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Comparison of OECD Nitrogen Balances of Korea and Japan

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ABSTRACT: The nitrogen (N) balance in Korea during 1985-1997 was calculated according to the surface balance method of the PARCOM guidelines and compared with Japanese N balance. The some differences were founded in the coefficients used on calculating N balance in two nations. Of the important parameters, which can make a big difference in balance, N input by organic fertilizers was not included in Korea different with Japanese, due to absence of reliable statistics and then made lower the input. Nitrogen destruction rate from livestock manure was adjusted differently with 15% in Korea but 28% in Japan. There was some difference in the conversion factors of livestock number into manure N quantity in two nations, but the gap was ignoble scale except beef cattle. Our manure N production rate of beef cattle might be evaluated to be so lower than Japanese. Biological N fixation by pulses was very higher in Korea than in Japan but scarcely affect the increase of total N input, due to small cultivation area. In contrast, N fixation rate by free-living organisms in Korean and Japanese wet paddies showed the big difference with 7.6 and 37.0 kg ha^{-1} yr^{-1}, respectively, and therefore 29.4 kg ha^{-1} yr^{-1} of nitrogen was estimated to be more inputted in Japan. Although there are many points to be more specified and improved, still, Korean N balance was very high with 250-257 kg ha^{-1} in the mid of 1990s, which was the second highest level in OECD countries and furthermore increased continuously during the investigation. In contrast in Japan, which has similar farming system with Korea, N balance was lower with 130-158 kg ha^{-1} and has decreased continuously since 1993. This high N balance was mainly due to a high usage of chemical fertilizers in our intensive farming system and the fast increment of livestock feeding. Therefore, the more active action to decrease chemical fertilizer utilization and reduce livestock feeding density is required in the government and farmer sides.

Key Words: Nitrogen balance; Korea, Japan, soil surface balance, OECD

INTRODUCTION

According to Agenda 21, the question of land use substantiality became more important in the recent years. Resource usage or efficiency of resource utilization is often cited as an important indicator. Soil nutrient balance takes into account inputs and outputs of the main nutrients in the production process. A highly positive balance can result in pollution of ground and surface water, while a negative balance may lead to mining of the soil nutrient stock with subsequent loss of soil fertility, diminishing crop yields and finally the abandoning of the previously suitable agriculture land[1)]. Since Korea participated OECD as a member country in December 12, 1996, Korean government has been drawing up nutrient balances for the agricultural sectors on the base of OECD guideline[1-3)]. A nutrient balance measures the difference between nutrient inputs into and outputs from an agricultural system and establishes a link between agricultural nutrient use, and changes in environmental quality and the sustainable use of soil nutrient resources. The purpose of calculating balances is to monitor the environmental performance in the agricultural sector with respect to nutrient surpluses.

In this paper, we tried to calculate N balance of Korea during the last thirteen years (from 1985 to

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1997) by surface balance method, which recommended by the OECD Secretariat (drawing on the work of Bomans et al.)[4] and compare with N balance of Japan, which has a similar farming system among OECD countries, to understand preliminary our nutrient utilization situation and establish a more effective nutrient-management strategy.

MATERIALS AND METHODS

With regard to the basic national nutrient balance the agricultural production system is considered, according to the PARCOM guidelines[5]. Only data for input and output have to be provided and the surplus is calculated as the difference between these two. Input and output quantities of products can be obtained from Agricultural & Forestry Statistical Yearbook[6]. National statistics were used, where available, to account for the input, use and output of N containing products. Sometimes the information is not available from regular statistical series, e.g. the nutrient content of most arable crops, N losses from manure, biological N fixation. In these cases information from miscellaneous sources (experts, technical literature and model calculations) is used. With respect to the natural processes like volatilization, leaching and denitrification, the information at a national level is usually limited because the spatial variation in magnitude and speed of these processes varies widely. Estimation of the amounts of nutrient involved in such natural processes is generally completed by expert advice and adopting other countries' coefficients. Lee et al.[7] reviewed fundamental data and calculation methods; in the following some items are explained. As shown in Table 1, atmospheric deposition of N was 7.3 kg ha^{-1} yr^{-1}, which adopted Japanese coefficient[8]. Biological N fixation coefficients by legume crops and free-living organisms were adjusted differently following as: soybeans and pulses fixed N with the levels of 100 and 80 kg ha^{-1} yr^{-1}, respectively, by OECD estimation[9], and free-living organisms fixed 7.6 kg N ha^{-1} yr^{-1} in paddy soil[10] and 4.0 kg N ha^{-1} yr^{-1} in dry soils and pasture fields (OECD estimation)[9]. Nitrogen loss from manure by destruction and evaporation during the storage and treatment was assumed to be 15% of total N content (OECD estimation)[9]. Nitrogen loss coefficients by denitrification were 70 kg ha^{-1} yr^{-1} in paddy soil and 30 kg ha^{-1} yr^{-1} in upland soil, which adopted from Japanese data[8]. Nitrogen efficiency was calculated by the ratio of total N output to the total N input in an agricultural system[9].

To compare Korean nitrogen balance with Japanese, we studied in detail the data sheet of Japan reported in OECD in 1999[8].

RESULTS AND DISCUSSION

Comparison of coefficients used in calculating N balance

Of composing factors, the important coefficients, which can affect significantly national N balance, were compared in Table 1. Of N input factors, there was big difference in the rates of N destruction and evaporation of manure in stocks and imports between Korea and Japan with 15 and 28%, respectively. Assumption ratio of the ammonia volatilization from livestock manure is varied from 15 to 40% of the total nitrogen among the OECD countries. The majority of OECD countries selected about 15% of the total nitrogen as the ratio of ammonia volatilization from livestock manure, which is recommended by OECD[8,11]. In particular, N loss classified more specifically in German N balance. 28% and 40% of total N of manure are lost by volatilization of liquid and solid manure, respectively[12-14]. With recalculating Korean data with Japanese value (28%), N withdrawal can increase from 48 thousand tones yr^{-1} to 90 thousand tones yr^{-1} in 1997, and therefore around 42 thousand tones yr^{-1} of N input can decrease in our N input. In coefficients to covert livestock number into manure N quantity, OECD guidelines suggested that livestock feeding heads and manure production classify in detail with species, sex, age, and purpose to get more precise products. However, total feeding number and average manure production rate of each livestock were considered simply in Korean data, since the statistics is changeable with time, different with Japanese. For example in Korea, cattle was classified simply with dairy and beef cows, and manure production rates were unified with 60.94 kg $head^{-1}$ yr^{-1} in dairy cow and 27.56 kg $head^{-1}$ yr^{-1} in beef cattle, irrespective with sex, age, weight and etc. In comparison in Japan, cattle were classified with dairy cows and beef cattle, and dairy cows were divided in detail with female < 2years (57.89 kg $head^{-1}$ yr^{-1}) and

Table 1. Comparison of coefficients used in calculating nitrogen surface balances of Korea and Japan

Description	Korea		Japan	
	Value	Source	Value	Source
Livestock manure				
Rate of destruction and evaporation in stocks and imports (%)	15	OECD	28	MAFF
Coefficients to convert livestock No. into manure N quantity (kg head^{-1} y^{-1})				
Diary cow	60.94	MAF	<2 year: 57.89 >2 year: 111.51	MAFF
Beef cattle	27.56	MAF	<2 year: 47.38 >2 year: 53.29	MAFF
Pig	17.60	MAF	<6 month: 12.48 >6 month: 18.62	MAFF
Chicken	0.84	MAF	Broiler: 0.96 Layer: <6 month: 0.26 >6 month: 1.20	MAFF
Coefficients to convert Crops and forages into N uptake (kg tonne^{-1})				
Wheat	21.94	MAF	25.20	MAFF
Rice	19.00	MAF	20.70	MAFF
Barley	19.59	MAF	20.30	MAFF
Soybeans	69.88	MAF	70.90	MAFF
Fruits	6.85	MAF	Citrus: 5.62 Other: 4.95	MAFF
Vegetables	6.08	MAF	4.48	MAFF
Pasture	8.34	MAF	6.70	MAFF
Biological N fixation by leguminous crops (kg ha^{-1} y^{-1})				
Pulses	80	OECD	Adzuki bean: 25.00 Kidney bean: 20.00	MAFF
Soybeans	100	OECD	100	OECD
Biological N fixation by free living organisms (kg ha^{-1} y^{-1})				
Wet paddy	7.6	MAF	37.0	MAFF
Dry field and pasture	4.0	OECD	4.0	OECD
Atmospheric N deposition in agricultural lands (kg ha^{-1} y^{-1})	7.36	MAFF	7.36	MAFF
Denitrification from in agricultural lands (kg ha^{-1} y^{-1})				
Wet paddy	70	MAFF	70	MAFF
Dry field and pastureDry field and pasture	30	MAFF	30	MAFF

Notes) MAF: Ministry of Agriculture and Forestry, Republic of Korea, MAFF: Ministry of Agriculture, Forestry and Fishery, Japan.

> 2 years, which sub-divided with milking cows (111.51 kg head^{-1} yr^{-1}) and dry up cows and heifer (35.15 kg head^{-1} yr^{-1}). In other livestock, coefficients adjusted to convert manure production were similar with those in cattle. Of parameters used in calculating livestock manure production, Korea conversion coefficient in beef cattle was very low (27.56 kg head^{-1} yr^{-1}) compared with Japanese (< 2years: 47.38 kg head^{-1} yr^{-1}, > 2years: 53.29 kg head^{-1} yr^{-1}). Even though this gap might be come from the differences of spices, average weight, feeding stuffs and etc., Korean value would be evaluated to be so low. It is comparable with 39.6-85.3 kg head^{-1} yr^{-1} of 1-2 years old of heifer in European countries[15]. It is required to investigate more precisely in this part to get more real data. Biological N fixation by pulses was 80 kg ha^{-1} yr^{-1} in Korea, which is OECD estimation, higher than 25 kg ha^{-1} yr^{-1} in adzuki bean and 20 kg ha^{-1} yr^{-1} in kidney bean cultivation fields in Japan. In Korea, cultivation area of pulses was just 26-60 thousand hectares during the

investigation, which account for 2-3% of total agricultural land, and therefore biological N fixation scarcely affected in total N input. In contrast, biological N fixation rate by free-living organisms in wet paddy, which affected definitely by soil properties, fertilization, climate condition and etc.[10], was 7.6 kg ha^{-1} yr^{-1} in Korea lower than 37.0 kg ha^{-1} yr^{-1} in Japan. In Korea, 60% of 2,225 thousand hectare of agricultural land was wet paddy field (1,325 thousand hectare) in 1985 and this rate was maintained during the investigation[6]. In Japan, 55% of 5,379 thousand hectare of agricultural land was irrigated rice paddy (2,952 thousand hectare) in 1985 and this rate was continued by 1997[8]. As a result, around 29.6 kg ha^{-1} of N was inputted more by biological N fixation of free-living organisms in wet paddy in Japan than in Korea on N balance calculation.

Of N output factors, there was a little difference between Korean and Japanese coefficients to convert crops and forage into nutrient uptake and composition, but it was ignorable. This difference can come from each regional characteristic like plant species, cultivation methods, weather condition and etc.

Atmospheric N deposition in and denitrification from agricultural lands were calculated with same coefficients in two countries. We did not prepare the coefficients in this part on reporting time and adjusted Japanese data[8] and then have filed up the data for getting more precise national balance.

Comparison of N balance

As shown in Table 2, agricultural N balance of Korea increased significantly from 162 kg ha^{-1} in 1985 up to maximum 257 kg ha^{-1} in 1995. In contrast, Japanese N balance was lower with 140 kg ha^{-1} in 1985 than Korean, increased a little to maximum 158 kg ha^{-1} in 1993 and thereafter decreased continuously to 130 kg ha^{-1} in 1997. The difference of N balances of two countries was a little in the mid of 1980s, but became bigger with time pass, which Korean N balance was higher 100 kg ha^{-1} than Japanese in the recent (1995-1997). The increase of Korean N balance is affected mainly by increasing total N input, rather than by decreasing N output. In comparison, total N input in Japan decreased continuously with time pass.

This N input increase in Korea was mainly due to a high usage of mineral fertilizer in the intensive farming system and increasing livestock feeding. Since

Table 2. Nitrogen surface balances for Korea and Japan, 1985-1997

OECD Code	Description	Thousand tonnes of nitrogen													
		Korea							Japan						
		1985	1987	1989	1991	1993	1995	1997	1985	1987	1989	1991	1993	1995	1997
	NITROGEN INPUTS	**630**	**682**	**716**	**651**	**753**	**773**	**759**	**1448**	**1487**	**1435**	**1400**	**1357**	**1329**	**1236**
F1	Fertilizers	414	451	483	403	477	472	446	729	755	700	675	638	638	568
	Net Input of Manure (M11-M21)	164	178	181	202	231	259	273	518	530	536	530	532	509	488
M11	Livestock Manure Production	193	210	213	238	272	304	321	788	808	817	808	811	777	752
M21	Withdrawals	29	31	32	36	41	46	48	270	277	281	277	279	267	264
	Other Nitrogen Inputs	51	53	52	46	45	42	41	201	202	199	195	186	181	179
D1	Atmospheric Deposition	16	16	16	16	16	15	15	40	39	39	38	38	37	36
B1	Biological Nitrogen Fixation	33	34	33	28	27	26	25	158	160	157	153	146	142	141
C11	Seeds and Planting Material	2	2	2	2	2	2	2	4	3	3	3	3	2	2
	NITROGEN OUTPUTS	**269**	**262**	**283**	**253**	**244**	**245**	**262**	**694**	**678**	**661**	**621**	**546**	**615**	**595**
C21	Total Harvested Crops	252	244	265	235	229	232	249	463	442	426	384	326	381	368
C22	Total Forage	17	18	18	18	16	13	13	230	236	235	237	220	233	226
	BALANCE (Inputs minus Outputs)	361	420	433	398	509	528	498	754	809	774	779	811	714	641
	Nitrogen balance in kg ha^{-1} of total agricultural land	**162**	**188**	**195**	**183**	**239**	**257**	**250**	**140**	**152**	**147**	**150**	**158**	**142**	**130**
D2	Denitrification	120	121	121	119	116	110	106	254	245	241	237	239	235	226
	Nitrogen balance excluding denitrification in kg ha^{-1} of total agricultural land	**108**	**134**	**141**	**128**	**184**	**204**	**197**	**93**	**106**	**101**	**104**	**112**	**95**	**84**
	Nitrogen efficiency (%)	43	38	40	39	32	32	34	48	46	46	44	40	46	48

the national arable land area is small, which accounts for only 24% of the total land area in Korea, maximizing agricultural productivity is essential to us. For this, the application rate of chemical fertilizers has been increased rapidly from the latter half of 1960s and reached the maximum in the mid of 1990s[16]. On the other hand in Japan, inorganic fertilizer consumption decreased continuously with time lapse during the investigation (Table 2). Inorganic N consumption rate in total agricultural land was 186 kg ha^{-1} in 1985 in Korea, which was comparable with 126 kg ha^{-1} in Japan (Fig. 1). It increased to 224 kg ha^{-1} in 1997, but Japanese N fertilizer consumption rate decreased contrary to 100 kg ha^{-1}. Permanent pasture area is very small in Korea, which accounts for only 3-4% of the total agricultural land in Korea, but comparatively smaller than that in Japan with 12-13% of agricultural land. Generally speaking, fertilization level in the pasture is lower than that in arable land. The lower portion of pasture would be one of the causes on the higher consumption rate of chemical fertilizers in Korean arable land than in Japan. Our nitrogen input by inorganic fertilizer accounted for 66% of total N input in 1985 and decreased continuously after 1990 to lees than 60% in 1997. Comparatively in Japan, N input by fertilizers was around 50% of input in 1985 and thereafter decreased slowly to 46% in 1997. In Korea, following a number of policy measures, such as the implementation of precise fertilizing system by soil diagnosis, and the supply of environment friendly fertilizers (e.g. slow release fertilizers, complex fertilizers

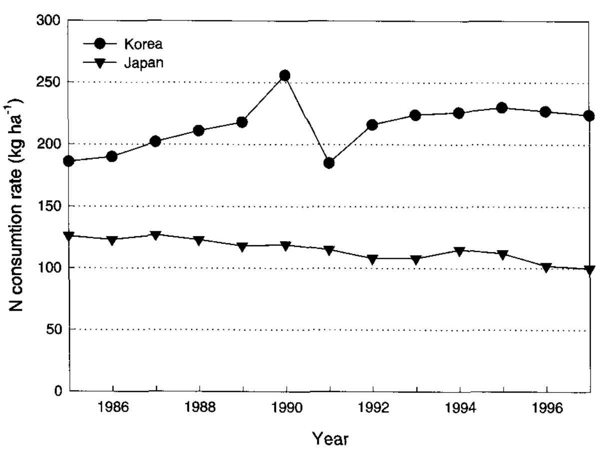

Fig 1. Changes of chemical fertilizer application rate in agricultural land of Korea and Japan.

contained low content of nitrogen and phosphorus, and etc.), N fertilizer input rate has decreased slowly since 1996[17], but this is one of the highest levels in the worldwide countries till now[18]. Nitrogen fertilizer application rate was 170 kg N ha^{-1} in Korean rice paddy, which is the highest level of rice cultivation countries in the world and comparable with 83 kg N ha^{-1} in Japan[19]. Out of concern for environmental protection, the Korean government introduced the "Policy for Promoting Environmentally Friendly Farming" in 2001, and therein established the national goal to reduce the chemical fertilizer utilization amounts by 70% of the 1998 levels by 2004[17]. In spite of this positive attempt by the Government, the chemical fertilizer consumption rate calculated from statistical data scarcely decreased[20]. Korean government should induce more powerful policy to decrease nitrogen surplus.

Of N input factors, N input by organic sources recycled from industrial sides such as sludge, organic wastes and etc. were not included in this calculation in Korea, since there was not reliable statistics data, but included in Japanese data with 70-80 thousand tones of N a year in 1986-1997, which accounted for 5-6% of total N input. Including N input by organic fertilizers on calculating nutrient balance, Korean N balance should be calculated to be much higher. To get the more precise nutrient balance in a national scale the more exact statistics will be required in organic fertilizer consumption.

The second highest N input source was livestock manure in Korea. In the latter of 1980s in Korea, N input by manure was about 26% of input, increased significantly after 1990 and then reached to 36% in 1997. In Japan, N input ratio by manure was higher with 36% of input than that in Korea from the initial stage of this investigation, and then this level was maintained. As shown in Fig. 2, the changes of animal feeding densities were so different between Korea and Japan. Animal feeding density (head ha^{-1}), which calculated by animal numbers in total agricultural land, increased with time pass in Korea during the investigation, but there was little change in Japan. For example in Japan, the feeding densities of cattle, pig and poultry were 874, 1,993, and 60,921 heads per 1000 hectare in 1985, respectively, and these levels were scarcely changed during the investigation. In contrast in Korea, cattle feeding numbers per 1000 hectare of agricultural land was 1,323 in 1985 and then increased to 1,655 in 1997, even though there was fluctuated somewhat in the late of 1980s, but pig and poultry feedings increased significantly with time pass during the investigation. In recent, the increase of N balance in Korea was significantly affected by increasing livestock feedings rather than chemical fertilizer consumption, and therefore the reduction of livestock feeding density would be essential to decrease nutrient balance in national scale. According to EU Directive, N from livestock manure must not exceed 170 kg ha^{-1} [21,22]. Korean N net input by this manure was about 137 kg ha^{-1} in 1997, less than the limitation of EU Directive, but manure in the intensive livestock feeding system of Korea can accumulate in a limited area and then make an environmental pollution problem.

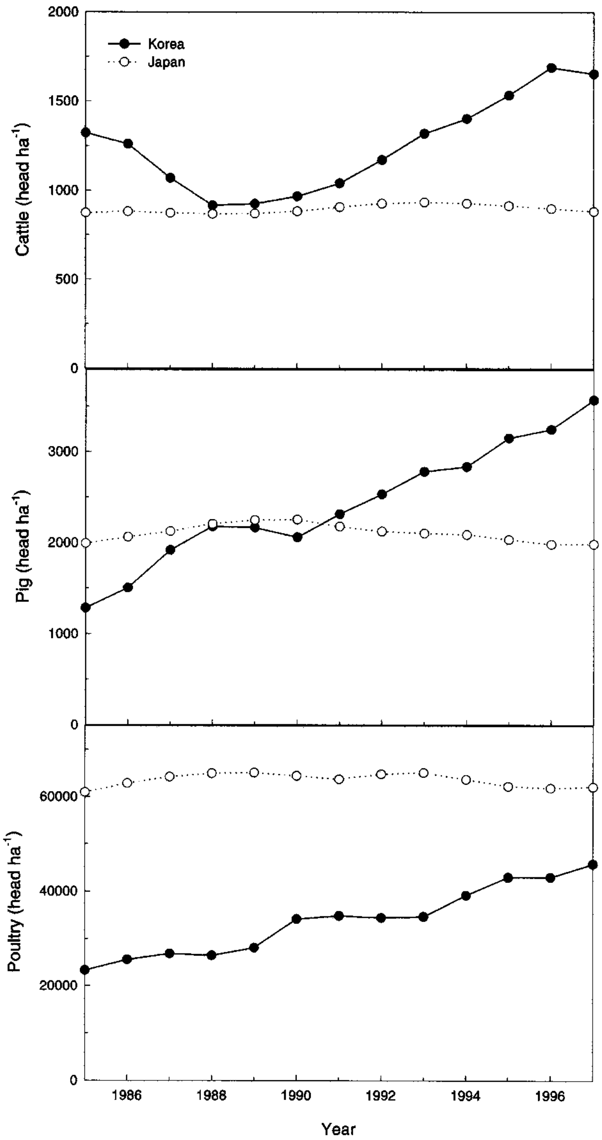

Fig. 2. Changes of livestock feeding densities in Korea and Japan.

Nitrogen output showed somewhat different tendency between Korea and Japan. In Korea, a most of N was outputted by crop production and only 5-7% of N output was removed by forage production. In contrast in Japan, 67 and 33% of N were outputted by crop and forage production in 1985, respectively. With time pass, N removal portion by crop removal decreased continuously to 62% of output in 1997, but by forage production increased comparatively to 38%. Due to the high N surplus, N efficiency, which means the nitrogen recovery rate by crop and forage production, was decreased with time lapse and showed very low level with 43% in 1985, and then continuously decreased to 32-34% in the latter of 1990s in Korea. As a result, around 60% of inputted nitrogen could be lost from agricultural sides, and then be air and watershed contamination sources. In compare in Japan, N efficiency was higher with 44-48% except 1993 than that in Korea and not changed during the investigation.

To compare directly with Japanese N balance, we tried to recalculate our N balance by using Japanese parameters: coefficient of convert beef cattle number into manure N quantity (50.3 kg $head^{-1}$ yr^{-1}), biological N fixation by free living organisms in wet paddy (37.0 kg ha^{-1} yr^{-1}), and rate of N destruction and evaporation of manure in stocks and imports (28%). About 20 kg ha^{-1} of N balance was increased more. As a result, modified N balance was 269 kg ha^{-1} in 1997, which means over 130 kg N ha^{-1} higher than in Japan can release from our arable lands to environment.

Korean N balance is the second highest level next to the Netherlands in OECD countries[1,7,9]. Unfortunately, our average N balance increased significantly with time pass from 173 kg ha^{-1} in 1985-87 to 253 kg ha^{-1} in 1995-97, which comparable with Japanese decreased from 145 kg ha^{-1} in 1985-87 to 135 kg ha^{-1} in 1995-97[9]. On considering nitrogen loss by denitrification in wet paddy, Korean N balance was around 200 kg ha^{-1} in 1995-97 (Table 2), but it was still the highest level of OECD countries. Most other OECD countries have also experienced substantial reductions in N surpluses over the past decade, most notably in Demark, Germany, Greece, Italy, the Netherlands, Sweden, Switzerland and the United Kingdom[9,11]. To reduce more effectively our nutrient balance, the stronger strategy might be required in the national scale.

Although there are many points to be more specified and improved, still, we confirmed in this preliminary analyzing result that Korean N balance was very higher than Japanese level, which has similar farming system each other. This was caused mainly by the higher rate of chemical fertilizer consumption and by steeply growing animal feeding density in recent in Korea. To improve soil sustainability and environment soundness, the strategy for integrated nutrient management and regulating livestock feeding number should be established in the government sides.

REFERENCES

1. Parris, K. (1998) Agricultural nutrient balances as agri-environmental indicators: an OECD perspective. Environmental Pollution 102 (S1): 219-225.
2. EUROSTAT (1997) Soil Surface Nitrogen balances in EU Countries, by Claude Vidal and Maria Pau Vall. Document Agrienv/97/2 Table Annexes Joint EUROSTAT/EFTA workshop on nitrogen balances, 13-14 February 1997, Luxembourg.
3. PARCOM (1995) PARCOM guidelines for calculating mineral balances. Oslo and Paris conventions for the prevention of marine pollution programs and measures committee (PRAM), Oviedo, 20-24 February 1995. 6 p.
4. Bomans, E., Vanongeval, L., Vandendriesseche, H., and Geypens, M. (1996) Development of Indicator for Agricultural Nutrient Balances for the OECD, Report No.: 96/AC/010 (prepared by the Soil Service of Belgium, for the Ministry of the Flemish Community; Environment and Infrastructure Department; Environment, Nature, Land and Water Management Administration); Brussels, Belgium.
5. PARCOM (Paris Convention for the Prevention of Marine Pollution) (1993) Third meeting of the ad hoc working group on measures to reduce the nutrient load from agriculture. Annex 5: PARCOM guidelines for calculating mineral balances, The Hague, 15-18 February 1993. 8 p.
6. MAF (Ministry of Agriculture and Forestry, Republic of Korea) (1986-1998) Statistical Yearbook of Agriculture and Forestry. Seoul.
7. Lee, C.S., Kim, P.J., Park, Y.H., and Kwak, H.K. (2000) Determination of nitrogen balance of agricultural land among OECD nutrient balance indexes. J. Korean Soc. Sci. Fert. 33(5): 347-355.
8. MAFF (Ministry of Agriculture, Forestry and Fishery, Japan) (1999) Agricultural Nitrogen Balances Provisional Calculation Sheet. *In* OECD Agri-Environmental Indicator Database. (restricted access to Electronic Discussion Groups, www.olis.oecd.org).
9. OECD (2001) OECD National Soil Nitrogen Balances: Preliminary Estimates 1985-1997, Paris, France. Available at: www.oecd.org/agr/env/indicators.htm.
10. NIAST (National Institute of Agricultural Science and Technology, Korea) (1983) Enhancing biological nitrogen fixation in rice paddy soil. *In* Annual Research Report in 1993. Suwon, Korea. 813-837 (in Korean).
11. OECD (2001) Use of Farm Inputs and Natural Resources. *In* Volume 3. Methods and Results, Environmental Indicators for Agriculture. OECD. Paris, France. pp. 116-139.
12. Bach, M. and Frede, H.G. (1998) Agricultural nitrogen, phosphorus and potassium balances in Germany Methodology and trends 1970 to 1995. Z. Pflanzenernhr. Bodenk., 161: 385-393.
13. Bach, M., Frede, H.G., and Lang, G. (1997) Entwicklung der Stickstoff-, Phosphorus- und Kaulium-Bilanz fr die Landwirtschaft in der Bundesrepublik Deutschland (Studie im Auftrag des Bundesarbeitsreis Bngung, Frankfurt a.M.). Gesellsch. F. Boden- unf Gewsserschutz e.V., Wettenberg, 77 p.
14. Bach, M., Frede, H.G., and Lang, G. (1997) Handbuch N-, P-, K-Bilanzierung. Gesellsch. F. Boden- und Gewsserschutz e.V., Wettenberg, 77 p.
15. van Eerdt, M.M., and P.K.N. Fong (1998) The monitoring of nitrogen surpluses from agriculture. Environmental Pollution 102, S1, 227-233.
16. Park, Y.H., Y. Lee, S.C. Kim, J.S. Noh, and J.Y. Lee (2002) Application effects and vision of bulk blending fertilizers in framing fields. 2002 Symposium On DevelopingBulk Blending Fertilizer (BB). 1 November, 2002. Chonnam National University. Kwangju, korea. 19-46. (*in Korean*)
17. MAF (2001) Five Year Plan to Promote Environmentally Friendly Farming. Kwachon, Korea, pp. 30. (*in Korean*).

18. Park, Y.H. (2001) Soil management in upland soil. 2001 International Symposium on Soil and Water Management. 12-13 October, 2001, Suanbo Sangrok Hotel, Korea. 88-119. (*In Korean with English summary*).
19. Harris, G. (1998) An analysis of global fertilizer application rates for major crops. IFA Annual Conference. Toronto, Canada. (http://www.fertilizer.org/ifa/publicat/PDF/1998_biblio_18.pdf)
20. MAF (2000) Statistical Yearbook of Agriculture and Forestry. Seoul.
21. Brouwer, F.M., Godeschalk, F.E., Hellegers, P.J.G.J., and Kelholt, H.J. (1994) Mineral Balances of the European Union at Farm Level, Agricultural Economics Research Institute, The Hague, The Ntherlands.
22. Leuck, D., Haley, S. (1995) The EU Nitrate Directive and CAP Reform, Effects on Agricultural Economic Report No. 255, Economic ResearchService, US Department of Agriculture, Washington, DC.