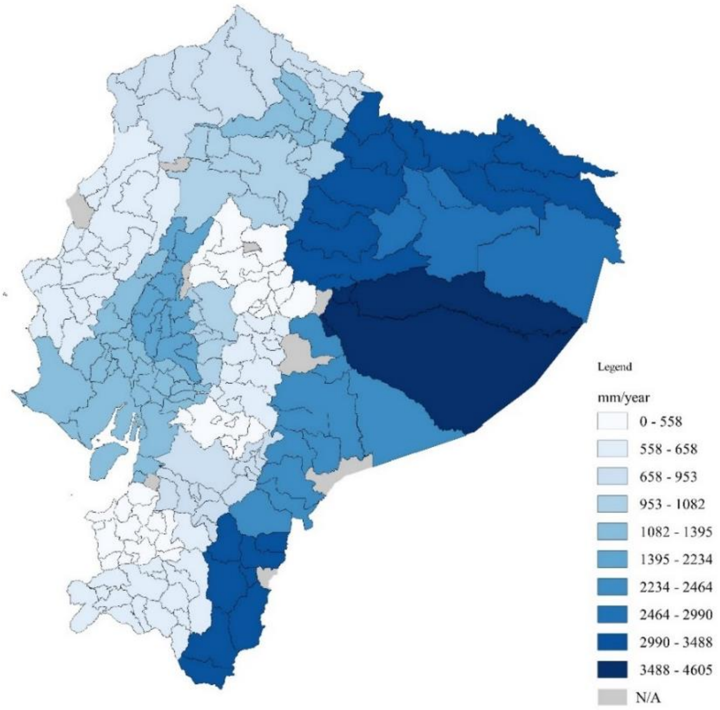


Figure 4.4 Precipitation in Ecuador

4.3 Results and Discussion

The results of nitrogen balance, that is nitrogen inputs minus outputs, was estimated at 33.8 kgN/ha/year positive in Ecuador as a whole. In detail, average inputs for each municipality were 23.5, 20.6, 4.9, and 0.1 kgN/ha from mineral fertilizer, livestock manure, atmospheric deposition and biological nitrogen fixation, respectively. In the case of outputs, 7.2, 1.9 and 5.7 kgN/ha from crop production, livestock production and gaseous losses, respectively. Notably, the amount of mineral fertilizer greatly contributed to excess nitrogen balance because the proportion of mineral fertilizer in nitrogen inputs was higher except Andean region (Figure 4.5.) and the amount of fertilizer application has increased year by year as shown in figure 4.2. Comparing between regions, the nitrogen balance was excessive, especially in the north coastal region where the agricultural area is greater and the Andean region where livestock production is active. On the other hand, the nitrogen balance was negative in the central and south coastal regions where there is intensive crop production with higher productivity from irrigation systems (Figure 4.6.).

In the case of nitrogen inputs from mineral fertilizer, the results showed higher nitrogen amounts in the north coastal region (Figure 4.7.). The amount of fertilizer application was assumed to be applied equally according to the agricultural area of each municipality. So a municipality with a large area of natural grassland and the Paramos (natural alpine grassland) showed lower values. The nitrogen amount from livestock manure was higher in the Andean region where livestock density was high (Figure 4.8.). Nitrogen input from atmospheric deposition was proportional to the amount of precipitation (Figure 4.9.). This is because the amount of atmospheric deposition is obtained by multiplying the precipitation amount by the nitrogen content (de Koning *et al.* 1997). The amount of biological nitrogen fixation is relatively small. The highest amount was only 0.3 kgN/ha/year (Figure 4.10.). These results were shown to be higher in Andean region where leguminous crop cultivation is active and greater cultivated pasture exists.

The amount of nitrogen output from crop production was higher in the south coastal region where intensive crop production using irrigation systems exist (Figure 4.11.). In the case of livestock production, the results showed that it was higher in the Andean and north coastal regions where active livestock production is thriving (Figure 4.12.). In the case of gaseous losses, the nitrogen outputs were higher in the coastal and Andean regions where the amount of precipitation is lower, although the nitrogen inputs were higher. As for atmospheric deposition, the Amazon region was not higher (Figure 4.13.).

Compared to a previous study which used the NUTMON model (Smaling and Fresco 1993) to estimate the nitrogen balance of crop production in Ecuador, the results showed -9.9 kgN/ha/year in the Coastal region, -20.1 kgN/ha/year in the Andean region and -0.3 kgN/ha/year in the Amazon region (de Koning *et al.* 1997). The reason for the negative value is that approximately one quarter of the mineral fertilizer was used when compared to this study and erosion was included as a nitrogen output in the estimation. Notably, the study indicated that erosion in Andean region was remarkable and has the highest amount of nitrogen outputs (de Koning *et al.* 1997). Therefore, the nitrogen amount might be lower in the Andean region due to erosion. Future studies may need to be conducted to estimate the nitrogen balance considering erosion as a factor.

Moreover, policies and guidelines controlling the amount of fertilizer application are required. For example, in Japan the prefectural policies and guidelines for appropriate fertilizer application have greatly contributed to avoid the excess use of nitrogen. In the case of livestock manure management in Japan, laws have been enacted to manage livestock manure to control nitrate leaching in underground water. Livestock manure was also an important factor of nitrogen inputs in Ecuador. The correlation analysis using non-parametric (Spearman) tests suggested a strong positive relationship ($r= 0.749$, $p<0.001$, $n=214$) between nitrogen balance and nitrogen from livestock manure (see appendix). It is likely that the nitrogen from livestock manure is not yet a big problem because grazing is the major animal production system in Ecuador. Many developing countries tend to face problems with livestock manure due to the increasing density of livestock resulting from economic growth. It will become increasingly important to promote the utilization of livestock manure as compost in crop production areas in Ecuador.

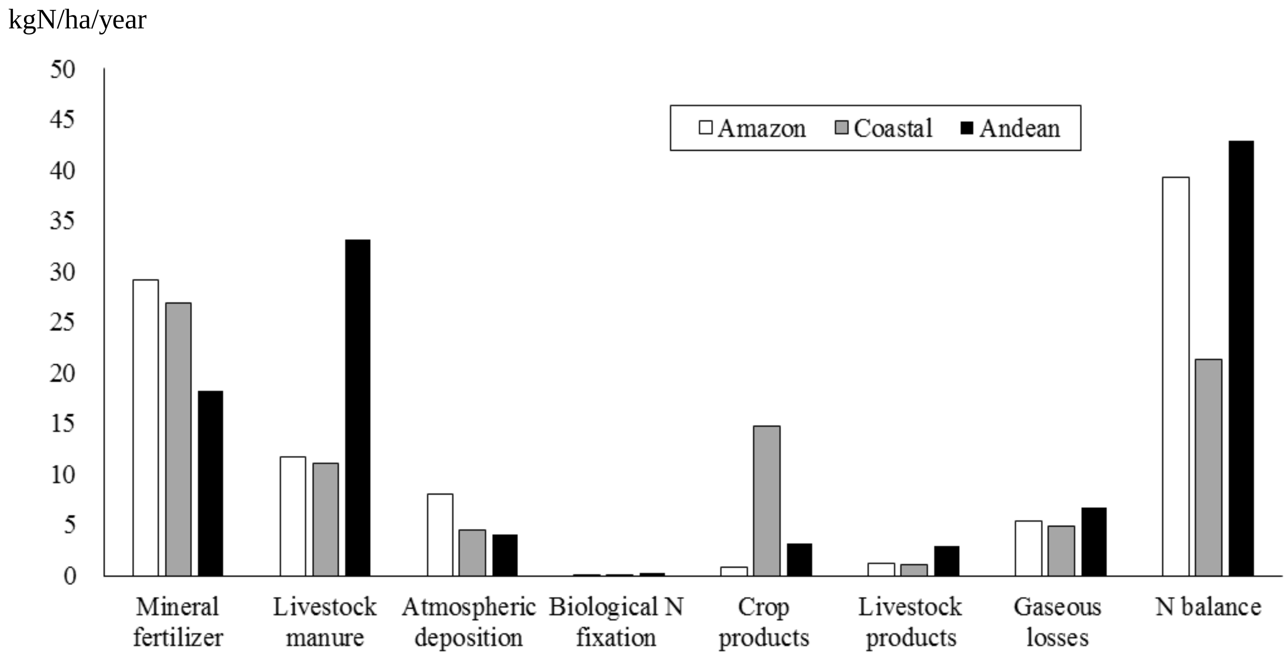


Figure 4.5 Detail of nitrogen inputs, outputs and balance by region

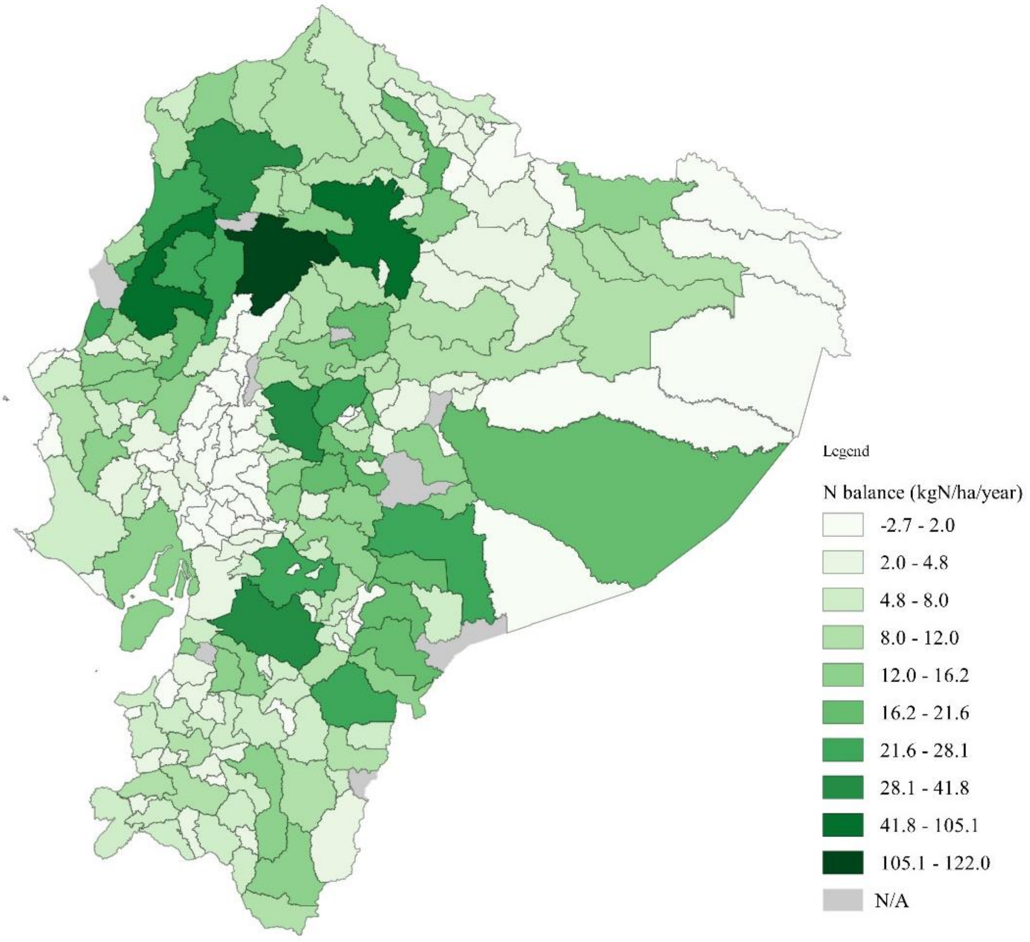


Figure 4.6 Total nitrogen balance in Ecuador

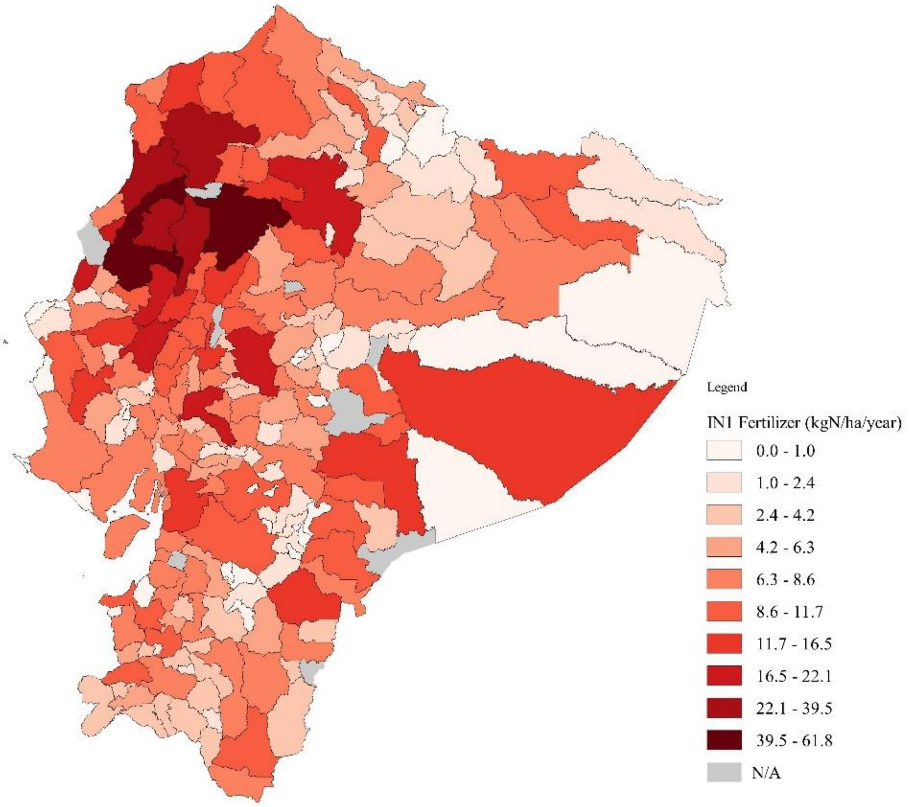


Figure 4.7 Nitrogen input from mineral fertilizer

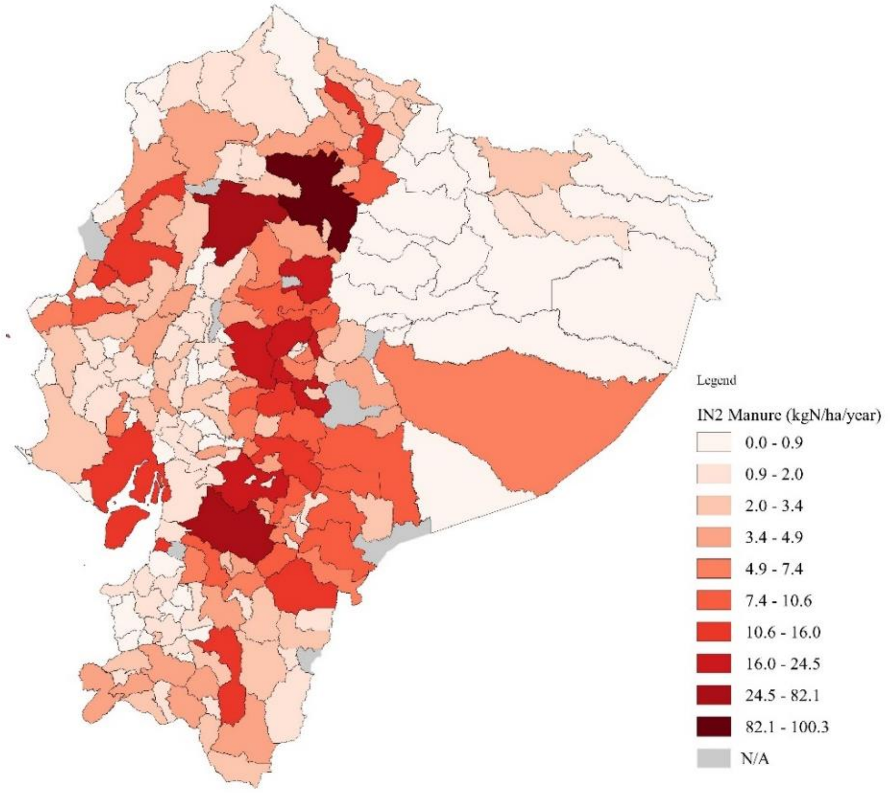


Figure 4.8 Nitrogen input from livestock manure

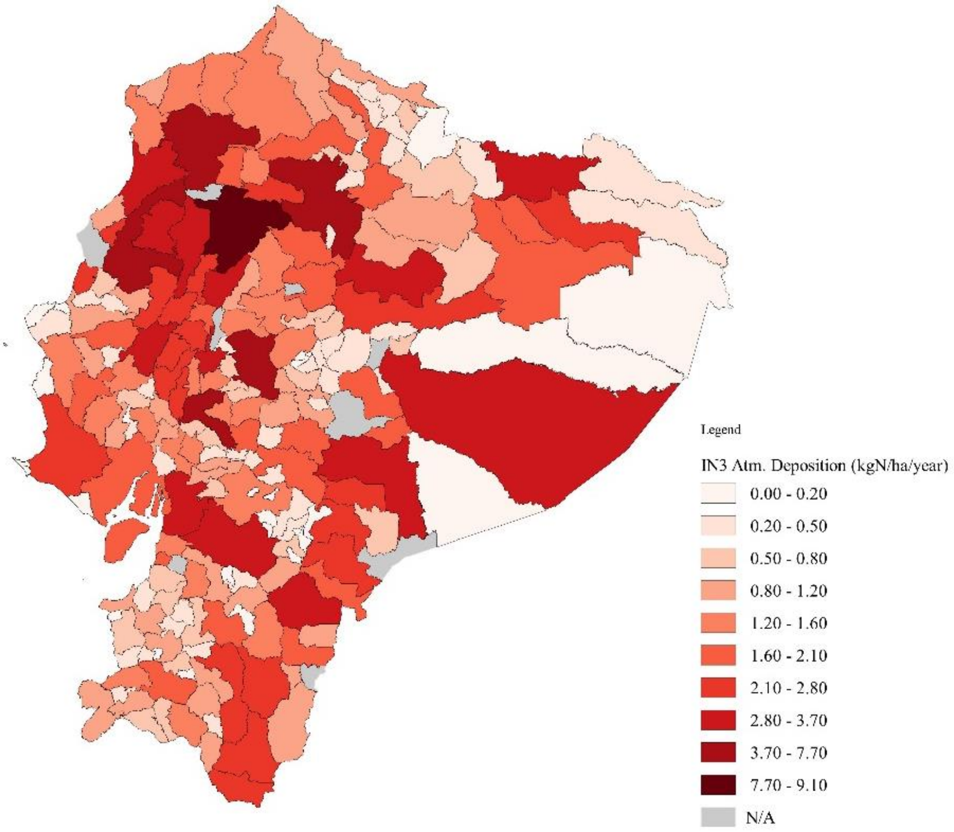


Figure 4.9 Nitrogen input from atmospheric deposition

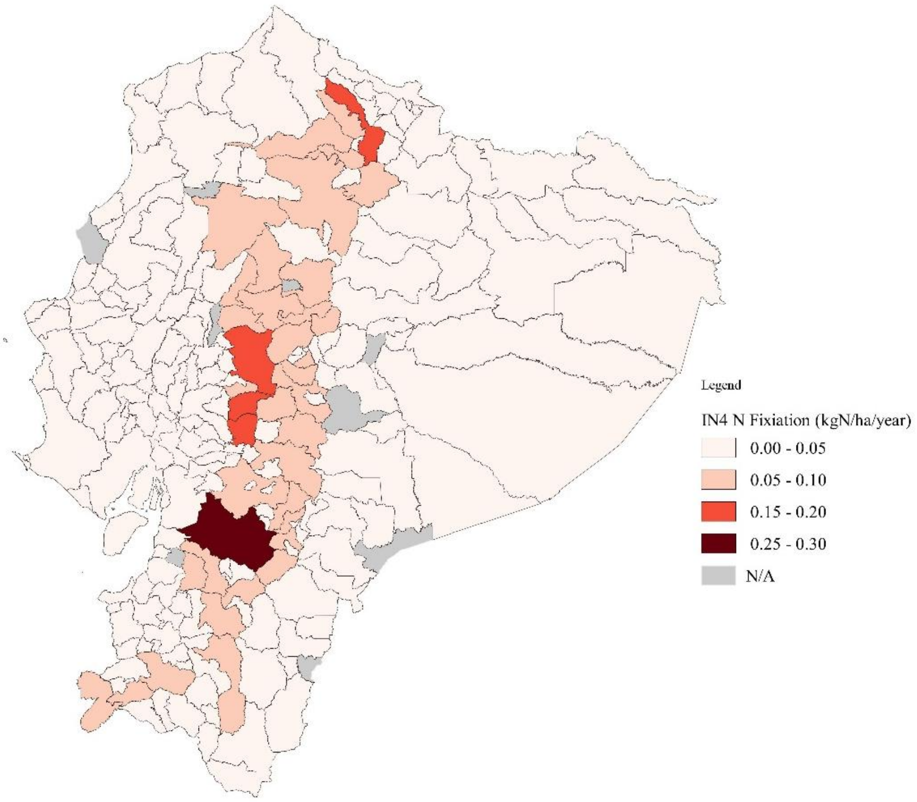


Figure 4.10 Nitrogen input from biological nitrogen fixation

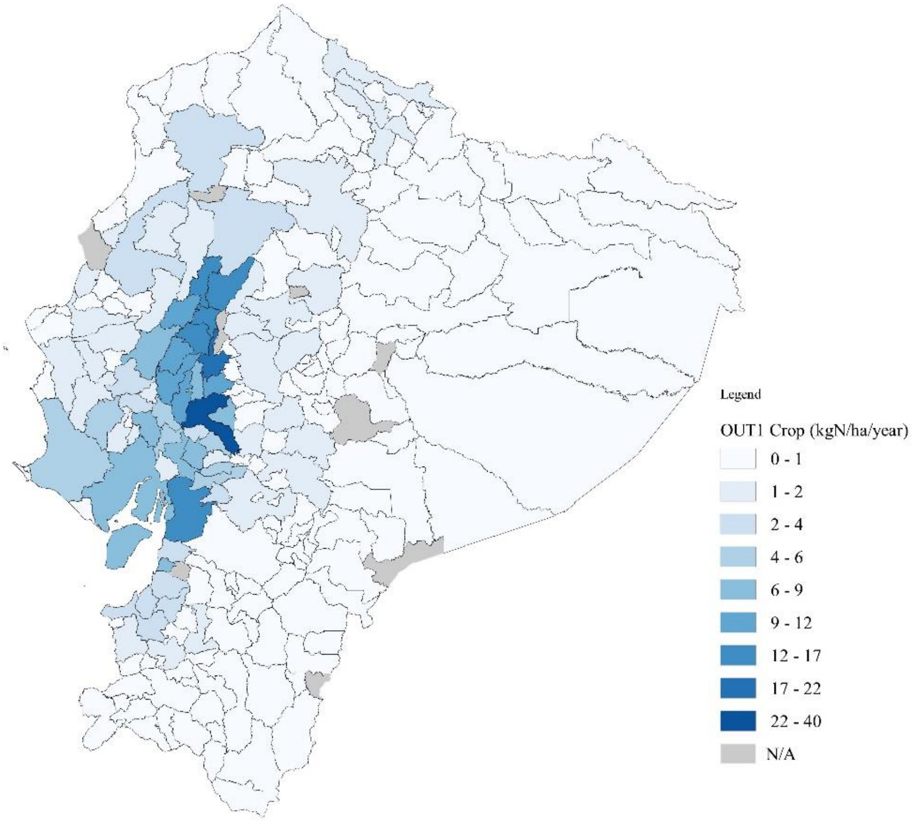


Figure 4.11 Nitrogen output from crop products

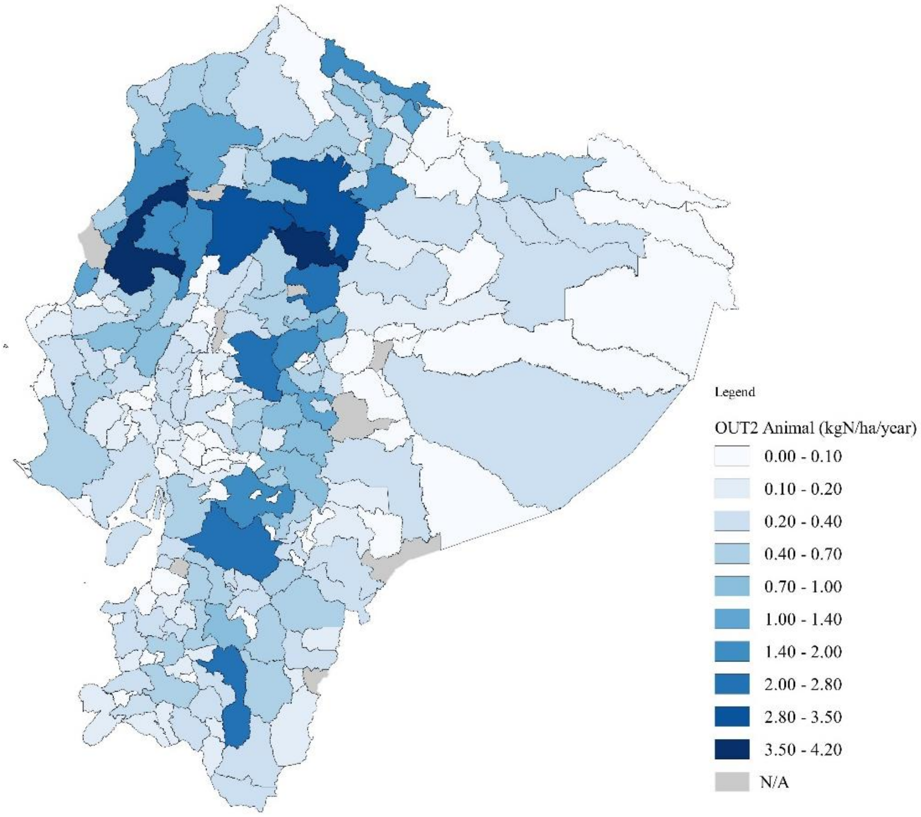


Figure 4.12 Nitrogen output from livestock products

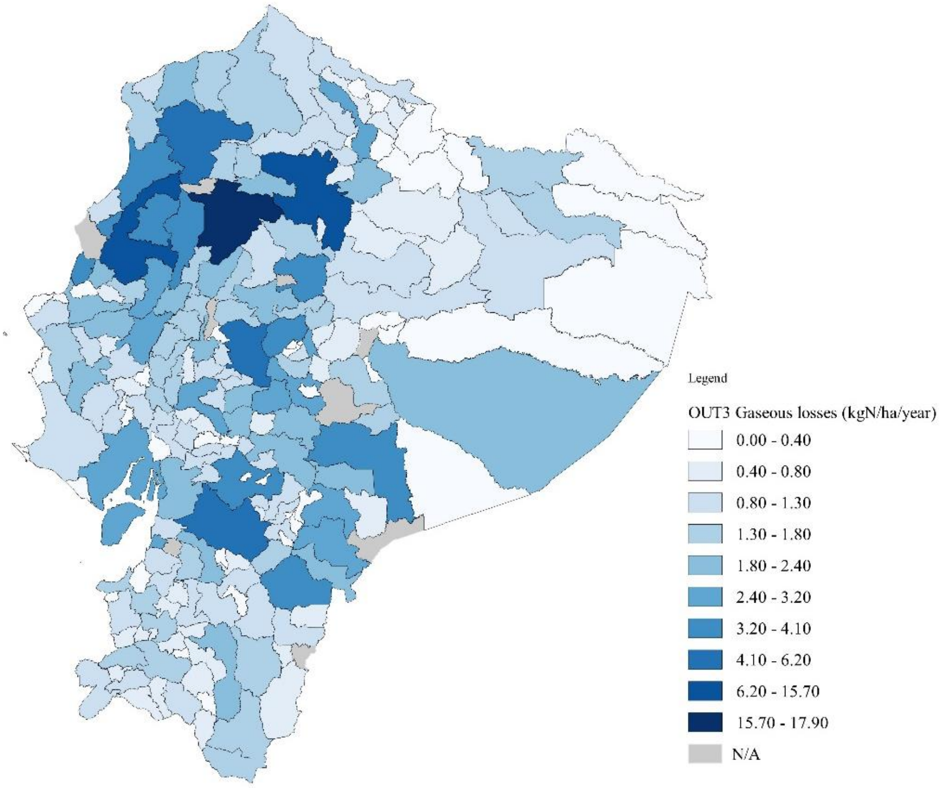


Figure 4.13 Nitrogen output from gaseous losses

4.4 Conclusions

The nitrogen balance of farmland in Ecuador as a whole was estimated to be excessive. Notably, mineral fertilizer application greatly contributes to excessive nitrogen balance. The nitrogen balance was excessive in the north coastal region and Andean region, and negative in the central region and south coastal region. In the Andean region the nitrogen balance may be lower than the current results when considering the influence of soil erosion. It would be a future challenge to include erosion in this study to determine the precise results for nitrogen balance. Moreover, policy making and guidelines to promote appropriate fertilizer application and the establishment of a livestock manure utilization system to produce compost are required. This is because livestock manure is also an important nitrogen input factor in Ecuador and will become increasingly important in the future due to the growing density of livestock from economic growth.

4.5 Summary

The importance of considering environmental impacts resulting from agricultural activities, including livestock production, are well known. In particular, nitrogen balance is required to be monitored for sustainable production. However, many developing countries do not have studies of nitrogen balance because, until recent years, the problem of nitrogen balance mainly occurred in developed countries. This study targeted Ecuadorian agricultural activities including livestock production to reveal the nitrogen balance of the whole country as well as each region. The nitrogen balance was estimated based on the soil surface balance of farmland. The balance included nitrogen inputs such as “mineral fertilizer”, “livestock manure by dry lot feeding”, “atmospheric deposition” and “biological nitrogen fixation”; and included nitrogen outputs such as “crop products”, “livestock products by grazing” and “gaseous losses”. The nitrogen balance of all farmland in Ecuador was estimated to be positive 33.8 kgN/ha annually. Notably, mineral fertilizer application greatly contributes to a positive nitrogen balance. The nitrogen balance was positive in the north coastal and Andean regions and negative in the central and south coastal regions. In the Andean region, the nitrogen balance may be lower than current results when factoring the influence of soil erosion. Moreover, policy making and guidelines to promote appropriate fertilizer application and the establishment of a livestock manure utilization system to produce compost are required. This is because livestock manure is also an important nitrogen input factor in Ecuador and will become increasingly important in the future due to the growing density of livestock from economic growth.

Chapter 5 Overall discussion

This study focused on the whole agricultural production system including animal production which greatly impacts the environment, in order to contribute to sustainable agricultural production by understanding the current situation. Chapter 1 focused on dairy production including feed production in some prefectures of Japan. Agricultural production including animal production was evaluated using statistical data at the national level from Japan and Ecuador, in Chapters 3 and 4 respectively. The Life Cycle Assessment (LCA) method was utilized in Chapter 1 to obtain precise environmental impacts, such as the global warming load (GWL), acidification load (AL) and eutrophication load (EL). The nitrogen balance was analyzed from municipality to nationwide in Chapters 3 and 4. The significant findings and recommendations from each chapter follow.

FINDINGS

[1] The results showed that environmental impacts from dairy production were lower in types using organic fertilizer even though the impacts of organic fertilizer use were higher in the case of self-supplying feed production itself.

[2] Large scale production systems had a lower environmental impact.

[3] The AL by NH_3 contributed the most to the amount of economic damage. The economic damage as a whole was 16% of production profits according to LIME2 (Life cycle Impact assessment Method based on Endpoint modeling 2).

[4] Overall, compost application contributed the most to EL.

[5] Enteric fermentation and feed production were high in GWL, composting and materials were high in AL, and composting and self-supplying feed production were high in EL.

[6] The nitrogen balance of all farmland in Japan was estimated to be positive 132.9 kgN/ha annually, which is above the Organization for Economic Cooperation and Development (OECD) standard.

[7] Mineral fertilizer application and livestock manure greatly contribute to a positive nitrogen balance.

[8] The nitrogen balance of all farmland in Ecuador was estimated to be positive 33.8 kgN/ha, which is below the OECD standard.

[9] Mineral fertilizer application greatly contributes to a positive nitrogen balance, however in the Andean region livestock manure contributes the most.

[10] In the Andean region the nitrogen balance may be lower than current results indicate when factoring the influence of soil erosion.

RECOMMENDATIONS

[1] The utilization of livestock manure in self-supplying feed production, and an effective production system by efficient machinery use, will contribute to reduce environmental impacts in dairy production including feed production.

[2] The increase of self-supplying feed and grazing will contribute to nitrogen circulation on the farm for sustainable production. If it is difficult to increase self-supplying feed and grazing due to land limitation issues, the utilization of livestock manure as compost in areas with vast tracks of farmland will assist the nitrogen balance of the nation as a whole to prevent nitrogen accumulation in specific areas where many livestock are kept.

[3] Guidelines and policy making are required to promote appropriate fertilizer application and to establish a livestock manure utilization system as compost. Livestock manure was also an important factor of nitrogen inputs in Ecuador. It will become more important in the future due to the increasing density of livestock resulting from economic growth.

5.1 Points to consider

The important factors to consider to mitigate the environmental impacts from agricultural production will be fertilizer application and livestock manure management. On the other hand, enteric fermentation is difficult to control at the local level, even though the Greenhouse gas Inventory Office (GIO) reported the dominance of CH_4 emissions at 41% from paddy fields and 22% from enteric fermentation. In addition, this study showed that enteric fermentation had the highest rate of GWL.

In the case of mineral fertilizer, particularly nitrogen application, though it is very important to analyze details there was specific data limitations on the amount of application by region. Therefore, though the amount of fertilizer application among crops and regions are quite different, in this study the nitrogen application rate was estimated using fertilizer application data on the national level divided equally into regions according to agricultural land area. Looking at FAO statistics (Figure 5.1) of European countries, particularly the Netherlands where intensive farming is common, reveals that nitrogen fertilizer has been applied at much greater than 200kg/ha. Although Japan is also well known for intensive farming, the amount of nitrogen application is lower over the country as a whole because wet paddy rice is a major crop which does not require much nitrogen. However, as vegetable and tea production generally require more fertilizer, the amount may be higher in some specific crop production areas. The amount of fertilizer is gradually increasing in the Americas, such as in Ecuador, though in lower amounts compared to countries conducting intensive farming. As a consequence, the nitrogen fertilizer application rate in Japan and Ecuador were at almost the same level in 2016. Although there are limitations to estimating the actual situation because the statistical data is simply an average of each nation, Ecuador is also required to manage fertilizer application in the country as a whole because the fertilizer rate has already been at the same level as Japan. Many other developing countries are also tending to increase the amount of fertilizer application. This is sometimes because of agricultural policy and subsidies to assist agricultural inputs, such as mineral fertilizer (World Bank 2008). On the other hand, the amount of fertilizer application in many developed countries has been decreasing because of the management of fertilizer application rates by agricultural policies through acts and guidelines.

The management of livestock manure utilization and the application of organic fertilizer are also quite important when considering environmental impacts. This study found that livestock manure (composting) was the highest contributor to AL and EL in dairy production (Chapter 2), and contributed to the excessive nitrogen balance of agricultural activities as a whole in Japan and the Andean region of Ecuador (Chapter 3 and 4). To minimize the environmental impacts from livestock manure, it is very important to consider the circulation. Compost application in dairy production was estimated by the LCA method to be relatively lower in environmental impacts, even though it was highest in feed production itself (Chapter 2). It is essential to circulate on the same farm and region as shown in Figure 5.2, however if this is difficult due to land limitations, circulation between crop production and livestock production areas is also effective to achieve balance in the nation. In this aspect, the use of imported feed negatively affects the balanced circulation. Moreover, the transport of imported feed consumes much fossil fuel, which causes massive greenhouse gas (GHG) emissions. Oita *et al*. (2016) described that high income countries perform worst in terms of sustainable consumption and production, and Japan placed eighth in having the highest net per capita imports of reactive nitrogen in trade (UNDP 2017). Because circulation is very important, especially in developed countries with high levels of imported feed for intensive farming, developing countries with increasing livestock densities must also consider circulation. The amount of livestock manure per agricultural area is gradually increasing in Ecuador as well as Japan, although the Netherlands has a significantly higher rate compared to other countries (Figure 5.3). European countries tend to have high amounts of livestock manure due to intensive farming, and animal production has been part of the culture, however the rate of organic agriculture is also high (3 to 7%) according to Figure 5.4. The rate of organic farming in Ecuador and Japan is under 1% (Figure 5.4). It is very important to promote organic farming to achieve sustainable production by utilizing livestock manure as compost. Around the world organic agriculture is defined as sustainable agriculture and each standard is indicated in detail. To be certified as organic in Japan there is the standard called the Japanese Agricultural Standard (JAS) organic. JAS organic is defined as sustaining and promoting the function of natural circulation in agriculture by avoiding synthetic mineral fertilizer and agrochemicals and by assisting the productivity of agricultural land according to soil characteristics in order to minimize environmental impacts from agricultural activities (MAFF 2018b). On the other hand, JAS organic does not indicate the amount of inputs to be used, although it clarifies which materials can be used in terms of fertilizers, composts and biological pesticides, etc.. This study found that GWL, AL, and EL from organic fertilizer use were highest in self-supplying feed production itself, though on the whole it was lower in dairy production systems including feed production. Therefore, the amount of organic fertilizer application should also be considered in order to minimize environmental impacts. On the other hand, the environmental impacts of compost use are lower when considering carbon accumulation. An integrated study considering those aspects to estimate environmental impacts are also required in future studies.

The share of total GHG emissions in the agricultural sector of Latin America is relatively high compared to other countries. For example, more than 20% in Brazil, more than 15% in Ecuador, and approximately 13% in Mexico, though only approximately 2% in Japan (see appendix). The Sustainable Development Goals (SDGs) report described that 80% of crops will be impacted on more than 60% of cultivated areas due to climate change in Latin America. Therefore, the consideration of environmental impacts from agricultural activities in Latin America is significantly important. The OECD estimates nitrogen balance of OECD countries and described the balance in Japan as stable, between 150 to 200 kgN/ha (Figure 5.5). The nitrogen balance in European countries, such as the Netherlands, dropped from more than 300 kgN/ha to approximately the same as Japan. The nitrogen balance of some other European countries were even lower than Japan, although the balance was higher in 1990. This is because agricultural policies and specific acts to control nitrogen application have been enacted. Japan also requires action to control nitrogen balance. There is no data on Ecuador, however the trend in Mexico may be similar to Ecuador. The nitrogen balance remains stable at under 50 kgN/ha on average as a whole in Mexico and the United States of America. However, nitrogen unbalance among regions is possible because of intensive crop and animal production hotspots (Bohr 2013). Therefore, the monitoring of nitrogen balance hotspots is very important to observe the current situation in Ecuador too.

5.2 Countermeasures

To promote sustainable production by minimizing the environmental impacts from agricultural activities in order to contribute to SDGs, this study proposes the following countermeasures and recommendations:

- **Development of a circulation system between crop and animal production.**

  It is extremely important to consider circulation to maintain a stable nitrogen balance. The circulation of resources, especially nitrogen, between feed production and animal production, as well as crop production, will be essential. In other words, it is very important to limit external inputs such as mineral fertilizer and imported feed and utilize internal inputs such as compost from livestock manure and self-supplying feed cultivated with internal inputs.

- **Adopting efficient methods according to production scale.**

  Efficiency of production should be considered because environmental impacts per product always depend on the productivity of the industry. Considering the efficiency of machinery use will be an essential way to reduce GHGs. Minimizing labor will also minimize environmental impacts, such as adopting the free-stall method and grazing in dairy production. Considering efficient composting methods is also important to minimize GHG emissions.

- **Enacting legislation to directly control nitrogen management.**

  Direct regulations, such as the “Mineral accounting system” in the Netherlands to control nitrogen application, will minimize nitrogen contamination in Japan. The nitrate content of agricultural products should also be restricted because it is poisonous to both animals and the human body. This will raise the awareness of consumers regarding nitrate poisoning. These actions will reduce nitrogen contamination of underground water. In the case of Ecuador, nitrogen accumulation is not yet significant, however it is important to take countermeasures such as establishing guidelines to control nitrogen balance.

- **Promote consumer awareness by indicating the level of environmental impacts from production.**

  It is essential for consumers to put pressure on the agricultural industry to promote environmentally friendly food production. To raise consumer awareness it is important to indicate the environmental impact level on each product. Results of the Environmental Impact Assessment (EIA) can be used to reveal, for example, the Carbon Foot Print (CFP) and the amount of GHG emissions through the production process per product estimated by the LCA method, and indicated on each product. According to this information, consumers select a product not only by price and quality, but also the environmental impact level. Certificates and standards to indicate how the product is made also incentivizes ethical consumption. However, this certification system sometimes excludes small scale producers. Therefore, a system that includes them will also be an important point to be considered. Under free trade, it is quite difficult to avoid the pressure of importing agricultural products. However, this kind of indication system will assist consumer awareness in terms of the negative environmental impacts of using of long distance imported agricultural products. This awareness will promote not only ethical consumption but also policy making which includes an environmental taxation system to minimize environmental impacts.

- **Promote the monitoring and investigation of nitrogen balance in developing countries too.**

  The monitoring of nitrogen balance, particularly from agricultural activities, is very important because excessive nitrogen will negatively and rapidly affect hotspots. However, many developing countries face a lack of data to estimate nitrogen balance due to budgetary limitations, etc. As the SDGs report mentioned, nitrogen balance is at the high-risk level, so it is essential to work on this topic worldwide, especially countries in rapid economic growth. The LCA method is able to give precise results, however investigations of nitrogen with only approximate inputs and outputs will be sufficient to monitor the situation. This is because most environmental impacts from agricultural activities are nitrate related activities, such as livestock manure, composting and fertilizer application. The results of monitoring will provide essential basic information to determine agricultural policies, especially subsidies for agricultural inputs which many developing countries have implemented. The reduction of GHGs is an urgent task in order to limit global warming to 1.5 degrees Celsius, with greenhouse gas emissions in 2050 required to be 40% to 70% lower than in 2010 (UNDP 2018). This number seems quite difficult to achieve unless all industries, including agriculture, try to seriously reduce GHG emissions. Developing countries should also work together to minimize environmental impacts because the rate of agricultural GHG emissions are relatively higher.

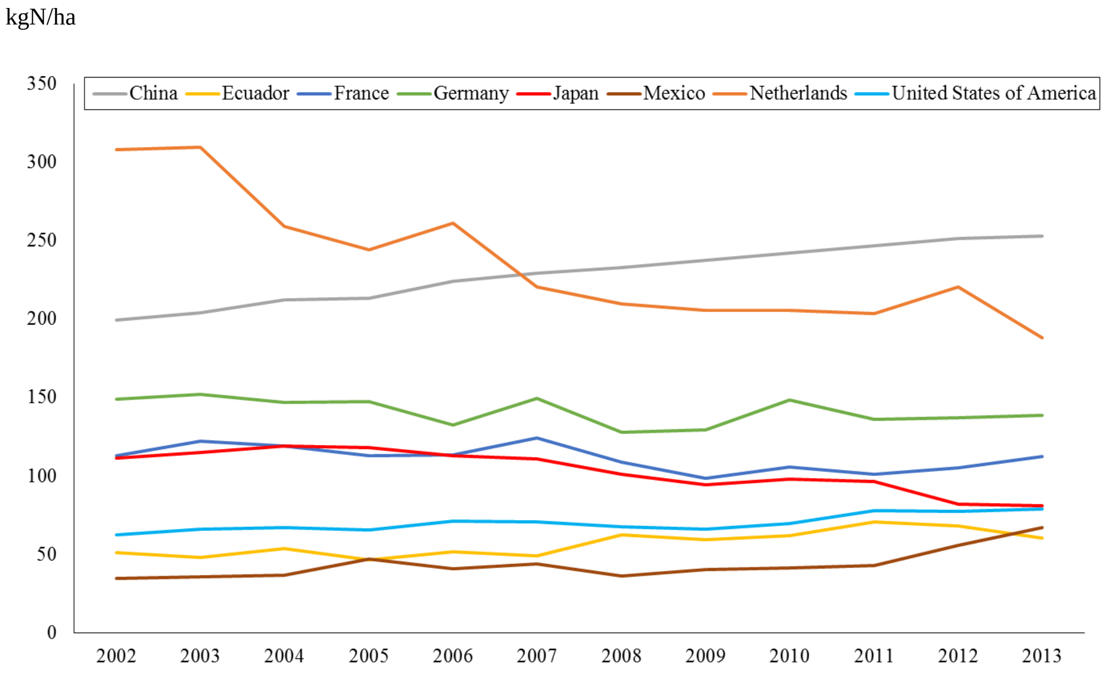


Figure 5.1 Amount of nutrient nitrogen fertilizer application (kgN/ha) (FAO 2018)

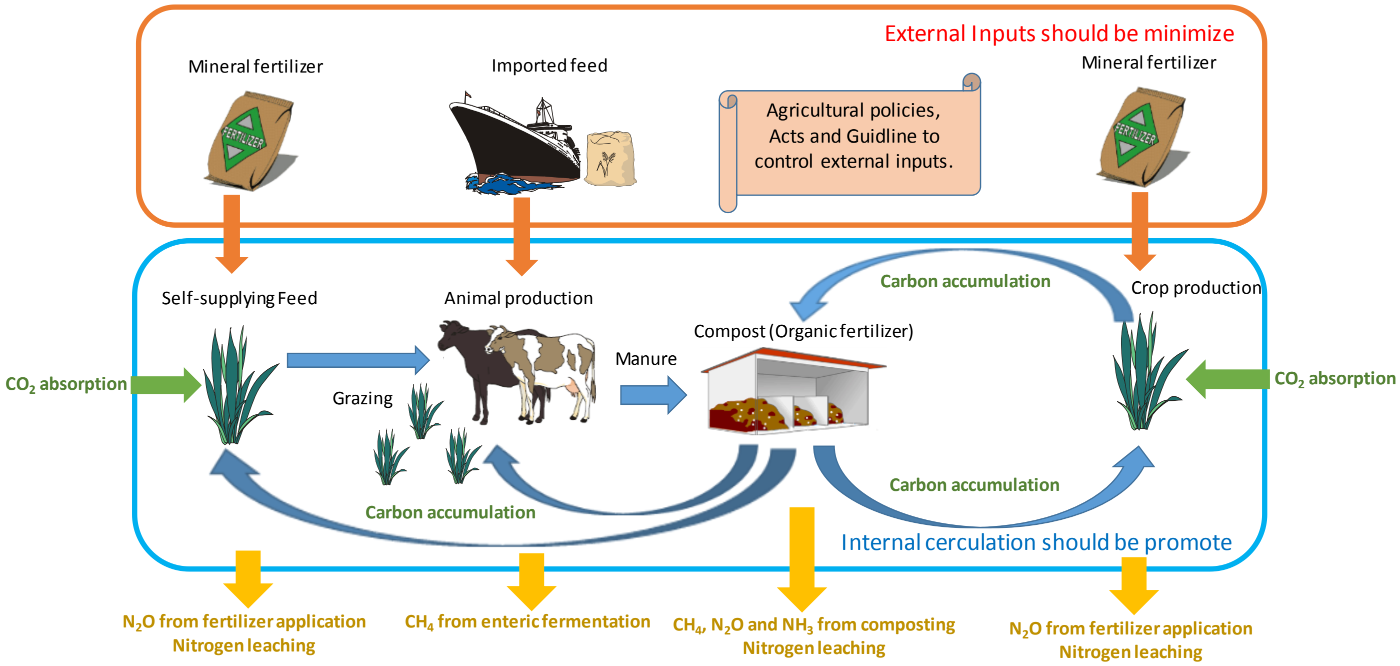


Figure 5.2 Recommended circulation of resources in addition to nitrogen

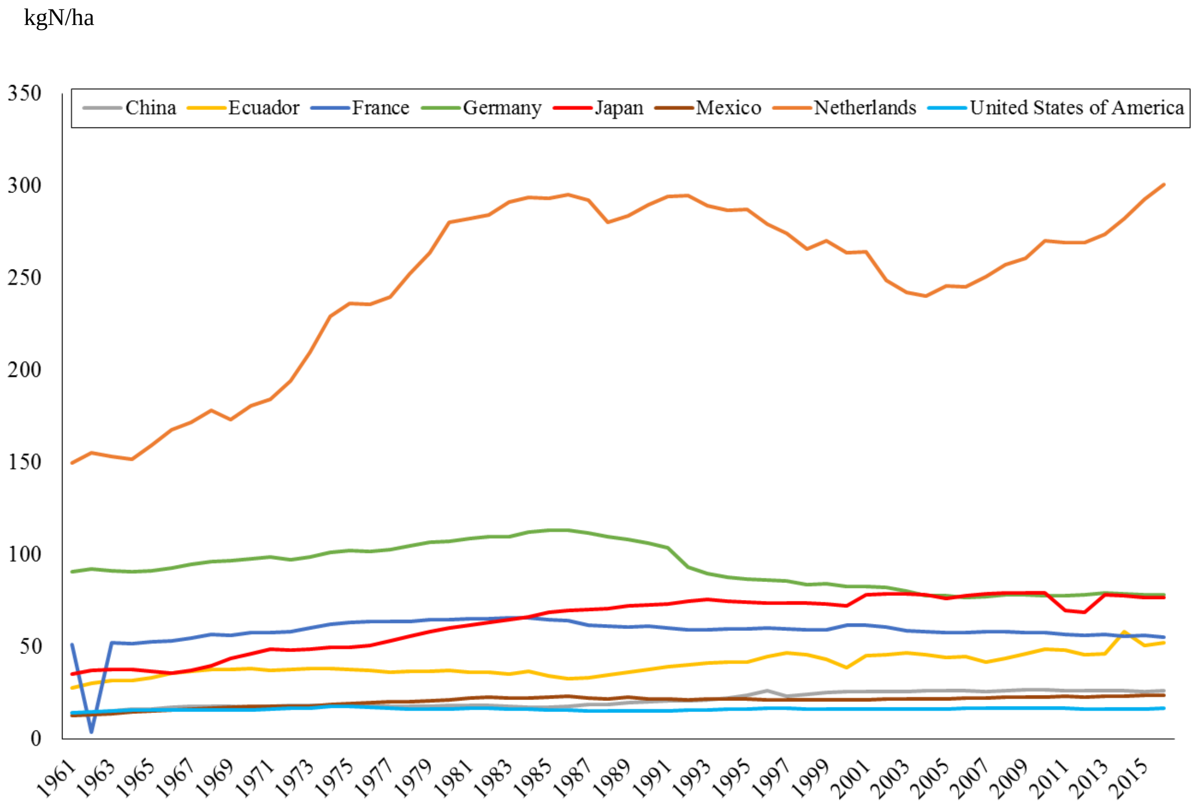


Figure 5.3 Amount excreted in manure (kgN/ha) (FAO 2018)

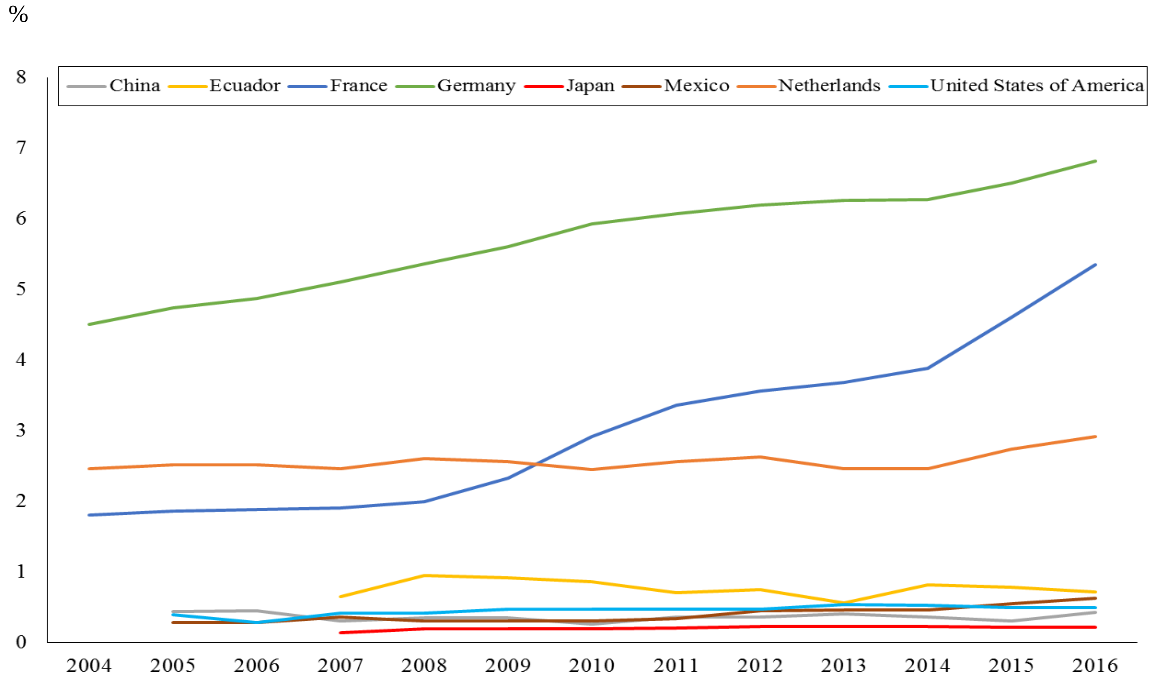


Figure 5.4 Rate of organic agriculture in agricultural sector (%) (FAO 2018)

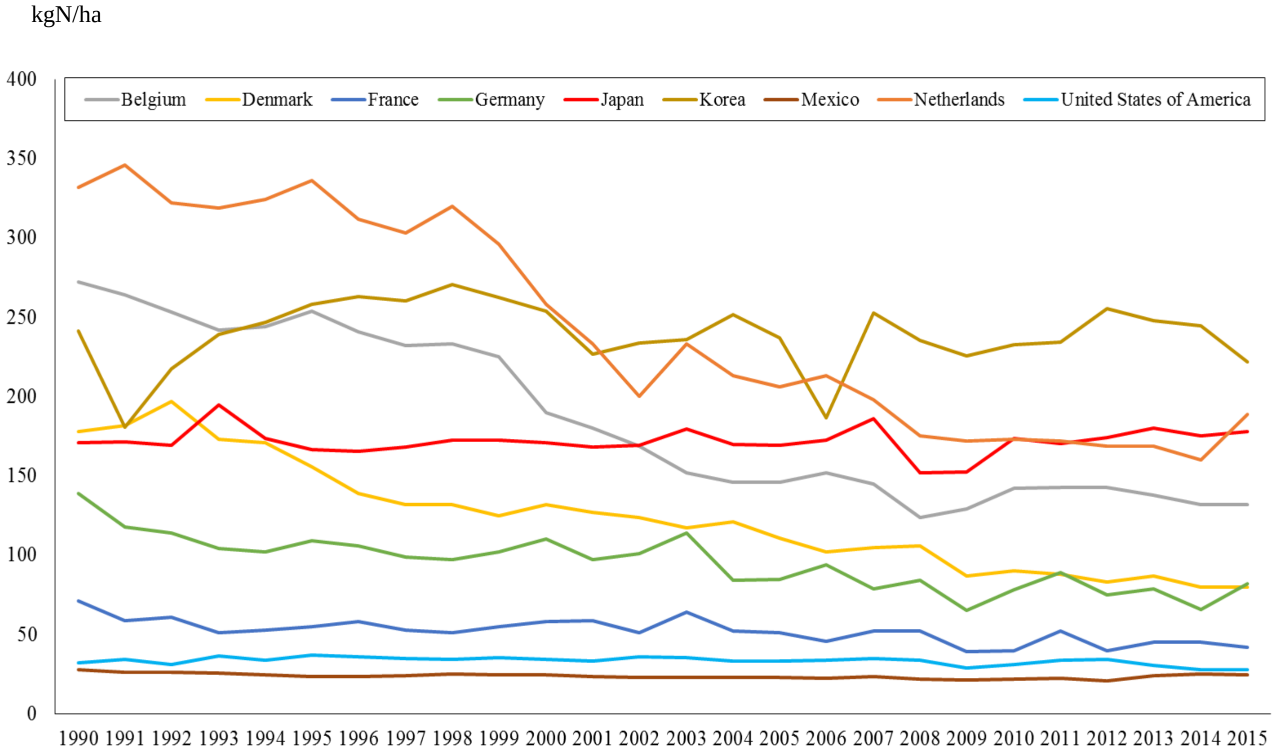


Figure 5.5 Changes to nitrogen balance in OECD countries (kgN/ha) (OECD 2015)

Chapter 6 Summary

Using local resources many traditional agricultural activities have been managed sustainably, in terms of food production as well as the environment, to sustain human life. However, both developed and developing countries have experienced environmental problems as a result of agricultural activities to solve the problem of food shortages due to the pressure of population increase (Kada 1998). The separation of animal and crop production to meet effective production systems leads to the massive waste of livestock manure. As a consequence, eutrophication by nitrogen accumulation has been a significant problem in the environment neighboring agricultural industries. Furthermore, in recent years greenhouse gas (GHG) emissions from agricultural activities are noted as an important global environmental problem (Shiyomi 1996). The CH_4 from enteric fermentation, livestock manure management, composting and paddy rice fields, and the N_2O from fertilizer application, livestock manure management and composting, are major GHG emissions in agriculture. On the other hand, a characteristic of agricultural activities in developing countries is to expand low-input agricultural land in order to increase food production. Moreover, some developing countries have been altering agricultural activities due to the availability of agricultural inputs as a result of economic growth. However, the environmental impacts from agricultural activities have been rarely investigated and monitored. These environmental problems create direct negative impacts to human life. The environmental degradation leads to low food productivity. The UNDP warned of this and put forward 17 Sustainable Development Goals (SDGs). In particular, goals 2 and 13 share the same objective as this study. Agriculture has changed dramatically from considering only productivity, to also considering environmental impacts. It is required to assess environmental impacts from agricultural activities in order to promote sustainable agricultural production (Hirooka *et al.* 2009). This study focused on the whole agricultural production system including animal production, which greatly impacts the environment, in order to contribute to adapting sustainable agricultural production in consideration of the current situation. There are many studies focusing on the individual farms or the crop and animal production system. This study would like to focus on the integrated evaluation of the agricultural environment of the farm, region and country. This study is based on cases in Japan and Ecuador located in Latin America.

The environmental impacts of dairy production including different types of self-supplying feed production systems were evaluated using the Life Cycle Assessment (LCA) method according to “Agricultural Production Technology Systems” (APTS) created by Hokkaido and Iwate Prefectures in

Japan. Four types of self-supplying feed production in Hokkaido and two types in Iwate were analyzed according to three types of fertilizer application, that is: chemical fertilizer, compost, and slurry application, respectively. These results were included into environmental impact assessments of dairy production scenarios, consisting of four types of production scales in Hokkaido and two types in Iwate. The global warming load (GWL), acidification load (AL) and eutrophication load (EL) were evaluated as environmental impacts. Furthermore, the Life cycle Impact assessment Method based on Endpoint modeling 2 (LIME2) was used for an integrated estimate to determine the total economic damage. The results showed that the environmental impact of dairy production was lower in the types using organic fertilizer, even though the impact was higher in the case of self-supplying feed production itself. Large scale production systems had a lower environmental impact. The results of integrated environmental impacts by LIME2 showed that the AL from NH_3 contributed the most to economic damage.

The nitrogen balance per agricultural activity, including livestock production, was estimated based on the soil surface balance of farmland in Japan. The balance was calculated from nitrogen inputs and outputs. Furthermore, the results were shown using the geographical information system (GIS) to visualize the differences of nitrogen inputs, outputs and balance according to municipality. The nitrogen balance of all farmland in Japan was estimated to be positive 132.9 kgN/ha annually. Notably, mineral fertilizer application and livestock manure greatly contribute to a positive nitrogen balance. The nitrogen balance was significantly positive in places with intensive livestock production, and less in places known for paddy rice cultivation. Therefore, the improvement and monitoring of livestock manure management will be essential in terms of considering nitrogen accumulation and contamination. The next study targeted Ecuadorian agricultural activities including livestock production in order to reveal the nitrogen balance of the whole country as well as each region. The nitrogen balance was estimated based on the soil surface balance of farmland. These results were also visualized using GIS. The nitrogen balance of all farmland in Ecuador was estimated to be positive 33.8 kgN/ha annually. Notably, mineral fertilizer application greatly contributes to a positive nitrogen balance. The nitrogen balance was positive in the north coastal and Andean regions and negative in the central and south coastal regions. In the Andean region, the nitrogen balance may be lower than current results indicate when factoring the influence of soil erosion.

As a consequence, the important factors to consider if mitigating the environmental impacts of agricultural production will be fertilizer application and livestock manure management. The rates of nitrogen fertilizer application in Japan and Ecuador were almost at the same level in 2016, according to

FAO statistics (FAO 2018). Like Japan, Ecuador is also required to manage fertilizer application. To minimize environmental impacts from livestock manure, it is important to consider resource circulation, in addition to nitrogen. It is essential to circulate on the same farm and region, however circulation between crop production and livestock production areas is also an effective way to achieve a balance in the country if it is difficult to circulate resources on the farm and region due to land limitations. In regards to this aspect, the use of imported feed negatively affects balanced circulation because the imported nitrogen is never taken out as livestock manure. Moreover, imported feed consumes large quantities of fossil fuel for transportation, which causes massive GHG emissions. European countries tend to produce high amounts of livestock manure due to intensive farming, and interestingly their rate of organic agriculture is also high. Although organic agriculture is not limited by the amount of fertilizer applied, the amount should also be considered in order to minimize environmental impacts. To promote sustainable production by minimizing environmental impacts from agricultural activities in order to contribute to SDGs, this study proposes countermeasures and recommendations: 1) The development of a circulation system between crop and animal production; 2) Adopting efficient methods according to production scale; 3) Enacting legislation to directly control nitrogen management; 4) Promote consumer awareness by indicating the level of environmental impacts from production; 5) Promote the monitoring and investigation of nitrogen balance in developing countries too.

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農畜産業による環境影響の統合的評価に関する研究

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要約

伝統的に農業は人間生活を支えるために地域資源を活用し、食糧生産や国土の保全が持続的に行われてきた。しかしながら人口増加の圧力により、食糧不足の問題を解決するために農業を推進する過程で、先進国、発展途上国ともに環境問題を経験している（嘉田　1998）。効率的な集約的農業を推進することで、畜産と作物生産が切り離され、大量の家畜糞尿が廃棄物となった。結果として、窒素の蓄積による富栄養化等が畜産が営まれる周辺環境で深刻な問題となった。さらに近年、農業による温室効果ガス排出が世界的な環境問題として注目されている（塩見　1996）。農業分野の温室効果ガスの排出としては、消化管内発酵、家畜糞尿処理、堆肥化によるメタン、施肥、家畜糞尿処理、堆肥化による一酸化二窒素の放出がある。一方で、発展途上国の農業の特徴は低投入で、農地を広げることにより食糧増産を目指す傾向がある。発展途上国は成長著しい国々もあり、農業資材の利用が推進されることにより現在の状況は一様ではない。しかしながら、発展途上国の農業活動による環境影響の調査やモニタリングの事例は少ない。環境劣化は食糧生産性を下げる等、人間生活に直接的に負の影響をもたらす。UNDPは、この状況を懸念し17の持続的開発目標（SDGs）を設定したが、特に目標2および13は、この研究の目的と合致している。農業は、生産性だけを考える時代から環境影響も考える時代へと変化してきており、持続的な農業生産を推進するために農業の環境影響を評価する必要がある（広岡ら　2009）。本研究は、現状を踏まえた持続的な農業生産の選択に貢献することを目指し、環境影響の大きい畜産を含む農業生産全体を対象とした。個別の農場、作物や動物の生産システムに着目した研究は多くあるが、本研究は研究事例の少ない一般化された生産体系、地域、国全体における農業環境の統合評価に着目し、日本と南米のエクアドルを対象としている。

北海道と岩手の生産技術体系に基づき、様々な自給飼料生産システムを含む酪農の環境影響をライフサイクルアセスメント手法（LCA手法）により評価した。北海道は4種類、岩手は2種類の自給飼料生産について、化成肥料型、堆肥併用型、そしてスラリー併用型の3種類の施肥型を分析した。この結果を酪農全体の環境影響の評価に加味し、飼料生産を含む酪農全体として北海道は4種類、岩手は2種類の生産規模について環境影響を評価した。環境影響項目は、地球温暖化負荷（GWL）、酸性化負荷（AL）、富栄養化負荷（EL）とした。さらに、日本版被害算定型影響評価手法であるLIME2を用いた環境影響の統合化により、各施肥型や生産規模別の経済的な被害額を推定した。全体的に、自給飼料生産のみでは堆肥やスラリー併用型の有機質肥料を使用した施肥型において環境影響は高くなったが、酪農全体としては環境影響が低くなった。生産規模は

大きいほど環境影響が低い結果となった。LIME2 による環境影響の統合化では、AL のアンモニアの被害額が最も高かった。

日本における畜産を含む農業による窒素バランスをサーフェイスバランスの考え方に基づき推定した。窒素の投入と収奪から全体としての窒素バランスを算出した。さらに、GIS を用いて窒素投入、収奪、バランスの結果を市町村ごとに表示し、視覚的に分析した。日本の農地全体の窒素バランスの平均は、132.9 kgN/ha プラスとなった。特に、化成肥料の施肥と家畜糞尿は、窒素バランスがプラスとなる重要な貢献要因であった。地域差を見ると、畜産が盛んな地域で特に窒素量がプラスとなっており、稲作が盛んな地域で窒素量は少なかった。そのため、窒素の蓄積やそれによる汚染を考えた場合、家畜糞尿管理を改善しモニタリングすることが効果的であるといえる。次に、エクアドルを対象として、市町村レベルから国全体の畜産を含む農業全体の窒素バランスをサーフェイスバランスの考え方に基づき推定した。この結果も GIS を用いて視覚化した。エクアドルの農地全体の窒素バランスの平均は、33.8 kgN/ha プラスとなった。特に、化成肥料の施肥は、窒素バランスがプラスとなる貢献要因であった。地域差を見ると、北部海岸地域とアンデス地域で顕著に窒素量がプラスとなり、中部から南部にかけての海岸地域で窒素量が少なく、マイナスとなるところもあった。しかしながら、アンデス地域は土壌流亡が著しいとの報告もあり、実際の窒素量は本研究により推定された窒素量より少ない可能性がある。

本研究結果から、農業による環境影響を軽減するためには、施肥と家畜糞尿管理を改善することが重要であることが分かった。FAO の統計によると、2016 年までにエクアドルの窒素の施肥量は日本と同程度になっている。そのため、日本と同様、エクアドルも国として施肥管理を推進する必要がある。家畜糞尿による環境影響を抑えるためには、資源や窒素の循環を考慮することが重要である。同じ農場や地域で循環をすることが理想的であるが、土地に関する制約があり難しい場合は、畜産が盛んな地域と作物栽培が盛んな地域で循環させることも国全体の均衡を保つという意味で効果的である。この視点から、輸入飼料に頼った畜産は、家畜糞尿が窒素として国外に持ち出されることはなく蓄積していくため、バランスのとれた循環が成り立たない状況を生み出すことが分かる。さらに輸入飼料の利用は、輸送のために大量の化石燃料を消費し、大量の温室効果ガスを排出する原因となる。ヨーロッパ諸国は、集約的な畜産が盛んであるため大量の家畜糞尿が生み出されるが、家畜糞尿を還元できる有機農業も盛んである。環境影響を軽減するためには有機質肥料であっても施肥量を管理していくことが重要である。農業による環境影響を最小限にし、持続的な生産を推進するために、1) 畜産と作物生産の間で窒素循環システムを確立する、2) 生産規模に応じた効率的な生産方法の選択、3) 窒素利用を直接的に管理する法整備、4) 生産における環境影響のレベルを表示することによる消費者の理解促進、5) 発展途上国においても窒素バランスを調査・モニタリングする、ことを本研究の結果に基づいた対策として提言する。