

**Localising the
nitrogen imprint of
the Paris food supply**

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Localising the nitrogen imprint of the Paris food supply: the potential of organic farming and changes in human diet

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Abstract

The Seine watershed has long been the food-supplying hinterland of Paris, providing most of the animal and vegetal protein consumed in the city. Nowadays, because of the land specialisation of agriculture made possible by the shift from manure-based to synthetic nitrogen fertilisation, the Seine watershed, although it exports 80 % of its huge cereal production, still provides most of the cereal consumed by the Paris agglomeration. The meat and milk supply originate, however, mainly from regions in the North and West of France, specialised in animal farming and importing about 30 % of their feed from South America. As it works today, this system is responsible for a severe nitrate contamination of surface groundwater resources. Herein two scenarios of re-localising Paris's food supply are explored, based on organic farming and local provision of animal feed. We show that for the Seine watershed it is technically possible to design an agricultural system able to provide all the plant- and animal-based food required by the population, to deliver sub-root water meeting the drinking water standards and still to export a significant proportion of its production to areas less suitable for cereal cultivation. Decreasing the share of animal products in the human diet has a strong impact on the nitrogen imprint of urban food supply.

1 Introduction

Food supply is a major factor in shaping cities (Steele, 2010) and determining their relationships with surrounding (close or distant) rural territories. The orientations of agricultural development in the city hinterland as well as the construction of large transport infrastructures has been largely dictated by the requirements of urban food markets (Keene, 2011; Charruadas, 2011; Billen et al., 2011). Because cities consume most of the final products of agriculture and dictate its orientation and location, urbanisation is a major driver of the human perturbation of the nitrogen cycle (Svirejeva-Hopkins and Reis, 2011). As shown by several authors, the anthropogenic introduction into the

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biosphere of reactive nitrogen, which subsequently cascades through a number of environmental compartments until it is finally denitrified back to the atmosphere, causing multiple harmful effects, is nowadays among the most severe environmental threats (Galloway et al., 2002; Sutton et al., 2011). Any attempt to eliminate or reduce the source of the nitrogen cascade should take into account the urban food supply issue.

There is presently a lively debate on the possibility of local sourcing of the urban food supply. Food-miles, i.e. the total transport distance covered by foodstuffs from their production to their consumption sites, have been proposed as an indicator of sustainability of the human food system (Paxton, 1994; Smith et al., 2005). However, in an analysis of the US food supply chain, Weber and Matthews (2008) showed that foodstuff transportation is only a minor term in its total carbon imprint and that changes in agricultural practices or in the composition of human diet would have a much more pronounced effect on greenhouse gas emission than reduction of the food transport distance. They conclude that the issue of localisation of the food supply is not a question of climate impact optimisation but is conditioned by the political will to support local agricultural communities and to restore the link between cities and their rural hinterland. The latter concern is revealed by the recent and quite rapid development in the Western world of citizen organisations aiming to reconnect food production and urban consumption, as well as directly controlling the quality of products and the environmental impact of their production, through direct contracts between farmers and groups of concerned consumers (Community Supported Agriculture in the North America and the UK, AMAP in France, Solodali in Italy, Teikei in Japan, etc.).

As water is also a food, drinking water provision is another important aspect of the food supply. Because of their intensive use of fertilisers and pesticides, modern agricultural practices often lead to severe degradation of the quality of water produced by rural territories. A conflict therefore exists in the allocation of land areas for either drinking water or food production. Some large cities, such as New York in the US, made the choice of reserving certain nearby lands for clean drinking water production, excluding agricultural activities (Swaney et al., 2011), while others, such as

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Athens in Greece (Stergiouli et al., 2011) and Barcelona in Spain (Tello et al., 2011) extend their water supply areas a very long distance. In a few instances, such as in Munich (<http://www.partagedeseaux.info/article226.html>), a deliberate policy was implemented to reconcile water and food production in the surrounding hinterland, with organic agriculture being promoted through the establishment of a strong public urban market demand.

The case of the huge Paris agglomeration offers an interesting example to study the potentiality of changes in the relationships between a large city and its food-supplying area, in particular in terms of its contribution to the nitrogen cascade. Previous studies (Billen et al., 2009, 2011) have traced back the geographical areas supplying food (measured as protein N content) to the Paris agglomeration during the last two centuries, a period when the city grew from 700 000 inhabitants in 1786 to 11 500 000 at the present time: its per capita N consumption rose from 5.4 to 8.0 kg N cap⁻¹ yr⁻¹, and the share of animal products in the diet increased from 39 to 69% of total protein intake. Surprisingly, these major changes in the city's food demand were not accompanied by a considerable extension of the mean food supply distance, but rather by deep reorganisation, specialisation and opening of agriculture in the hinterland. On the other hand, the Seine watershed still represents the only source of drinking water for Paris, with two-thirds coming from surface water and one-third from groundwater resources, both threatened by increasing nitrate contamination (Billen et al., 2007; Ledoux et al., 2007). Previous studies have also shown that only radical changes in agricultural practices would be able to durably reduce nitrate pollution of ground and surface water in the Seine watershed (Thieu et al., 2010a,b; Lancelot et al., 2011).

This paper pursues the analysis of the environmental imprint of Paris's food consumption on the biogeochemical functioning of its rural hinterland and attempts to bring out the relations between urban demand for foodstuffs, nitrogen cycling in agricultural systems, and nitrate contamination of water resources. We then explore the potentialities of radically changing both the agricultural practices and the urban diet patterns for reducing the environmental imprint of urban food consumption.

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2 Approach and methods

The approach applied herein takes inspiration from the concepts and methods of territorial ecology as defined by Barles (2010). Starting from the urban demand, we first delimited the territory supplying food to the Paris agglomeration, then analysed the fluxes of material involved in its production and supply. Based on the results of this analysis, alternative scenarios able to fulfil the same functions while meeting additional constraints are imagined.

To define the historical and current food supply areas of the Paris agglomeration and to analyse the functioning of their agricultural system, a combination of agricultural and transport statistics were used. In particular for the present period, the national agricultural statistics (Agreste, Ministry of Agriculture www.agreste.agriculture.gouv.fr/), the SitraM database on commodity transport between French *départements* (French Ministry of Environment, www.statistiques.developpement-durable.gouv.fr/) and the FAO statistics on production and international trade of food products (<http://faostat.fao.org/>) were compiled. All crop and animal product quantities, originally provided in tons, were converted to their nitrogen weight equivalent using the N content figures (1.8 % N for cereals, 3.4 % N for meat, 0.5 % for milk and 0.1–0.4 % for most fruits and vegetables) presented in Billen et al. (2009). The relationship between crop production (in terms of N content) and total N fertilisation of arable land (manure, synthetic fertilisers, symbiotic N fixation and atmospheric deposition) was established at the *département* scale. Data on the use of synthetic fertilisers by *département* were provided by Unifa (2008). This relationship was used to assess the environmental losses of nitrogen by the agro-systems and to calculate yields in the different scenarios explored (see below).

3 The current nitrogen imprint of Paris food consumption

Until the middle of the 20th century, Paris was still mainly supplied by an area roughly corresponding to a 150-km circle around the city, including most of the Seine

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watershed. Although a certain degree of agricultural specialisation was already present within this area, the agricultural system was fundamentally based on a close relation between cereal cultivation and livestock farming, the latter producing the organic fertilisers required by the former. The increase of grain yield during the 19th century mostly resulted from an improvement in animal feeding and manure management, owing to the replacement of the triennial fallow by a N₂-fixing legume fodder crop, which provided a considerable increase in livestock density (Billen et al., 2009, 2011).

The 20th century agrarian revolution, following the generalisation of the use of synthetic N fertilisers, led to pronounced spatial segregation between the regions of the Central Paris basin – specialised in cereal cultivation at the expense of livestock farming – and the more peripheral regions, which specialised in cattle rearing and imported a large share of the feed from other regions, countries or continents. Today, Paris's main food-supplying area is composed of three areas with quite different biogeochemical functioning (Billen et al., 2011):

- i. The directly surrounding area corresponding to the Seine watershed is now mainly devoted to intensive cereal farming and provides most of the vegetal proteins consumed in Paris. It exports 80 % of its production.
- ii. The area made up of Brittany, Normandy and Nord-Pas-de-Calais produces the largest fraction of the animal proteins consumed in Paris, but depends on massive imports of feed from other regions.
- iii. Among the imports of vegetal proteins required for feeding the livestock of the latter territory, soybean and oilcake meals from Brazil and Argentina are the most significant: the size of the agricultural surfaces involved is similar to that of the two other territories.

These three areas together contribute 70 % of the needs of Paris consumption. The remaining 30 % is supplied half by other French *départements* and half by foreign countries.

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From these data, the environmental imprint of the Paris food supply can be represented in terms of (i) the land area required and (ii) per capita nitrogen fluxes involved, exactly as is currently done for wastewater domestic effluents (Fig. 1). To satisfy the needs in vegetal products of one Paris inhabitant, only 0.018 ha of cereal crop area from the Seine watershed is required, but 0.2 ha of agricultural land in polyculture–animal farming areas such as those of Brittany, Normandy and Nord-Pas-de-Calais are required to satisfy the needs in meat and milk of the same person; in addition, an area of about 0.1 ha in South America is required to supplement the feed of the livestock in the latter region.

To estimate the losses occurring through leaching and volatilisation from agricultural soils in the two French supply areas, we calculated the difference between total fertilisation and crop production of agricultural land (both expressed in N content) at the *département* scale. The relationship between crop yield and total fertilisation follows an asymptotic curve (Fig. 2a), with the surplus (i.e. the difference between fertilisation and yield) increasing regularly with increasing fertilisation (Fig. 2b). The surplus is generally lower in the cereal crop regions of the centre of the Paris basin than in the intensive livestock farming areas of the West of France. If the surplus is assumed to be entirely diluted in the infiltrating water depth (as a mean 300 mm yr⁻¹ for the areas described herein), the corresponding theoretical sub-root nitrate concentration can be calculated. In most *départements*, the value is far above the drinking water standard of 11 mg NI⁻¹ (50 mg NO₃ l⁻¹).

For the two French agricultural areas supplying food to Paris, the estimated environmental losses of nitrogen are estimated at 15 kg N cap⁻¹ year⁻¹, i.e. three times the load discharged as urban wastewater by one inhabitant.

4 A local and organic farming scenario for the Seine watershed

Thieu et al. (2010b) have shown that organic agriculture, if generalised to the entire agriculture area of the Seine watershed, has the potential to restore nitrogen

contamination to a level below the ecological water resources standards. In order to explore the potential of reducing the nitrogen imprint of the Paris food supply, we constructed a hypothetical scenario based on the following constraints:

The organic and local scenario (OrgLoc) first requires that most of the food supply be produced within the limits of the Seine watershed, Paris's traditional food-producing hinterland. This necessarily implies restoring livestock farming within the area. The scenario assumes, however, that this livestock be reared with only local feed: no import of proteins from outside the Seine watershed limits would be allowed. To calculate the feed consumed by this livestock, we used a nitrogen conversion ratio of 17%, the current average value calculated for the Brittany-Normandy-Nord-Pas-de-Calais regions.

The scenario also assumes organic agricultural practices, implying no use of synthetic fertilisers, all the fertilisation of arable land being ensured through symbiotic nitrogen fixation and manure application. Our calculations assume that the currently observed relationship between yield and total fertilisation shown in Fig. 2 also holds for organic practises. This assumption implies that at a similar fertilisation rate, whether the fertilisation is organic or mineral, the yields are identical. In other words, the often observed lower yields of organic vs. conventional farming are the results of lower fertilisation rather any other difference. The upper relationship illustrated in Fig. 2 (Yield = $Y_{\max}(1 - \exp(-\text{fertilization}/Y_{\max}))$ with $Y_{\max} = 350 \text{ kg N ha}^{-1} \text{ yr}^{-1}$) is used in the calculation, once the total fertilisation (manure, legume N_2 fixation and atmospheric deposition) is known, to calculate both the yield of arable land and the nitrogen surplus defined as the difference between fertilisation and yield. In the construction of the OrgLoc scenario, the first step is to assess the size of the livestock required to sustain the needs of the local population. The current area of permanent grassland in the Seine watershed is maintained unchanged. The size of the nitrogen-fixing arable land (temporary grassland involved in crop succession and legume fodder crops) is adjusted so as to meet the feed requirements of livestock, with the production of the permanent grassland, 70% of the production of nitrogen-fixing crops (30% used as

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green manure) and an adjustable fraction of non-legume crops. The nitrogen surplus of arable land is then calculated as the difference between total fertilisation and yield, and the theoretical sub-root nitrate concentration is calculated by dividing the surplus by the infiltrated water depth. Finally, the calculated production of non-fixing cropland which has not been allocated to human or animal feeding is considered available for export. Table 1 and Fig. 3 summarise the calculations and compare the results with the current situation.

These calculations show that it is quite possible to conceive a scenario of organic farming locally meeting the quantitative food requirements of the current population of the Paris agglomeration (and of the other cities of the Seine watershed, totalling 4 million inhabitants), provided that the livestock density is increased from the current value of 18 to 50 LU km⁻². The basin should still be able to export about 1630 kg N km⁻² yr⁻¹. This should be compared to the current cereal export of 4820 kg N km⁻² yr⁻¹, an amount reduced to a net protein export of 800 kg N km⁻² yr⁻¹ if the import of feed and animal products, as well as the vegetal proteins required for the production of the latter, are deducted (Fig. 3a). In this OrgLoc scenario, however, the nitrogen surplus, although lower than in the current situation, would still represent a sub-root water nitrate concentration double the drinking water standard.

5 Changing the human diet

The present human consumption of animal products in France accounts for 65% of the total protein intake. This rate is among the highest in the world (Fig. 4). The trend shown in Fig. 4 suggests that the share of animal product consumption in the human diet increases with the gross domestic product, as if meat and milk consumption were a sign of economic wealth. Yet the adverse public health effects of a high animal-protein diet are well documented both in terms of cardiovascular diseases (Llod-Williams et al., 2008) and colorectal cancer risks (Norat et al., 2005). A reduction of animal protein consumption in industrialised countries is also advocated for environmental reasons

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by NinE (2009) (The Barsac Declaration for a “demitarian” diet of 35–40 % animal proteins), and as a condition for world food security and equity in the Agrimonde scenario (Paillard et al., 2010).

We therefore decided to vary the share of animal products in the human diet and calculate the resulting effect on the organic-localised scenario described above. Figure 5 shows the effect of reducing the proportion of animal protein in the total human diet of the Seine basin inhabitants from the present value of 65 % to a “demitarian” diet of 35–40 % (NinE, 2009). Obviously, the area’s self-sufficiency in terms of meat and milk production can be achieved in this scenario with lower livestock density, decreasing the total fertilisation rate of arable land and the nitrogen surplus, without decreasing the area’s cereal export capacity. With a demitarian diet, the Seine watershed should be able to feed its population, still export about 1950 kg N km⁻² yr⁻¹ as cereal, and produce sub-root water meeting the best quality standards (Table 1 and Fig. 3).

The per capita imprint of the individual Parisian according to this organic-localised-demitarian (OrgLocDem) scenario is represented in Fig. 6. Compared with the current imprint as represented in Fig. 1, the area required to feed the individual Parisian in this scenario is similar to that required today, but can be mainly restricted to the surrounding traditional hinterland of Paris. The total reactive nitrogen injected into the process of food production is reduced to 20 kg N cap⁻¹ yr⁻¹ compared to the 30 kg N cap⁻¹ yr⁻¹ required in the current situation. The losses of reactive nitrogen by soil leaching are much lower, accounting for 40 % of the losses at the final consumption stage, while these losses are 300 % of this value in the current situation.

6 Discussion and conclusion

The impassioned controversy about localisation of food supply has been very well analysed by Cowell and Parkinson (2003). The defenders of the so-called Food-Miles movement put forward the benefits to be expected from localising agriculture in terms of both food security and environmental impact. They claim that regional self-sufficiency of food production and consumption is more likely to increase food security

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than a globalised food system. They also stress the negative environmental impacts of transporting foodstuffs over long distances. Finally they wish to reconnect people with food, neighbouring producers and seasonality, as well as to reduce the potential of environmental degradation and human exploitation by avoiding “out of sight, out of mind” effects produced by long-distance trade.

The opponents criticise the Food-Miles logic for its negation of productivity differentials between geographical locations, claiming that feeding a rapidly growing world population in a sustainable manner requires long-distance trade to ensure that food is produced most efficiently in the most suitable locations (Desrochers and Shimizu, 2008). Ballingal and Winchester (2008) go further by stating that local preference in food choices in Europe would lead to “starving the poor” by depriving Southern countries of important commercial income.

One particular aspect of the debate, the question of greenhouse gas (GHG) emissions related to the transportation of foodstuffs, is probably the simplest to assess. All lines of evidence show that the benefits of localising food production are minor in that respect. For instance, Heyes and Smith (2008) showed that daily familial shopping trips between home and supermarket use as much energy as the overseas transport of the same amount of food, while Weber and Matthews (2008) demonstrated that transport is responsible for only a minor share of GHG emissions of the whole food production chain in the US and concluded that changes in agricultural practices or in the consumer diet composition have a much greater impact than localising production.

However, the debate has never included the question of drinking water supply even though drinking water production often competes with food production in the same land areas, particularly in the densely populated regions of Europe. This paper addresses the question of the compatibility of agriculture and water production in rural areas. For the Seine watershed, both the traditional feeding hinterland of Paris and its sole drinking water supply, we show that it is possible to conceive an agricultural system able to reconcile the dual function of rural areas, namely feeding the city and producing high-quality water.

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The Paris basin area is emblematic because it is currently one of the most intensive cereals-producing areas in the world; some people even consider as its vocation to export grain to the rest of the world. This view should be tempered by the fact that most of these exports are currently intended for other European countries where a large part is used for animal feed. Nevertheless, what is striking in the OrgLoc and OrgLocDem scenarios is that they allow the Seine basin area to continue exporting a large share of its cereals production and in fact have a larger *net* export of proteins than in the current situation.

This purely biogeochemical approach is obviously restrictive and does not take into account the reluctance of either farmers, invested in their current technical, economic and social network, to shift their practices to organic farming, or consumers to change their eating habits so deeply embedded in both culture and commercial advertising influences. We simply delineate here the physical possibilities of a particular area.

In this respect also we are aware that the conclusions drawn herein can be quite easily caricatured. We know for instance that a number of foodstuffs consumed in Paris are imported from far away because they cannot be grown in the North of France. Our analysis of the nitrogen flows involved in the import of such products shows that these are minor (Billen et al., 2011), while they can account for a significant share of the monetary fluxes involved in feeding the city. This has always been the case, as Abad (2001) showed that already at the end of the 18th century, import to Paris of exotic and luxury agricultural goods (such as citrus fruits, tea, coffee, spices, etc.) already accounted for a significant value in the food “Great Market”. Our approach is focused on the major biogeochemical fluxes associated with food production and consumption, because these are the most significant in terms of environmental impact, including water quality. There is no reason in this respect to advocate the complete cessation of exotic product imports. The localisation option explored in this paper concerns the general organisation of the agro-food system feeding Paris and the general balance of its inhabitants’ diet, not the details of their occasional consumption of luxury products. In that sense, the suggestion that a shift to localising the food supply in Europe

would “starve the poor” and “increase global inequality”, as suggested by Ballingall and Winchester (2008), is irrelevant.

In a recent report (Westhoek et al., 2011), a scenario of 50% reduction of animal protein in the human diet in the EU has been explored at the global scale using the IMAGE model of the Netherlands Environmental Assessment Agency. The results are a strong decline in the import of protein-rich feed into Europe and an increase in cereal, meat and milk exports from Europe, so that the scenario would mainly have effects on land use and environmental quality outside the EU. Our approach differs from this one because we first constrained the local agricultural system to self-sufficiency for feed and for meat and milk products. This additional constraint explains the strong local response of the system to decreasing the animal protein consumption observed in our scenario, in particular in terms of water quality. It therefore appears that localising as far as possible the major fluxes of food and feed supply at the regional scale is a prerequisite to get environmental benefits from a change to lower animal products in the human diet.

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		2006		OrgLoc	OrgLocDem	
Total arable land						
Arable area	1000 ha	4319	N ₂ fixing and non fixing crops	4319	4319	N ₂ fixing and non fixing crops
Total N ₂ fixation	kg N ha ⁻¹ yr ⁻¹	19	= N ₂ fixation/arable area	97	56	= N ₂ fixation/arable area
Synthetic fertilizers	kg N ha ⁻¹ yr ⁻¹	161	Unifa (2009)	0	0	No synthetic fertilizers
Manure	kg N ha ⁻¹ yr ⁻¹	32	manure production/arable area	90	55	Manure production/arable area
Atmospheric deposition	kg N ha ⁻¹ yr ⁻¹	12	N _{tot} deposition, EMEP	12	12	N _{tot} deposition, EMEP
Total fertilization	kg N ha ⁻¹ yr ⁻¹	224	Sum	199	123	Sum
Total crop exportation	kg N ha ⁻¹ yr ⁻¹	124	N ₂ fixing used as feed and non fixing crops	130	102	N ₂ fixing used as feed and non fixing crops
System performance						
Coverage of livestock needs						
Local feed production	kt N yr ⁻¹	145		464	286	
Local coverage of feed requirements	%	95		100	100	
Import of feed	kt N yr ⁻¹	8		0	0	No import of feed
Coverage population needs						
Human needs for animal products	kt N yr ⁻¹	77	= population*animal pdcts consumptn	77	47	= population*animal pdcts consumption
Local coverage in animal pdcts	%	20	= local prod of animal pdcts/human needs	101	101	= local prod of animal pdcts/human needs
Human needs for vegetal products	kt N yr ⁻¹	41	= population*vegetal pdcts consumptn	41	71	= population*vegetal pdcts consumption
Local coverage in vegetal pdcts	%	1176	= local crop prod not used as feed/human needs	464	354	= local crop prod not used as feed/human needs
Import(+)/export(-) animal pdcts	kt N yr ⁻¹	62	= local animal pdcts prod – local consumption	0	0	= local animal pdcts prod – local consumption
Import(+)/export(-) vegetal pdcts	kt N yr ⁻¹	-445	= local vegetal food prod – local consumption	-151	-180	= local vegetal food prod – local consumption
Hydrosphere contamination						
N _{surplus} on arable land	kg N ha ⁻¹ yr ⁻¹	99	= total fertilization – total cop prodctn	69	21	= total fertilization – total cop production
Infiltration rate	mm yr ⁻¹	300	Average for Seine watershed	300	300	Average for Seine watershed
Sub-root NO ₃ conc	mg N l ⁻¹	33	= N _{surplus} /infiltration rate	23	7	= N _{surplus} /infiltration rate

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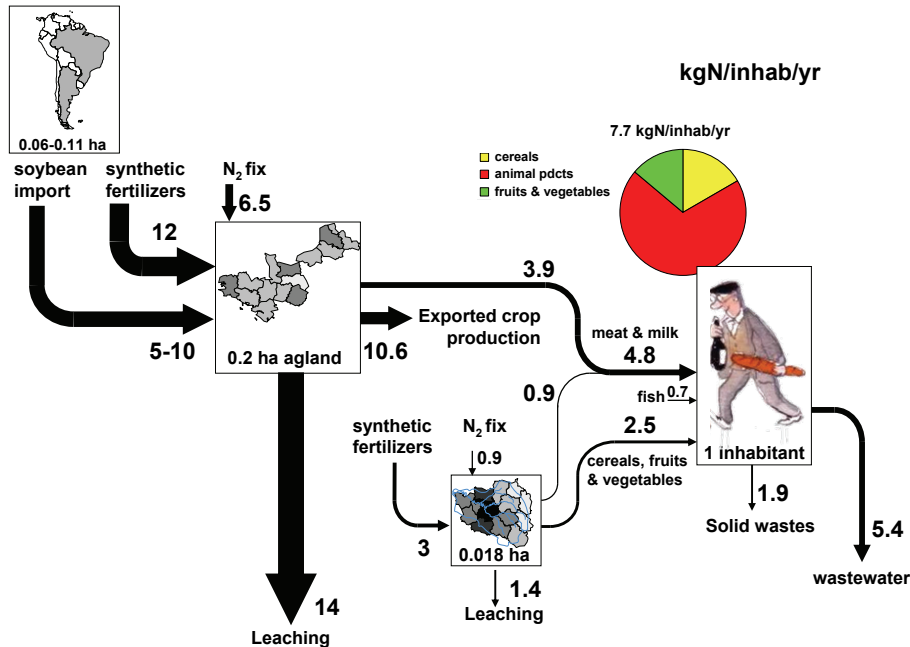


Fig. 1. Schematic representation of the nitrogen imprint of the food supply of one Paris inhabitant. Nitrogen fluxes involved are expressed in kg N inhab⁻¹ yr⁻¹. The figures are derived from the description established in Billen et al. (2011).

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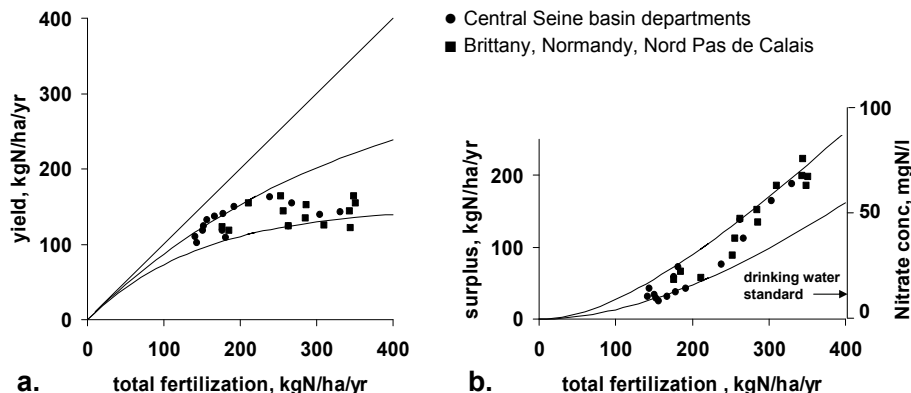


Fig. 2. (a) Relationship between crop yield and total fertilisation (both expressed in $\text{kg N ha}^{-1} \text{yr}^{-1}$) of agricultural land of the different French *départements* mainly involved in the Paris food supply. The following mathematical function has been fitted to give the upper and lower bounds of the data points: $\text{yield} = Y_{\text{max}} \cdot (1 - \exp(-\text{Fert}/Y_{\text{max}}))$, with $Y_{\text{max}} = 350 - 150 \text{ kg N ha}^{-1} \text{yr}^{-1}$. (b) Agricultural surplus (total fertilisation minus crop yield) plotted against fertilisation. The corresponding theoretical sub-root water concentration, calculated assuming a mean runoff depth of 300 mm yr^{-1} , is also indicated (right scale). The data available for a number of organic farms are also shown (open symbols).

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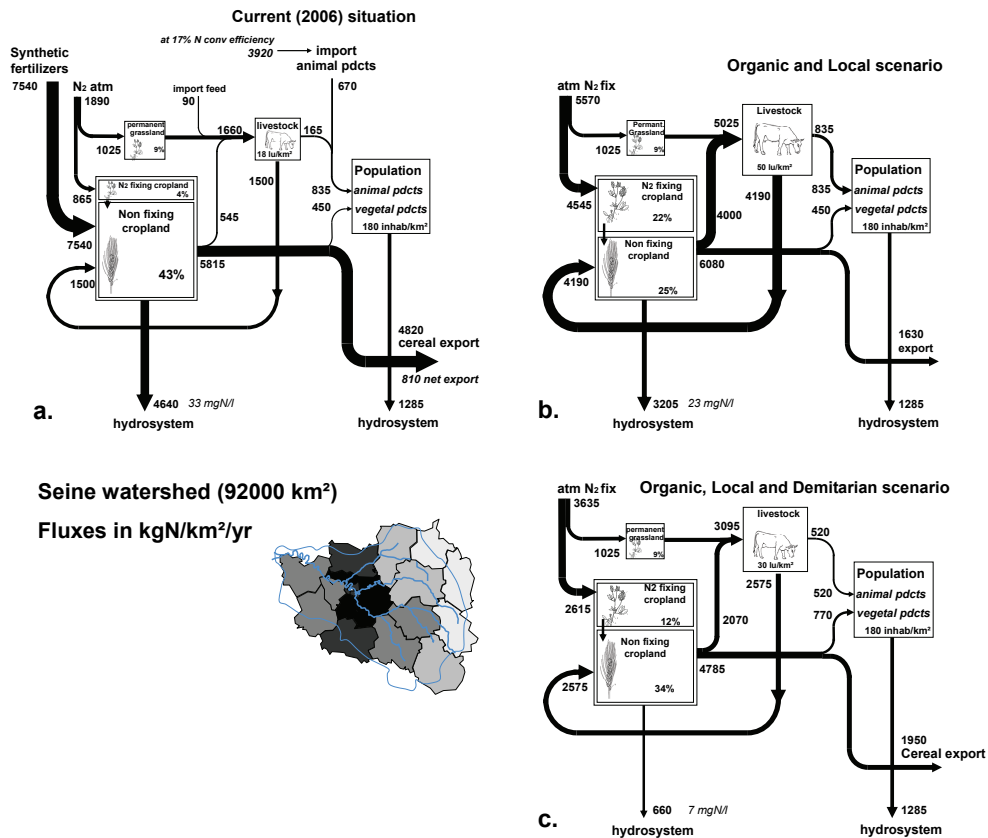


Fig. 3. Nitrogen fluxes in the agricultural system of the Seine watershed. **(a)** Current situation (2006). **(b)** Organic and local scenario (OrgLoc). **(c)** Organic, local and demitarian scenario (OrgLocDem).

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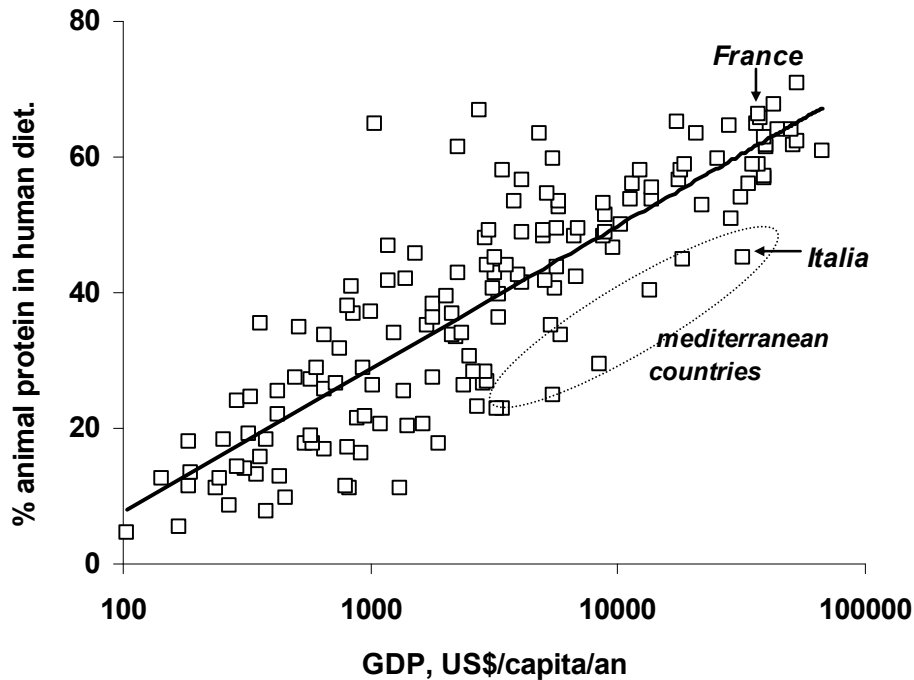


Fig. 4. Share of animal products in human total protein consumption of the world's countries in 2003, plotted against their GDP (sources: FAOstat, 2010).

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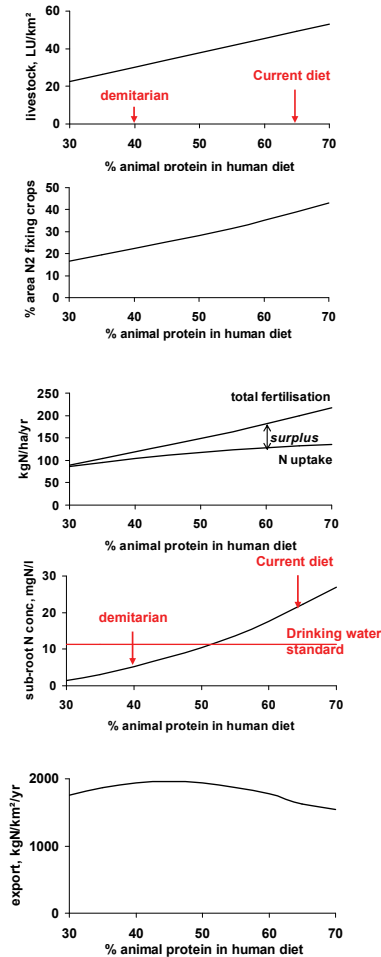


Fig. 5. Effect of reducing the proportion of animal-based protein in the human diet on the N fluxes through the agricultural system in an organic, local scenario of the Seine watershed.

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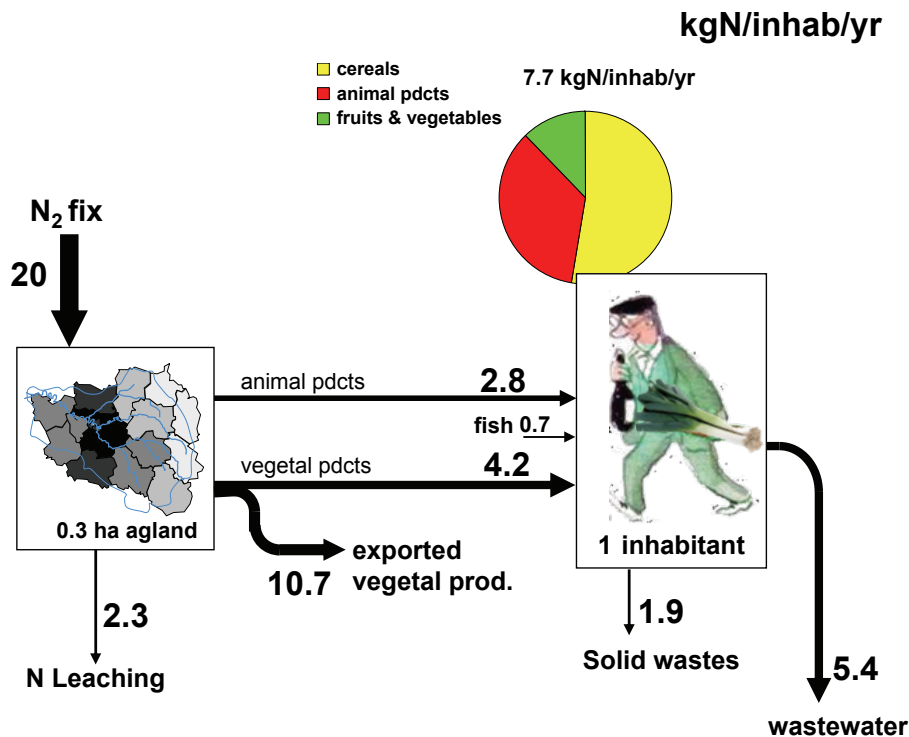


Fig. 6. Schematic representation of the nitrogen imprint of the food supply of one Paris inhabitant in the organic-local-demitarian scenario. The nitrogen fluxes involved are expressed in $kg\ N\ inhab^{-1}\ yr^{-1}$.

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