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Nitrogen Efficiency in Agriculture in Europe and India

Klaas W. Van der Hoek

National Institute for Public Health and the Environment, RIVM, P.O. Box 1, NL-3720 BA Bilthoven, The Netherlands

Nitrogen balance sheets are useful tools for studying the quantitative aspects of nutrients. Nitrogen balance sheets have been prepared for the animal production system, crop production system, and for the agricultural sector as a whole for all 15 member states of the European Union (EU15) and for the Indian subcontinent. The EU15 and India were chosen for this study on nitrogen efficiency using balance sheets because they each occupy roughly 300 million ha of land and use about 65 kg nitrogen fertiliser per hectare of agricultural land. Balance sheets were constructed for three systems: animal production, crop production, and the agricultural sector as a whole. In addition to detailed descriptions of the nitrogen balance sheets, brief recommendations for reducing nitrogen surpluses are also given. Surprisingly, the balance sheets for crop production and the agricultural sector as a whole showed a surplus of about 60 kg of nitrogen per hectare of agricultural land.

KEY WORDS: animal production, animal manure, nitrogen fertiliser, crop production, nitrogen efficiency, nitrogen surplus, human diet, EU15, India

DOMAINS: plant sciences, agronomy, global systems, environmental sciences, environmental management and policy, environmental modeling, environmental monitoring, information management

INTRODUCTION

Nitrogen is an essential nutrient for agricultural production. In crop production, plants require nitrogen for biomass production, while animals require nitrogen for maintenance, growth, reproduction, production of milk, eggs, wool, and labour (draft animals). Harvested biomass from crop production is used as human food or animal feed. Some types of agricultural biomass like grass and fodder, and green crops, are suitable only for ruminating animals. Some types of harvested biomass such as oil crops must be processed before human consumption, with the residues being fed to animals. Finally, some crops, like cereals, can be used for both human and animal consumption. This paper focuses on the nitrogen efficiency in three distinct systems: animal production, crop production, and the agricultural sector as a whole. Nitrogen efficiency is calculated by constructing nitrogen balance sheets for these three systems. Each balance sheet is characterised by system boundaries. The systems are interrelated; output from one balance sheet is input for another. For example, animal manure as output serves as input for fertilisation of crops.

The surplus of nitrogen on the balance sheets constructed for crop production and the agricultural sector remains behind in both systems and is subject to loss or accumulation in the soil. Nitrogen losses are in volatile form, for example, ammonia (NH_3), nitrous oxide (N_2O) and di-nitrogen (N_2), or in the form of nitrate (NO_3) leaching and runoff. Improving nitrogen efficiency in the agricultural sector lowers the nitrogen surplus on the balance sheet and also lowers nitrogen emissions.

Nitrogen balance sheets can be used on different scales, ranging from farm and catchment level to county and country level[1,2,3,4]. In this paper calculations are made for the 15 European Union states, consisting of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg,

E-mail: klaas.van.der.hoek@rivm.nl

the Netherlands, Portugal, Spain, Sweden, and the U.K., and for India. For reasons of compatibility all data used have been taken from the FAOSTAT database, with 1998 as the reference year[5].

AGRICULTURE AND HUMAN FOOD IN THE EU15 AND INDIA

The EU15 and India each occupy roughly 300 million ha of land. Their respective use of nitrogen fertiliser is about the same when expressed per hectare of agricultural land (see Table 1). Nitrogen fertiliser is used on 30 million ha of permanent pasture in the EU15 and the average fertiliser input is 93 kg/ha of fertilised grassland[6].

There is a great discrepancy in number of inhabitants between the EU15 and India, and also in the food intake and composition of the average human diet (see Table 1). Whereas the average food intake in EU15 is 3439 cal per capita per day and the protein intake is 6.19 kg N/year, the respective corresponding values for India are 2399 cal per capita per day and 3.33 kg N/year. Moreover, the share of protein from animal products is 60% in the EU15 and 17% in India. Globally, animal products contribute 37% to the human protein consumption.

NITROGEN BALANCE SHEET ON ANIMAL PRODUCTION

The system boundaries on the animal production balance sheet are the animals themselves, without the corresponding land area. The size of the animal population in the EU15, India, and the world is given in Table 2. The animal production balance sheet (Table 3) starts with the calculation of the amount of nitrogen contained in animal products (meat, milk, eggs, and wool). Table 4 details their production by category of animal, such as dairy cattle, chickens, and so on. The next step is the calculation of the nitrogen contained in animal manure and urine (Table 5). The nitrogen excretion rates for cattle were calculated using standard feeding tables for the minimum protein requirement for maintenance and production of milk and meat. The calculated intake of nitrogen by animals was reduced by the amount of nitrogen in animal products, under the assumption that the remaining nitrogen was excreted by the animal[7,8]. These values compare well with the literature[9,10,11,12]. The nitrogen excretion rates for pigs and poultry were taken from the Dutch literature[7,8] and are in line with other European values[13,14,15,16]. With regard to biological production, it is assumed that pigs and poultry in India have similar excretion rates to pigs and poultry in the

TABLE 1
Land Use, Fertiliser Consumption, Human Population, and Human Food Intake in EU15, India, and the World in 1998

	EU15	India	World
Area[a]			
Total land area	313.2	297.3	13,048
Agricultural land	142.5	180.6	4,938
Arable land	75.6	161.5	1,380
Permanent crops	10.9	8.0	132
Permanent pasture	56.0	11.1	3,427
Fertiliser			
Total N input[b]	9,697	11,354	82,421
Total N input per agricultural land[c]	68	63	
Human population[d]	375	982	5,901
Human food intake			
Food intake[e]	3,439	2,399	2,798
Protein intake[f]	6.19	3.33	4.38
Vegetable products	2.45	2.75	2.74
Animal products	3.74	0.58	1.64
Share animal products	60%	17%	37%

[a] Million ha.
[b] Million kg.
[c] kg N/ha.
[d] In millions.
[e] Calories per capita per day.
[f] kg N per capita per year.

Source: FAO (2001) FAOSTAT database collections. FAO, Rome. Available on the Internet at http://www.apps.fao.org.

TABLE 2
Number of Animals
in EU15, India, and the World in 1998

Animal Category	EU15	India	World
Cattle	83.2	212.1	1338.8
Dairy	21.5	35.0	224.1
Non-dairy	61.7	177.1	1114.7
Buffalo	0.16	90.1	160.7
Sheep	115.9	57.1	1055.2
Goats	12.1	121.4	698.0
Pigs	120.6	16.0	880.4
Chickens	1,005	375	13,219
Horses	2.2	1.0	58.5
Asses	0.41	1.0	43.2
Mules	0.22	0.20	13.5
Camels	—	1.0	19.2

Note: Numbers are given in millions.

Source: FAO (2001) FAOSTAT database collections. FAO, Rome. Available on the Internet at http://www.apps.fao.org.

TABLE 3
Nitrogen Balance Sheets for Animal Production,
Crop Production, and the Agricultural Sector in EU15 and India in 1998

EU15 INPUT		EU15 OUTPUT		INDIA INPUT		INDIA OUTPUT	
Animal Production				**Animal Production**			
Feedstuffs	4.227	Animal products	2.167	Feedstuffs	3.266	Animal products	0.625
Consumed grass	6.378	Animal manure	8.439	Consumed grass	1.337	Animal manure	15.404
				Consumed in forests	4.000		
Unaccounted-for N				Unaccounted-for N	7.426		
Total	10.606	Total	10.606	Total	16.029	Total	16.029
Crop Production				**Crop Production**			
Fertiliser	9.697	Harvested crops	4.705	Fertiliser	11.354	Harvested crops	6.039
Animal manure	8.439	Consumed grass	6.378	Animal manure	5.135	Consumed grass	1.337
N-fixation	1.300			N-fixation	1.650		
Unaccounted-for N		Surplus	8.353	Unaccounted-for N		Surplus	10.763
Total	19.436	Total	19.436	Total	18.139	Total	18.139
Agricultural Sector				**Agricultural Sector**			
Fertiliser	9.697	Animal products	2.167	Fertiliser	11.354	Animal products	0.625
N-fixation	1.300	Crop products	2.384	N-fixation	1.650	Crop products	5.611
Feedstuffs	1.906			Feedstuffs	6.838	Animal manure	10.269
Unaccounted-for N		Surplus	8.353	Unaccounted-for N	7.426	Surplus	10.763
Total	12.904	Total	12.904	Total	27.268	Total	27.268

Note: Amounts given in Tg N (1 Tg = 10^{12} g).

TABLE 4
Animal Production in EU15, India, and the World in 1998

Animal Category	EU15	India	World
Meat Production			
Beef and veal	7647	1400	55,078
Buffalo	1.5	1380	2949
Horses	87		660
Sheep	1065	226	7403
Goats	89	462	3479
Pigs	17,711	543	87,647
Chickens	8757	540	61,688
Milk Production			
Dairy cattle	121,965	35,500	483,060
Buffalo	156	35,850	58,200
Sheep	2186		8067
Goats	1560	3150	12,032
Egg Production	5368	1658	48,000
Wool Production	182	44	2371

Note: Amounts given in million kg.

Source: FAO (2001) FAOSTAT database collections. FAO, Rome. Available on the Internet at http://www.apps.fao.org.

TABLE 5
Nitrogen Excretion (in kg N) Per Animal Per Year for the Main Animal Categories

Animal Category	EU15	India
Dairy cattle	100	60
Non-dairy cattle	50	40
Young cattle	46	25
Suckling cows	80	60
Beef cattle	40	
Draft cattle		40
Buffalo		45
Sheep	10	10
Goats	9	9
Pigs	11	11
Chickens	0.5	0.5
Horses	50	45
Camels		55

Sources: Van der Hoek, K.W. and Couling, S. (1996) Manure Management, SNAP code 100500. In Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook. 1st edition. G. McInnes, Ed. European Environment Agency, Copenhagen. p. B1050.1–B1050.16. and Van der Hoek, K.W. (1998) Nitrogen efficiency in global animal production. *Environ. Pollut.* **102** Suppl. 1, 127–132.

EU15. In summing, the amount of nitrogen in animal products and animal manure in this study was assumed equal to the total nitrogen intake in feed ingested by all animals.

Partitioning feed nitrogen between feedstuffs and consumed grass is based on assumptions on the share of consumed grass in the total intake. For the EU15, cattle are assumed to have a share of 80%, whereas for horses, sheep, and goats this share is 95%. The remaining nitrogen for these animal categories is produced as feedstuffs. The feed demand of pigs and chickens is supplied by 100% feedstuffs. The calculated nitrogen in consumed grass corresponds with an animal intake of 115 kg N/ha of grassland, which is a reasonable figure. The animal feeding situation in India is based on a literature survey[17,18,19,20,21,22,23]. The share of grass that the animals consume is assumed at 10% for cattle, horses, sheep, and goats, and 5% for buffalo. The share of feedstuffs in the ration is assumed to be 5% for sheep and goats, 10% for cattle and buffalo, and 67% for pigs and chickens. The feedstuffs are supplemented with crop residues, assumed to be 25% of the harvested crops. Animals grazing in forests consume grass with an estimated nitrogen uptake of 4 Tg, about three times more than the uptake from permanent pastures. Totalling feedstuffs and consumed grass in pastures and forests shows that 7426 Tg N is not accounted for. Home gardens, backyard plots, and residues from the kitchen, roadsides, and arable land provide part of this unaccounted-for nitrogen. In the balance sheet the amount of unaccounted-for nitrogen is 46% of the total calculated animal intake. This value is comparable with other studies, which show protein deficits of up to 50%[21,24].

The nitrogen efficiency is calculated as the ratio of nitrogen output in products to nitrogen input in feed. From the animal production sheet it can be calculated that nitrogen efficiency values for EU15 and India are 20 and 4%, respectively. The low value for India is explained by the relatively low beef and veal meat production and by the use of buffalo as draft animals. Draft animals produce power and consume feed but do not gain weight[25].

NITROGEN BALANCE SHEET ON CROP PRODUCTION

The second balance sheet shown in Table 3 comprises crop production, which includes harvested crops and consumed grass. It is emphasised that only the amounts of nitrogen that effectively leave the arable field or pasture are taken into account. This means that crop residues left in the field and spilt grass are not considered. Crop production in the EU15, India, and the world is presented in Table 6, while the amount of consumed grass has already been discussed in the foregoing section. The nitrogen supply in the EU15 consists of fertiliser, animal manure, and N fixation, this last factor based on a global N fixation of 45 Tg of nitrogen[26]. The amount of fixed nitrogen in the EU15 and India is assumed to be proportional to the agricultural land. For India it is assumed that only 33% of the manure is used as fertiliser[27,28]. Some of the manure is produced outside the crop production system, in forests and on roadsides, while another part is used as fuel and thus leaves the crop production system.

Nitrogen efficiency is indicated by the ratio of nitrogen output in harvested crops and consumed grass to nitrogen input in fertiliser, animal manure, and nitrogen fixation. From the crop production sheet (Table 3) nitrogen efficiency in the EU15 and India is calculated at 57 and 41%, respectively. The lower value for India can most likely be explained by the relatively high fertiliser losses in rice production due to high ammonia volatilisation losses caused by application of urea fertiliser[29].

NITROGEN BALANCE SHEET ON THE AGRICULTURAL SECTOR

The third balance sheet envelops all agricultural activities (see Table 3). Most entries are taken from the animal and crop production sheets. Part of the harvested crops are fed to animals and another, smaller, part is used as seed for the next crop; these quantities do not leave the agricultural sector. The amounts for feed and seed are taken from the FAO Commodity Balances and subtracted from the harvested crops[5]. The animal production balance sheet shows the required amount of feedstuffs. The amount not delivered by harvested crops has to be supplied from outside the agricultural sector (for example, from by-products of food and oilseed processing).

The amount of feedstuffs on the balance sheet for India includes the nitrogen uptake in forest grazing. As mentioned in the previous section, only 33% of the animal manure is used as fertiliser in crop production, so 67% of the manure is recorded as an output entry on the balance sheet. Nitrogen efficiency is defined as the ratio of nitrogen output in products leaving the agricultural sector to nitrogen input from an external origin, such as fertiliser, nitrogen fixation, and external animal feed. The overall nitrogen efficiency in the agricultural sector of the EU15 is 35%; for India, 23%. With reference to the remarks already made on the animal and crop production sheets, this sounds reasonable.

THE FATE OF THE NITROGEN SURPLUS

The nitrogen balance sheets for animal production, crop production, and the agricultural sector, as discussed in previous sections, are presented in Table 3. The balance sheets from crop production and the agricultural sector as a whole display the same surplus quantity. This is not surprising because their system boundaries are the same: total agricultural land. This phenomenon of equal surpluses can be used in reverse as a check on the calculations. Dividing the surplus by the total agricultural land results for the EU15 in a surplus of 59 kg N/ha and for India, in 60 kg N/ha. These are average figures, but it is evident that both EU15 and India have locations with higher surpluses per hectare as well as locations with lower surpluses per hectare. The nitrogen surplus is subject to loss as NH_3, N_2O, N_2, and NO_3; the remainder is accumulated in the soil. Ammonia emissions present an environmental threat, and volatilised ammonia means a financial loss for the farmer[29,30]. Ammonia emissions are not taken into account in these balance calculations. The majority of the emitted ammonia will be deposited on agricultural lands. The nitrogen in the ammonia leaving the agricultural system is assumed to be replaced by NO_x deposition. EU15 and Indian greenhouse

TABLE 6
Crop Production in EU15, India, and the World in 1998

Crop Category	N Content[a]	EU15	India	World
Cereals	16	213,649	226,946	2,081,766
Starchy roots	3	43,750	24,848	641,669
Sugar crops	2	115,260	262,090	1,522,824
Pulses	35	5827	12,972	56,032
Oil crops				
Soybeans	59	1582	6942	159,957
Groundnuts	40	3	9160	34,320
Sunflower seed	28	3589	1170	25,318
Rapeseed	35	9556	4703	35,842
Seed cotton	30	1523	6223	51,723
Vegetables	2	53,698	57,096	624,271

Note: Amounts given in million kg.

[a] Nitrogen content in crop products is expressed as g N/kg and values are taken from the literature[52,53].

Source: FAO (2001) FAOSTAT database collections. FAO, Rome. Available on the Internet at http://www.apps.fao.org.

gas emissions of agricultural origin amount to 683 and 234 Gg N_2O, and to 8551 and 14,760 Gg CH_4, respectively[30,31,32,33]. Converted to CO_2-equivalents, the agricultural emissions in the EU15 and India are 391 and 382 Tg CO_2-equivalents, respectively.

Nitrate leaching affects the quality of the groundwater. While standards on the nitrate content are set to ensure the use as drinking water for humans and animals, high levels of nitrate are found in the EU15 as well as in India [3,34,35].

CLOSING THE NITROGEN CIRCLE

Much research is devoted to more efficient nutrient use in agriculture. Some research focuses on improvement of animal production systems[17,36,37,38,39,40] and crop production systems[41]. Other research is devoted to the role of animals in global food production [42,43] and global food production in the next decades[44,45,46].

Promising means for improving nitrogen efficiency are (1) more efficient use of nitrogen fertiliser and animal manure by preventing loss of ammonia[29,47] and (2) more efficient use of animal feeds by providing feed to growing animals in sufficient quantities (feeding above maintenance level of the animal means that feed is available for production of meat and milk)[8,17].

Another aspect is the ratio of animal to vegetable products in the human diet[48]. Changing the human diet in European countries by lowering the share of animal protein will decrease the demand for and production of animal products, which will, in turn, lead to increased nitrogen efficiency in the agricultural system.

Finally, environmental costs of animal and crop products differ in terms of greenhouse gas emissions[49,50,51]. Beans, potatoes, and cereals have relatively low greenhouse gas emissions, followed by tomatoes grown in greenhouses; pork and rice have relatively high greenhouse gas emissions. The composition of the human diet therefore has an impact on global climate change.

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BIOSKETCH

Klaas W. Van der Hoek is senior scientist at RIVM, the Dutch National Institute for Public Health and the Environment in Bilthoven. His activities include the coordination of the agricultural emission data for the annually published Environmental Balance. Klaas graduated with a M.Sc. in food technology from the Wageningen Agricultural University, The Netherlands in 1975. After working for 15 years on environmental issues in several national extension services of the Dutch Ministry of Agriculture, Nature Management and Fisheries he assumed a position in 1991 at RIVM. His activities there have included Conference Secretary and Proceedings Editor for the First International Nitrogen Conference held in Noordwijkerhout, The Netherlands in March 1998. His current research interests are nutrient balances, sustainable animal and crop production systems, and use of animal manure.