Advances in Animal Biosciences (2014), **5:s1**, pp 68–71 © The Animal Consortium 2014
doi:10.1017/S2040470014000314

advances in animal biosciences

Nitrogen flows and livestock farming: lessons and perspectives

J.-L. Peyraud[1†], P. Cellier[2], F. Aarts[3], F. Béline[4], C. Bockstaller[5], M. Bourblanc[6], L. Delaby[1], J. Y. Dourmad[1], P. Dupraz[7], P. Durand[8], P. Faverdin[1], J. L. Fiorelli[9], C. Gaigné[7], P.J. Kuikman[10], A. Langlais[11], P. Le Goffe[7], P. Lescoat[12], T. Morvan[8], C. Nicourt[13], V. Parnaudeau[8], P. Rochette[14], F. Vertès[8], P. Veysset[15], O. Réchauchère[16] and C. Donnars[16]

[1]INRA, Research Unit 1348, Pegase, F-35042, Rennes Cedex, France; [2]INRA, Research Unit 1091 EGC, F-78850 Grignon, France; [3]Plant Research International, WUR, Agrosysteemkunde, Wageningen, The Netherlands; [4]IRSTEA UR F-35044 Rennes, France; [5]INRA Research Unit, 1132 LAE, F-68021 Colmar, France; [6]CIRAD – Research unit G-EAU (Montpellier, France)/CEEPA, University of Pretoria, Afrique du Sud; [7]INRA, Research Unit 1302 SMART, F 35042 Rennes Cedex, France; [8]INRA Research Unit 1069 SAS, F-35042 Rennes Cedex, France; [9]INRA, Research Unit 0055 Aster, F-88500 Mirecourt, France; [10]ALTERRA, Dienst Landbouwkundig Onderzoek, Wageningen University (WUR), The Netherlands; [11]CNRS-Université Rennes I, Research Unit 6262 IODE, France; [12]INRA Research Unit 0083 URA, F-37880 Nouzilly, France; [13]Agriculture and Agrifood Canada, Quebec City G1V, Canada; [14]INRA Research Unit 1323 RITME, F-94200 Ivry-sur-Seine, France; [15]INRA Research Unit 1213 URH, F-63122 St Genès-Champanelle; [16]INRA Depe, F-75338 Paris Cedex 7, France

In conclusion, here are the main lines of this scientific assessment on nitrogen flows in livestock farming systems and perspectives for research.

Current knowledge on nitrogen on livestock farms

This assessment has highlighted the major role of livestock farming systems in nitrogen flows in France, and the resulting potential impacts on the environment. Slightly more than half of annual nitrogen supply to fertilise fields is in the form of chemical fertilisers (2110 kt) and slightly less than half is from livestock farm waste (1820 kt) and symbiotic nitrogen fixation by legumes (about 500 kt). More than three fourth of nitrogen is used for feed production for animals that consume 70% of the plant biomass produced (grasslands, maize and cereals mainly, while proteins come from Americas). However, France (and some other countries) is not a homogeneous territory for agriculture; thus, organic and inorganic nitrogen pressure vary largely according to local agricultural orientations. The highest nitrogen pressures are found in regions with both ruminant and monogastric production systems, where the quantities of nitrogen in animal manure are sometimes in large excess compared with the capacities of farmland to recycle, and of the crops to use applied N. Inversely, nitrogen pressures in more extensive livestock farming regions are very low.

The spatial concentration of animal farms plays a key role on the impacts of nitrogen pollution

The tendency to geographic concentration of certain links in the livestock farming chain has often been advanced as a determining cause of nitrogen excesses in livestock farming regions. The drivers for this change have been examined in the scientific literature and are technical, economic and legal in nature. However, the literature points out the difficulty to emerge from a scenario of intensification and specialisation, in particular, because the technical and economic operation of players in the chain – input producers, farmers, processors – are intimately linked.

The analysis of the 'nitrogen cascade' explains dynamic nitrogen flows from livestock farming systems

The transformation of plant products by animals is part of the biogeochemical cycle of nitrogen and explains why scientists have long studied agricultural nitrogen flows. The nitrogen cascade provides a relevant framework for analysis explaining the relationships between animal production systems and the environment. It illustrates the whole chain of transfers and transformations of reactive nitrogen in the different compartments of the environment (and the impacts at different levels). The consumption of plant products by animals leads to decrease in the coupling of carbon and nitrogen cycles and yields highly mobile and reactive nitrogen compounds (urea, ammoniacal and nitric nitrogen, amino acids) a part of which will more or less rapidly end up as nitrate or organic dissolved nitrogen in water, and as ammonia and nitrous oxide in the atmosphere. The importance of nitrogen flows fluxes is highly variable between production systems as well as inside a given system, linked to surrounding conditions and farmers' strategies. The nitrogen cascade shows that the different forms of reactive nitrogen should be considered at specific levels: from the very local level for impacts on a sensitive ecosystem in proximity (by NH_3 for example), passing through the regional level for impacts on water and air quality (NH_3, NO_3), up to the global level for climate change (N_2O emissions).

† E-mail: jean-louis.peyraud@rennes.inra.fr or pierre.cellier@grignon.inra.fr

https://doi.org/10.1017/S2040470014000314 Published online by Cambridge University Press

Gazeous emissions, in particular NH_3 was an issue undervalued in France until now

In France, the nitrate issue has long been the focal point of discussion, whereas in some northern European countries, ammonia has long been the centre of concern. Ammonia, first studied for its role in the acidification and eutrophication of environment compartments, is now being examined in the context of air pollution by particles at the scale of regions. The contribution of livestock farming systems to national emissions in France is 80% if only emissions from livestock farm waste are taken into account, and up to 90% if we include the part of industrial fertilisers destined for crops used to produce animal feed. The leading contributor is the bovine farming system (% animals, % emissions), but at the same time its management can reduce the emissions, for example, by grazing grasslands compared with indoor herds.

Risks and impacts depend on regions

The same nitrogen pressure can result in different environmental impacts depending on the agricultural practices, the sensitivity of the local environment and its capacity to use or eliminate nitrogen from animal waste. The nitrate contents of water in fact depend on the level of nitrogen balance surpluses, but also of land use: animal density, proportion of croplands or permanent pastures, etc. It is also depending on regional sensitivity related to climate, soil, hydrographical network and landscape, and structure (importance of buffer zones). Part of the sources of variation is rarely quantified, although they may play a role in the impact of nitrogen excesses on the environment: nitrogen storage in the soil, other gaseous losses, inhibition of nitrification, residence time in aquifers, etc.

Nitrogen use efficiency is usually low and variable depending on the scale at which it is determined

Efficiency, calculated as the ratio between usable outputs and nitrogen inputs is low when calculated at the level of the animal: less than half of ingested nitrogen is found in milk, eggs or meat proteins, with the major part of nitrogen being excreted into the environment. At the scale of the livestock farm, the N use efficiency increases thanks to recycling the animal excretions for agricultural (or energy) purposes, mainly as fertiliser on crops. It nevertheless remains low (generally <50%) and highly variable, linked in particular to the part of crops in the outputs. Animal production systems are characterised by their nitrogen inputs (the most important being feed, fertiliser, symbiotic nitrogen fixation) and a variety of emissions (nitrate, NH_3, N_2O, N_2) into the environment. These input flows are combined with internal flows of the system that are closely linked. In summary, the search for better efficiency must take the entire chain into account: improvement at the scale of one step of the chain, for example, animal feeding, can cause the degradation of another link, thus not resulting in an overall increase in efficiency at the farm scale. The literature also showed that in general, the more a system is productive per unit of surface, the greater the risk of nitrogen leakages into the environment.

Options for improvements on farm

Many possibilities were published concerning actions to better use and re-use nitrogen. Progress is defined not only by the advances and improvements of methods and practices, but also by the diagnosis and reduction of sources of inefficiency in different aspects of a farm (herds, livestock housing, storage and manuring waste, cropping systems and fodder systems) and better control of the risks of pollution transfers between and among these different areas.

Optimising practices

Although it is still possible to reduce protein supplies to animals, expected gains are modest as considerable progress in nitrogen nutrition has already been made over the past 15 years, at least for granivores. On the other hand, a major path for preserving nitrogen and reducing purchases of inorganic fertilisers is the control of the entire waste management chain: depending on management methods, emissions can vary from 30% to 75% of the nitrogen emitted by animals. Technical measures and innovations are now available to limit emissions, in particular ammonia inside livestock housing, during storage and when manuring, even if not always easy to implement and if scientific uncertainties persist on emissions and their variation factors. Gains in efficiency can also be obtained at the level of plant production with better use of manures and also by increasing the contribution of legumes in pastures (pure or in mixtures). The positive role of cover crops and the possibility of changing rotations to reduce the risks of nitrate leaching have been demonstrated. Permanent cropping systems are also an interesting possibility but that still requires considerable research and development, as techniques for planting on existing ground cover are still only partly understood. Integrated methods at the scale of the farm for the detection of major sources of inefficiency have been developed in northern Europe, in particular The Netherlands. Implementation of these methods at the scale of the country is impeded by the lack of decision-making assistance tools at the scale of the farm.

Options for improvements at the scale of regions

In regions with high animal density and/or with particular vulnerability towards the organic nitrogen load (water catchment areas, catchment areas sensitive to green tides, etc.), optimising the use of nitrogen alone is not sufficient to reduce nitrate contents of water to any appreciable extent. Obtaining significant theoretical gains concerning impacts requires restructuring agricultural activity.

Take the particular vulnerability of ecosystems into account or improve their capacity to catch nitrogen

In vulnerable areas or in those where there are major environmental stakes, research has shown that agricultural activity in the region had to be completely reorganised, with development of forests, pastures and low input or organic

https://doi.org/10.1017/S2040470014000314 Published online by Cambridge University Press

farming systems. These local initiatives require the involvement of all participants and a system for compensating decreased agricultural production: livestock farmers are remunerated by a private water company or a regional government or institution.

At the scale of regions, the literature shows that landscape approaches increases the pollution attenuation potential of the environment. Well-managed wetlands can significantly reduce the quantities of nitrate fluxes to streams. A significant fraction of ammonia released by livestock housing can be captured by hedges planted at the periphery. Nevertheless, those mitigation measures still let the questions of the fate of nitrogen captured or transformed, as well as that of the collective management of spaces with shared functions.

In regions with high nitrogen surpluses, treatment of livestock farm waste for export

The technological treatment of effluents creates manoeuvring room for better management of nitrogen balances among regions. Apart from energy production (for methanisation) the aim is to produce standardised and marketable fertilisers that can be more easily exported (nitrogen but also phosphorus) to other regions, especially those of large-scale crop farming where they at least partially replace inorganic fertilisers, or those with soil structure problems needing organic amendment. This solution, already used on a small scale by several players, requires more study. The competitive advantages or drawbacks of these treatment systems also remain to be determined in comparison with those of inorganic fertiliser production. A potential downside of this change would be to accentuate the concentration of livestock farming systems if the profitability of treatment processes requires a greater geographic concentration of the 'raw material', that is, animal waste.

Reduce the concentration of livestock farming systems on a case-by-case basis

Encouraging conversion to organic production, grass-based milk production can be an efficient option, however, it most often relies on stake-holders' cooperation at regional scale and commercial issues well valued. Although the scientific literature does not deal with this question to any great extent, it nevertheless indicates possibilities based on a partial geographic displacement of production, aimed at reducing the animal density and thus the nitrogen load in certain regions. These relocations exist in northern Europe, primarily on pig farms. They remain possible for other types of livestock farms and at highly varied scales, from the very local – between neighbouring municipalities – or more distant regions in the country. These case-by-case approaches could re-establish regional balances in nitrogen load. However, the difficulties in their implementation should not be minimised as transfers of animal waste and manure or the establishment of new livestock farming systems raise questions of perception and problems of acceptance by the hosting regions.

Tools to favour and assist changes

The French application of the Nitrates Directive has resulted in a complex legal architecture. Public reports and scientific publications have pointed out a certain ineffectiveness of the system. They identified factors with negative effects, because of a collective – and not individual – approach motivated by the diffuse nature of agricultural pollutions. In addition, economic and social preoccupations are preeminent on environment policies.

Subsidies, taxes or quotas?

The economic literature shows that pollution abatement subsidies, especially if not limited over time, can orient towards certain technologies, for example, resorption of nitrogen by aerobic treatment of liquid pig manure, by reducing their operating costs. They thus do not motivate producers to find the least costly means of resorption and ultimately confer a competitive advantage to non-sustainable systems. Subsidising the treatment of liquid manure has led to the generalisation of this practice, even on livestock farms where it is not profitable. Inversely and temporarily, subsidies can promote taking an initial risk to implement practices that go beyond recommendations of good practices and standards.

A tax is a means of having the principle of environmental responsibility applied. Systematic taxation of nitrogen inputs, especially inorganic, would seem easy to put into practice but it has to be set at a high rate in order to be effective, in other words lead to significant reductions of nitrogen losses. This principle of taxation has been abandoned in several countries.

The alternative to a tax is a policy of quotas (setting a maximal nitrogen surplus level) that guarantees reaching an environmental result provided these quotas are followed. Quotas may be adjusted as a function of the sensitivity of environmental compartments and of regions. The costs involved in controlling a quota policy may be high. Combining a quota policy with penalties in case of excesses is a solution often mentioned in the literature, as it is in the context of a quotas' market where supply and demand enable exchanges to avoid penalties. The regions concerned, however, are already highly saturated with nitrogen, a fact that could limit the possibilities of this market of rights.

Work in the field of economics has led to a series of arguments showing that environmental regulation could be more effective if it is also applied to the entire animal production chain. The animal industry often obtains its supplies from farmers in townships with nitrogen excesses, without being required to contain the environmental impacts of livestock farming activities. There are also fewer participants involved, thereby reducing transaction costs for public authorities.

Tools for ecological zoning of agroecosystems

The literature also shows that gains in economic efficiency are made by differentiating policies on a spatial basis, as vulnerability differs with the region in question. It is possible to take the sensitivity of environmental compartments into account to a

https://doi.org/10.1017/S2040470014000314 Published online by Cambridge University Press

greater extent in order to re-define ecological zoning, based on the concept of 'critical load'. Critical load is the maximal quantity of nitrogen that the region can receive at the same time as limiting environmental impacts to a level of nitrogen leakages judged acceptable. This involves taking the vulnerability of the region and larger scale impacts into account. This approach would enable ecological zoning of the region to be defined based on an assessment of internal capacities of the environment to act as a buffer or to absorb nitrogen pressure.

This assessment clarifies research and R&D priorities primarily concerning

Nitrogen dynamics in production systems: implementing innovations on livestock farms to develop systems that more effectively recycle nitrogen requires the more detailed understanding of nitrogen flows and their regulation. In particular, this involves acquiring knowledge of critical processes (gaseous emissions, nitrogen dynamics in the soil, etc.) and conducting engineering work on production systems that include biotechnical and organisational facets.

Development of decision-assistance tools in order to provide farmers and their advisors with the means necessary to conduct 'nitrogen diagnoses' and prepare case-by-case recommendations that include the complexity of livestock farm systems. These tools require extensive data on farms that are not currently available. In addition, implementing and monitoring farming systems will provide representative reference values that can be used to develop these tools and to better understand practices.

Integration of livestock farming systems in regional context and associating businesses: faced with the heterogeneity of regions in terms of nitrogen load, a change of scale in the reasoning of nitrogen flows in livestock farming systems could open new possibilities. The construction of scenarios, their evaluation and the analysis conditions required for success, all require the development of bio-economic models that can simulate the multitude of effects of a change in the spatial distribution of livestock farming systems.

Effectiveness of environment policies: the question of transaction costs of policies remains an essential research subject in order to optimise their effectiveness. Several potentially interesting concepts have been published but have yet to be put into practice. This is particularly the case for the notion of critical load that appears to be well suited to situations where the geographic variability of damage implies a geographic differentiation of environment policy.

Acknowledgement

We thank the reviewers for their thoughtful and reliable advices in the course of the drafting of the French report: Marc Benoît (Inra, F-88500 Mirecourt, France), Gilles Billen (CNRS, F-75252 Paris Cedex 05), Isabelle Doussan (Inra, F-06050 Nice), Amédée Mollard (Inra, F-38400 St Martin d'Hyères), Philippe Leterme (Agrocampus ouest, F-35042 Rennes), Didier Stilmant (CRA Wallonie, B-6800 Libramont).

We also thank the French Ministry of the Environment and Sustainable Development and the Ministry of Agriculture who funded this scientific assessment; a special acknowledgement to Valerie Maquere, Rosine Travers and Philippe Jeannot who were our administrative correspondants.

Thanks to the steering committee with whom the dialogue was rich and helpful: Sophie Agasse (APCA), Philippe Vissac and Emmanuel de Chezelles (ACTA), José Martinez (IRSTEA), Romain Joya (CITEPA), Delphine Antolin (Coop de France), Christophe Chassande, Jimmy Annet and Clément Villien (Ministry of Agriculture), Bjorn Desmet, Pascal Blanquet and Lucile Gauchet (Ministry of Environment and Sustainable Development).

Thanks must also go to Philippe Chemineau, former director of the DEPE-INRA and Cledwyn Thomas (AABS) who encouraged this publication.

The French version of this document was first presented at a conference on the 19 of January 2012. It is the synthesis of a global report 'Nitrogen flows in livestock farming systems – Reduce losses, restore balances' (*Les flux d'azote liés aux élevages, réduire les pertes, rétablir les équilibres*) which is in open access on the INRA web site: http://inra.dam.front.pad.brainsonic.com/ressources/afile/223277-92bc0-resource-expertise-flux-d-azote-rapport-complet.html.

https://doi.org/10.1017/S2040470014000314 Published online by Cambridge University Press