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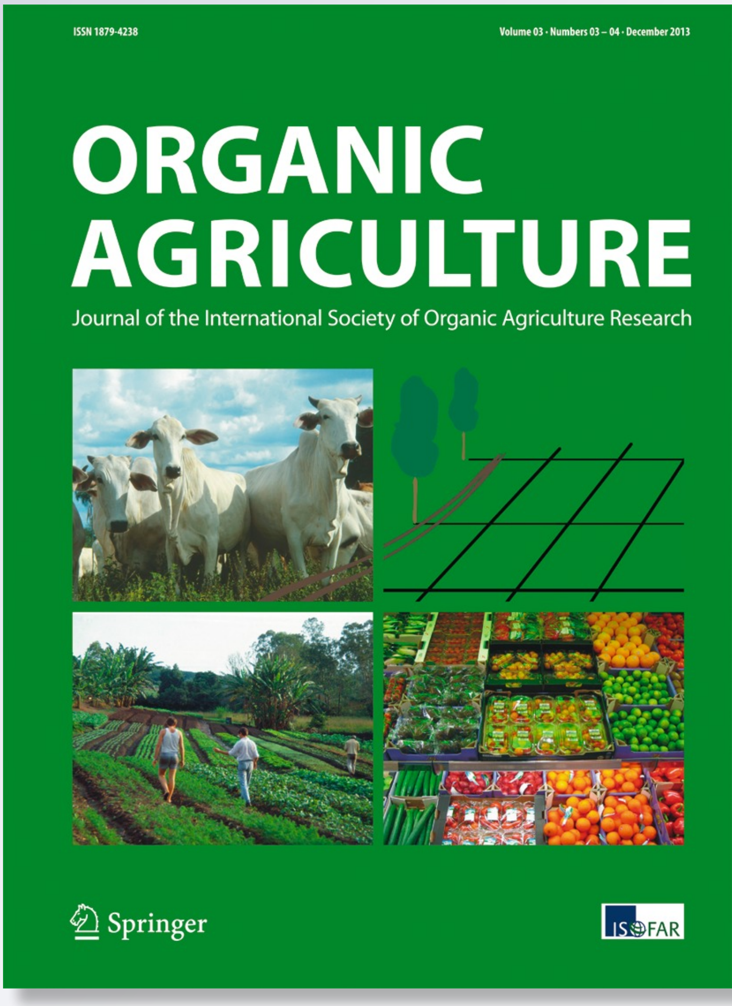

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Managing nutrient in organic farming system: reliance on livestock production for nutrient management of arable farmland

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Abstract Organic agriculture is a production system which relies on ecosystem management and ecological processes rather than on the external flow of agricultural inputs. The development of the organic sector has induced a spatial decoupling of livestock and crop production. This has increased the flow of nutrients that occurs between farms compared to what happens within individual farms. Organic systems have replaced synthetic inputs with site-specific management practices to balance input and output nutrients to ensure short-term productivity and long-term sustainability. This paper addresses the nutrient management of mixed and specialized farming systems, with a special emphasis on the reliance on livestock production for the nutrient management of arable farmland. We assessed the nutrient budgets of nitrogen (N), phosphorus (P), and potassium (K) of 28 organic farms selected according to livestock density from three French counties. The farms were classified as stockless, mixed, and cattle farming systems. A soil surface nutrient budget was calculated for each farm based on inputs (N fixation, excreta, and manure) and outputs (grazing offtake, harvests) on annual crops and grasslands. Inputs due to N atmospheric deposition and seeds and losses due to leaching and volatilization were not considered in this study. Nutrient budgets of the 28 farms revealed N, P, and K deficits, although disparities between farming systems and their geographical location were also observed. Stockless farms presented high N deficit whereas mixed and livestock farming systems presented lower deficits (close to equilibrium) or even surpluses in a county with a high density of livestock farms. Differences between farming systems in terms of P and K budgets followed the same trend, but regional specificities appeared significant in stockless and livestock systems (related to the size of farms and the stocking rate). None of the farms purchased off-farm organic fertilizers when exchanges of manures and straw were observed at the regional scale. When livestock is present on the farm, the nutrient resources came mainly from recycling internal resources (manures, excreta, and N fixation), whereas stockless farming systems purchased organic manure from neighboring farms (14 to 58 % of total N inputs, 10 to 100 % of total P and K inputs). The sustainability of stockless organic farming systems is questioned, noticeably those that were located in regions where resources of organic matter are scarce. Only farming systems producing large quantities of manure or which purchased feed showed balanced nutrient budgets.

Keywords Nutrient budgets · Organic farms · Crop production · Livestock · Stocking rate · Intensity

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Introduction

Over the last 50 years, the intensity of agriculture in north-western Europe has increased dramatically with higher yields per hectare to cope with demand in human and animal food. The intensification of agricultural production has led to farm specialization as well as higher dependency on nutrients, essentially nitrogen (N), phosphorus (P), and potassium (K) (Fangueiro et al. 2008). This trend has produced potential damage on soil, water, air, and habitat resources (Loges et al. 2009).

The increase in food demand related to demographic growth and evolving world nutritional needs (Paillard et al. 2011) and the preservation of environmental resources are major challenges for agriculture.

Agroecological practices based on natural processes (e.g., symbiotic fixation of legumes) and ecological practices (e.g., use of the soil's nutrient resources by multispecies crops) could allow fewer nutrients from fossil sources to be used (Hauggaard-Nielsen et al. 2009; Nemecek et al. 2008; Pelzer et al. 2012). The presence of livestock on farms generally leads to better completion of the nutrient cycle, limiting the use of fossil inputs as well as risks for the environment (Korsaeth and Eltun 2000; Loges et al. 2009; Neumann et al. 2011). Agroecological practices should be based on a double management strategy regarding nutrients, one seeking to increase the proportion of nitrogen coming from atmospheric nitrogen fixation by legumes, and the other to distribute nutrients present on the farm in space and over time.

Organic agriculture has been promoted as being environmentally beneficial by reducing agricultural impacts on water quality, biodiversity, and soil fertility. To optimize crop production, organic farming systems rely on the management of soil organic matter to enhance the chemical, biological, and physical properties of the soil (Marinari et al. 2006). On mixed and livestock farms, animal manures are an important currency for re-distributing nutrients as it is important to ensure that fertility has not been built in some fields at the expense of others (Watson et al. 2002a). In the past few years, the development of the organic sector has induced a spatial decoupling of livestock and crop production, leading to the disappearance of livestock production and grasslands on organic grain systems (David et al. 2013). This specialization has weakened the autonomy of these farms, which often must resort to off-farm inputs to satisfy their needs in nutrients or livestock or crop production.

Nutrient budgets have been used widely in a range of farming systems to assess nutrient use efficiency, long-term sustainability, and the environmental impact of farming systems (Berry et al. 2003). Budgets are the outcome of a simple nutrient accounting process which detail all the inputs and outputs to a given and defined system over a fixed period of time. Nutrient budgets therefore have the potential to illustrate, both qualitatively and quantitatively the flows of nutrients into, out of, and within, a given system (Watson et al. 2002b). Nutrient budgets have been widely used at the farm gate scale (Steinshamn et al. 2004; D'Haene et al. 2007; Gourley et al. 2007; Fangueiro et al. 2008) and assess the overall level of a farm's dependence on off-farm resources and indicate a level of polluting pressure at the farm scale (Korsaeth and Eltun 2000; Berry et al. 2003; Aronsson et al. 2007; Korsaeth 2008; Loges et al. 2009). For example, Fortune et al. (2000) used simple nutrient budgeting approaches at the farm gate scale to suggest that organic farming systems have the potential to maintain soil fertility and minimize losses.

Soil surface budgets are used to determine crop nutrient requirements from fertilizers and manures (Watson et al. 2002b) at the total usable area scale (including annual crops and grasslands). Few studies have taken an interest in nutrient flows over a crop sequence at this scale. These nutrient budgets express the difference between inputs, from on-farm resources (organic matter and atmospheric nitrogen fixation) and off-farm resources (fertilizer or organic manures) and outputs from harvests and grazing. This approach allows the origin of the deficits or excesses in nutrients to be identified and thus to conclude on the sustainability of the farms. It also detects strategies used to cover nutrient requirements for the production of annual crops and grasslands. Inputs due to N atmospheric deposition and seeds and losses due to leaching and volatilization were not considered in our study.

The objective of this paper was to evaluate the interest of combining livestock and crop production to balance soil surface budgets of N, P, and K at the total usable agricultural scale (including grasslands and annual crops). More specifically, our aim was to (1) assess the degree of autonomy in N, P, and K on organic farms; (2) quantify a farm's internal nutrient cycle; and (3) evaluate potential dependence on livestock production but also imported off-farm inputs of organic farms.

Material and methods

Characteristics of the farms surveyed

The 28 farms surveyed were located in three French counties. The survey took place in 2010 and considered the data from the year 2009 for each farm. From a climatic point of view, 2009 was considered a normal year. The Lorrain county (47° 80 N 7 E to 49° 60 N 5 E) is located in eastern France (18 farms) where the traditional livestock farming system produces milk and beef with grass and maize crops. The climate is oceanic, with continental influences, characterized by long cold winters and mild and stormy summers with regular precipitation distributed throughout the year. Annual precipitation varies between 700 and 1,000 mm. Plain of Forez (45.68° N 4.166° E) is located south of the Massif Central mountain range (six farms) where the traditional farming system mainly produces milk and cereals. The climate is classified as continental with dry and warm summers and cold winters. Annual precipitation varies between 550 and 800 mm. Plain of Valence (44.94°N 5.03 E) is located at the confluence of the fertile Rhône, Drôme, and Isere River valleys where loamy and sandy soils dominate (four farms). Annual precipitation varies between 700 and 1,000 mm. The climate combines continental and Mediterranean influences. The traditional farming system mainly produces grains.

The farms surveyed were livestock farms (dairy or meat cattle), mixed (dairy or meat cattle with annual crops), or arable farms without or with very small livestock units (Table 1). The farms chosen could be classified as having a medium to high degree of specialization (three to six crops in the rotation and the main production—cattle or grains—represented 60 to 100 % of the gross farm income). They had converted to organic farming at least 5 years ago. They were also selected so as to represent the diversity of organic farms in their respective counties. Eight farms specialized in crop production, six had no livestock production, and two had a small livestock production from an economic perspective. Sixteen farms were cattle farms (specializing in dairy or meat) and four were mixed farms combining cattle and crop production with equal economic value (Table 1). The size of the herds and farms varied from one county to the other and within each county.

Nutrient budget assessment

The soil nutrient budget assessment (Oenema et al. 2003) was calculated at the scale of the total usable agricultural area (UAA; including grasslands and annual crops and excluding rangelands and forests). The inputs and outputs of N, P, and K were inventoried (Fig. 1). The inputs comprised atmospheric nitrogen fixation by legumes, manures, or composts from livestock production or from other farms, organic fertilizers purchased, and grazing excreta. The outputs were composed of quantities of N, P, and K exported by the harvested or pastured crops. In other words, the quantities of nitrogen fixed freely by bacteria in the soil, the atmospheric deposition of nitrogen, and losses by leaching and volatilization were not taken into account in the calculation.

The amount of organic matter (OM) added per hectare and crop yields (grasslands and crops) were estimated by the farmers. The references used to calculate organic matter composition in N, P, and K and the amounts of nitrogen fixed by legumes were found in the literature (Tables 2, 3, and 4). During the pasturing period, the estimation of the animal inputs (excreta) and outputs (grazing offtake) was based on Comité d'Orientation pour des Pratiques agricoles respectueuses de l'ENvironnement (CORPEN) references (1999) classified by animal categories (Table 3).

Inputs

Inputs of N, P, and K per hectare of the total cropped area (kg N, P or K ha^{-1} year^{-1}) were calculated using Eq. 1:

$$Input = NFix + OM\,Int + OM\,Ext \quad (1)$$

NFix represents the quantity of nitrogen biologically fixed by legumes (kg N ha^{-1} year^{-1}), *OM Int* is the quantity of N, P, or K brought by manures produced on the farm (farmyard manure, compost) and by animal excreta during grazing,

Table 1 Characteristics of the 28 farms

No.	Faming system	County	Type of cattle	Cattle in livestock unit (LTU)	Usable agricultural area (ha)	Grasslands proportion	Arable land proportion	Legumes proportion[a]	Stocking rate ($LTU.ha^{-1}$)	Proportion of manure applied on arable land[b]
1	Livestock	Lorraine	Dairy	39	65	0.5	0.5	0.8	0.6	1
2	Livestock	Lorraine	Beef	101	114	0.9	0.1	0.9	0.9	0.8
3	Livestock	Lorraine	Dairy	121	197	0.7	0.3	0.9	0.6	1
4	Livestock	Lorraine	Dairy	111	190	0.8	0.2	0.9	0.6	0.9
5	Livestock	Lorraine	Dairy	84	116	0.6	0.4	0.7	0.7	0.8
6	Livestock	Lorraine	Dairy	234	332	0.8	0.2	0.9	0.7	0.5
7	Livestock	Lorraine	Dairy	114	200	0.9	0.1	0.9	0.6	0.5
8	Livestock	Lorraine	Dairy	122	210	0.7	0.3	0.7	0.6	0.8
9	Livestock	Lorraine	Beef	84	101	0.6	0.4	0.6	0.8	0.8
10	Livestock	Lorraine	Beef	40	71	0.7	0.3	0.7	0.6	1
11	Livestock	Plain of Forez	Dairy	89	105	0.9	0.1	0.9	0.8	1
12	Livestock	Plain of Forez	Dairy	54	75	0.8	0.2	0.9	0.7	1
13	Livestock	Plain of Forez	Dairy	38	59	0.9	0.1	0.9	0.6	1
14	Livestock	Plain of Forez	Dairy	34	42	0.9	0.1	0.9	0.8	0.9
15	Livestock	Plain of Forez	Dairy	35	60	0.8	0.2	1.0	0.6	0.6
16	Livestock	Plain of Forez	Dairy	70	65	0.8	0.2	0.8	1.1	0.9
17	Mixed	Lorraine	Beef	41	101	0.4	0.5	0.6	0.4	1
18	Mixed	Lorraine	Beef	125	201	0.5	0.5	0.6	0.6	0.9
19	Mixed	Lorraine	Dairy	102	328	0.5	0.5	0.6	0.3	1
20	Mixed	Lorraine	Beef	42	98	0.5	0.4	0.7	0.4	1
21	Arable	Lorraine	Beef	32	162	0.2	0.8	0.4	0.2	1
22	Arable	Lorraine	Beef	25	127	0.2	0.8	0.5	0.2	1
23	Arable	Lorraine	None	0	76	0.4	0.6	0.6	0	1
24	Arable	Lorraine	None	0	31	0.4	0.6	0.5	0	-
25	Arable	Plain of Valence	None	0	23	0.3	0.7	0.3	0	1
26	Arable	Plain of Valence	None	0	62	0.1	0.9	0.3	0	1
27	Arable	Plain of Valence	None	0	80	0.2	0.8	0.2	0	1
28	Arable	Plain of Valence	None	0	95	0.3	0.7	0.5	0	0.9

[a] Total surface area of legumes (grasslands + leys + grain legumes)/usable agricultural area

[b] Arable land comprises annual crops and temporary grasslands

and *OM Ext* is the quantity of N, P, or K brought by manures produced off the farm (purchased or exchanged). The calculation of the different parameters for nutrient inputs is described below.

N fixation

The atmospheric nitrogen fixation, *NFix* (kg N ha^{-1} $year^{-1}$), was calculated using Eq. 2:

$$NFix = (1+R)\left[\left(\sum_{j=1}^{n} a_j\left(Y_j F_j S_j\right) + b_j\right) + \left(\sum_{k=1}^{n} a_j\left(DMI_k G_k C_k F_k\right) + b_j\right)\right] \quad (2)$$

where Y is the crop yield (kg DM ha^{-1} $year^{-1}$), F is the proportion of legumes in the field, and S is the surface (ha); DMI is the dry matter ingested by animals during grazing (kg $month^{-1}$) based on CORPEN references

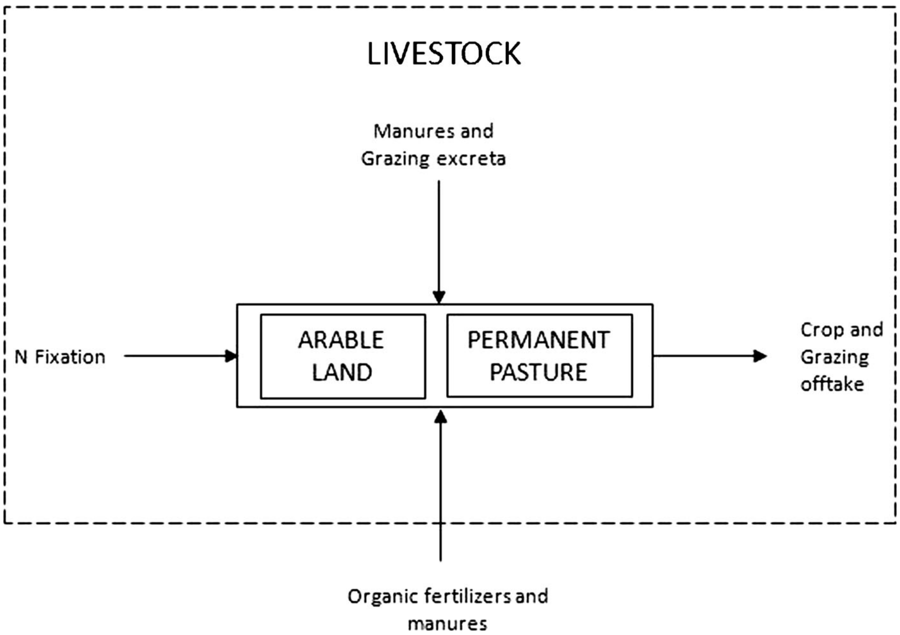

Fig. 1 Nutrient flows at the soil surface level used to calculate nutrient budgets. Farm boundary

(1999, 2001; Table 3), G is the duration of grazing (in months), C is the number of animals per hectare; a and b correspond to the coefficient determined by Carlsson and Huss-Danell (2003) for estimating nitrogen fixation of different legume species (Table 4), subscript j indicates legume species, and subscript k indicates the type of livestock. R is the proportion of N fixed by roots. It was fixed at 30 % as estimated by Huss-Danell et al. (2007).

Organic matter

Organic matter resources from farm (manures and excreta; *OM Int*) and external (purchased or exchanged; *OM Ext*) were differentiated to assess the degree of autonomy in nutrient. The quantities of N, P, and K delivered by internal organic resources (*OM Int*; kg N, P, K ha^{-1} year^{-1}) were calculated using Eq. 3:

$$OM\,Int = \sum_{p=1}^{n} Q_p E_p + \sum_{k=1}^{n} C_k G_k X_k \tag{3}$$

where Q is the quantity of organic matter delivered per hectare (t ha^{-1} year^{-1}), E is the concentration in N, P, or K of the organic matter (kg element t^{-1}; Table 2) and subscripted p corresponds to the type of organic matter; G is the duration of grazing (in months), C is the number of animals per hectare, X is the quantity of excreta (kg N, P, or K ha^{-1} month^{-1}) and subscripted k indicates the animal category (CORPEN 1999, 2001; Table 3).

The quantities of N, P, and K brought by external organic resources (*OM Ext*; kg N, P, K ha^{-1} year^{-1}) were calculated using Eq. 4:

$$OM\,Ext = \sum_{p=1}^{n} Q_p E_p \tag{4}$$

where Q is the quantity of organic matter delivered per hectare (t ha^{-1} year^{-1}), E is the concentration in N, P, or K of the organic matter (kg element t^{-1}; Table 2) and subscripted p corresponds to the type of organic matter.

Outputs

The nutrient outputs (*Output*; kg N, P, K ha^{-1} year^{-1}) included harvests (grain, straw, forage) and grazing (Tables 2 and 3). The concentration in nutrients of whole plants (grain and straw) was obtained from references for grain (Table 2) with an add-on factor for straw (+30 % N, +25 % P, and +250 % K; CORPEN 1988). Outputs were calculated using Eq. 5:

$$Output = \sum_{i=1}^{n} Y_i S_i N_i + \sum_{k=1}^{n} C_k G_k O_k \tag{5}$$

Table 2 Concentrations of N, P, and K inputs and outputs used to calculate the N, P, and K soil surface budgets in Eqs (3), (4), and (5)

Inputs/Outputs	N	P	K	Reference
Crop nutrient content (% nutrient)				
Wheat (*Triticum aestivum*) grain (dwt)	1.7	0.3	0.5	Berry et al. (2003)
Barley (*Hordeum vulgare*) grain (dwt)	1.3	0.3	0.5	Berry et al. (2003)
Oat (*Avena sativa*) grain (dwt)	1.6	0.3	0.5	Berry et al. (2003)
Triticale (*Triticosecale*) grain (dwt)	1.5	0.4	0.5	Berry et al. (2003)
Spring/winter beans grain (dwt)	3.4	0.5	1	Berry et al. (2003)
Other cereals	See triticale			
Wheat straw (dwt)	0.46	0.1	0.8	Berry et al. (2003)
Wheat (*Triticum aestivum*) whole plant (dwt)	2.2	0.4	1.2	Grain with add-on factor
Barley (*Hordeum vulgare*) whole plant (dwt)	1.7	0.4	1.2	Grain with add-on factor
Oat (*Avena sativa*) whole plant (dwt)	2.1	0.4	1.2	Grain with add-on factor
Triticale (*Triticosecale*) whole plant (dwt)	2	0.5	1.2	Grain with add-on factor
Spring/winter beans whole plant (dwt)	4.4	0.6	2.5	Grain with add-on factor
Forage crop (dwt)	2.02	0.26	2.35	Mean from Aronsson et al. (2007)
Sunflower (*Helianthus annuus*) (fwt)	1.9	1.5	2.3	CORPEN (1988)
Rapeseed (*Brassica napus*) (fwt)	3.5	1.4	1	CORPEN (1988)
Potatoes (*Solanum tuberosum*) (kg nutrient.t^{-1} fwt)	3.5	1.7	6.5	CORPEN (1988)
Organic matter (cattle)				
Fresh solid manure (kg element t^{-1} fwt)	4.9	1.1	8.5	Zenboudji (2012), Clement (2013)
Composted manure (kg element t^{-1} fwt)	5.8	1.8	8.9	Zenboudji (2012), Clement (2013)
Field heap (kg element.t^{-1} fwt)	5.3	1.3	7.9	Zenboudji (2012), Clement (2013)
Slurry (kg element m^{-3})	1.6	0.4	3.3	Zenboudji (2012), Clement (2013)
Organic matter (poultry)				
Composted manure (kg element t^{-1} fwt)	12	11	10	Leclerc 2001
Feather meal (kg element t^{-1} fwt)	110	11.5	2.7	Leclerc 2001

Table 3 Nutrient inputs and outputs from cattle grazing used for soil surface NPK budgets

Livestock offtake during grazing (kg NPK $month^{-1}$)	DMI (Eq. 2)	Grass offtake (Eq. 5)			Excreta (Eq. 3)			Reference
		N	P	K	N	P	K	
Dairy cow (5,000 kg milk $year^{-1}$)	450	13	1.87	14.1	9	1.2	11.3	CORPEN (1999)
Dairy heifer 6–12 months	155	3.7	0.6	4.2	3.1	0.4	4.1	CORPEN (2001)
2-Year-old calves–dairy heifers 12–18 months	208	5	0.8	5.6	4.6	0.6	5.6	CORPEN (2001)
2 Years calving–dairy heifers 18–24 months	256	6.1	0.9	6.9	5.9	0.8	7.1	CORPEN (2001)
3 Years calving–dairy heifers 18–24 months	225	5.4	0.8	6.1	5.1	0.7	6	CORPEN (2001)
3 Years calving–dairy heifers 30–36 months	303	7.3	1.1	8.2	7	1	8.2	CORPEN (2001)
Suckler cow and calf	468	11.2	1.7	12.6	10.6	1.6	12.6	CORPEN (2001)
Suckler heifer/beef 15–21 months (350 kg)	177	4.2	0.6	4.8	4.1	0.6	4.8	CORPEN (2001)
Suckler heifer/beef 27–33 months (460 kg)	250	6	0.9	6.7	5.6	0.8	6.7	CORPEN (2001)
Suckler heifer/beef 15–21 months (387 kg)	206	4.9	0.8	5.6	4.7	0.7	5.6	CORPEN (2001)
Suckler heifer/beef 27–33 months (510 kg)	280	6.7	1	7.6	6.3	0.9	7.6	CORPEN (2001)
Suckler heifer/beef 15–21 months (425 kg)	227	6.5	0.8	6.1	5.2	0.8	6.2	CORPEN (2001)
Suckler heifer/beef 27–33 months (560 kg)	305	7.3	1.1	8.2	6.9	1	8.2	CORPEN (2001)

Table 4 Parameters used for calculation of biologically fixed nitrogen by legumes (a and b correspond to the parameters determined by Carlsson and Huss-Danell 2003)

Legume species	Management	Utilization	a	b
M. sativa	With grass mixtures	Harvest	0.021	+16.9
Other spp.	With grass mixtures	Harvest	0.017	+21.1
Other spp.	Legume monocultures	Harvest	0.017	−0.65
T. repens	With grass mixtures	Grazing	0.033	+25.8

where Y is the crop yield (kg of dry matter ha^{-1} year^{-1}), S is the surface of the crop (ha year^{-1}), N is the nutrient content of the harvested crops (N, P, or K in %) and subscripted i indicates the type of crop and organ harvested; for calculating grass offtake, we considered C which is the number of animals per hectare, G the duration of grazing (in months), and O the concentration in nutrients (kg N, P, or K ha^{-1} year^{-1}) ingested during grazing, where subscripted k indicates the animal category (CORPEN 1999, 2001; Table 3).

Calculation of nutrient budgets

The N, P, and K budgets (kg N, P, K ha^{-1} year^{-1}) were calculated for each farm and expressed per hectare of the total usable agricultural area (UAA) as indicated in Eq. 6:

$$\text{Balance} = \frac{NFix + OM\,Int + OM\,Ext - Output}{\text{Usable Agricultural Area}} \qquad (6)$$

Data analysis

The N, P, and K nutrient budgets were established for each farm studied at the UAA scale. The source of the nutrient flow was detailed for each of these farms (proportion of the N fixation for N inputs and proportion of nutrients coming from the farm or purchased).

The farms were grouped by their main economic orientation (livestock, mixed, and arable farms) and counties (Table 1), giving five categories in all: arable farms in Lorraine and Plain of Valence, livestock farms in Lorraine and Plain of Forez, and mixed farms in Lorraine. For each category, inputs and outputs of N, P, and K per hectare of UAA and per year were calculated. The balance was calculated as indicated in Eq. 6.

A multivariate analysis was performed in order to verify the difference between farm categories and then to characterize these differences. The quantitative variables used for this characterization were internal recycling in N, P, and K added per hectare and per year (N, P, K *Int*; Eq. 3, Fig. 2) or external sources added per hectare and per year (N, P, K *Ext*; Eq. 4, Fig. 2); the quantity of atmospheric N fixed per hectare (*Nfix*; Eq. 2, Fig. 2); the total of N, P, and K inputs and outputs per hectare (N, P, K inputs and N, P, K outputs; Fig. 2) and the balance (Inputs − Outputs; Eq. 6) of N, P, and K per hectare and per year.

The descriptive variables used in the principal components analysis (PCA) include the total usable agricultural area of the farms (UAA), livestock units per hectare (LTU.ha), and the proportion of legumes on the farm (Leg.UAA), as well as the proportion represented by the main fodder area (MFA.UAA). The significance of the graphic structures revealed by the PCA was tested using the Monte Carlo procedure (1,000 random permutations).

All the tests were carried out using R version 2.12.1 software (R Development Core Team 2008) at a 5 % significance threshold.

Results

Classification of the farms studied

The main characteristics of the farms are described in Table 1. The PCA (Fig. 2) enabled the farms to be characterized according to their structural characteristics (usable agricultural area, stocking rate, grassland surfaces…) and the calculation of N, P, and K flows.

The PCA separated the farms on the basis of their main economic orientation and their geographical origin (Monte Carlo test, $p<0.001$). Axis 1 separated the arable farms from livestock farms (Fig. 2b). Axis 2 separated Lorraine (bottom of axis 2) from Plain of Forez (upper left of axis 2) and Plain of Valence (upper right of axis 2).

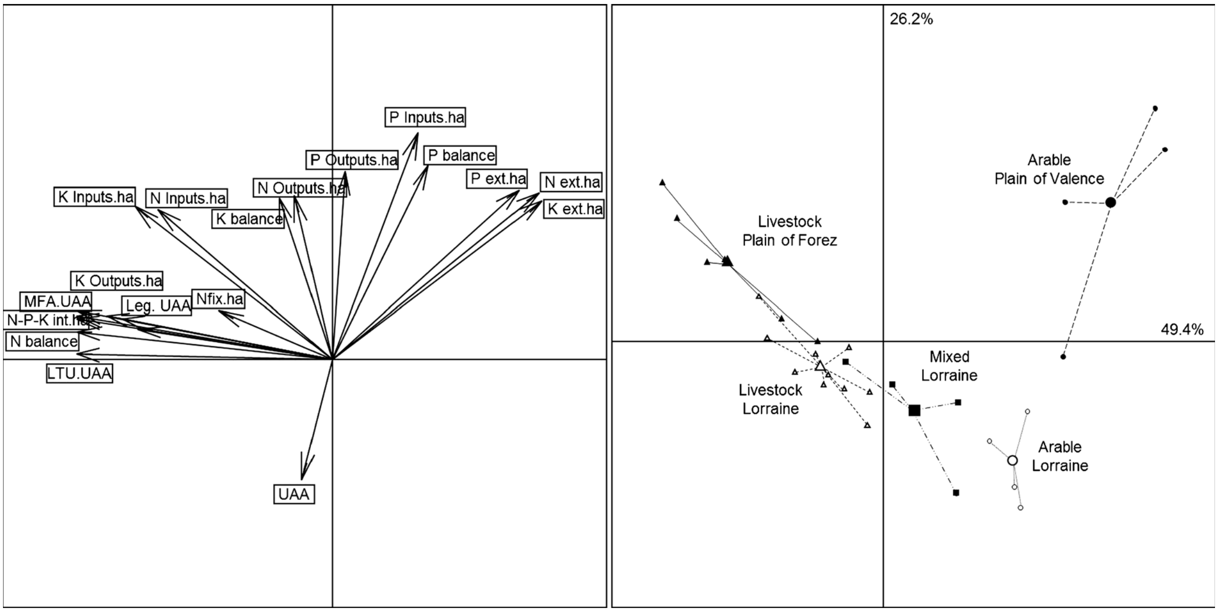

Fig. 2 Principal component analysis (PCA) of the farm categories. **a** projection of variables on the factorial plan; **b** projection of the farms on the factorial plan

Arable farms, notably in Plain of Valence, were characterized by the use of off-farm N, P, and K resources (Fig. 2a). Livestock farms, on the other hand, were characterized by N, P, and K resources from internal inputs: organic manures and excreta from livestock and atmospheric N fixation from legumes.

For all categories, the farms from in Plain of Forez and Plain of Valence were characterized by greater N, P, and K inputs per hectare than the farms in Lorraine (Fig. 2a).

The PCA also separated the farms on the basis of their structural components and their geographical origins. The farm area studied varied from 65 ha for dairy cattle breeding farms in Plain of Forez to 332 ha for dairy cattle breeding in Lorraine (Table 1). The total usable agricultural area of the farms in Plain of Forez and Plain of Valence was smaller (68 and 65 ha on average, respectively) than on farms in Lorraine (151 ha on average). Arable farms were also smaller than breeder and mixed farms (82, 125, and 182 ha, respectively). Livestock units were greater for the livestock farms (86) than the other type (78 and 7 for the mixed and arable farms, respectively). Livestock units per farm were also greater in Lorraine (105) than in Plain of Forez (53) while arable farms in the Plain of Valence had no livestock. The stocking rate per hectare of the mixed and livestock farms was relatively low and rarely surpassed one livestock unit per hectare. Livestock farms in Plain of Forez had a higher stocking rate per hectare (0.8 LTU.ha^{-1}) than other livestock farms (0.7 LTU.ha^{-1}) or mixed farms (0.4 LTU.ha^{-1}) in Lorraine.

The proportion of annual crops covered 74 % of the total usable agricultural area of the arable farms and 48 and 23 % of the mixed and livestock farms, respectively. Arable farms in Plain of Valence had a higher proportion of annual crops than arable farms in Lorraine (78 and 70 %, respectively). Livestock farms in Lorraine had a higher proportion of annual crops than those of Plain of Forez (28 and 15 %, respectively). Inversely, the proportion of grasslands (temporary + permanent grasslands) represented 77 % of the agricultural surface on the livestock farms and 48 and 16 % for the mixed and arable farms, respectively. Regardless of the type of farm or county, the proportion of organic matter applied on the arable land (annual crops + temporary grasslands) represented more than 80 % of the total organic matter inputs applied on the total usable surface. Arable and mixed farms applied almost the totality of their organic inputs on the arable land, whereas livestock farms applied 81 and 90 % of their total organic inputs on their arable land in Lorraine and Plain of Forez, respectively. A very small proportion of organic matter was applied on permanent grasslands on breeder farms.

The proportion of the total usable surface area occupied by legumes (permanent and temporary grasslands, and annual crops like soya, pea, etc.) represented 33 % in Plain of Valence and 50 % in Lorraine for the arable farms.

For the livestock farms, this proportion was 90 % in Plain of Forez and 80 % in Lorraine and 63 % for the mixed farms of Lorraine.

Nutrient budgets per hectare

Nitrogen budget

Only the nitrogen budget of livestock farms in Plain of Forez showed a surplus (20.8 kg N ha^{-1} year^{-1}) while all the others were negative (Table 5). The nitrogen budget was almost balanced on livestock and mixed farms in Lorraine, whereas arable farms in Lorraine and Plain of Valence presented high deficits (−30.2 and −34.9 kg N ha^{-1} year^{-1}, respectively). The common N deficits indicated a long-term impoverishment of the soil in organic nitrogen. The arable farms presented a greater nitrogen deficit than mixed and livestock farms insufficiently compensated by off-farm inputs. Overall, the organic farms studied presented an annual deficit in nitrogen of 6 kg N ha^{-1} year^{-1}.

Inputs The quantity of *Nfix* accounted for 64 and 42 % of the total N inputs for the arable farms in Lorraine and Plain of Valence, respectively. It accounted for 46 % for mixed and livestock farms in Lorraine and 35 % for livestock farms from Plain of Forez.

Organic nitrogen coming from a farm's internal recycling practices (*OM Int*) was low for arable farms (between 0 and 10 kg N ha^{-1} year^{-1} for Plain of Valence and Lorraine, respectively). These inputs accounted for 21 and 0 % of the total N inputs per hectare for the arable farms of the Lorraine and Plain of Valence, respectively. The quantity of organic nitrogen originating from the farm was higher in livestock farms in Plain of Forez compared to mixed and livestock farms in Lorraine. This internal recycling accounted for 64 % of total N inputs per hectare for the livestock farms of Plain of Forez and 54 and 48 % of total N inputs per hectare for the livestock and mixed farms of Lorraine, respectively.

Nitrogen inputs per hectare from off-farm resources (purchases or exchanges) were negligible for livestock and mixed farms. However, they were high for the arable farms of Plain of Valence, representing more than 58 % of their total N inputs per hectare and per year (versus 14 % for the arable farms of Lorraine).

The use of internal resources (*Nfix* + *OM Int*) covered nearly 100 % of the total N inputs on mixed and livestock farms and 85 and 42 % for the arable farms in Lorraine and Plain of Valence, respectively.

Outputs The organic farms in Plain of Forez and Plain of Valence had higher outputs per hectare (kg N ha^{-1} year^{-1}) than the farms in Lorraine. The lowest nitrogen outputs were observed on arable and mixed farms in Lorraine.

Phosphorus budget

The P budgets of the farms studied were negative for the farms in Lorraine whatever the farming system, positive for the arable farms in Plain of Valence, and nearly balanced for livestock farms in Plain of Forez (Table 6). Overall, the organic farms studied presented a deficit in P of 1.4 kg P ha^{-1} year^{-1}.

Inputs The total inputs in P per hectare per year for the majority of the farms came from internal recycling of livestock manures and animal excreta. For the arable farms, this source covered 52 and 0 % of the total inputs

Table 5 Nitrogen soil surface balance for a typical year (2009) (kg N ha^{-1} year^{-1}) calculated by farm category

kg N ha^{-1} year^{-1}	Arable Lorraine *n*=4	Arable Plain of Valence *n*=4	Mixed Lorraine *n*=4	Livestock Lorraine *n*=10	Livestock Plain of Forez *n*=6	All *n*=28
Fixation	31.1 (±6.6)	37.8 (±23.7)	37.0 (±16.3)	49.8 (±12.1)	49.4 (±12.9)	43.5 (±15.3)
OM int	10.3 (±12.3)	0.0 (−)	38.5 (±16.2)	57.9 (±9.3)	90.4 (±20.6)	47.0 (±34.0)
OM ext	6.9 (±10.7)	53.1 (±17.6)	4.1 (±5.0)	0.0 (−)	0.9 (±2.3)	9.4 (±19.7)
Total input	48.3 (±12.2)	90.9 (±18.5)	79.6 (±31.4)	107.8 (±19.0)	140.7 (±31.9)	99.9 (±36.5)
Total output	78.5 (±3.7)	125.8 (±49.8)	85.1 (±21.6)	108.7 (±13.0)	119.9 (±27.9)	105.9 (±28.5)
Balance	−30.2(±14.4)	−34.9 (±33.1)	−5.6 (±13.1)	−1.0 (±12.4)	20.8 (±28.0)	−6.0 (±27.2)

Numbers in brackets indicate the standard deviation to the mean of farm category

Table 6 Phosphorus soil surface balance for a typical year (2009) (kg P ha^{-1} year^{-1}) calculated by farm category

kg P ha^{-1} year^{-1}	Arable Lorraine n=4	Arable Plain of Valence n=4	Mixed Lorraine n=4	Livestock Lorraine n=10	Livestock Plain of Forez n=6	All n=28
OM int	2.3 (±2.9)	0.0 (−)	8.4 (±3.3)	10.9 (±1.8)	17.9 (±3.4)	9.3 (±6.6)
OM ext	2.1 (±3.3)	36.9 (±19.9)	1.3 (±1.6)	0.0 (−)	0.3 (±0.7)	5.8 (±14.6)
Total input	4.4 (±3.4)	36.9 (±19.9)	9.6 (±3.4)	10.9 (±1.8)	18.2 (±3.5)	15.1 (±12.3)
Total output	12.9 (±0.6)	20.8 (±6.1)	14.2 (±2.4)	16.1 (±1.9)	18.0 (±3.5)	16.5(±3.8)
Balance	−8.5 (±3.6)	16.2 (±20.1)	−4.6 (±2.1)	−5.2 (±1.5)	0.2 (±2.9)	−1.4(±10.5)

Numbers in brackets indicate the standard deviation to the mean of farm category

of P per hectare per year in Lorraine and Plain of Valence, respectively. Internal resources of P represented 87 % for the mixed farms and more than 98 % for livestock farms in Lorraine and Plain of Forez.

Only arable and mixed farms used organic resources rich in phosphorus from external sources (purchase or exchange). These sources covered from 48 % (Lorraine) to 100 % (Plain of Valence) of the total inputs of P per hectare on the arable farms, respectively, and 13 % for mixed farms.

As we had observed with nitrogen, the farms in Plain of Forez and Plain of Valence presented the highest inputs of organic phosphorus (18.2 and 36.9 kg P per hectare per year, respectively).

Outputs The outputs of phosphorus per ha and per year were greater in farms in Plain of Forez and Plain of Valence (18 and 20.8 kg P ha^{-1} year^{-1}, respectively).

Potassium budget

A surplus in K per hectare and per year was only measured for the livestock farms of Plain of Forez (15.7 kg K ha^{-1}year^{-1}) (Table 7). The organic farms in Lorraine presented the highest deficits in K ranging from −37.2 for the arable farms to −18.9 kg K ha^{-1} year^{-1} for the mixed farms. Arable farms in Plain of Valence presented a slight deficit (−2.5 kg K ha^{-1} year^{-1}). Overall, the studied farms presented a deficit of 15 kg K ha^{-1} year^{-1}.

Inputs As with P, the majority of the inputs in K per hectare and per year came from the internal recycling manure and animal excreta (Table 7). These inputs accounted for 57 % of the total annual K inputs per hectare on the arable farms of Lorraine (versus 0 % for those in Plain of Valence), 89 % for the mixed farms and more than 98 % for the livestock farms of both counties studied.

Only the arable and mixed farms used external K sources. These sources covered 43 and 100 % of the total annual inputs in K per hectare on arable farms in Lorraine and Plain of Valence, respectively, and approximately 11 % on mixed farms.

Livestock farms presented the highest total annual inputs in K per hectare, especially those of Plain of Forez with 133.1 kg K ha^{-1} year^{-1} (versus 81.9 kg K ha^{-1} year^{-1} for livestock farms in Lorraine).

Table 7 Potassium soil surface balance for a typical year (2009) (kg K ha^{-1} year^{-1}) calculated by farm category

kg K ha^{-1} year^{-1}	Arable Lorraine n=4	Arable Plain of Valence n=4	Mixed Lorraine n=4	Livestock Lorraine n=10	Livestock Plain of Forez n=6	All n=28
OM int	13.9 (±16.8)	0.0 (−)	53.0 (±18.9)	81.9 (±15.2)	131.7 (±31.3)	67.0 (±49.5)
OM ext	10.6 (±16.4)	60.6 (±18.0)	6.3 (±7.7)	0.0 (−)	1.4 (±3.5)	11.4(±22.5)
Total input	24.5 (±18.0)	60.6 (±18.0)	59.3 (±19.2)	81.9 (±15.2)	133.1 (±31.2)	78.4(±39.6)
Total output	61.7 (±14.4)	63.1 (±27.0)	78.2 (±23.7)	110.0 (±14.9)	117.4 (±20.1)	93.5(±29.4)
Balance	−37.2(±28.7)	−2.5 (±40.6)	−18.9 (±11.6)	−28.1 (±16.9)	15.7(±23.8)	−15.0(±29.3)

Numbers in brackets indicate the standard deviation to the mean of farm category

Outputs The annual outputs of K per hectare were greater for livestock farms irrespectively of the county studied. No differences appeared between counties regarding potassium outputs.

Nutrient transfers between farms

The balance of nutrient transfers with other organic or conventional farms is presented in Table 8. These transfers only concern 21 of the 28 farms studied because 7 farms did not purchase or exchange organic matter, straw, or forage with other farms.

Only the arable farms in Lorraine presented negatives balances of nutrient transfers. The N and K deficits were high (respectively, −19.4 and −21.6 kg ha^{-1} $year^{-1}$), whereas the P deficit was low (−1.5 kg ha^{-1} $year^{-1}$). This trend means that the arable farms in Lorraine have sold a higher quantity of N, P, and K in the form of straw or forage than that contained in the organic matter that they purchased from other organic farms in the county. The arable farms in Plain of Valence presented the highest N, P, and K surpluses (respectively, 21.9, 33.0, and 25.0 kg ha^{-1} $year^{-1}$), but also the highest variability in the results within the same category. The other categories presented an intermediate surplus ranging from 1.7 to 9.6 kg N ha^{-1} $year^{-1}$, 0 to 1.6 kg P ha^{-1} $year^{-1}$, and 1.9 to 12.3 kg K ha^{-1} $year^{-1}$. The farms in Plain of Forez and Plain of Valence had higher balances than the farms in Lorraine. Generally, organic farms from these counties purchased higher quantity of nutrients than they sold via the forage, straw, or organic matter.

Details of transfers between farms

Arable and mixed farms imported manures from neighboring organic or conventional livestock farms (farmyard manure in Lorraine and poultry manure in Plain of Valence). The maximum distance between farms which conducted an exchange was 40 km. Arable farms from Plain of Valence imported the highest quantity of N, P, and K per year (respectively, 7-fold more N, 18-fold more P, and 6-fold more K than the other farms). Livestock farms, for the most part, only purchased straw. Few breeders purchased forage and only one purchased organic matter (composted manure).

The N, P, and K sold to other farms were greater in the case of arable farms, especially those of Plain of Valence. Livestock farms in Plain of Forez did not sell forage, straw, or organic matter to neighboring farms; only one farm purchased straw and organic matter. The nutrients transferred from arable and mixed farms involved sales of straw and forage. These annual transfers were very low for mixed farms (0.5 kg N, 0.1 kg P, and 0.8 kg K ha^{-1} $year^{-1}$). The N, P, and K transfers from the livestock farms of Lorraine comprised sales of manures.

Discussion

The importance of livestock production for nutrient balance

The nutrient budgets show clear differences between the categories and make it possible to distinguish farming

Table 8 N, P, and K transfers between farms for a typical year (2009) (kg nutrient ha^{-1} $year^{-1}$)

kg N, P, and K ha^{-1} $year^{-1}$	Arable Lorraine n=4	Arable Plain of Valence n=4	Mixed Lorraine n=3	Livestock Lorraine n=7	Livestock Plain of Forez n=3
N imported	6.9 (±10.7)	52.2 (±18.8)	5.5 (±5.2)	5.6 (±6.9)	9.6 (±7.4)
N exported	26.3 (±29.7)	30.3 (±24.3)	0.5 (±0.5)	3.9 (±5.1)	0 (±0)
N balance	−19.4 (±26.9)	21.9 (±37.7)	5.0 (±5.2)	1.7 (±6.7)	9.6 (±7.4)
P imported	2.1 (±3.3)	37.1 (±20.1)	1.7 (±1.6)	1.0 (±1.0)	1.6 (±1.7)
P exported	3.6 (±4.19)	4.1 (±3.3)	0.1 (±0.1)	1.0 (±1.3)	0 (±0)
P balance	−1.5 (±3.8)	33.0 (±21.1)	1.6 (±1.6)	0.0 (±1.1)	1.6 (±1.7)
K imported	10.6 (±16.4)	61.6 (±18.5)	8.4 (±8.0)	8.3 (±8.8)	12.3 (±10.6)
K exported	32.2 (±36.0)	36.6 (±29.0)	0.8 (±0.8)	6.4 (±8.6)	0 (±0)
K balance	−21.6 (±31.8)	25.0 (±43.3)	7.6 (±8.0)	1.9 (±10.1)	12.3 (±10.6)

systems in terms of presence or absence of livestock production.

Nitrogen

Livestock and mixed farms generally present smaller N deficits than stockless farms (Table 5). Internal recycling from animal production allowed livestock farms to partially satisfy total cropland nitrogen needs. Farms specialized in grain production must turn to commercially available fertilizers and/or organic soil amendments, which remain expensive (David et al. 2005a) or rare. Consequently, the amount of fertilizer purchased did not entirely cover the needs of crops on stockless farms; nitrogen remains the main factor limiting organic agricultural productivity (Berry et al. 2002; David et al. 2005b; Aronsson et al. 2007) on these farms. Livestock and mixed farms benefited from animal excreta during the grazing and recycling of organic matter produced by cattle. Moreover, the large surface area given over to grasslands (comparatively to stockless farms) contributed to equilibrate the N balance, thanks to biological N fixation by legumes. The latter was also an important issue for stockless farms. Those which presented a lower deficit in N per hectare and per year had devoted a significant part of cropland to soy, pea, or alfalfa. The presence of livestock production and the part of land cultivated with forage legumes within livestock farms, together, covered the annual crop and grassland needs in N per hectare per year.

The N balances of livestock and mixed farms were lower than the livestock farms studied by Berry et al. (2003) at the rotational scale (between 18–64 kg N ha^{-1} $year^{-1}$) and similar for stockless farms (−15 and −19 kg N ha^{-1} $year^{-1}$ in the study of Berry et al. 2003). These balances indicate the impact of farm management on the accumulation or depletion of soil N. The livestock and mixed farms in our study are probably sustainable in terms of N management, even if we observed a slight depletion in N on some farms in Lorraine (on the contrary, we observed a potential build-up of N on those in Plain of Forez). However, the sustainability of stockless farms in terms of N management is questioned. We observed a deficit in N as Berry et al. (2003) did in their study. These farms had a high proportion of cereals and also cultivated grain legumes in a lower proportion. Generally, grain legumes are followed by 2 or 3 cereals and these cereals have to rely on soil mineralization rather than on soil N enrichment due to the previous crop. Moreover, the effect of grain legume on soil N enrichment is limited and thus this type of rotation is exploitative for soil N (Berry et al. 2003).

Overall, the organic farms studied mainly relied on N fixation by legumes (44 % of total N inputs) and internal recycling (47 % of total N inputs) to cover total crops and grassland needs in N per year rather than purchasing organic matter (9 %). Nitrogen fixation is thus an important criterion of the nitrogen budget. It represents 1/3 of total inputs for the livestock systems versus 2/3 of total N inputs for the stockless systems. But the quantity of N fixed per hectare is difficult to estimate. Numerous factors can modify the quantity of N fixed per hectare. For instance, the quantity of N fixed could be variable due to the crop species (grain legumes or forage legumes), the grazing or cutting management, the rhizobium strains, soil type, and microclimate (Carlsson and Huss-Danell 2003). The methodology used in this study gives, therefore, only an approximation of the total quantity of N fixed per hectare. But the robustness of this method based on simple parameters (yields estimations plus the type of leguminous) calculated at the field or farm scale has been demonstrated by Huss-Danell et al. (2007) who evaluated the coherence of the data obtained thanks to this method with measurements based on natural ^{15}N abundance and ^{15}N isotope dilution.

Regardless of the type of organic farm studied in this paper, each seemed to be sustainable in terms of their N management even if we observed a slight depletion overall in N (−6 kg ha^{-1} $year^{-1}$, Table 5). The calculated balances also indicated the potential for N leaching, although our results showed that this risk is limited in organic farming. Some of the studied farms did present N surpluses, especially those in Plain of Forez, and thus could generate N losses in the environment. This trend can also be reinforced by the spatial distribution of organic fertilizers and manures—not considered in this study—that were mainly concentrated on cereals and temporary grasslands. The comparison of the data from this study on organic farms with data from conventional farms remains difficult. Indeed, most of the latter studies evaluated nutrient balances at the farm scale (farm gate nutrient balances) by evaluating the quantity of nutrients imported and exported without considering internal nutrient flows between animal and plant compartments (D'Haene et al. 2007; Fangueiro et al. 2008). But the high surplus observed in these studies (more than 100 kg

N ha^{-1} year^{-1} in the study by D'Haene et al. 2007 and more than 400 kg N ha^{-1} year^{-1} in the one by Fangueiro et al. 2008) suggest that organic farms present a lower risk of generating N losses in the environment than conventional ones. Nutrient budgets give indicators of the potential losses from the systems (Dalgaard et al. 1998). Aronson et al. (2007) also demonstrated that N leaching from organic systems, estimated by a pipe-drainage system, is determined by the presence of growing crops during autumn in cold-temperate regions. The presence of forage crops or green manure can reduce the risk of leaching substantially if crop incorporation is managed after the drainage period. Therefore, tillage practices, cropping, freezing, and thawing of plant material during winter and soil properties are the factors that have a major impact on the risk of P and N leaching, all of which are not usually reflected in nutrient field budgets (Ulen et al. 2005).

Phosphorus and potassium

The differences between farm categories are not as pronounced for P and K as for N. Although livestock production makes it possible to cover total N outputs of annual crops and grasslands, this is less true for P and K (except for the farms in Plain of Forez).

The P flows on organic farms were quantitatively much smaller than those of N. We observed a small deficit overall in P (−1.4 kg P ha^{-1} year^{-1}) (Table 6). Two categories of the studied farms presented positive P budgets (16.2 kg P ha^{-1} year^{-1} for arable farms in Plain of Valence and 0.2 kg P ha^{-1} year^{-1} for livestock farms in Plain of Forez) while the three other categories had negative P budgets ranging from −8.5 to −4.6 kg P ha^{-1} year^{-1}. These P budgets were close to those found in the study by Berry et al. (2003) at the rotational scale (which ranged from −8 to +34 kg P ha^{-1} year^{-1}). Livestock and mixed farms compensated partially for total P outputs mainly with their internal recycling (which represented more than 87 % of the total P inputs). Purchased organic matter remained rare on these farms. On the contrary, stockless farms mainly relied on external sources to compensate total P outputs (respectively, 48 and 100 % of the total P inputs for arable farms of Lorraine and Plain of Valence). None of the studied farms, during the year studied, used supplementary P fertilizers in the form of rock phosphate to correct P deficits observed on the majority of the farms. The capacity of soil reserves to match the demand for P made by annual crops and grasslands depends mainly on the soil type. Berry et al. (2003) indicated that on a non-sandy-soil, an annual P deficit of 2–4 kg P ha^{-1} year^{-1} caused no decline in the content of extractable P over 10 years. The sustainability of the studied farms regarding P management is questioned because P deficits are generally greater than 4 kg P ha^{-1} year^{-1} especially on the arable farms in Lorraine. The P surpluses observed on livestock farms and arable farms in Plain of Forez and Plain of Valence, respectively, are mainly due to higher organic matter inputs per hectare and to the nature of the organic matter applied. The geographical differences between the farms are detailed below.

We observed negative K budgets for the organic farms (−15 kg K ha^{-1} year^{-1}) (Table 7) close to those measured by Berry et al. (2003). As with P, the majority of the K resources used came from internal recycling, in the case of livestock and mixed farms, and from purchased external sources for stockless farms. These inputs did not entirely cover total P outputs, except for livestock farms in Plain of Forez. Total P outputs were greater on livestock and mixed farms than on stockless farms. The N and K concentrations in forage and grass from temporary and permanent grasslands are higher than those found in annual crops (Moller 2009). Consequently, the proportion of grasslands in livestock and mixed farms resulted in higher outputs than on arable farms. The negative K budgets observed challenges the sustainability of these farming systems, which draw on soil resources (Pellerin et al. 2004). Berry et al. (2003) indicated that K deficits greater than 25 kg K ha^{-1} year^{-1} in any rotation was likely to be problematic for the sustainability of these systems and that K depletion should be monitored, especially on livestock and arable farms in Lorraine.

Geographical features

The differences observed between farms could also be explained by their geographical origins. Livestock farms in Plain of Forez presented surpluses in N, P, and K per hectare while livestock farms in Lorraine presented N, P, and K deficits per hectare. These differences were mainly due to the volume and extent of the internal recycling. Indeed, the biological N fixation by legumes and the quantity of external sources were quite similar on livestock farms in Lorraine and Plain of Forez (Tables 5, 6, and 7). Livestock farms in Plain of Forez had smaller surface areas than the farms in Lorraine (68 vs 160 ha), but a higher stocking rate per hectare (0.8 vs 0.65 LTU.ha^{-1}) despite having smaller cattle herds (53 vs 105). The quantities of organic matter and excreta per hectare are therefore greater on livestock farms in Plain of Forez. Moreover, livestock farms in Lorraine exchanged part of their OM for straw and forage with neighboring farms, thus reducing the amount of internal recycling. Livestock farms in Plain of Forez, on the other hand, retained all of the OM produced, which reinforced the difference in the amount of N, P, and K inputs per hectare between these two counties. Total N, P, and K outputs were greater for the livestock farms in Plain of Forez. Livestock farms in Lorraine were essentially based on permanent grasslands while the proportion of temporary grasslands was higher in Plain of Forez. The higher productivity of temporary grasslands explained the higher outputs observed in Plain of Forez, these temporary grasslands being mainly utilized for hay or forage production. The intensification of the surface areas therefore seems greater in Plain of Forez and can generate certain environmental problems via nitrate leaching.

We also observed differences between arable farms in Lorraine and Plain of Valence. The N flows were different between these two counties. Stockless farms in Lorraine relied on N fixation (more than 60 % of their total N inputs vs 41 % for those of Plain of Valence) and on their internal recycling (21 vs 0 % for Plain of Valence). Arable farms in Lorraine had a higher ratio of temporary grasslands and legumes than those in Plain of Valence. The proportion of annual crops was greater for arable farms of Plain of Valence. The main difference between these counties was, however, due to the utilization of purchased organic matter to compensate N, P, and K outputs on arable farms in Plain of Valence. Indeed, farmers there purchased organic fertilizers (poultry compost or feather meal) which are rich in N (Table 2). The amount they chose to spread was based on the N needs of their annual crops. But, these organic fertilizers were also concentrated in P, which partially explains the surpluses in P observed on these farms. Arable farms in Plain of Valence were localized in a region where a high density of poultry farms produced high quantities of compost. Consequently, arable farms had access to these resources whereas arable farms in Lorraine were located in a region where organic matter resources are scarce or limited. Indeed, livestock farms in this county were mainly orientated towards cattle production (dairy or meat) and had a high usable agricultural surface on which they could valorize the OM produced by their herds. Moreover, the local demand in forage and straw is strong. Arable farms in Lorraine consequently sold their straw and forage (which are rich in P and K) but could not buy sufficient quantities of OM to compensate for the loss. The exchanges between arable and livestock farms were thus unbalanced, especially in terms of P and K flows, and unfavorable for stockless farms.

Differences observed between the counties reflect the specialization in either breeding or arable farms, common in French regions since 1970. These specializations are the result of numerous factors: political, economic, and sociological (Mignolet et al. 2012). The characteristics of the production, cropping, and forage systems differed between regions and can explain the differences observed in fertilization management for example (Mignolet et al. 2007; Simon et al. 1994). Different socio-economic logics, in conjunction with local industry and/or socio-professional networks (farmers, agricultural advisors…) have a bearing on differences between and within regions. Thus, in the east of France (Lorraine in this study), organic dairy farms rely mainly on their own forage production to produce milk without any purchases. This strategy is based on forage autonomy and a valorization of permanent grasslands, which rarely leads to an intensification of milk production (Hellec and Blouet 2012). On the contrary, the objective of livestock farms in Plain of Forez was to maximize milk production. Consequently, farmers intensified their forage production on the temporary grasslands (silage, hay) and purchased supplementary forages or food supplements for the herd. This food import for animals contributed to the equilibrium of P and K balances as reported by Berry et al. (2003).

Soil surface autonomy in N, P, and K

The soil surface autonomy of the farms was determined as the percentage of internal resources used to cover total N, P, or K inputs.

Nutrient autonomy at the soil surface level was higher in the farming systems with animals. Indeed, livestock and mixed farms were autonomous in N at the soil surface level compared to the stockless farms which presented an autonomy in N of 42 and 86 % in Plain of Valence and Lorraine, respectively. Regarding P and K, none of the farms purchased natural P and K fertilizers. However, livestock farms were autonomous in P and K at the soil surface level. Mixed farms presented autonomy in P and K of 88 and 89 %, respectively. They purchased organic matter to partially compensate their deficits. Stockless farms in Lorraine presented autonomy in P and K of 52 and 57 %, respectively, while those in Plain of Valence are totally dependent on external resources (0 % of autonomy). From this point of view, farming systems with animals (livestock or mixed) were autonomous and thus responded to the sustainable development of organic agriculture (Watson et al. 2002b). However, their nutrient balances at the total usable agricultural area were often negative, which raises the question of soil fertility maintenance over the long term (Watson et al. 2002b; Berry et al. 2003). This is particularly true for stockless farms in Lorraine. They were dependent on external resources which remained scarce in this region, thus exhibiting high deficits in N, P, and K per hectare and per year. Stockless farms in Plain of Valence had easily accessible OM resources from neighboring farms due to the high density of poultry production. But stockless farms could also improve their nutrient autonomy (especially N autonomy) at the soil surface level by increasing the area of cultivated surface devoted to legumes (Watson et al. 2002b). For example, we observed that certain grain farms in Plain of Valence presented a higher level of N autonomy than other farms because they cultivated a high proportion of legumes. In general, these farms had a specific outlet that allowed them to grow multiannual forage legumes (notably alfalfa). The introduction of this type of multiannual crop into the rotation reduced the dependence of these farms on outside resources and thus increased their N autonomy at the soil surface level.

Nutrient autonomy of annual crops and grasslands was also influenced by OM transfers between farms. The purchases of manure by arable farms and of straw and forage by breeder farms showed that these specialized farms were dependent on each other. These exchanges were important for the soil surface nutrient autonomy of the farms, especially in Lorraine. Indeed, the purchases of straw and forage by these farms reinforced their production of manure which in turn contributed to soil surface nutrient autonomy as long as this additional manure was not sold or exchanged.

Conclusion

Livestock farming systems were more autonomous in nutrients at the soil surface level. Almost 100 % of the N, P, and K needs of the annual crops and grasslands were provided by internal flows from recycling OM (manures and excreta) and from the N fixation by legumes. However, extensive farms presented negative budgets in N, P, and K per hectare and per year which hampered their sustainability (destocking N, P, and K in soils). Only the farming systems that had an intensive farming system (based on temporary grasslands and complements for feeding cattle) presented positive balances in N, P, and K ha^{-1} $year^{-1}$.

Stockless farms were mainly dependent on organic resources coming from neighboring livestock farms and thus were not autonomous in nutrient at the soil surface level. Some of these farms presented high deficits per hectare and per year which poses questions as regards their sustainability. Our results have strongly demonstrated regional specificities. In regions where OM resources were ample, the stockless farms had access to a sufficient quantity of nutrients to satisfy crop needs, especially if this OM was rich in N, P, and K as it was the case with poultry compost. While equilibrium in P and K can be achieved or even surpassed by choosing rich organic matter, the nitrogen balances of these stockless farming systems were always in deficit. This could be compensated by increasing the legume surfaces area in the crop rotation. The data presented here suggest that there is scope for individual organic farms to increase the efficiency with which they use nutrients within the rotation to minimize losses to the environment. In contrast to dairy farms where all production strategies are focused on a high-yielding dairy herd, a mixed farm which integrates a suckler herd for beef production while cultivating an organic cash crop has to adapt to shifting production demands and conditions. Instead of selling certain crops (e.g., faba beans or peas, serving as N sources) and simultaneously exporting N, pulses will be fed to the cattle. A high return of fed nutrients, in the form of manure, could preserve nutrients in the closed-N farm cycle. This paper underlines that stockless farm systems are extremely dependent on neighboring sources of nutrients. There is a need to better understand the drivers of fertilizing materials and nutrient flows at the regional scale.

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References

Aronsson H, Torstensson G, Bergstrom L (2007) Leaching and crop uptake of N, P and K from organic and conventional cropping systems on a clay soil. Soil Use Manag 23:71–81. doi:10.1111/j.1475-2743.2006.00067.x

Berry PM, Sylvester-Bradley R, Philipps L, Hatch DJ, Cuttle SP, Rayns FW, Gosling P (2002) Is the productivity of organic farms restricted by the supply of available nitrogen? Soil Use Manag 18:248–255. doi:10.1079/sum2002129

Berry PM, Stockdale EA, Sylvester-Bradley R, Philipps L, Smith KA, Lord EI, Watson CA, Fortune S (2003) N, P and K budgets for crop rotations on nine organic farms in the UK. Soil Use Manag 19:112–118. doi:10.1079/sum2003176

Carlsson G, Huss-Danell K (2003) Nitrogen fixation in perennial forage legumes in the field. Plant Soil 253:353–372

Clement, A (2013) Etude des flux de matieres et d'elements en relation avec les prairies agricoles au sein d'un systeme de polyculture-élevage autonome en AB. ESITPA, Rouen. Data obtained in experimental organic farm at INRA Mirecourt from 2005–2012

CORPEN (1988) Bilan de l'azote à l'exploitation. Comité d'Orientation pour des Pratiques agricoles. Respectueuses de l'Environnement, Paris

CORPEN (1999) Estimation des flux d'azote, de phosphore et de potassium associés aux vaches laitières et à leur système fourrager. Comité d'Orientation pour des Pratiques agricoles Respectueuses de l'Environnement, Paris

CORPEN (2001) Estimation des flux d'azote, de phosphore et de potassium associés aux bovins allaitants et aux bovins en croissance, issus des troupeaux allaitants et laitiers, et à leur système fourrager. Comité d'Orientation pour des Pratiques agricoles Respectueuses de l'Environnement, Paris

Dalgaard T, Halberg N, Sillebak Kristense I (1998) Can organic farming help to reduce N-losses? Nutr Cycl Agroecosyst 52: 277–287

David C, Jeuffroy MH, Laurent F, Mangin M, Meynard JM (2005a) The assessment of a decision making tool for managing the nitrogen fertilization of organic winter wheat. Eur J Agron 23:225–242

David C, Jeuffroy MH, Henning J, Meynard JM (2005b) Yield variation of organic winter wheat: a crop diagnosis on a field network in South-East of France. Agron Sustain Dev 25:1–11

David C, Abecassis J, Carcea M, Celette F, Friedel J, Hellou G, Hiltbrunner J, Messmer M, Narducci V, Peigné J, Sansom MF, Schweinzer A, Thomsen I, Thommen A (2013) Organic bread wheat production and market in Europe. In: Lichtfouse E (ed) Sustainable Agriculture Reviews 11, 43-62

Development Core Team R (2008) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

D'Haene K, Magyar M, De Neve S, Palmai O, Nagy J, Nemeth T, Hofman G (2007) Nitrogen and phosphorus balances of Hungarian farms. Eur J Agron 26:224–234. doi:10.1016/j.eja.2006.10.005

Fangueiro D, Pereira J, Coutinho J, Moreira N, Trindade H (2008) NPK farm-gate nutrient balances in dairy farms from Northwest Portugal. Eur J Agron 28:625–634. doi:10.1016/j.eja.2008.01.007

Fortune S, Conway JS, Philipps L, Robinson JS, Stockdale EA, Watson C (2000) N, P and K for some UK organic farming systems±implications for sustainability. In: Rees RM et al (eds) Sustainable management of soil organic matter. CAB International, Wallingford, pp 286–293

Gourley CJP, Powell JM, Dougherty WJ, Weaver DM (2007) Nutrient budgeting as an approach to improving nutrient management on Australian dairy farms. Aust J Exp Agric 47:1064–1074. doi:10.1071/ea07017

Hauggaard-Nielsen H, Gooding M, Ambus P, Corre-Hellou G, Crozat Y, Dahlmann C, Dibet A, von Fragstein P, Pristeri A, Monti M, Jensen ES (2009) Pea–barley intercropping for efficient symbiotic N2-fixation, soil N acquisition and use of other nutrients in European organic cropping systems. Eur J Agron 28:625–634. doi:10.1016/j.eja.2008.01.007

Hellec F, Blouet A (2012) Technicite versus autonomie- Deux conceptions de l'elevage laitier biologique dans l'est de la France. Terrains Trav 20:157–172

Huss-Danell K, Chaia E, Carlsson G (2007) N-2 fixation and nitrogen allocation to above and below ground plant parts in red clover-grasslands. Plant Soil 299:215–226. doi:10.1007/s11104-007-9376-4

Korsaeth A (2008) Relations between nitrogen leaching and food productivity in organic and conventional cropping systems in a long-term field study. Agric Ecosyst Environ 127:177–188. doi:10.1016/j.agee.2008.03.014

Korsaeth A, Eltun R (2000) Nitrogen mass balances in conventional, integrated and ecological cropping systems and the relationship between balance calculations and nitrogen runoff in an 8-year field experiment in Norway. Agric Ecosyst Environ 79:199–214

Leclerc B (2001) Guide des Matières Organiques – Tome 2, 2nd edn. Institut Technique de l'Agriculture Biologique, Paris

Loges R, Kelm M, Taube F (2009) Comparative analysis of conventional and organic farming systems: nitrogen surpluses and nitrogen losses. In: Neuhoff D et al. (eds) Cultivating the future based on science. Volume 1: Organic crop production. Proceedings of the Second Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), 16th IFOAM Organic World Conference, Modena, Italy, pp 312–315

Marinari S, Mancinelli R, Carnpiglia E, Grego S (2006) Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy. Ecol Indic 6:701–711. doi:10.1016/j.ecolind.2005.08.029

Mignolet C, Schott C, Benoît M, Meynard JM (2007) Spatial dynamics of farming practices in the Seine basin: Methods for agronomic approaches on a regional scale. Sci Total Environ 375:13–32

Mignolet C, Schott C, Benoît M, Meynard JM (2012) Transformation des systèmes de production et des systèmes de culture du bassin de la Seine depuis les années 1970: une specialisation des territoires aux conséquences environnementales majeures. Innovations Agronomiques 22:1–16. http://www6.inra.fr/ciag/Revue/Volume-22-Octobre-2012

Moller K (2009) Inner farm nutrient flows between arable land and permanent grassland via the stable in organic cropping systems. Eur J Agron 31:204–212. doi:10.1016/j.eja.2009.07.007

Nemecek T, von Richthofen JS, Dubois G, Casta P, Charles R, Pahl H (2008) Environmental impacts of introducing grain legumes into European crop rotations. Eur J Agron 28:380–393. doi:10.1016/j.eja.2007.11.004

Neumann A, Torstensson G, Aronsson H (2011) Losses of nitrogen and phosphorus via the drainage system from organic crop rotations with and without livestock on a clay soil in southwest Sweden. Org Agric 1:217–229. doi:10.1007/s13165-011-0017-0

Oenema O, Kros H, de Vries W (2003) Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. Eur J Agron 20:3–16. doi:10.1016/s1161-0301(03)00067-4

Paillard S, Treyer S, Dorin B (2011) Agrimonde: scenarios and challenges for feeding the world in 2050. Quae, Paris

Pellerin S, Le Clech B, Morel C, Linères M (2004) Gestion de la fertilité phospho-potassique en agriculture biologique: questions posées et premiers résultats. CR Acad Agric Fr 89:30–34

Pelzer E, Bazot M, Makowski D, Corre-Hellou G, Naudin C, Al Rifai M, Baranger E, Bedoussac L, Biarnes V, Boucheny P, Carrouee B, Dorvillez D, Foissy D, Gaillard B, Guichard L, Mansard MC, Omon B, Prieur L, Yvergniaux M, Justes E, Jeuffroy MH (2012) Pea-wheat intercrops in low-input conditions combine high economic performances and low environmental impacts. Eur J Agron 40:39–53. doi:10.1016/j.eja.2012.01.010

Simon JC, Le Corre L, Vertes F (1994) Nitrogen balances on a farm scale: results from dairy farms in north west France. In: Grassland and society, Proceedings of the 15th General meeting of the European Grassland Federation, Wageningen (DEU), pp 429–433

Steinshamn H, Thuen E, Bleken MA, Brenoe UT, Ekerholt G, Yri C (2004) Utilization of nitrogen (N) and phosphorus (P) in an organic dairy farming system in Norway. Agric Ecosyst Environ 104:509–522. doi:10.1016/j.agee.2004.01.022

Ulen B, Aronsson H, Torstensson G, Mattsson L (2005) Nutrient turnover and risk of waterborne phosphorus emissions in crop rotations on a clay soil in south-west Sweden. Soil Use Manag 21:221–230

Watson CA, Atkinson D, Gosling P, Jackson LR, Rayns FW (2002a) Managing soil fertility in organic farming systems. Soil Use Manag 18:239–247. doi:10.1079/sum2002131

Watson CA, Bengtsson H, Ebbesvik M, Loes AK, Myrbeck A, Salomon E, Schroder J, Stockdale EA (2002b) A review of farm-scale nutrient budgets for organic farms as a tool for management of soil fertility. Soil Use Manag 18:264–273. doi:10.1079/sum2002127

Zenboudji EH (2012) Bouclage des cycles de nutriments au sein d'un système d'élevage herbager biologique. Université de Lorraine-ENSAIA, Nancy. Data obtained in experimental organic farm at INRA Mirecourt from 2005-2012