Diffuse Pollution by Livestock Production Systems and Manure Management

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Abstract

Manure management systems are conducive to nutrient and carbon losses, but the magnitude of the loss highly depends on the nutrient element, the manure management system and the environmental conditions. The aim of this paper is to contribute to the understanding of the diffusive nutrient losses. Firstly, we discuss the main mechanisms loss path ways of nutrients from manure management systems to groundwater, surface waters and air, using some data from the European Union (EU-27). Secondly, we discuss possible measure to decrease diffuse pollution and to increase the environmental performance of livestock production and manure management. Finally, we give some policy recommendations.

In general, losses from animal manure decrease in the order: C, N >> S > K, Na, Cl, B > P, Ca, Mg, metals. The total N excretion by livestock in EU-27 was ~10400 kton in 2000. About 65% of the total N excretion was collected in barns and stored for some time prior to application to agricultural land. Almost 30% of the N excreted in barns was lost during storage; approximately 19% via NH_3 emissions, 7% via emissions of NO, N_2O and N_2 to the air and 4% via leaching and run-off from manure storage systems. Another 19% of the N excreted in animal housing systems was lost via NH_3 emissions following the application of the manure to land. The results indicate that maximally 52% of the N excreted in barns was effectively recycled as plant nutrient. Various emission abatement measures can be implemented and have been implemented already in some Member States to reduce the emissions of NH_3 and N_2O, and the leaching of N and P. There is large scope to decrease diffuse pollution by livestock production systems through policy and measures and improved management, but the economic costs are relatively high.

Keywords: ammonia, diffusive losses, environmental policy, European Union, manure management, nutrients, nitrogen, nitrate, nitrous oxide, phosphorus

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1. Introduction

Livestock production systems exert various influences on the environment. The influences greatly depend on the livestock production system itself, the management and the environmental conditions. Much of the influence of livestock systems on the environment occurs via its effects (direct and indirect) on land use (changes) and nutrient element cycling. These effects have increased greatly over the last decades, particularly in response to the current trends in livestock production: up-scaling, intensification, specialization and regional conglomeration (Foley *et al*., 2005; Naylor *et al*., 2005; Steinfeld *et al*., 2006).

Though the global picture of the impact of the intensification of livestock production on the environment has become clearer during the last years, many of the complex relationships between livestock production systems and environmental impact are not yet well-understood. This holds especially for the fate of nutrients and carbon from the livestock manure, as little is known about the management of manure in practice. There is a huge diversity in livestock production systems, and there is a wide variety in the management of these systems. This diversity in systems and in management contrasts with the small number (14) of types of domestic animals in the world, and especially with the small number of types of the most important categories (from an economic point of view): cattle, pigs and poultry (Diamond, 2002). Though livestock consumes less than 3% of the global net primary production (Smil, 2002), its contribution to the global burden of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere ranges between 10 and 40% (Bouwman *et al*., 1997; Oenema and Tamminga, 2005). Globally, livestock excretes about 100 Tg (range 70-140 Tg) nitrogen (N) per year, but only 20-40% of this amount is recovered and applied to crops (Sheldrick *et al*., 2003; Oenema and Tamminga, 2005). The remainder is dissipated into the environment. The estimated amounts of phosphorus (P) and potassium (K) in livestock manure are 1.5 and 3 times the current amounts of P and K in mineral fertilizers (Sheldrick *et al*., 2003), but only a fraction of manure P and K is efficiently utilized. In general, the potential for recycling the nutrients from animal manure effectively is not fully realized and seems difficult to realize fully without drastic improvements in manure management, use of environmental technology, and restructuring conglomerations of landless livestock production systems (Sims *et al*., 2005). The total amounts of N and or P excreted per unit surface area are proper indicators for the environmental pressure of livestock production systems. Fig. 1 shows the mean spatial distribution of P from livestock in the world. Clearly, livestock is unevenly distributed over the globe. There are large concentrations in parts of China (especially pigs and poultry), Europe (cattle, pigs and poultry), India (cattle), and to a smaller extent America (cattle, poultry pigs).

The aim of this paper is to contribute to the understanding of diffusive nutrient losses from livestock production and manure management to the environment. Firstly, we discuss the main mechanisms loss path ways of nutrients from manure management systems to groundwater, surface waters and air. Secondly, we discuss possible measure to decrease diffuse pollution and to increase the environmental performance of livestock production and manure management. Finally, we give some policy recommendations.

2. Nutrient losses from manure and its environmental impacts

Elements are lost from livestock manure management systems at different rates. Roughly, the descending order is as follows: C> N >> S > K, Na, Cl, B > P, Ca, Mg, Fe, Mn, Cu, Zn, Mo, Co, Se, Ni. This order is related to the reactivity, speciation, solubility and fugacity of the nutrient element species and their mass fractions in manure. The double mobility of C, N and S, in soluble waterborne compounds as well as in gases, makes their cycling and loss pathways much faster and more complex than those of the mineral elements. Carbon is released from manure in gaseous forms (mainly CO_2 and CH_4), in dissolved forms as inorganic and organic C (ΣHCO_3, DOC), and as particulate matter (via run-off). Nitrogen is also released in gaseous forms (mainly NH_3, N_2, N_2O, NO), in dissolved forms as inorganic and organic N (NO_3^-, NH_4^+, DON), and as particulate matter (via run-off). Sulfur is mainly lost via volatilization of sulfides (H_2S) and sulfur oxides (SO_2) and the leaching of sulfate (SO_4^{2-}) and particulate matter.

The mineral elements can be lost via leaching in dissolved form or via run-off in particulate matter at various stages of the feed – animal – manure – soil – crop chain (Fig. 2). Leaching of effluents from ensiled feed and manure from animal houses and storage systems is negligible when the ground is sealed and the drainage water collected. High concentrations of, for example, K, Cl and NO_3^- in wells near farm houses are often seen as evidence of leaching losses from manure heaps on top of unsealed soil. Potassium (K), sodium (Na), chloride (Cl) and boron (B) have high solubility in water, and the main loss pathway is via leaching. Finally, the elements P, Ca, Mg, Fe, Mn, Cu, Zn, Mo, Co, Se and Ni have low mobility because of their low solubility and high reactivity with soil constituents. Some of these elements (Fe, Mn, Se) are redox-active and more mobile in chemically reduced forms. Some elements may form complexes with dissolved organic carbon and inorganic anions and thereby increase there mobility.

Few studies have quantified nutrient losses from animal manure storage systems via leaching and run-off. The available information suggests that N leaching losses from slurries in unsealed lagoons in EU-27 are in the range of 5% of the N in slurry when covered, and in the range of 10% when uncovered. Similarly, N leaching losses from solid manure in unsealed heaps are in the range of 2% of N in the manure when covered, and 5 to 10% when uncovered. Needless to say, the uncertainty in these estimates is high.

Current environmental concerns relate mainly to gaseous emissions of NH_3, N_2O and CH_4 from manure management systems to the atmosphere, and the leaching of NO_3^- to groundwater and N (NO_3^-, NH_4^+) and P (ΣPO_4, particulate matter) from manure management to surface waters. The excessive accumulation of Cu and Zn in soils following heavy applications of pig and poultry manures has received considerable attention in Europe in the 1980s and 1990s, but is now less a concern following governmental regulations on the additions of Cu and Zn in animal feed, and on manure application rates. However, this is not yet the case in many countries in Asia and Latin America.

2.1 Pollution of fresh water ecosystems

The effects of livestock wastes on aquatic ecosystems are basically the same as in case of household and municipal wastes. These effects can be summarized by eutrophication and toxification, which lead subsequently to ecosystem changes. The effects follow from the presence of degradable organic matter, nutrients (mainly N and P), heavy metals (mainly Cu and Zn), and possibly pathogenic micro-organisms, hormones and antibiotics in the wastes.

Eutrophication has been among the main water quality issues since decades. It is caused by excess loads of nutrients (mainly N and P) and organic matter to surface waters. It leads to excessive growth of phytoplankton and subsequently to decreases of water clarity and biodiversity, oxygen depletion, fish kills, and odor problems, while harmful toxic algal blooms may develop more frequently (Rabalais, 2004). Agriculture contributes roughly 50% to the total loading of surface waters with N and P, but the specific contribution of animal agriculture is unknown. Eutrophication can be exacerbated by the natural growth of toxic cyanobacteria (sometimes incorrectly referred to as blue-green algae). These micro-organisms are commonly occurring in all water bodies, but are particularly abundant in tropical and subtropical climate, and are notorious for their production of toxins that are detrimental or even deadly for human and animals incidentally consuming water with high concentration of cyanobacteria.

Pathogens associated with livestock and belonging to such microbial groups as viruses, bacteria, protozoa and helminths are known to penetrate into aquifers and surface water bodies. They present a real threat to humans and animals alike These threats are taken more and more seriously particularly in the light of recent SARS and avian influenza epidemics. These epidemics though viral by nature, demonstrate and accentuate an intrinsic potential danger of all groups of microorganisms emanating from livestock through wastes.

2.2 Pollution of marine coastal ecosystems

Through the transport of nutrients via rivers, and the deposition of ammonia-N originating from manure, livestock production also contributes to euthrophication of marine coastal ecosystems. The flux of nutrients from land to sea has increased since the 1960s by over 3-4 time, and nutrients originating from livestock production played a prominent role in this. Eutrophication stimulates the growth of marine algae's, be it microalgae (which lead to 'red and brown tides') or macroalgae (seaweeds). Transfer of pathogens from livestock wastes to sea is not an uncommon occurrence and results in temporary closures of marine aquaculture farms due to health risks resulting from elevated coliform counts. Furthermore, eutrophication-related impacts on sensitive estuaries, coast zones and coral ecosystems, which are among the most productive ecosystems on the planet, lead to loss of biodiversity which may lead to coastal erosion. This may coincide with decreased commercial harvests of marine products and necessitates rehabilitation associated with high costs. Eutrophication of marine ecosystems is a global concern.

2.3 Groundwater pollution

The leaching of nitrate to groundwater is considered a problem because when used as drinking water, the nitrate is consumed by humans and may cause methemoglobinemia (blue baby disease). Livestock excrements contribute to nitrate leaching, indirectly through crops and grassland highly fertilized with manure and when grazing livestock is fed protein-rich diets. The nitrate is generated by the nitrification of ammonium from fertilizer and excreta. The nitrate may also originate from leakages of manure storage systems (Oenema *et al*., 2007). Nitrate pollution of groundwater impacts water resources available to communities leading to health and social problems. However, there is still debate about the actual toxicity of nitrates in drinking water consumed by humans.

2.4 Nutrient accumulation in soil ecosystems

Plants need N, P, K and 10 other nutrients for their growth and functioning. In crop production, nutrient uptake per crop from the soil may range from 50 to 300 kg ha^{-1} for N, from 10 to 40 kg ha^{-1} for P and from 50 to 400 kg K ha^{-1} for K. In double and triple cropping systems, uptakes of N, P and K may be even higher. These wide ranges reflect differences between crop types, and soil fertility and fertilization levels (Laegreid *et al*., 1999). Theoretically, the whole nutrient requirement of the crops could be met by livestock manure. However, in practice this is usually not feasible, because the ratio of the different nutrients in manure is not the same as that for crop requirements and because it sometimes is not possible to spread manure when there is a particular N demand of the crops (e.g. during a wet spring in Europe or during the rainy season in the tropics). When application rates exceed the uptake capacity of the crop, surplus nutrients accumulate in the soil or are lost to the wider environment, depending on the mobility and reactivity of the nutrients and the environmental conditions (rainfall, topography). Phosphorus and also zinc and copper are strongly sorbed to the soil, and therefore have low mobility and hence tend to accumulate in soils. In contrast, nitrogen and sulfur have high mobility and tend to dissipate into the wider environment. Calcium, magnesium and potassium take an intermediate position.

For P, the strong accumulation in the top soil will be a concern for aquatic ecosystems when topsoil with a high concentration of P will enter surface waters via erosion. High K concentrations in soils may lead to a high K uptake by the crop, which may lead to grass tetany (or hypomagneseamia) in grazing dairy cows. Furthermore, high amounts of K can cause an increase of soil salinity with negative impact on crop yield and soil fertility. Lowering high P and K levels in soils may take many years; it requires that the application rates of animal manure (and fertilizers) are decreased strongly.

2.5 Soil pollution with heavy metals and organic compounds

Some heavy metals are used in livestock feed in amounts surpassing the essential animal requirements. Especially copper (Cu) and zinc (Zn) are often used in relatively high doses in pig production because of their growth promoting and therapeutic effects. Other heavy metals that are sometimes added to animal feed are chromium (Cr), cobalt (Co) and, arsenic (As). Well over 90 % of the heavy metal inputs to feedstuffs are excreted by the animal. Manure, especially pig and to a lesser extent poultry manure, therefore contains relatively high concentrations of heavy metals. The Cu and Zn content commonly found in pig slurry in Europe already leads to an accumulation of these metals in the soil. Excessive manure application to soils will further increase this accumulation. As heavy metals are not degraded or lost, it is only a question of time until a level is reached where the soil fertility is harmed and crop yields are affected. Especially in areas with fast growing livestock production, high livestock density and weak environmental legislation, heavy metals are increasingly gaining importance as a threat to the environment.

2.6 Emissions to the atmosphere

Apart from the effects of N from livestock manure in groundwater and surface waters, livestock manure also contributes to volatilization of ammonia into the atmosphere and to increased atmospheric N deposition. Atmospheric N deposition is especially a problem in vulnerable ecosystems sensitive to high N input (Galloway *et al*., 2003). Typically, 20 to over 50 % of the N excreted by housed livestock is lost through ammonia volatilization (Oenema *et al*., 2007). Thus, livestock production typically contributes 70 to over 90 % of the total ammonia emissions (Bouman *et al*., 1997). Furthermore livestock production (especially ruminants) and manure management are an important source of methane (CH_4) emissions and also contribute to nitrous oxide emission, which are both important greenhouse gases.

Fig. 3 shows the spatial distribution of N losses from agriculture via emissions of ammonia and nitrous oxide to the atmosphere and the leaching of nitrate to groundwater and surface waters. It shows that the patterns of emissions are rather similar. Hot spots of emissions are related to regions with intensive agriculture, mainly in The Netherlands, Belgium, Denmark and parts of France, Italy and United Kingdom.

3. Improving the performance of livestock farming

There are various options to improve the environmental performances of intensive livestock production systems. These options can be divided in measures related to improving (i) the management, (ii) the technology and (iii) the system or structure of the production – consumption chain. Management-related options are based on improved insights and knowledge (software) and are usually relatively cheap. Technological measures (hardware) are often part of management and system related measures; they require capital investments. Structural measures deal with fundamental adjustments of the structure of the whole ‘supply – production – processing – marketing – retail – consumption chain (orgware)’, and therefore not easy to implement by single farmers. From a cost-effectiveness point of view, management-related measures must be considered first. While doing so, technological measures have to be considered. Structural measures must be considered when management and technological measures do not bring solutions.

Improving the performance requires farm specific analyses of the feed – animal – animal produce – animal manure – crop production chains. The weakest part of this chain in terms of agronomic, economic and environmental performances usually determines the best options for improvement, in terms of effectiveness and efficiency. A series of consecutive steps have to be considered (Oenema and Pieterzak, 2001; Oenema and Tamminga, 2005). The weakest part of the chain in intensive livestock production systems commonly is the storage and utilization of the animal manure produced in these systems. Therefore, focus in this chapter is on improving ‘animal manure management'. However, we start our discussion with the producers of manure; the livestock component.

3.1 Improving livestock management

The amounts and composition of the animal excrements are directly dependant on the number, type (species), productivity and feeding of the animals, while the total amounts of manure to be handled strongly depends on the amounts of water and litter used in animal housing. Therefore, the following aspects of livestock management are relevant for manure management:

- The higher the productivity and the more efficient the feed conversion, the lower the amount of manure produced per animal and per unit product. This is a key option for improving the economic and environmental performances of livestock farms. It requires improvement of the genetic potential of the herd, phase feeding (precision feeding) and proper housing of the animals. However, improved productivity might not diminish the load to the environment if it is achieved with commercial feed that substitutes local resources.
- The protein and P concentrations in the diet should be limited to the minimum requirement of the animals, so as to minimize the amount of N and P in the manure and to maximize resource use efficiency.
- Concentrations of heavy metals in animal feed must be limited to the minimum requirement of the animals, to limit heavy metal concentrations in the manure and to prevent accumulation in the soil.

3.2 Improving manure management

Manure contains valuable nutrient elements and these must be recycled via application to cropped land. Proper manure recycling and application to crops means that all the livestock excreta must be collected, stored with minimal losses until the nutrients they contain are needed by the crop, transported to the field, applied evenly and in doses corresponding to the nutrient requirements of the crops. This implies minimizing the amount of water being collected together with the slurry, sufficient leak-tight storage capacity, and minimizing NH_3 volatilization through covered slurry stores and low emission spreading techniques.

There is a wealth of information about improving the recycling of manure nutrients effectively in crop production through proper implementation of management and technological measures. Some of this information is derived from experiments, but some also from practice. For example, the default N fertilizer and P fertilizer values of pig slurry in Denmark are 70 % and 100 %, indicating that 70 % of the N and 100 % of the P in the pig slurry must be accounted for in the nutrient balance, or in other words be considered as effective as high quality N and P fertilizers. Moreover, a fraction of the residual N may be utilized in subsequent years following the mineralization of the organically bound N in the manure. However, in many countries the mean utilization of manure nutrients is much lower than in Denmark, in part because of poor management and technology, in part also because of system constraints, as further discussed below.

3.3. System improvements and structural adjustments

A fundamental flaw of intensively (industrialized) livestock production systems is the large-scale geographic uncoupling of feed production from animal production. Landless intensive livestock production systems tend to agglomerate near large markets, and import essentially all animal feed from elsewhere, often from abroad. By doing so, nutrients in soils of crop producing area are depleted while livestock producing areas become enriched with nutrients. Nutrient depletion in soils can be remediated via fertilizer applications, but nutrient enrichment can not be solved without carrying the nutrients away from the site of manure production. Basically, nutrient depletion and nutrient enrichment are naturally occurring processes, but the current scale and intensity of nutrient depletion and nutrient enrichment associated with intensive livestock production in some regions is unprecedented, and is likely to increase further.

3.4 Towards sustainable livestock production systems

The question emerges ‘are current agglomerations of intensive livestock production systems sustainable in the long-term’? If the answer is no, the next question is ‘what solutions are available’?

The answer to the first question is largely ‘no’, although the answer depends in part on the scale and intensity of the agglomerations and on the perception of ‘sustainability’. The sustainability is less of an issue when the manure from intensive livestock production systems can be disposed off properly on nearby crop land, compared to systems that would have to transport the manure hundreds of kilometers away, and therefore dump or discharge the manure locally. Further, the term ‘sustainability’ is value-laden; basically it deals with the quality of life and about the possibilities to maintain that quality in future. It depends on the notions in the society about the quality of life and its geographic distribution, as well as on the scientific understanding of the functioning of humans and natural ecosystems on earth. Current scientific understanding is that the disruption of the natural nutrient cycles through agglomerations of industrialized livestock production systems is not sustainable. It leads to massive eutrophication and loss of biodiversity in livestock producing areas and to soil depletion and degradation in animal feed producing areas. Note also that the easily accessible phosphorus rock reserves will be depleted in 50 to 100 years (Laegraid *et al.*, 1999; Smil, 2000). Further, society may not accept the local dumping and discharge of manure nutrients from industrialized livestock farms and may call for governmental policy and measures as is the case in the European Union (Romstad *et al.*, 1997). Restrictions on dumping and discharge of manure will increase the cost of production and will force farmers of intensive livestock production systems to search for innovative solutions.

What sort of innovative solutions are available? When management and technological measures are insufficient to solve the nutrient unbalance, fundamental changes in the structure of the production – consumptions chain are needed. Such structural adjustments may lead to transitions of the agricultural systems. In this case, the structural adjustments have to correct the fundamental flaw associated with industrialized livestock production systems. Roughly, four lines of thoughts of structural adjustments are possible:

1. High-tech manure processing, yielding marketable manure products that can be stored, transported and applied to crop land elsewhere within economic, environmental and social constraints. However, manure processing techniques that yield marketable manure fractions (for example, separation with anaerobic digestion, composting and/or drying of the solid fraction, and ultra-filtration and reverse-osmosis of the liquid fraction) are expensive. As a result, intensive livestock production systems with manure processing technology may have to be combined and integrated with intensive crop production systems, food processing and heat and element re-cycling units in high-tech agro-production parks. Because of their high-tech, knowledge-intensive and cost-effective and environmental friendly re-use and recycling of wastes, these systems may have a comparative advantage relative to conventional livestock farms that dispose off their manure inappropriately. A few of these agro-production parks are now under development in China, India and The Netherlands; its success in practice still needs to be proven.
2. Spatial zoning and planning of intensive livestock production systems to such an extent that the livestock density within a region allows the proper disposal of all untreated animal manure on nearby crop lands within environmental, economic and social constraints. Evidently, this spreading of intensive livestock production systems over larger areas goes against the trend of agglomeration to benefit from site-specific conditions (markets, logistics, marketing, extension

and research services, etc.). Such spatial zoning and planning has been introduced via (tradedable) pig and poultry quota per farm combined with ceilings of the maximum number of pigs and poultry per region in The Netherlands, so as to limit the further expansion of the intensive livestock pig and poultry sector. However, such an animal quota system may also introduce (economic) side-effects. To be maximally effective, a quota system should be implemented when livestock stocking density in a region does not yet exceed critical limits.

3. A greater structural change occurs when animal production will be made land-bound again. It will connect crop production to animal production locally and regionally. The large-distance transport of animal feed will be replaced by large-distance transport of meat, while the small-distance exchange of animal feed and animal manure allows effective recycling of nutrient elements at low cost. Evidently, achieving such a structural change requires a major transition, as the whole production – consumption chain has to be relocated. It may take generations and it requires strategic international agreements, as it relates to food security, entrepreneurship, stewardship and trust.
4. Even greater structural changes will be brought about through a transition in protein production and consumption, shifting from meat to plant proteins, or from ‘pigs to peas’ (Fig. 4). A shift from a diet with relatively large proportions of meat protein to plant-derived protein products appears to be environmentally more sustainable, technological feasible and socially desirable (Aiking *et al*., 2006). Such a transition will also contribute to releasing pressure on freshwater resources and will decrease the energy-intensity of food production. Again, such a protein transition will have to be implemented at the global level. A full transition will more than halve the needed agricultural land and will more than halve the euthrophication associated with food production.

Clearly, these 4 lines of thought encompass transitions of the whole food production (and consumption) chain. Fundamental to transitions is the change in structure and characteristics of (part of the) society, its large scale, and its large impact.

3.5 Governmental policy measures

Governmental policy and measures aim at changing humans’ behaviour; they are meant to correct unwanted behaviour and/or to stimulate desired behaviour. Environmental policy and measures in agriculture aim at changing farmers’ behaviour and thereby aim at improving the environmental performance of the farms. The changes brought about by the change in farmers’ behaviour can be categorized in three types of effects, namely (i) managerial changes, (ii) technological changes, and (iii) structural changes. A distinction between these types of changes is important as it will contribute to increased understanding of the effects of governmental policy and measures. Managerial changes involve investments in the ‘software’ of the farm, in the execution of day-to-day farm practices. These changes require a better integration of farmers’ knowledge and scientific knowledge through interactive training, education and demonstration activities. And they require suitable platforms for interaction between farmers, researchers and industry. Technological changes involve investments in the ‘hardware’ of the farm, in the buildings, machines, and equipment. These investments are often costly, and usually are only made when combined with up-scaling (enlargement of the farm) to make the investment cost-effective, or following suitable incentives (subsidies, tax reduction, fines). Structural changes concern changes in the orgware of agriculture, in the type (land-based versus landless systems, specialized versus mixed systems), size and location of farming systems, in the vertical (from suppliers to consumers) and horizontal (co-operation among farmers) organisation. Structural changes involve changes in the relative importance of production factors and resources (land, labor, capital, energy and management), and may involve changes in ownership of farms and farm land, and in the organization of farmers and the institutionalization of farmers’ organizations.

It is important to note that the way in which policy is designed and implemented is subject to changes over time. Many developed countries may rely on the functioning of classical-modernist state structures that have strong legitimating from the people, although this automatic trust and legitimating has been decreasing during the last three decades. Notably, the polity and the role of knowledge in the policy-making process are changing. Polity can be understood as the political setting in which policy-making takes place. During the last decades, stakeholders like environmental NGO’s and consumer organisations increasingly have a say in the policy making process. Further, the role of scientific knowledge is changing. Scientific knowledge is crucial for developing sound environmental policy and measures, but at the same time it is clear that science can no longer pretend to hold all facts and provide clear blueprints for policy. In environmental issues the processes involved are so complex and heterogeneous that uncertainty in policy outcomes is high.

There are three policy approaches to design environmental policies that vary in the extent of governmental coercion, namely (i) hierarchical control, (ii) interactive steering and (iii) self-governance. In the policy approach of hierarchical control it is the (central) government that initiates, executes and controls the policy. The underlying reasoning is based on expert knowledge.

The policy instruments are laws, fines and subsidies. The interactive steering approach leaves a greater role for private parties. The approach is based on the premise that necessary societal changes can only be successfully started if institutionalized private parties are involved in the policy-making process. Agreements are written down in covenants and contracts. Interactive steering can be successful in situations of great complexity and important dependency relationships. Self-governance takes the private company or organisation as a point of departure. Self-governance can therefore be defined as “private regulation within a public framework”. The government steps aside and leaves execution and sanctioning to a system of control on self-control. The government does state the structure within which private parties can operate. Self-governance works best when the own interest of the individual company overlaps with governmental interests.

Once the rationale, approach and objective of the policy have been formulated, instruments have to be selected to implement the policy in practice. Policy instruments can be divided into three main categories: (i) regulatory or command-and-control instruments, (ii) economic or market-based instruments and (iii) communicative or persuasive instruments. These are briefly described below.

Regulatory instruments (regulation) involve a restriction on the choice of agents, methods and actions. Regulations are compulsory measures imposing requirements on producers to achieve specific levels of environmental quality, including environmental restrictions, bans, permit requirements, maximum rights or minimum obligations. They are the most common policy measure used in EU-environmental policies, as for example in the IPPC and Nitrates Directives.

Economic instruments (stimulation) are common in agricultural policy but are not very common in environmental policy (yet). Environmental taxes and tradable rights/quotas have only been implemented in a few countries. Subsidies are increasingly used as a policy instrument to promote environmentally friendly practices and the introduction of new technology.

Communicative instruments (persuasion) include collective projects to address environmental issues and measure to improve information flows to promote good practices and environmental objectives. This information can be provided to both producers, in the form of technical assistance and extension, and to consumers, via labelling. Technical assistance and extension are policy measures providing users with information and technical assistance to plan and implement environmentally friendly practices.

3.6 Governmental policies and measures in practice

Governmental legislation is a most important determinant for proper manure management and thus for reducing the environmental pressure arising from intensive livestock production.

Governmental legislations may contribute to overcome the following barriers for implementing proper manure management in practice:

1. Manure is considered to be a waste product, especially in the case of landless livestock production systems, which has to be disposed off at minimal economic costs.
2. Proper manure management is associated with considerable investments in capital, labor and knowledge, which increase the production costs.
3. The value of nutrients lost is relatively low compared to the costs associated with proper management and farmers therefore do not have any personal incentive to reduce emissions (losses).
4. Livestock farmers that do produce part of the animal feed often have little incentive to use slurry properly instead of fertilizers, because slurry is voluminous and has a low and variable nutrient content, while artificial fertilizer has a high and known nutrient content and is relatively cheap in developed countries.
5. The awareness and knowledge of farmers about the long-term consequences of environmental pollution through animal manure is still limited.

Though legislation may contribute to even out some of these barriers, there often is a gap between the theory and practice of governmental policy measures (Romstad *et al.*, 1997; Gunningham and Grabosky, 1998). The variable and slow responses of environmental policies in agriculture have been ascribed to (i) the huge differences in farming systems and environmental conditions in practice, (ii) a variable interpretation of the governmental policy measures, (iii) legislative delays and lack of enforcement, (iv) failure by farmers to implement measures, due to within system constraints, perceived costs and the needed learning time, and (v) antagonisms between measures, due to lack of integration of measures. Moreover, there is lack of agreement about environmental protection at global level, at the level of the World Trade Organization. Within a globalizing world agreements about trade liberation and environmental protection must go hand in hand. Implementation of environmental policies at national level or regional levels creates unfair competition as intensive livestock production systems increasingly produce for the global market. Unfair competition is often a major reason why farmers in developed countries are reluctant to invest in proper manure management.

The EU Nitrates Directive (EC 1991) sets a limit of 170 kg per ha per year of manure N to be applied to agricultural land. This Directive is meant to reduce and prevent the pollution of groundwater and surface waters with nitrate from agricultural sources. Through its manure application limit, it couples animal production to crop production indirectly within regions. This Directive has been heavily debated and has a significant influence on the further development of the intensive livestock production sector in the EU (Romstad *et al*., 1997). The Directive also includes various good agricultural practice guidelines for the proper application of manure and fertilizers to land.

Summarizing, environmental policy is a relatively new subject that emerged firstly in the European Union in the late 1980s. The policy measures aimed at decreasing N and P emissions to air and water. They have been developed and implemented in practice, while the understanding of the processes, cycling and functioning of N and P in the biosphere, in air, water, soil, plants and animals were still limited. In part because of our limited understanding of the complex N and P cycles, and because of the compartmentalization of our society and especially also governments, the focus in developing policy measures aimed has been on single N species (NO_3^-, NH_3, N_2O or NO_X), on single P measures, on single sectors (households, industries, traffic, crop production, animal production), on single environmental compartments (air, water, nature, humans), and or on single effects (human health, animal health, food quality, eutrophication, acidication, biodiversity loss, global warming). This multi-aspect approach has contributed to a ‘wealth’ of policies, with some interactive effects (both synergistic and antagonistic effects). As a result, there is an increasing quest for integrating environmental policy measures. Livestock farmers in especially EU feel squeezed by the large number of regulations. Yet, these regulations have contributed to improving the environmental performance of intensive livestock farms.

4. Outlook

Projections for 2030 suggest further increases in animal numbers in the range of 30 to 50 % relative to 2000, with largest increases for poultry and pigs kept in intensive livestock farms (Bruinsma, 2003). Increases will be relatively large in the developing countries near markets (large cities), while a (further) decrease is anticipated in some affluent countries, in response to globalization of markets, societal concerns about animal welfare and eating too much animal protein, and environmental policy measures. If there is no change in current practices, the projected increases in intensive livestock production systems will double the current environmental burden of livestock production, unless appropriate measures are taken.

Current trends of globalization and liberalization of agricultural markets, and the economics of scale, specialization and intensification will further contribute to the agglomeration of intensive livestock production systems near rapidly developing markets. Small, mixed farming systems will be outcompeted and less people will be living in the country side. Some people in the country side may even eat animal products produced in urban areas, because it may be cheaper to produce meat in large facilities in urban areas than in small mixed farms in the countryside. This may further increase the environmental pressures of intensively livestock production systems, unless appropriate measures are taken.

These sobering projections are largely based on extrapolations of current trends. At the same time, there is overwhelming evidence that the environmental performances of livestock production systems can be improved greatly, when proper incentives are provided to livestock farmers, together with training, demonstrations, best available techniques and management tools. Currently, there is a lack of proper incentives, standards, and control in various areas with intensive livestock production systems. Clearly, there is a need of international agreements about animal production and animal manure management standards among countries with intensive livestock production systems. Such agreements should provide a basis for environmentally sound and socially acceptable production systems, and should also provide a level-playing ground to prevent unfair competition. The agreements should include regional livestock stocking density limits, expressed in livestock units per ha or preferably in P excretion or P surplus per ha.

Intensive livestock production systems can make a significant contribution to reducing the load of N and P into the wider environment. This requires cooperation among countries in setting standards for livestock production and manure management. It also requires collaboration among animal scientists, agronomists, technologists, economists and ecologists to derive these standards, and the required best available techniques and management tools. Foremost, it requires cooperation among the stakeholders along the food chain, including consumers, retail, food processing industry, representatives of livestock farmers, animal feed processing companies and technology companies. Adoption of standards and improved technologies requires additional skills, labor and investments in new technology and equipment by farmers. They need convincing information on expected costs and benefits. Evidently, a joined effort is needed.

Capacity building on good manure management means that reliable recommendations are available and accepted. To provide these is a challenge for joint activities of scientists, extension officers and progressive farmers and should also rely on pilot farms demonstrating the feasibility of the proposed measures.

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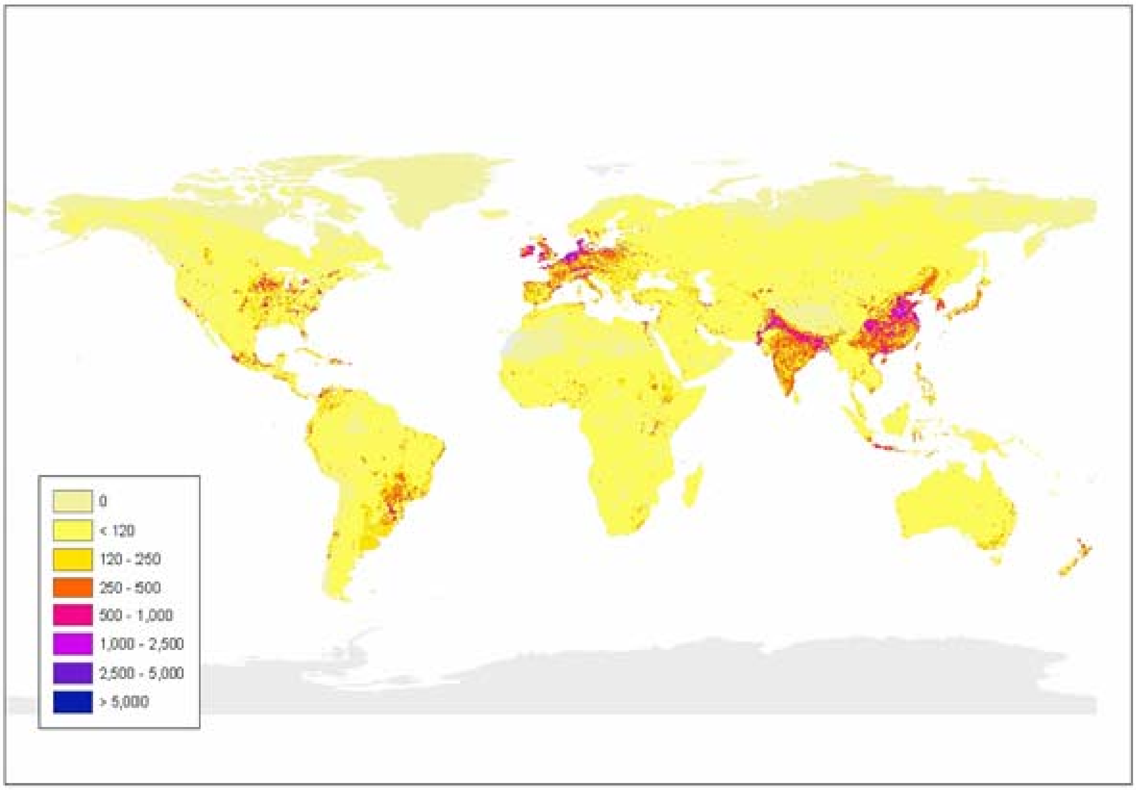

Fig. 1. Global distribution of the total amount of P_2O_5 in livestock excreta (kg km^{-2}), after Menzi *et al*., 2009.

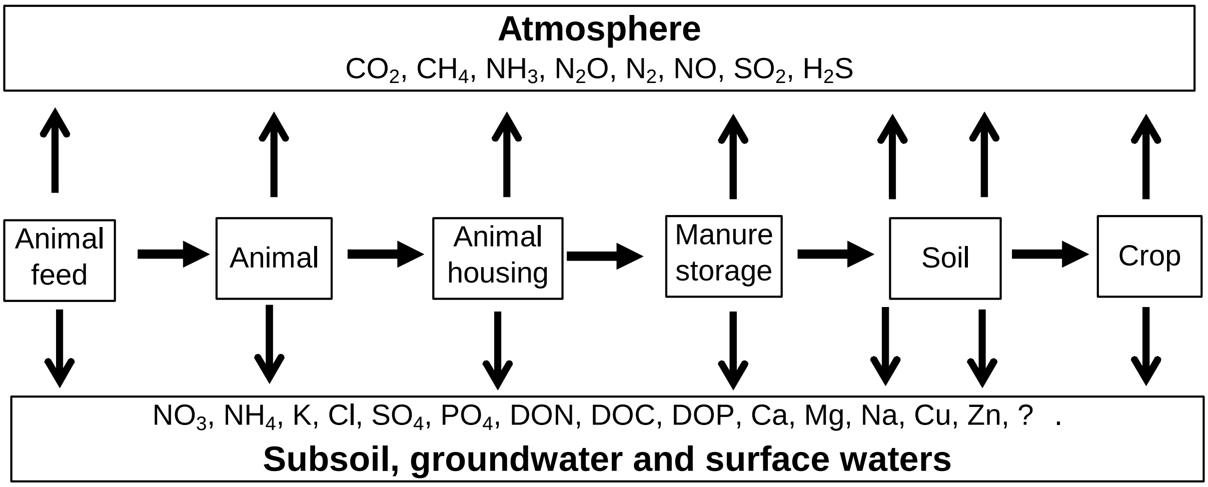

Fig. 2. Possible loss pathways of nutrient elements from the feed – animal – manure – soil – crop chain. Losses via gaseous emissions to the atmosphere are shown in the upper half, losses via leaching and run-off of nutrient elements to the subsoil and to groundwater and surface waters in the lower half (from Oenema *et al*., 2006)

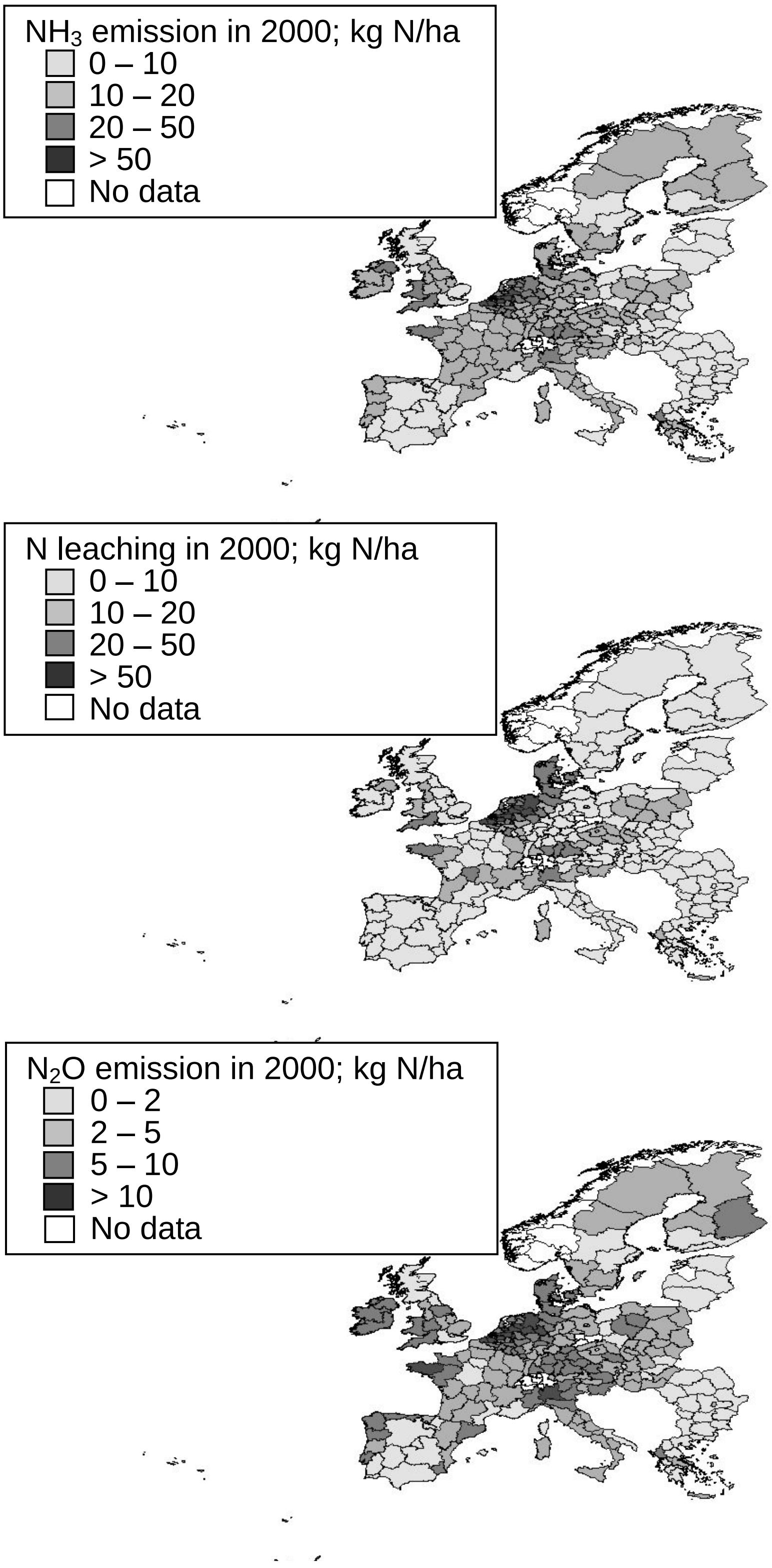

Fig. 3. Spatial distribution of ammonia emissions, nitrate leaching and nitrous oxide emissions in EU-27 (From Oenema *et al*., 2007).

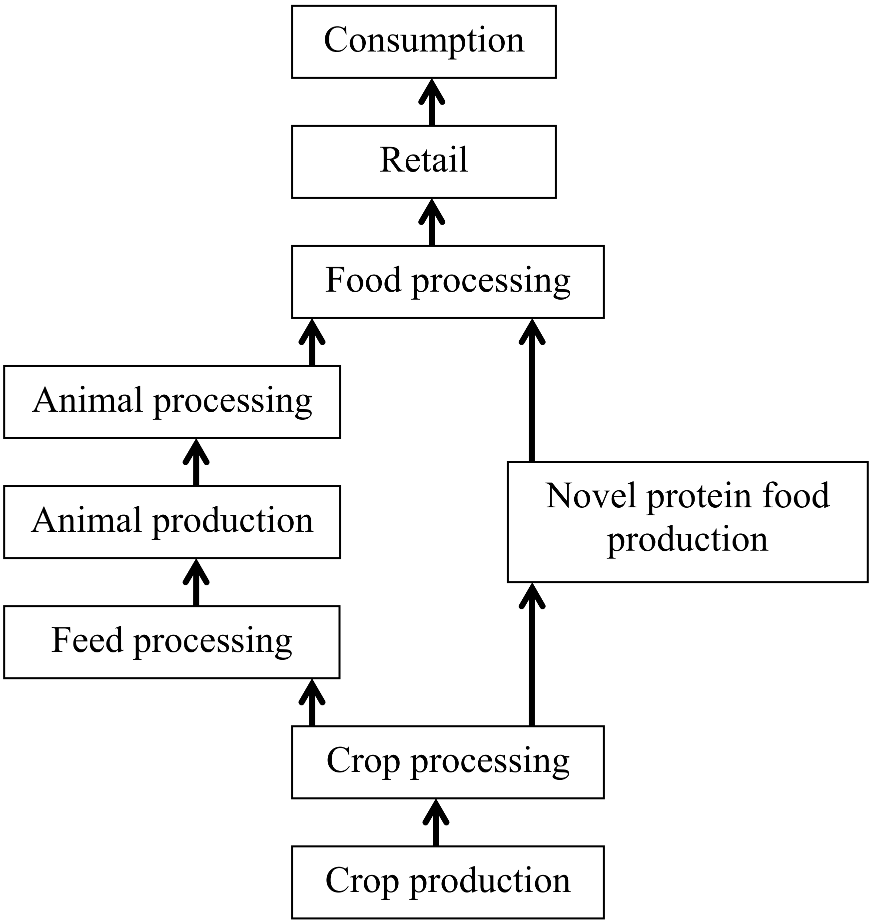

Fig. 4. The food chain from production to consumption. On the left-hand side the chain from crop production via animal production to consumption. On the right-hand side the chain from crop production via novel protein production to consumption. After Aiking *et al*., 2006.