Journal of Global Environment Engineering, Vol. 3, pp. 77–97, 1997

STUDY ON ENVIRONMENTAL LOADS OF FOODSTUFF PRODUCTION AND THEIR TRADE IMPLICATIONS FOR JAPAN

Hidefumi Imura[1]
Takashi Mizuno[2]
Tohru Matsumoto[3]

Abstract

This study presents an estimate of the trade balance of environmental load accompanying commercial production and trade of grains and meat. The US, Canada, Australia, France, and Argentina are taken up as major exporters, and Africa, the EU and Japan as importers. Estimates are made of agricultural land area and the amounts of fresh water and fertilizer used for the production of beef, wheat, rice, barley, maize and soybeans. Japan's consumption of food requires 19.5 million ha of pasture land and 7.5 million ha of crop land in other nations, a land area equivalent to about 70% of the total land area of Japan. Moreover, 45 billion tons of fresh water and 994 thousand tons of nitrogen fertilizer are annually used in the US, Canada, Australia, France, and Argentina for export agricultural production to Africa, the EU and Japan. The energy efficiency, *i.e.*, the ratio of the caloric value of the product grains to the energy input for their production, is estimated for soybeans, wheat, rice and maize in Japan and the US. The efficiency in Japan is lower than that in the US, reflecting Japan's high-density agricultural practices. For Japanese rice, the ratio is as low as about 1.3. Furthermore, the international flow of the nitrogen nutrients associated with trade in agricultural products and fertilizer is estimated. Japan imported 600 thousand tons of nitrogen contained in foodstuffs in 1994, and exported 180 thousand tons contained in fertilizers the same year.

KEYWORDS: *trade and environment, agriculture and environment, international flow of the nutrients, fertilizer and environment, energy use in agriculture*

1. Introduction

As the economy becomes globalized, there is increased interest in problems of international trade and the environment. By importing goods and services, nations can reduce the environmental load generated domestically. Exporting nations, on the other hand, generate environmental load, export the produced goods and services, and thereby earn foreign currency. A number of developing nations are advancing industrialization without sufficient attention to environmental measures, and achieving economic growth by exporting industrial products

1 D. Eng., Professor, Institute of Environmental Systems, Faculty of Engineering, Kyushu University, Higashi-ku, 812-81 Fukuoka, Japan
2 Okayama Prefectural Office
3 M. Eng., Research Associate, Institute of Environmental Systems, Faculty of Engineering, Kyushu University, Higashi-ku, 812-81 Fukuoka, Japan

with relatively large environmental loads to the developed nations (Imura and Moriguchi, 1995; Imura *et al.*, 1996). This situation applies to a number of nations in Asia, where industrial production is growing rapidly. A similar problem is occurring in trading of agricultural products, except that in this case the primary exporters are the industrialized nations such as the US, Canada, Australia and the EU. These nations or regions have commercial foodstuff production intended for export, supported by large-scale use of agricultural machinery and extensive expenditure of water and fertilizer resources, and there is concern over the environmental impact this represents. Nations like Japan, which provide a smaller fraction of their own required foodstuffs, are consuming large amounts of agricultural land and water resources in exporting nations like the US and Australia through the import of foodstuffs. In addition, they are also causing the release of nutrients such as nitrogen and phosphate to the environment in quantity through the large-scale use of fertilizer in exporting nations.

On the other hand, Asian nations such as China attract growing attention to the future international balance of food supply and demand (Brown, 1995). The population in this region is large and the rate of growth high, plus which the consumption of meat has been increasing with economic development. Compared to grains, meat represents a larger environmental load per unit caloric output (Japan Environment Agency, 1996). Therefore, if these nations increase their foodstuff import, it would cause larger environmental loading in exporting nations.

Recognizing the above situation, this paper attempts to quantify environmental loading associated with the production of foodstuffs, and examine its trade implications. Toward this objective the following analyses are made:

1. A quantitative evaluation is made of the resources such as land, water and fertilizer consumed for foodstuff production in exporting nations.
2. Quantification of environmental loading due to foodstuff production is made in terms of energy consumption. Energy here includes fuels used for agricultural machinery, energy required to manufacture such machinery, and energy required to manufacture fertilizer and agrochemicals, and energy required for transportation.
3. A quantitative analysis is made of international nitrogen transfer accompanying trade in fertilizers and foodstuffs. Here, nitrogen is chosen as an index of environmental load as it is a key factor in water eutrophication.

2. Quantification of Environmental Load Accompanying Agricultural Production and Trade

2.1 Framework of Analysis

Grains and beef, which represent a large volume in international trade, are chosen, and estimates are made of the land, water and fertilizer resources used to produce these agroproducts which are then consumed in Japan (Fig. 1). Five nations, *i.e.*, the US, Canada, Australia, France and Argentina are chosen as major exporters of foodstuffs, along with three nations and regions, *i.e.*, Japan, the EU, and Africa as importers. The analysis is based on agrotrade data for 1973, and for 1983 through 1993 (United Nations, 1974, 1984-1994).

2.2 Japan's High Dependence upon Import: Case of Beef

To examine the degree of dependence on imported foodstuffs by category in Japanese consumption, beef is taken up because Japanese dependence is greater for beef than for other

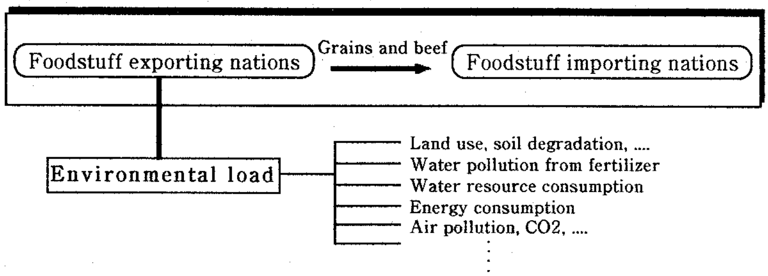

Figure 1. Transfer of environmental loading through agroproduct trade

livestock products. The dependence of Japanese consumption of beef protein on overseas supply is calculated. First, the amount of protein in a gram of beef (*i.e.*, 0.14 gram protein/gram beef) is multiplied by the total annual import weight of beef, and the resulting figure divided by the total population of Japan to yield the per capita dependence on imported beef protein (FAO, 1991; United Nations, 1973; United Nations, 1993). The results are shown in Fig. 2, in which the bold line indicates the daily per capita consumption of beef protein in Japan, and the solid line the dependence on imported beef which are primarily from the US and Australia.

This figure shows that the amount of beef consumed by Japanese has roughly doubled over the decade from 1983 to 1993, and that 40% of this beef protein is imported in 1993. Here, these figures only include actual beef imports into Japan, and do not take into account imported calves which are then raised in Japan. If this beef is taken into account, the dependence on imported beef rises even higher.

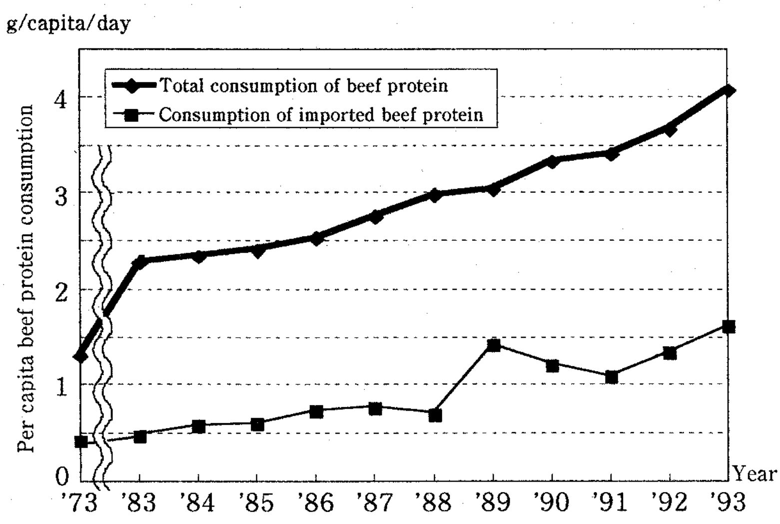

Figure 2. Per capita beef protein consumption in Japan

2.3 Environmental Loading Accompanying Foodstuff Production

(1) Natural resources expended into foodstuff production

Foodstuff production requires utilization of agricultural land, water and fertilizer resources. Usage of land may result in soil degradation, such as the loss of fertile topsoil. Usage of water resources requires the construction of water facilities such as dams, which might exert significant impact on the natural ecosystem. As a result of using water for agriculture, it is possible that insufficient water may be available for other purposes. The usage of fertilizer leads to eutrophication of rivers and lakes through release of nutrients such as nitrates and phosphates, and contamination of underground water from nitrates.

The expenditure of massive amounts of resources into foodstuff production is closely related to environmental impact in the production region. The actual relationship between the resources expended in production and the resulting environmental impact, however, is complex, varying with specific natural conditions and agricultural practices, and making it difficult to discuss the relationship in general terms. Therefore, this paper uses the amount of resources expended in production as an index of environmental load. While the resulting simplified analysis is a trial, it does provide an insight on the overall relationship of agricultural production and environmental loading.

(2) Use of land

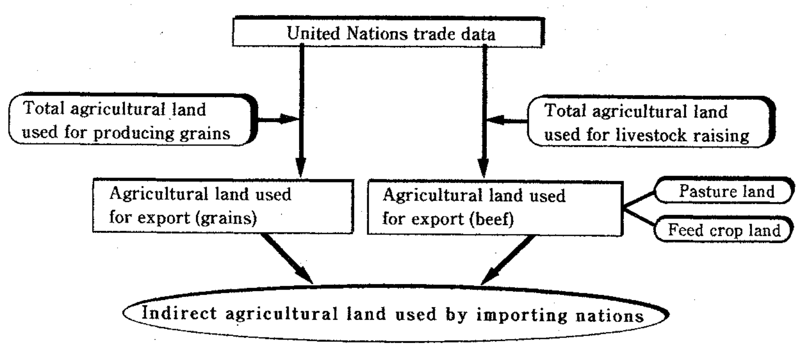

Figure 3. Calculation of agricultural land area used in agroproduct trade

The land area L_{ge} used for the production of key grains (*i.e.*, wheat, barley, rice, and corn) and soybeans which are exported (FAO, 1995) are calculated, using the following expression for each product:

$$L_{ge} = L_{gt} \frac{G_e}{G_t} \tag{1}$$

where L_{gt} is the total tilled area [ha], G_e volume of grain export [ton] and G_t total grain production [ton].

Land used to produce livestock products includes not only the pasture land needed to raise the livestock, but also agricultural land needed to raise feed crops (Fig. 3).

First the number of cattle needed to produce the volume of beef exported is calculated. Cut production data is used to determine that a single carcass yields 300 kilograms of beef on the average, and the weight of beef is then used to determine the number of carcasses needed (U.S.

Department of Commerce, 1990). The following expression is used to calculate the amount of agricultural land L_{ce} needed to produce these cattle and beef:

$$L_{ce} = L_{ct}\frac{C_e}{C_t} \quad (2)$$

where L_{ct} is the total cattle pasture land area [ha], C_e the number of cattle exported, and C_t the total number of cattle raised in exporting nation. Here, relevant data from United Nations commodity trade statistics for beef are used (United Nations, 1994). Many nations report the trade volume in number of carcasses, but there are some which report by weight. In such cases, the weight is converted into carcasses at the ratio of 500 kilograms per carcass (Hori,1969).

Agricultural land area used for the production of feed corn is calculated from the amount of corn consumed per animal per year (*i.e.*, about 570 kilograms) and the number of cattle. The percentage of the total corn crop for cattle raising is then calculated (Japan Ministry of Agriculture Forestry and Fisheries, 1995). This percentage is multiplied by the total land area used for corn production to determine the land area required for cattle raising. Imported corn feed is also possible, but this analysis assumes that all corn feed is produced domestically. The total of the pasture land needed for raising cattle and the agricultural land needed for raising corn yields the total agricultural land area needed for beef export.

Fig. 4 shows the agricultural land area used to produce the grains and beef: the bars pointing upward indicate the land area used indirectly through the import of agricultural products by Japan, Africa and the EU; and the bar pointing downward indicate the land area used by various exporting nations for exports to Japan, Africa, and the EU. Fig. 5 summarizes the agricultural land area used overseas to produce grains and livestock products consumed in Japan. As import of foodstuffs rises, the overseas land area used by Japan is also increasing sharply. In 1993 the total land area utilized by Japan for imported foodstuffs was about 27 million hectares (19.5 ha for beef and 7.5 million ha for grains), which is roughly 70% of the total land area of Japan (*i.e.*, 38 million hectares), and roughly six times the total agricultural land area of Japan. Similarly the EU used 9.2 million hectares and Africa 6.6 million hectares of land in other nations (1993).

The Japan Environment Agency (Quality of the Environment in Japan, 1994) estimates that the land area used overseas to produce agricultural products such as grains is 10.3 million hectares, but this is calculated only for eight items (*i.e.*, wheat, barley, sorghum, corn, soybeans, coffee beans, cotton and natural rubber) which are produced for import into Japan, and does not include agricultural land area used for the production of beef in the form of pasture land and feed crop land. The present results indicate that even for only five exporting nations, actual land use is 2.6 times larger than the estimate presented by the Japan Environment Agency. These results indicate the size of environmental loading accompanying livestock production.

Growth of grain import is greatest for Africa, while there is a decline in import volume for the EU. For exports, the US accounts for the majority of grain export and Australia for the majority of beef export, indicating that these two nations serve as the key agricultural production centers for the world.

(3) Use of water

Increases in population and demand for agricultural water are leading to a shortage in global fresh water resources. Here, the data for water demand for each crop is multiplied

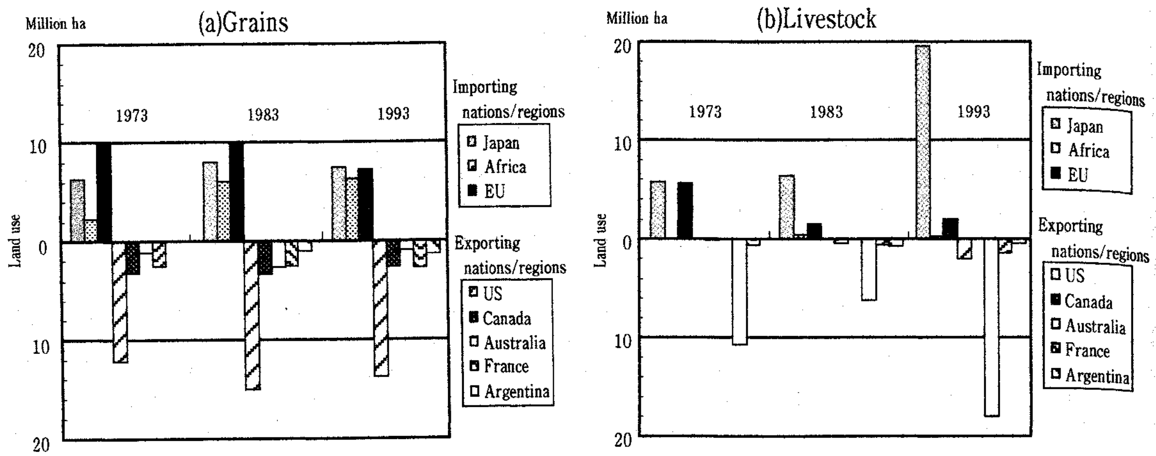

Figure 4. Indirect agricultural land use accompanying the trade of foodstuffs

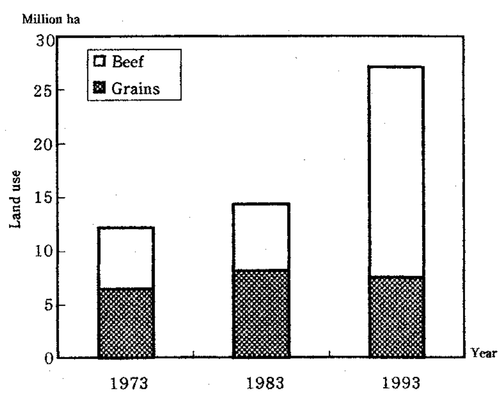

Figure 5. Agricultural land area used in other nations for the production of foodstuffs consumed in Japan

by the trade volume to determine the agricultural water used in the production of export agroproducts, and used as an index of environmental load.

Demand for agricultural water varies greatly with climate, soil, crop and agricultural practice, and it is very difficult to obtain this value for different nations and regions. For this reason, this paper uses the intermediate value for water demand from the US (Table 1) as a common unit for all nations (Tokari *et al.*, 1961). A comparison of water demand by agroproduct for Japan and the US, however, shows that the US demand is about three times higher than that in Japan. As the US data are not available for soybeans, Japanese data (United Nations, 1994) is multiplied by the above factor to provide an estimated water demand (*i.e.*, 1200 tons per ton of soybeans).

Results calculated through the above method are indicated in Fig. 6. Japan used 13 billion

Table 1. Water demand per unit of production for various crops (Tokari *et al.*, 1961)

Crop	US	Japan
Wheat	460~550	191
Rice	690~710	295
Barley	510~530	175
Corn	230~380	94
Soybeans	(1200)	429

Unit: tons of water / ton of crop product

tons of agricultural water indirectly in other nations through imported foodstuffs, while the amount of water used for agriculture in Japan is about 45 billion tons (1993). In the same way, the EU used 18 billion tons and Africa 10 billion tons of foreign water indirectly. While it changes from year to year, there is an overall trend toward an increase in the amount of water used indirectly in other nations through the import of agroproducts by Japan.

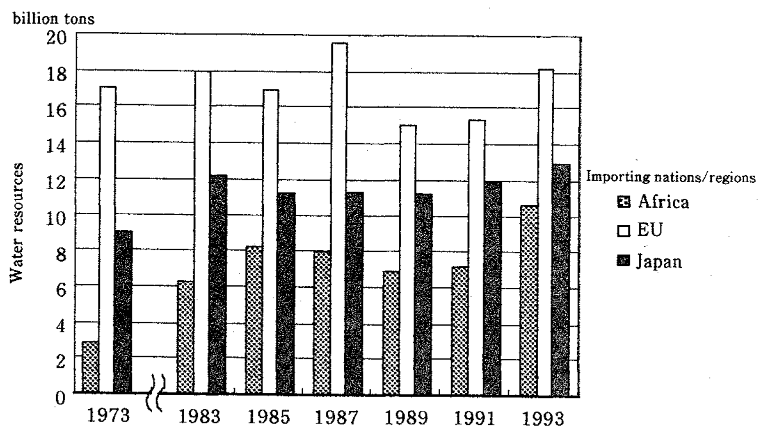

Figure 6. Water resources indirectly consumed by importing nations/regions

(4) Use of fertilizer

With the expansion of agricultural production, both land and fresh water are experiencing a shortage. An increase in commercial production, however, usually means an increase in fertilizer input, which represents a risk of pollution for rivers, lakes and seas. To evaluate this, the amount of nitrogen, phosphate and potassium fertilizers needed for production of foodstuffs is estimated.

First the amount of fertilizer used per unit area is multiplied by the cultivated area, for each crop, to determine fertilizer consumption in the foodstuffs producing nation. This is allocated according to the volume of each foodstuff imported by each importing nation to determine the amount of fertilizer indirectly consumed overseas by that importing nation. The volume of fertilizers applied to major crops in Japan is summarized in Table 2 (Noguchi, 1961). No such data, however, were available for other nations: total fertilizer usage data is available for each nation as shown in Table 3, but it is for all agricultural uses, and not broken down by crop. As in the case of water resources, the amount of fertilizer used also varies with soil, crop

Table 2. Fertilizer applied to major crops in Japan (Noguchi, 1961)

Crop	Nitrogen fertilizer	Phosphate fertilizer	Potassium fertilizer
Wheat	4.5～9.7	4.8～8.2	2.2～9.0
Rice	6.3～17.2	6.3～7.8	4.8～9.0
Barley	6.7～9.0	4.1～8.2	4.8～8.2
Corn	7.1	5.6	6.0
Soybeans	1.5	3.7	4.1

(Unit: kg / 10a)

Table 3. Nitrogen fertilizer usage (OECD, 1994)

	Usage
Japan	13
The US	5
Canada	3
France	13

(Unit: tons / km^2)

and agricultural practice. Therefore, it is assumed that the ratios of nitrogen, phosphate and potassium fertilizers are the same for all nations. Furthermore, the data of total fertilizer use for the US are applied to Australia and Argentina for which relevant data were not available and whose agricultural practices are thought to be similar to the US.

Results yielded by this method are given in Fig. 7, indicating the change over time in the amount of nitrogen fertilizer indirectly consumed by Japan through imports of foodstuffs. Annual indirect fertilizer consumption is generally 120 to 140 thousand tons, with a slight rising trend. The majority of this increase is due to the increase in imports from the US. The same trend is evident in phosphate and potassium fertilizers.

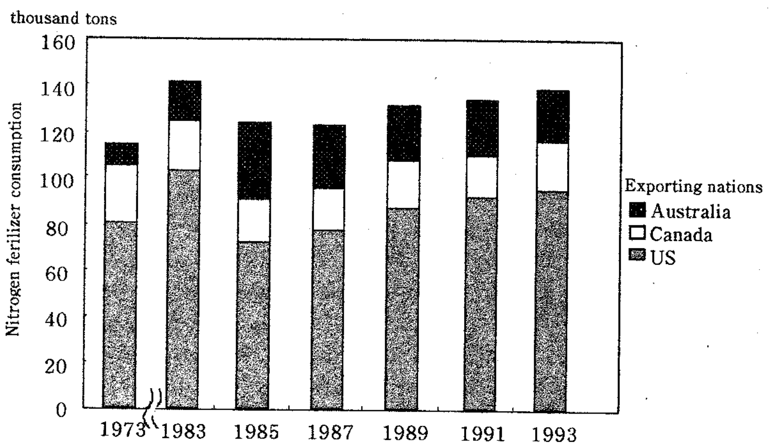

Figure 7. Indirect nitrogen consumption by Japan in exporting nations

Table 4 indicates the nitrogen fertilizer indirectly consumed by Japan, Africa and the EU through the import of foodstuffs in 1993. The amount of nitrogen fertilizer indirectly used by Japan in other countries was 155 thousand tons in 1993 while about 600 thousand tons were directly used in Japan. In the same way indirect consumption by the EU was 505 thousand tons, and by Africa 334 thousand tons. One can take it that the fertilizer used in production of the foodstuffs is itself exported. In this case, it is clear that there is a massive flow of fertilizer from major foodstuff producers, *i.e.*, the US to the rest of the world. There is also a considerably large flow from France to Africa and the EU. One of the causes for this is the large volume of fertilizer used per unit area in France (FAO, 1995).

Table 4. International nitrogen flow accompanying fertilizer trade (1993)

From: \ To:	Africa	EU	Japan	Total
US	119	35	110	264
Canada	18	5	19	42
Australia	0	0	26	26
France	189	441	0	630
Argentina	8	24	0	32
Total	334	505	155	994

Unit: thousand tons

3. Energy Expended in Agricultural Production

3.1 Life Cycle Energy of Foodstuffs

Energy is a key index for the evaluation of environmental load accompanying the production and consumption of goods and services. In general, energy consumption, as a result of the use of fossil fuels, leads to emission of atmospheric pollutants and carbon dioxide which is a cause of global warming. Research into life cycle assessment (LCA), a means of evaluating the total environmental loading from the production through consumption to final disposal of products, is becoming popular in recent years (UNEP, 1996). Below, the total amount of energy consumed in the production of agricultural products is calculated, not only for energy directly consumed in the operation of agricultural machinery, but also energy indirectly consumed in the production of fertilizer, agrochemicals and machinery. The significance of this energy consumption is discussed in terms of international trade.

3.2 Energy Expended for Fertilizer Production

Fertilizer consumption data (FAO, 1995) for each nation is multiplied by the energy expended to produce a unit weight of fertilizer (Helsel, 1992), yielding the total energy required for fertilizer production. Here, it is assumed that the methods of fertilizer manufacturing are identical worldwide, and that data for the US is universally applicable.

Table 5 shows the energy required for manufacturing a unit weight for each type of fertilizer, indicating that the value for nitrogen fertilizer is several times larger than those for phosphate or potassium fertilizer. This is because considerable amounts of coal are consumed as a raw material during the manufacturing process of nitrogen fertilizer, and this is included in energy consumption.

Table 5. Energy requirement for fertilizer manufacturing in the US (Helsel, 1992)

N	1.87
P_2O_5	0.42
K_2O	0.33

(Unit: TOE/ton)

Fig. 8 is a breakdown of the total production energy in the US by fertilizer type. Energy expended in production of nitrogen fertilizer is significantly greater than the energy used in the production of phosphate or potassium fertilizer. Fig. 9 indicates the amount of fertilizer used per unit of agricultural land area in various nations (FAO, 1995). Values for Japan and the US are essentially flat, while China has increased six times from about 10 kg/ha in 1970 to about 60 kg/ha in 1991. In other words, the amount of fertilizer used per unit area in China has increased significantly, bringing about a sharp increase in the energy expended in fertilizer production. Fig. 10 indicates results for estimations of total energy expenditures for various nations for the production of fertilizer. The values for the US and China are considerably larger than those of other nations, and in particular the values for China have risen sharply since the 1970s.

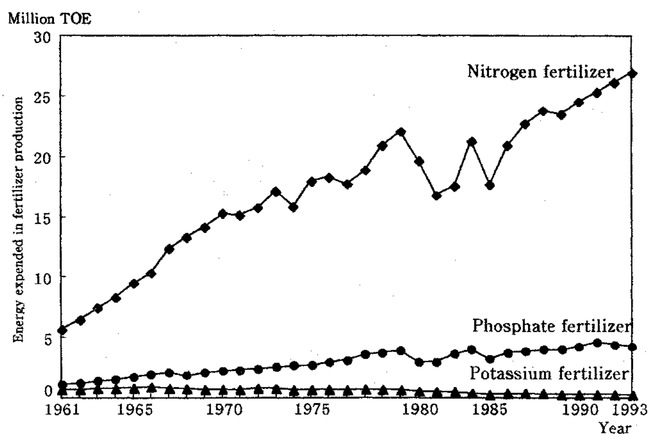

Figure 8. Energy expended in fertilizer production in the US

3.3 Energy Required for Agricultural Production

The direct and indirect energy expenditures in Japan and the US for the production of foodstuffs ("energy input") are compared with the food energy in terms of caloric values of produced foodstuffs ("energy output"). The ratio of energy output to energy input for foodstuffs is then evaluated (Kyuma and Soda, 1995). The items chosen here are wheat, soybeans and rice in Japan, and wheat, soybeans and corn in the US.

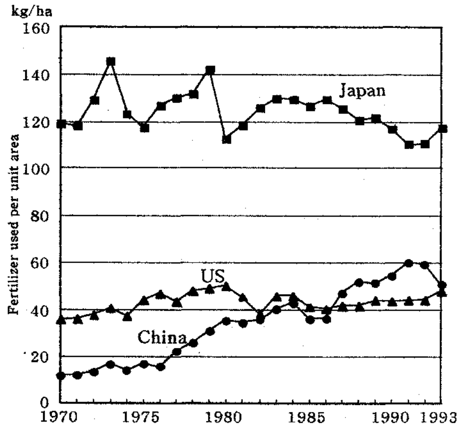

Figure 9. Fertilizer used per unit area

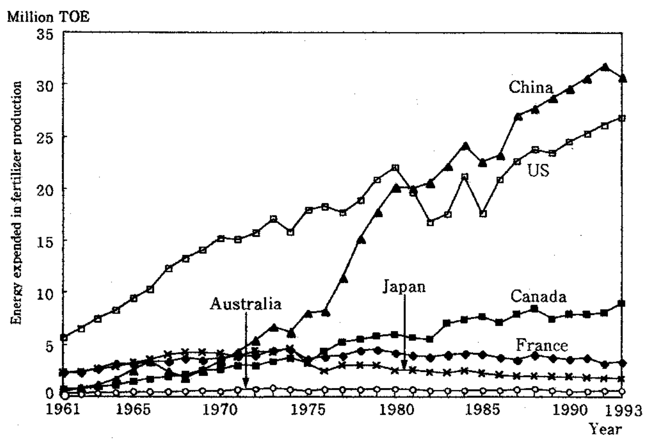

Figure 10. Energy expended in fertilizer production in various nations

Expended energy is the total of energy consumption for the production of fertilizer, agrochemicals and agricultural machinery ("indirect" energy expenditure), and electricity and petroleum used directly in agriculture ("direct" energy expenditure). Energy expended in the manufacturing of agrochemicals and agricultural machinery is determined by multiplying the capital expenditure on agrochemicals and agricultural machinery (Japan Ministry of Agriculture, Forestry and Fisheries, 1996; U.S. Department of Agriculture,1995) by the energy consumption induced by a unit final demand of these items. Here, the unit amount is calculated from the 1985 Japan-U.S. Input-Output Tables (Ministry of International Trade and Industry, 1985; Shiratsuchi 1995). Energy output, on the other hand, is calculated by using the data for the energy value (kcal) per unit weight (100g) of each foodstuff item (Japan Science and Technology Agency, 1992).

The calculation results are given in Table 6 and Table 7. In large-scale, relatively low-density American agriculture, the ratio of energy output to input is between 3.99 and 5.71 for various agroproducts (average values of three different years). The values for the high-density agriculture of Japan are from 1.08 to 1.88, representing low output efficiency. The value for

Table 6. Energy expended in agroproduct production in the US (thousand TOE)

			1985	1990	1994	Average
Soybeans	Input:	Fertilizer	1,413	1,296	1,396	1,368
		Erectricity and petroleum	2,176	1,996	2,149	2,107
		Agrochemicals	754	957	1,138	950
		Agricultural machinary	83	56	58	66
		Total	4,425	4,305	4,742	4,490
	Output:	Caloric value of product	24,736	22,696	29,662	25,698
	Output/Input		5.59	5.27	6.26	5.71
Wheat	Input:	Fertilizer	2,382	–	–	2,382
		Erectricity and petroleum	2,901	–	–	2,901
		Agrochemicals	272	–	–	272
		Agricultural machinary	89	–	–	89
		Total	5,645	–	–	5,645
	Output:	Caloric value of product	22,530	–	–	22,530
	Output/Input		3.99	–	–	3.99
Corn	Input:	Fertilizer	8,873	7,899	8,602	8,458
		Erectricity and petroleum	5,117	4,547	4,948	4,870
		Agrochemicals	1,447	1,253	1,407	1,369
		Agricultural machinary	367	117	188	224
		Total	15,803	13,815	15,145	14,921
	Output:	Caloric value of product	78,909	70,537	89,820	79,755
	Output/Input		4.99	5.11	5.93	5.34

Note: "Total" is the total for fertilizer, electricity and petroleum, agrochemicals, and agricultural machinery.

Table 7. Energy expended in agroproduct production in Japan (thousand TOE)

			1985	1990	1994	Average
Soybeans	Input:	Fertilizer	–	8	3	6
		Erectricity and petroleum	–	356	12	184
		Agrochemicals	–	55	2	29
		Agricultural machinary	–	15	4	9
		Total	–	435	22	228
	Output:	Caloric value of product	–	113	41	77
	Output/Input		–	0.261	1.89	1.08
Wheat	Input:	Fertilizer	42	47	27	39
		Erectricity and petroleum	99	57	38	65
		Agrochemicals	71	9	5	28
		Agricultural machinary	35	34	11	27
		Total	248	147	81	159
	Output:	Caloric value of product	291	317	188	265
	Output/Input		1.17	2.16	2.31	1.88
Rice	Input:	Fertilizer	637	564	601	601
		Erectricity and petroleum	2,120	1,310	1,331	1,587
		Agrochemicals	230	173	162	188
		Agricultural machinary	1,078	525	475	692
		Total	4,064	2,572	2,569	3,068
	Output:	Caloric value of product	4,093	3,685	4,205	3,995
	Output/Input		1.01	1.43	1.64	1.36

Note: "Total" is the total for fertilizer, electricity and petroleum, agrochemicals, and agricultural machinery.

rice, in particular, is as low as 1.3.

Fig. 11 and Fig. 12 indicate the input energy per ton of produce in Japan and the US. The values for soybeans and wheat are higher for Japan than for the US, indicating a large difference in the use of agricultural machinery. From 1970 to 1993, the number of tractors per 1000 hectares of agricultural land in the US has been flat slightly above 10, while in Japan it rose from over 50 in 1970 to about 400 in 1993, representing an eight-fold increase (FAO, 1995). As a result, there has been a major increase in the amount of energy expended in agricultural machinery in Japan: a direct result of the difference in "merit of scale" between the two nations. There are also significant differences between the energy expenditure of electricity and petroleum for wheat and soybeans, and of agrochemicals for wheat, between the two nations.

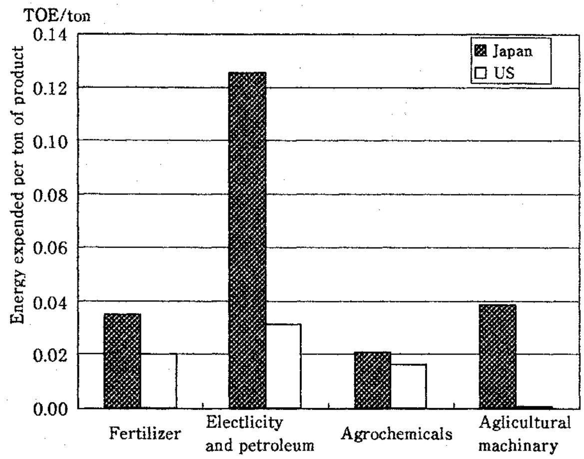

Figure 11. Comparison of energy expended per ton of soybeans production in Japan and the US (1994)

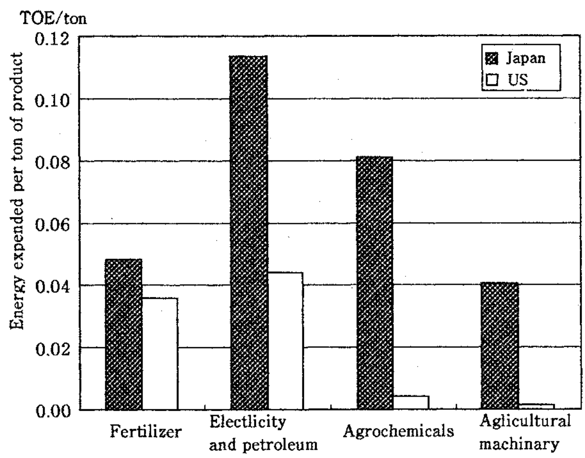

Figure 12. Comparison of energy expended per ton of wheat production in Japan and the US (1985)

3.4 Energy Required for International Transport of Foodstuffs

In the above, it is demonstrated that the energy requirement per unit production of foodstuffs is remarkably smaller in the US than Japan. Traded foodstuffs, however, must be transported over thousands of kilometers from producer countries to consumer countries. Moreover, in a continental country like the US, they must also be transported over a long distance within the country before shipping from the port. The question here is how large is the energy expended in the stage of transport. To answer this question, the energy required for transporting foodstuffs from the US to Japan is estimated. In this case, transportation energy is the sum of the energy required for the domestic land transport and that for international maritime transport.

First the energy required for domestic land transport in the US is estimated by multiplying the annual average energy consumption of a truck in the US and the number of trucks engaged in the transport of agricultural products (U.S. Department of Commerce, 1995). Then, the energy required for sea transport between Seattle and Tokyo is estimated, using the data for the number of voyages, and fuel consumption by tonnage of cargo boats. The details of this estimation was published elsewhere (Yashima *et al.*, 1997).

Fig. 13 compares the energy required for two categories of soybeans and wheat consumed in Japan: the Japanese products, and the US products exported to Japan. Even if transport energy is added, energy required for the US soybeans and wheat is less than a half of that required for Japanese products.

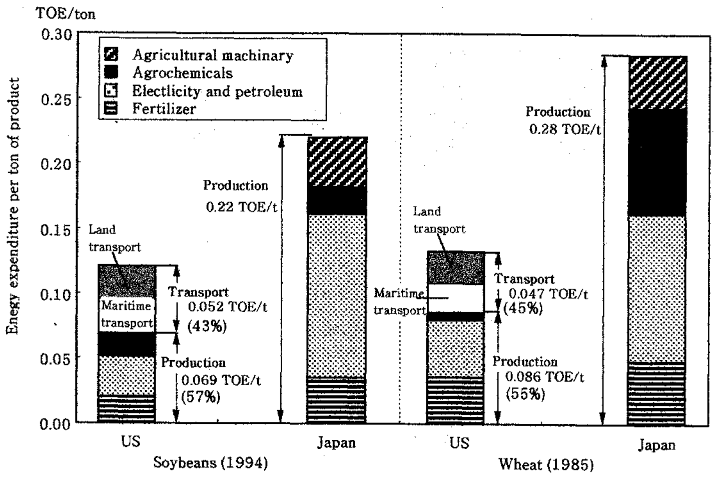

Figure 13. Total energy expenditure of soybeans and wheat production in Japan and those imported from the US

3.5 Comparison of the Total Energy Expenditure Between Japan and the US

A comparison of the energy efficiencies of agricultural production in Japan and the US shows that Japan's high-density approach has a low efficiency. Energy efficiency is especially low for rice cultivation. If other factors are ignored and only energy efficiency examined, it is more efficient for Japan to import grains produced in the US than to grow them in Japan. Trade and environmental implications of this result, however, should be considered from more comprehensive viewpoints.

4. Nitrogen Flow Caused by Foodstuff Trade

4.1 Balance of Nitrogen Fertilizer Input and the Nitrogen Contained in Agroproducts

Nitrogen is an essential element which supports life on the earth. It is an important factor in determining the fertility of soil, and its release into water may cause eutrophication. Thus the flow of nitrogen in the natural ecosystem as well as that caused by human activities such as industrial and agricultural production has been studied by various authors (Kawashima, 1996). The Japan Environment Agency, in particular, presented a comprehensive review of nitrogen flow based on various study reports (Quality of the environment in Japan, 1994) .

Japan exports fertilizers manufactured domestically to other nations, and other nations exporting agroproducts to Japan use fertilizers in agricultural production. A portion of the nitrogen expended in production is recovered in the form of the agroproducts, and the remainder released to the environment. The nitrogen captured in the agroproducts moves internationally through trade. This paper presents the balance of international flow of nitrogen resulting from the trade of foodstuffs and fertilizers.

First, the relationships between nitrogen fertilizer input and crop yield, for the foodstuffs discussed in Section 3.2, are indicated in Table 8 and Table 9. Here, the amount of nitrogen contained in foodstuffs is determined by dividing the protein content for each item from the foodstuff supply and demand tables by the nitrogen-protein conversion coefficient (Japan Science and Technology Agency,1992) (Table 10). The excess amount of nitrogen is then defined as the nitrogen fertilizer expenditure for producing foodstuffs minus the nitrogen contained in the foodstuffs. In both Japan and the US, excess amount of nitrogen occurs, with the exception of soybeans which have nitrogen-fixation ability. The excess amount of nitrogen is larger for rice and corn than for wheat. Japan, which uses a denser cultivation method for wheat production than the US, releases about three times as much nitrogen per unit land area to the environment.

Table 8. Nitrogen balance in Japanese cultivated land (kg/ha)

		1985	1990	1994
Rice	Nitrogen fertilizer used	118	118	118
	Nitrogen recoverd in crops	35	36	38
	Excess amount of nitrogen	82	82	79
Soybeans	Nitrogen fertilizer used	15	15	15
	Nitrogen recoverd in crops	101	110	96
	Excess amount of nitrogen	−86	−95	−81
Wheat	Nitrogen fertilizer used	72	72	72
	Nitrogen recoverd in crops	53	52	53
	Excess amount of nitrogen	19	20	19

Table 9. Nitrogen balance in American cultivated land (kg/ha)

		1985	1990	1994
Corn	Nitrogen fertilizer used	133	133	133
	Nitrogen recoverd in crops	55	55	64
	Excess amount of nitrogen	79	79	69
Soybeans	Nitrogen fertilizer used	12	12	12
	Nitrogen recoverd in crops	136	136	165
	Excess amount of nitrogen	−123	−123	−152
Wheat	Nitrogen fertilizer used	42	42	42
	Nitrogen recoverd in crops	36	38	36
	Excess amount of nitrogen	6	4	6

Table 10. Nitrogen-Protein conversion coefficient (Japan Science and Technology Agency, 1992)

Wheat	5.83
Rice	5.95
Soybeans	5.71
Others	6.25

(Unit: grams of protein / gram of nitrogen)

4.2 International Nitrogen Flows

(1) Framework of analysis

The nitrogen flows between the regions of Japan, Asia, Europe, North America, Latin America, Africa and Oceania for 1980, 1985, 1990 and 1994 are estimated, for trade in major agricultural commodities, *i.e.*, wheat, corn, soybeans, rice, other grains, beef, vegetables, and fruit, and nitrogen fertilizer. Trade in foodstuffs is based on Commodity Trade Statistics of the UN (United Nations, 1980, 1985, 1994), and the nitrogen content of agroproducts is determined as described in the above.

This analysis is similar to that presented by Japan Environment Agency (Quality of the Environment in Japan, 1994), but it presents a time series analysis based on updated trade data.

(2) Results

The nitrogen flows between regions calculated through the above method are indicated in Table 11. In 1994, for example, about 600 thousand tons of nitrogen contained in foodstuffs and 59 thousand tons of nitrogen contained in fertilizer were imported to Japan. On the other hand, there was only a minimal export of nitrogen contained in foodstuffs from Japan, showing Japan's massive excess import of nitrogen. When nitrogen fertilizers are taken into consideration, however, we have a totally different balance. Japan exports about 180 thousand tons of nitrogen annually (1994), especially to Asian nations. An overall view of nitrogen flow shows an influx from North America to Japan accompanying foodstuffs trade, and then outflow from Japan to other Asian regions accompanying fertilizer trade. In 1994, the US exported about 1.9 million tons of nitrogen contained in foodstuffs, about 47% of which were imported by Asian nations.

Table 11. Nitrogen flow accompanying agroproduct and fertilizer trade (Unit: T-N)

(A: Nitrogen contained in agroproducts, F: Nitrogen contained in fertilizer)

		Year		Africa	North America	Canada	US	Latin America	Asia	Japan	Europe	Oceania	Austraria	Total
US	Import from	1980	A	20	6,200	3,800	–	6,600	78	1	220	11,200	8,000	24,300
			F	–	275,000	275,000	–	14,100	2,000	1,900	144,000	–	–	435,000
		1985	A	25	16,000	16,000	–	8,600	590	4	6,600	10,200	5,800	42,100
			F	220	322,000	322,000	–	14,700	25,000	2,800	292,000	14,900	–	668,000
		1990	A	9	32,400	28,600	–	7,600	1,200	7	1,200	12,200	7,900	54,600
			F	2,500	429,000	429,000	–	83,400	8,700	550	189,000	–	–	713,000
		1994	A	29	107,000	107,000	–	9,200	2,100	18	12,900	9,900	6,100	141,000
			F	31,200	556,000	556,000	–	126,000	75,600	400	279,000	1,900	–	1,070,000
	Export to	1980	A	77,100	29,700	29,700	–	265,000	808,000	408,000	960,000	1,800	1,800	2,140,000
			F	17,500	35,400	35,400	–	352,000	182,000	–	161,000	11,100	5,900	758,000
		1985	A	105,000	12,200	12,200	–	230,000	716,000	397,000	521,000	160	74	1,580,000
			F	13,700	29,800	29,800	–	104,000	91,100	810	–	8,700	7,500	247,000
		1990	A	98,600	29,400	29,300	–	222,000	783,000	320,000	483,000	5,600	4,100	1,620,000
			F	–	–	–	–	–	–	–	–	–	–	–
		1994	A	171,000	15,400	15,400	–	352,000	881,000	369,000	456,000	6,900	6,700	1,880,000
			F	–	–	–	–	–	–	–	–	–	–	–
Canada	Import from	1980	A	–	39,500	–	39,500	–	6	–	4	1,000	500	40,500
			F	–	26,400	–	26,400	–	–	–	2,000	–	–	28,400
		1985	A	–	18,400	–	18,400	2,200	90	–	400	940	430	22,000
			F	–	35,900	–	35,900	4,500	–	–	14,900	–	–	55,300
		1990	A	17	24,300	–	24,300	720	310	–	83	1,200	710	26,700
			F	8,500	36,000	–	36,000	–	1,800	–	27,200	–	–	73,600
		1994	A	30	11,300	–	11,300	410	470	5	130	2,500	1,300	14,800
			F	–	18,600	–	18,600	–	10,900	–	56,100	–	–	85,600
	Export to	1980	A	16,000	11,000	–	51,700	45,400	90,700	30,800	64,000	14	1	227,000
			F	–	279,000	–	279,000	2,000	17,200	–	140	4,900	4,900	303,000
		1985	A	23,300	18,900	–	18,900	31,700	102,000	36,600	40,000	150	140	216,000
			F	2,500	299,000	–	299,000	5,300	40,500	–	1,800	12,900	12,900	362,000
		1990	A	23,100	41,900	–	43,600	30,000	172,000	21,400	11,300	150	140	279,000
			F	840	431,000	–	431,000	12,200	11,600	1,100	9,300	31,500	31,000	496,000
		1994	A	28,600	120,000	–	120,000	58,200	202,000	37,800	25,000	1,300	970	436,000
			F	–	560,000	–	560,000	19,800	1,200	1,200	87	42,600	34,600	624,000
Japan	Import from	1980	A	6,700	473,000	33,100	440,000	4,500	9,400	–	560	33,700	33,600	529,000
			F	–	230	–	230	5,100	1,000	–	1,700	–	–	8,000
		1985	A	580	462,000	37,900	424,000	36,400	42,400	–	2,400	41,300	40,900	585,000
			F	–	1,400	–	1,400	3,800	8,500	–	1,900	–	–	15,700
		1990	A	8,000	434,000	41,700	395,000	64,200	30,900	–	2,000	27,800	27,300	557,000
			F	–	7,900	1,100	6,700	–	44,900	–	7,300	–	–	60,000
		1994	A	15,100	426,000	41,300	385,000	64,800	49,800	–	8,200	42,400	41,600	606,000
			F	–	6,700	1,200	5,500	87	43,100	–	7,900	1,700	1,700	59,400
	Export to	1980	A	840	11	10	1	72	4,000	–	–	2	–	5,000
			F	3,100	–	–	–	2,600	336,000	–	–	15,700	–	358,000
		1985	A	1	17	14	2	–	17	–	–	–	–	34
			F	8,300	330	–	330	750	151,000	–	–	9,800	230	170,000
		1990	A	–	11	8	2	–	19	–	–	–	–	30
			F	9,000	490	–	490	3,200	159,000	–	–	1,700	110	174,000
		1994	A	–	22	4	18	–	10	–	1	–	–	33
			F	210	250	–	250	4,200	177,000	–	15	1,300	140	183,000

Note: Agroproducts in the traded total of wheat, corn, soybeans, rice, other grains, beef, vegetables and fruit.

Table 11. Nitrogen flow accompanying agroproduct and fertilizer trade (Unit: T-N) [cont.]
(A: Nitrogen contained in agroproducts, F: Nitrogen contained in fertilizer)

		Year		Africa	North America	Canada	US	Latin America	Asia	Japan	Europe	Oceania	Austraria	Total
Australia	Import from	1980	A	–	1,900	–	1,900	–	5	–	–	67	–	1,900
			F	–	13,800	8,400	5,400	–	92	92	2,300	–	–	16,200
		1985	A	–	–	–	–	–	–	–	–	160	–	160
			F	–	–	–	–	–	–	–	–	–	–	–
		1990	A	–	42	2	39	–	–		7	7	–	55
			F	–	–	–	–	–	–	–	–	–	–	–
		1994	A	–	–	–	–	–	–	–	–	–	–	–
			F	–	–	–	–	–	–	–	–	–	–	–
	Export to	1980	A	26,700	8,200	540	7,600	4,300	145,000	32,200	2,400	3,100	–	189,000
			F	–	–	–	–	–	–	–	–	5,100	–	5,100
		1985	A	38,200	6,500	470	6,100	6,700	227,000	44,300	1,200	3,600	–	286,000
			F	–	–	–	–	–	–	–	–	–	–	–
		1990	A	26,900	9,600	790	8,800	3,300	189,000	27,700	2,900	5,100	–	236,000
			F	–	–	–	–	–	12,600	–	–	3,200	–	15,900
		1994	A	210	7,300	1,300	5,900	73	18,100	11,600	740	710	–	27,100
			F	–	–	–	–	–	9,600	1,800	450	8,500	–	18,600
France	Import from	1980	A	850	55,200	1,900	53,300	9,100	1,100	–	18,800	45	–	85,200
			F	690	114,000	–	114,000	–	–	–	304,000	–	–	418,000
		1985	A	750	29,600	1,600	28,000	12,700	1,400	–	17,400	17	–	61,800
			F	3,100	20,100	–	20,000	3,500	–	–	601,000	–	–	628,000
		1990	A	900	11,000	650	10,300	13,200	1,900	–	27,200	41	–	54,300
			F	39,000	144,000	15,800	141,000	15,400	22,300	–	754,000	–	–	975,000
		1994	A	1,100	19,000	6,000	12,900	11,100	2,000	–	30,800	120	–	64,000
			F	29,500	19,000	–	19,100	16,800	640	–	687,000	–	–	753,000
	Export to	1980	A	50,000	6	4	3	2,000	18,900	2	176,000	6	–	247,000
			F	29,600	–	–	–	7,400	28,000	–	70,200	–	–	135,000
		1985	A	57,500	24	6	17	4,400	23,200	5	213,000	24	–	298,000
			F	18,800	440	650	290	2,500	17,100	–	111,000	–	–	150,000
		1990	A	66,700	14	3	11	4,800	43,600	5	242,000	41	–	357,000
			F	5,300	6,000	400	5,900	6,300	7,200	–	129,000	–	–	154,000
		1994	A	15,300	23	5	19	15,700	27,100	11	233,000	45	–	291,000
			F	9,600	4,900	5,500	3,700	12,200	6,200	–	180,000	3,000	2,900	216,000

Note: Agroproducts in the traded total of wheat, corn, soybeans, rice, other grains, beef, vegetables and fruit.

Fig. 14 and Fig. 15 show the nitrogen flow balance for Japan's foodstuffs trade. The net import (*i.e.*, import minus export) of nitrogen by Japan was about 170 thousand tons in 1980, but increased to about 480 thousand tons in 1994.

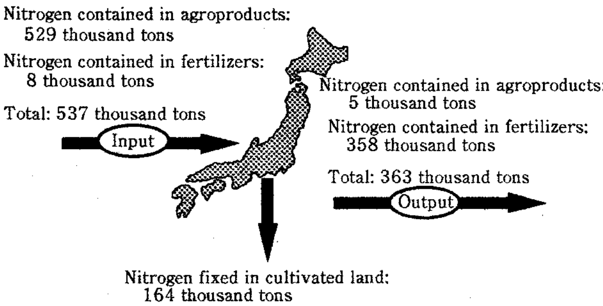

Figure 14. Nitrogen balance in Japan (1980)

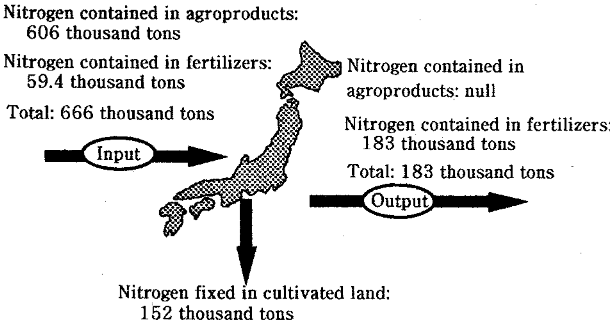

Figure 15. Nitrogen balance in Japan (1994)

Next question is how to estimate the amount of nitrogen fixed in cultivated land in Japan. There is little reliable data to estimate the speed of fixation in cultivated land. Therefore, we simply assume that values for lands such as Japan, which are relatively fertile, are thought to be about 30kg/ha/year (Kawashima, 1996). Applying this value, it is estimated that nitrogen fixation was at about 160 thousand tons in 1980, and at about 150 thousand tons in 1994. Therefore, the amount of nitrogen Japan imported in the form of foodstuffs was about 3.2 times larger than the amount of nitrogen fixed in cultivated land in 1980. This gap further expanded: import was 4.4 times larger in 1994.

The majority of the nitrogen imported into Japan through foodstuffs is eaten by the Japanese or consumed as livestock feed, eventually released into the water, soil and atmosphere in the form of various nitrates and salts. Water pollution in rivers, lakes and closed water bodies in Japan, due to effluents from household waste water, has become a major issue, and it is clear that a large contributing factor is the influx of nitrogen through imported foodstuffs.

5. Conclusions

Under today's free-trade regime, trade among nations takes place in accordance with the laws of comparative advantage. Nations with larger environmental capacities are able to utilize that capacity as a resource to produce, and export the products: there is little to condemn here. There is a different view, however, that the current free-trade stance is destroying the foodstuff self-supply capabilities of nations, thereby making it difficult for nations to maintain their intrinsic natural ecosystem. One key issue in finding an interface for discussion between these two seemingly opposing viewpoints is how to assess the international balance of environmental loading pertinent to trade.

Based on the above thought, this paper presented an estimate of the international balance of environmental loading, using as an index the resources expended for production of agricultural products. The major results are as follows:

1. Approximately 27 million hectares of agricultural land are used in other nations to produce the foodstuffs consumed in Japan (1993), which is equivalent to roughly 70% of the land area of Japan and roughly 600% of the agricultural land area of Japan. In the same way, the EU uses 9.2 million hectares and Africa 6.6 million hectares of land in other nations. Usage of land for the livestock trade is especially high, and is increasing.
2. Japan uses 13 billion tons of agricultural water indirectly in other nations through imported foodstuffs, while the amount of water used for agriculture in Japan is about 45 billion tons (1993). In the same way, the EU used 18 billion tons and Africa 10 billion tons of foreign water indirectly.
3. The amount of nitrogen fertilizer indirectly used by Japan in other countries was 150 thousand tons in 1993 while about 600 thousand tons were directly used in Japan. Indirect consumption by the EU 500 thousand tons, and by Africa 330 thousand tons.
4. A comparison of the energy efficiencies of agricultural production in Japan and the US shows that Japan's high-density approach has a low efficiency. Energy efficiency is especially low for rice cultivation. In other words, if other factors are ignored and only energy efficiency examined, it is more efficient for Japan to import grains produced in the US than to grow them in Japan, and environmental loading in Japan would of course be that much lower.
5. In 1994, Japan imported about 600 thousand tons of nitrogen in the form of foodstuffs, and exported about 180 thousand tons in the form of fertilizer. The amount of nitrogen contained in the imported foodstuffs to Japan was about four times the amount fixed in Japanese cultivated land in 1994. In order to clarify the environmental effects of such imported nitrogen, its effect to local water quality of rivers and seas should be studied.

In the above analysis, some simplifications and assumptions are made mainly due to the limited availability of consistent data for differing nations and regions. The results presented in this paper, therefore, should be regarded as rough estimates, but they are significant as a starting point for considering environmental implications of the production and trade of foodstuffs.

Acknowledgments

The authors would like to thank Dr. R. Fujikura for his valuable suggestions and Mr. T. Akutagawa for his assistance in preparing this paper.

References

Brown, L.R., ed. (1992): *State of the World 1992*, Chapter 5.

FAO (1991): *Food Balance Sheets 1984-86 average.*

FAO (1993): *Trade Yearbook 1993.*

FAO (1995): *FAOSTAT PC* (in Diskette).

Helsel, Z.R. (1992): Energy in Farm Production, Vol.6, *Energy in World Agriculture*, pp.177–201.

Hori, K.(1969): *Animal Feed Industry*, Special Issue, Section 2, p.10, 1969 (in Japanese).

Imura, H., and Moriguchi, Y. (1995): Economic Interdependence and Eco-balance: Accounting for the Flow of Environmental Loads Associated with Trade, *Toward Global Planning for Sustainable Use of the Earth*, Elsevier, pp.189–208.

Imura, H., Fujikura, R., Mizuno, T., and Shiratsuchi, H.(1996): Study on the Trade Eco-balance of Embodied Energy with Special Regard to the Asia-Pacific Region, *Journal of Global Environment Engineering*, Vol.2, pp.39–49.

Institute of Energy Economics, Japan (1995): *Handbook of Energy and Economic in Japan 1995.*

Japan Environment Agency (1994): *Quality of the Environment in Japan*, 1994.

Japan Environment Agency (1995): *Quality of the Environment in Japan*, 1995, pp.155–157 (in Japanese).

Japan Environment Agency (1996): *Final Report on ECO ASIA Long-Term Perspective Project.*

Japan Ministry of Agriculture, Forestry and Fisheries (1989, 1993, 1995, 1996): *Pocket Statistics for Agriculture, Forestry and Fisheries.*

Japan Ministry of Agriculture, Forestry and Fisheries (1995): *Feed Yearbook 1995.*

Japan Ministry of Agriculture, Forestry and Fisheries (1996): *Pocket Fertilizer Yearbook 1996.*

Japan Science and Technology Agency (1992): Japanese Foodstuff Constituent Tables, Ishiyaku-Shuppan.

Kawashima, H. (1996): Food Supply and Nitrogen Cycle in Japan, *Environmental Science*, Vol.9, No.1, pp.27–33.

Kuma, K., and Soda, S. (1995): *Agriculture and the Environment*, pp.13–20, 1995 (in Japanese).

Ministry of International Trade and Industry, Japan (1985): *The 1985 Japan-U.S. Input-Output Tables.*

Noguchi, Y., ed. (1961): *Encyclopedia of Agriculture*, p.736, p.1344, 1961 (in Japanese).

OECD (1994): *OECD Environmental Performance Reviews, Japan.*

Shiratsuchi, H.(1995): Study on the Export-Import Balance of Environmental Loads Pertinent to the International Trade of Goods and Services, *Master's Thesis*, Kyushu University (in Japanese).

Tokari Y., Yamada N., and Hyashi T. (1961): *Water Demand of Agroproducts, the Course of Agroproducts Physiology*, Chapter 3, pp.40–41 (in Japanese).

UNEP (1996): *Life Cycle Assessment: What It Is and How to Do It*, pp.3–35.

U.S. Department of Agriculture (1994): *Annual Summaries 1990.*

U.S. Department of Agriculture (1995): *Economic Indicators of Farm Sector.*

U.S. Department of Commerce (1990): *Statistical Abstract of the United States 1990.*

U.S. Department of Commerce (1995): *Statistical Abstract of the United States 1995.*

United Nations (1973, 1983-1994): *Commodity Trade Statistics 1973, 1983-1994.*

World Resources Institute (1992): *World Resources 1992-93*, pp.348–349.

Yashima H., Matsumoto T., and Imura H. (1997): Energy Consumption and CO_2 emission due to Japan's International Marine Freight Transport, *Environmental System Research*, Vol.25 (to be published).