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ORIGINAL ARTICLE

Assessing phosphorus management among organic farming systems: a farm input, output and budget analysis in southwestern France

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Abstract Organic farming is gaining interest worldwide due to its low environmental impact. However, questions still remain about its long-term sustainability, particularly in terms of nutrient management. There is debate about the ability of organic farming systems to compensate for nutrient exports due to crop and animal production. Stockless systems are considered as the most critical and they are generally associated with negative farm-gate nutrient budgets. In this study, we examined the farm-gate nutrient budgets of 23 organic farms located in southwestern France, with special focus on stockless farming systems. Phosphorus (P) was taken as a case study due to the issue of its critical management in organic farming systems. The farms were characterised on the basis of interviews with farmers and the soil nutrient status was assessed through soil sampling. Results showed that none of the farms imported rock phosphate fertiliser. On the contrary, most farms imported organic fertiliser and/or compost and manure, the latter from neighbouring farms or urban areas. As a consequence, stockless farm P budgets were not necessarily negative and options existed from achieving better nutrient cycle closure. However, soil P test was low to moderate in many cases. These results suggested that P management in organic farming systems is not simply related to the mixed versus specialised characteristics of the farms and that nutrient cycling should be addressed and assessed at a larger, e.g., district, scale.

Keywords Phosphorus · Organic farming systems · Farm-gate budget · Soil phosphorus test · Livestock farm

Introduction

Organic farming is a form of agriculture that relies on techniques such as crop rotation, compost and biological pest control to maintain soil productivity and control pests. Organic farming uses fertilisers and pesticides but excludes the use of synthetic fertilisers and strictly limits the use of synthetic pesticides in Europe. Animal feeding must rely on materials that were organically produced (Council Regulation (EC) No. 834/2007). Organic farming is gaining interest worldwide due to its environmental benefits compared to conventional, intensive agriculture (Sandhu et al.

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2010; Mäder et al. 2002). Public policies encourage the expansion of organic farming in Europe and some scenarios have been proposed to extend organic farming on large scales, e.g., catchment (Thieu et al. 2011) or global scales (Badgley et al. 2007a). However, questions still remain about its productive abilities (Badgley et al. 2007b) and its nutrient budget. In particular, the ability to compensate for nutrient export in food products at the farm scale is questionable (Steinshamn et al. 2004; Modin-Edman et al. 2007; Möller 2009). Since input products containing nutrients may be prohibited (e.g., synthetic fertiliser), expensive (e.g., organic fertiliser), relatively ineffective (e.g., rock phosphate) or difficult to transport (e.g., manure), the risk of decreased use of farm fertilisers may arise, resulting in the depletion of soil nutrients over the long-term.

Nutrient management at the farm scale is generally assessed by the farm-gate budget (D'Haene et al. 2007; Gourley et al. 2007; Fangueiro et al. 2008), which is defined as the difference between total nutrient farm inflow through purchased products (fertiliser, animal feed, manure, straw, etc.) or fixed from the atmosphere, and the total nutrient outflow through exported products or losses to the environment (due to leaching, erosion, denitrification, etc.). The budget gives insight into the increase or decrease in nutrient stock within the farm soils. It also provides information about the inflows and outflows that contribute the most to the budget. Different types of farm-gate budgets may be calculated, depending on the limits of the system modelled and the flows under consideration (Watson et al. 2002b). Farm-gate budgets have been applied to organic farms in recent years (Berry et al. 2003; Steinshamn et al. 2004; Modin-Edman et al. 2007; Möller 2009; Oelofse et al. 2010), but the need for pluriannual case studies of commercial farms still exists. A general conclusion of these studies is that animal feed largely contributes to nitrogen (N) and phosphorus (P) farm inflow. In stockless farms, the absence of animal feed is often compensated for by the use of biological N fixation. Since the latter is not possible for P, stockless farming systems are generally attributed negative P farm-gate budgets, with a risk of soil nutrient depletion (Oehl et al. 2002; Berry et al. 2003; Kirchmann et al. 2008; Oelofse et al. 2010). This means that the P management issue is critical in organic, stockless farming systems. On the contrary, mixed organic farms (crops + animals) are presented as being more sustainable, i.e., having higher P budgets than stockless, specialised farms (Kirchmann et al. 2008). The objectives of this study were: (1) to calculate the budget of different organic-type farms, (2) to assess whether organic farms have necessarily negative P budgets, and (3) to evaluate which inflows and outflows contribute the most to the farm P budget. In that perspective, we applied farm-gate budgets to 23 organic farms in a small agricultural region in France.

Materials and methods

Study area

Farm surveys were performed in a small agricultural area in the Dordogne Department in southwestern France (0°1′ W and 45° N). The climate there is warm and oceanic, with a cumulative annual rainfall of 812 mm, 808 mm of reference evapo-transpiration and a mean annual temperature of 12.6°C. Winters are mild whereas summers are warm and dry. Soil types are diverse with a large dominance of calcareous and loamy soils. Agricultural production is mixed within the region: cereals, fruit trees, beef and duck are the major products produced. Organic farming represented 2.8% of Dordogne farms at the time of the study. A specialised technical extension service was offered to organic farms by the AgroBio Périgord Association.

Data collection

Twenty-three farms were characterised on the basis of interviews with farmers in spring 2009. The mean farm agricultural area was 78 ha. All of the farms grew cereal crops and 12 also had a significant share of animals i.e. greater than 0.1 livestock unit per total farm agricultural area, mainly beef cows, milk ewes and goats (Table 1). Some farms also grew fodder (e.g., alfalfa), vegetables or fruits (e.g., walnut, kiwifruit). All of the farms had been entirely converted to organic farming systems for 2–39 years, but most of them had been converted for 5–10 years.

Farmers were contacted either with the help of the local specialised extension service, AgroBio Périgord, or at the recommendation of other farmers. A large diversity of farming system was considered, that can

Table 1 Farm characteristics

Farm number	Agricultural area (ha)	Animal production	Perennial crop production	Main arable crop production	Livestock density (LU/ha of agricultural area)
1	24	–	Permanent grassland (11 ha)	Red clover/wheat/spelt (13 ha)	–
2	33	Beef cows (38 LU)	Permanent grassland (5 ha)	Temporary grassland/wheat/sorghum (28 ha)	1.2
3	69	Horses (14 LU)	Permanent grassland (20 ha) Walnut (9 ha)	Temporary grassland/maize/soybean/wheat/rye (40 ha)	0.2
4	84	Beef cows (23 LU)	Permanent grassland (13 ha) Temporary grassland/maize//maize/wheat/cereal mixture (32 ha)	Temporary grassland/sunflower/wheat (39 ha)	0.3
5	78	–	–	Maize/cereal mixture/sunflower/rapeseed/cereal mixture (78 ha)	–
6	134	Milk sheep (190 LU)	Permanent grassland (39 ha)	Temporary grassland/maize or cereal (95 ha)	1.4
7	173	Beef cows (107 LU)	Permanent grassland (113 ha)	Temporary grassland/maize/oat (60 ha)	0.6
8	60	Beef cows (50 LU)	Permanent grassland (10 ha)	Temporary grassland/cereal (50 ha)	0.8
9	100	Milk sheep (65 LU)	Permanent grassland (3 ha) Walnut (22 ha)	Temporary grassland/maize/cereal mixture (75 ha)	0.7
10	130	Beef cows (10 LU)	Permanent grassland (20 ha) Wheat/sunflower/barley/soybean/ Wheat/chickpea (100 ha)	Alfalfa (10 ha)	0.1
11	96	Beef cows (66 LU)	Permanent grassland (32 ha)	Temporary grassland/pea/cereal mixture/barley (60 ha) Potato/maize/cereal mixture (4 ha)	0.7
12	60	Milk goats (29 LU)	–	Alfalfa/cereal mixture/maize (42 ha) Temporary grassland/triticale–pea (18 ha)	0.5
13	155	Dairy cows (130 LU) Beef cows (30 LU)	Permanent grassland (25 ha)	Alfalfa or temporary grassland/maize/wheat or barley (130 ha)	1.0
14	52	–	Permanent grassland (17 ha)	Temporary grassland/triticale–pea/wheat (35 ha)	–
15	37	–	Permanent grassland (8 ha)	Alfalfa/wheat/sunflower/faba bean (29 ha)	–
16	56	Beef cows (29 LU)	Permanent grassland (11 ha)	Temporary grassland/triticale–pea (45 ha)	0.5
17	55	–	Permanent grassland (10 ha)	Alfalfa/wheat/wheat/maize/faba bean/wheat/maize (45 ha)	–
18	100	Beef cows (87 LU)	Permanent grassland (40 ha)	Alfalfa/maize/wheat/triticale–pea/maize/barley (60 ha)	0.9

Table 1 continued

Farm number	Agricultural area (ha)	Animal production	Perennial crop production	Main arable crop production	Livestock density (LU/ha of agricultural area)
19	78	–	Permanent grassland (5 ha) Kiwifruit (6 ha)	Alfalfa/wheat/sunflower (67 ha)	–
20	13	Some animals (10 heifers, 7 goats) for some months	Permanent grassland (2 ha)	Temporary grassland/wheat/rye (11 ha)	<0.1
21	85	–	Permanent grassland (13 ha)	Soybean/soybean/wheat/maize (72 ha)	–
22	65	–	–	Soybean/soybean/soybean/wheat (45 ha) Alfalfa/oat (20 ha)	–
23	31	–	Permanent grassland (1 ha)	Soybean/soybean/wheat/sunflower (30 ha)	–

LU livestock unit

be compared to the diversity of French organic farms (Table 2). However, specialised systems such as viticulture or horticulture were excluded since they represent small agricultural areas or may use small quantities of nutrients as input or output. On the contrary, the percentage of specialised farms in cereals, grain legumes and oilseeds was higher in the surveyed sample than in whole France since a special attention was given to stockless farms in this paper. Interviews were semi-directive and lasted approximately 2 h. Farmers were asked to describe their farming system, to then explain their P fertilisation management and, finally, to detail their input and output at the farm scale. Most farmers used their written notes from field books and ledgers to give accurate data on cropping areas, livestock number, crop yields and farm input/output. Data related to input/output were collected over 3 years (2006, 2007 and 2008).

Table 2 Main production of French and surveyed organic farms

Main agricultural production	% of French organic farms	% of surveyed farms
Vegetable and fruit	27	4
Beef and dairy cows	19	35
Annual crops (cereals, grain legumes and oilseeds)	16	48
Viticulture	14	–
Pig, poultry and other animals	9	–
Sheep and goats	8	13
Other	7	–
Total	100	100

The data for French organic farms are derived from AgenceBio public organisation (AgenceBio 2010)

Soil P availability was tested through chemical extraction to complement farm-gate P budget. Two plots per farm that were representative of the average farm conditions were chosen with the help of the farmer. In each plot, soil was sampled with an auger by collecting 15 samples over the first 20 cm of soil from May to July 2009. The samples were pooled per plot, not per farm. The samples were dried and sieved using a 2 mm mesh. Soil P availability was tested according to the Olsen method. When available, the wheat yield given by the farmers for the plots considered was also collected.

Data processing

Farm-gate P budget was calculated as farm P input minus output. The budgets were computed annually for each farm based on data collected from interviews. Inputs were live animals, animal feed, straw, seeds,

Table 3 Phosphorus content of fodder, straw, grain crops, tuber and fruits, compost and manure

Product	Water content (%)	P content (kg P/t dry mass)
Fodder		
Grass silage	20	2.4
Maize silage	30	1.8
Alfalfa hay	85	2.3
Temporary grassland hay	85	2.5
Permanent grassland hay	85	2.0
Temporary grassland	18	2.9
Permanent grassland	18	2.3
Sorghum	21	2.6
Straw		
Wheat straw	88	0.7
Barley straw	88	0.4
Rye straw	88	1.3
Triticale straw	88	0.9
Pea, faba bean and oat straw	87	1.0
Grains		
Oat	85	3.2
Wheat	85	2.8
Rape seed	91	5.5
Faba bean	86	5.2
Lentils	86	3.9
Flax	91	5.9
Grain maize	85	2.6
Oat	85	2.8
Pea	86	3.5
Chickpea	86	3.1
Rye	85	2.8
Soy bean	86	4.3
Sorghum	85	3.1
Sunflower	91	5.2
Triticale	85	2.8
Cereal mixture	85	3.1
Tubers and fruits		
Potato	20	1.0
Kiwifruit	80	0.33
Walnut	30	2.1
Compost and manure		
Fungi compost	50	2.6
Green waste compost	50	3.5
Bovine manure compost	33	6.6
Ovine manure compost	36	8.5

Table 3 continued

Product	Water content (%)	P content (kg P/t dry mass)
Poultry manure compost	63	11.9
Bovine manure	22	4.5
Sheep manure	30	5.8
Goat manure	45	5.0
Poultry manure	75	10.3
Bovine slurry	10	8.9
Sawdust	30	0.1
Meat meal	94	45.7
Bone meal	93	75.0
Feather meal	93	7.5
Guano	84	48.8
Commercial organic fertiliser	–	30–50 (depending on the fertiliser characteristics)

organic manure and organic fertiliser purchase. Outputs included live animals, animal products (e.g., eggs, milk or meat), crop products, organic manure and fertiliser sales. Atmospheric deposition, drainage, run-off, farm household consumption and stock variation were not taken into account since they were considered to be much lower than other inputs or outputs (Watson et al. 2002b). The P budget was computed by multiplying each input and output by its respective P concentration taken from the literature. Due to the small number of references about P concentration in materials resulting from organic farming in the literature (Watson et al. 2002b), we used P concentration data from conventional farming systems (Tables 3, 4). Due to the large differences in farm

Table 4 Phosphorus content of animal products

Animal product	P content (kg P/t fresh mass)
Bovine and equine live animals	7.5
Sheep and goat live animals	6
Egg	2
Cow and goat milk	0.9
Sheep milk	1.3

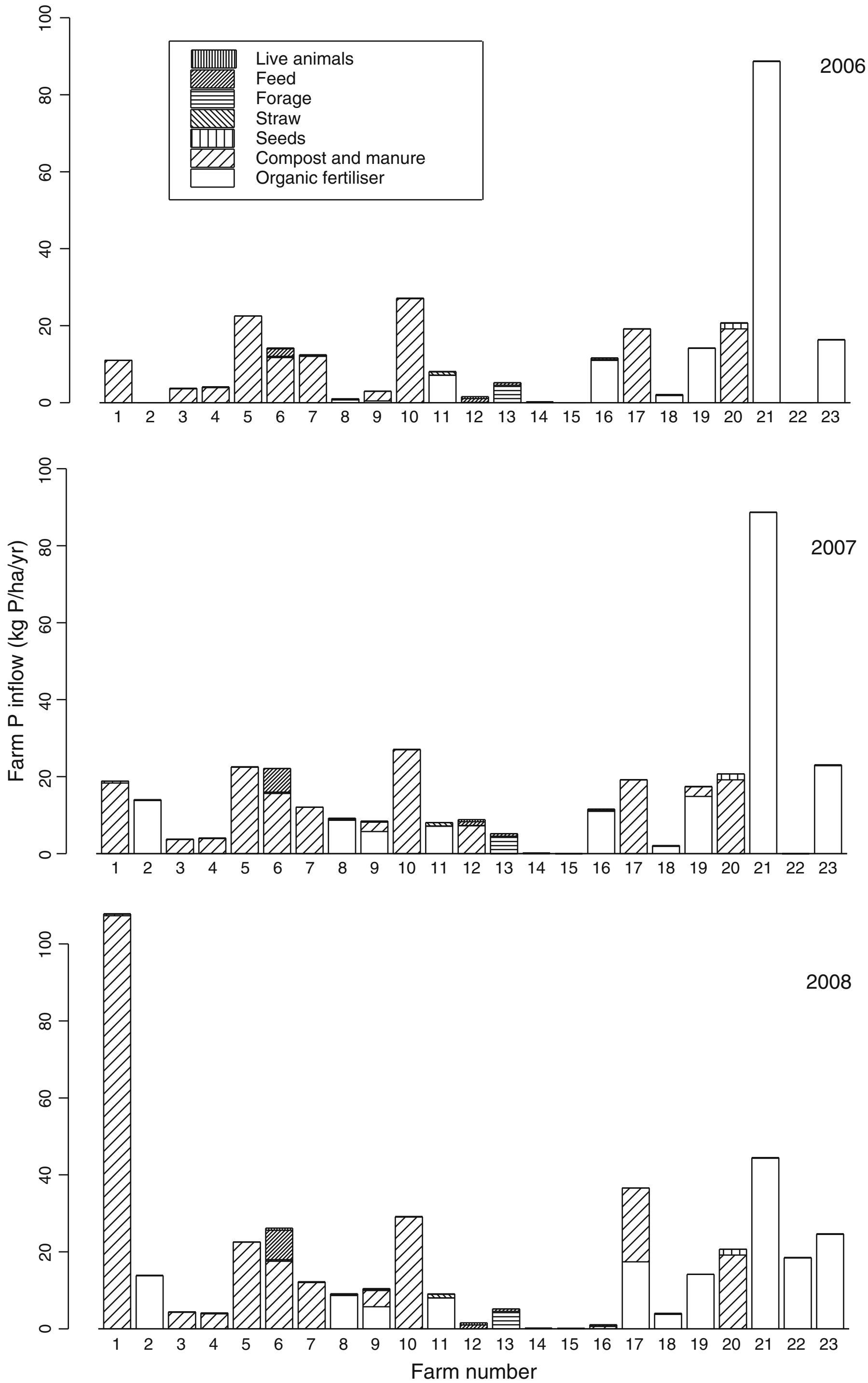

Fig. 1 Farm-gate P inflow for years 2006, 2007 and 2008

areas (from 13 to 173 ha), the P input, output and budget were expressed on a per hectare basis. The farm-gate P budgets were compared according to the livestock density by means of Anova. The livestock density was calculated as the number of livestock units divided by the farm agricultural area.

All data treatment was performed with S+ software (Chambers and Hastie 1992).

Table 5 Average (±standard error) 2006–2008 farm-gate P inflow, outflow and budget

Inflow (kg P/ha/year)		Outflow (kg P/ha/year)	
Organic fertiliser	6.9 (± 3.3)	Crop products	2.7 (± 0.7)
Compost and manure	7.6 (± 2.5)	Forage	0.9 (± 0.4)
Seeds	0.1 (± 0.1)	Straw	0.1 (± 0.0)
Straw	0.1 (± 0.0)	Compost and manure	0.7 (± 0.7)
Forage	0.2 (± 0.2)	Animal products	0.7 (± 0.2)
Feed	0.3 (± 0.2)		
Live animals	0.1 (± 0.0)		
Total inflow	15.3 (± 3.5)	Total outflow	5.1 (± 1.0)
Budget	+10.2 (± 3.2)		

Results

Farm-gate P input and output

All farms imported products containing P, except two (Fig. 1). During the 2006–2008 period, rock phosphate was not imported by these farms due to its low solubility in calcareous soils. Six to ten farms out of the 23 considered imported organic fertiliser mainly in the form of commercial compound products (e.g., containing meat meal). Ten to twelve farms imported manure (e.g., from bovine or poultry farms) or compost (e.g., from urban green waste, fungi production or horse farms). Live animals, straw and seed imports were negligible for all of the farms. Feed and forage imports were only marginally significant. The average 2006–2008 P input was 15.3 (±3.5) kg P/ha/year, highly dominated by organic fertiliser and compost and manure imports (Table 5). In particular, import of urban green waste represented on average from 1.4 (±0.77) (in 2006) to 4.5 (± 3.1) kg P/ha/year (in 2008). Farm-gate P outputs were more diverse and, as expected, varied according to farm production (Fig. 2). Crop product outputs were higher than animal product outputs, even though 12 of the 23 farms had a significant share of animals. Five farms exported a significant amount of P as forage to organic stock farms and one farm was a significant source of compost and manure for other, stockless organic farms.

Farm-gate P budget

Farm P inputs were approximately three times higher than P outputs, leading to an average positive P budget of 10.2 (±3.2) kg P/ha/year (Table 5). Farm-gate P budget varied among farms, with only 2–3 farms having a negative P budget (Fig. 3). Farm P budget also varied over time due to yearly differences in crop and animal yields and fertiliser and compost purchase strategies. The P budget did not depend on the farm livestock density ($P > 0.1$): many stockless farms showed a positive P budget (Fig. 3), leading to an average highly positive P budget for stockless farms (Table 6).

Soil-P test

Soil P test in organic plots was variable, ranging from 3.3 (farm #2) to 53 (farm #17) mg P Olsen/kg soil (Fig. 4). However, 68% of the plots exhibited Olsen P test of less than 19.7 mg P/kg soil, the latter corresponding to the limiting soil P value for low-demanding crops (such as maize or wheat) in calcareous clay soils (Denoroy et al. 2004). No clear relationship could be established between soil P test and cumulated plot P budget over the preceding 3 years (Fig. 5) or anteriority in organic farming (data not shown). Soil P test was poorly correlated to wheat yield but low yields were mostly associated with low soil P test (Fig. 6).

Discussion

Previous studies had concluded that the organic farm-gate P budget was strongly influenced by the stock versus stockless characteristics of the farm (Kirchmann et al. 2008; Pellerin et al. 2003; Watson et al. 2002b). However, our sample demonstrated that this relationship was weak. Organic farm P budget was not related to the farm livestock density alone in our sample. First, even if the presence of animals may facilitate within-farm nutrient recycling (e.g., from animals to crops through manure), it did not lead to the absence of organic fertiliser import of animal farms (Fig. 1). In particular, different organic fertiliser strategies may be applied by farmers, ranging from the pure substitution of chemical fertilisers by organic ones, to the complete redesign of the farming system in order to improve within-farm nutrient cycling (Lamine and Bellon

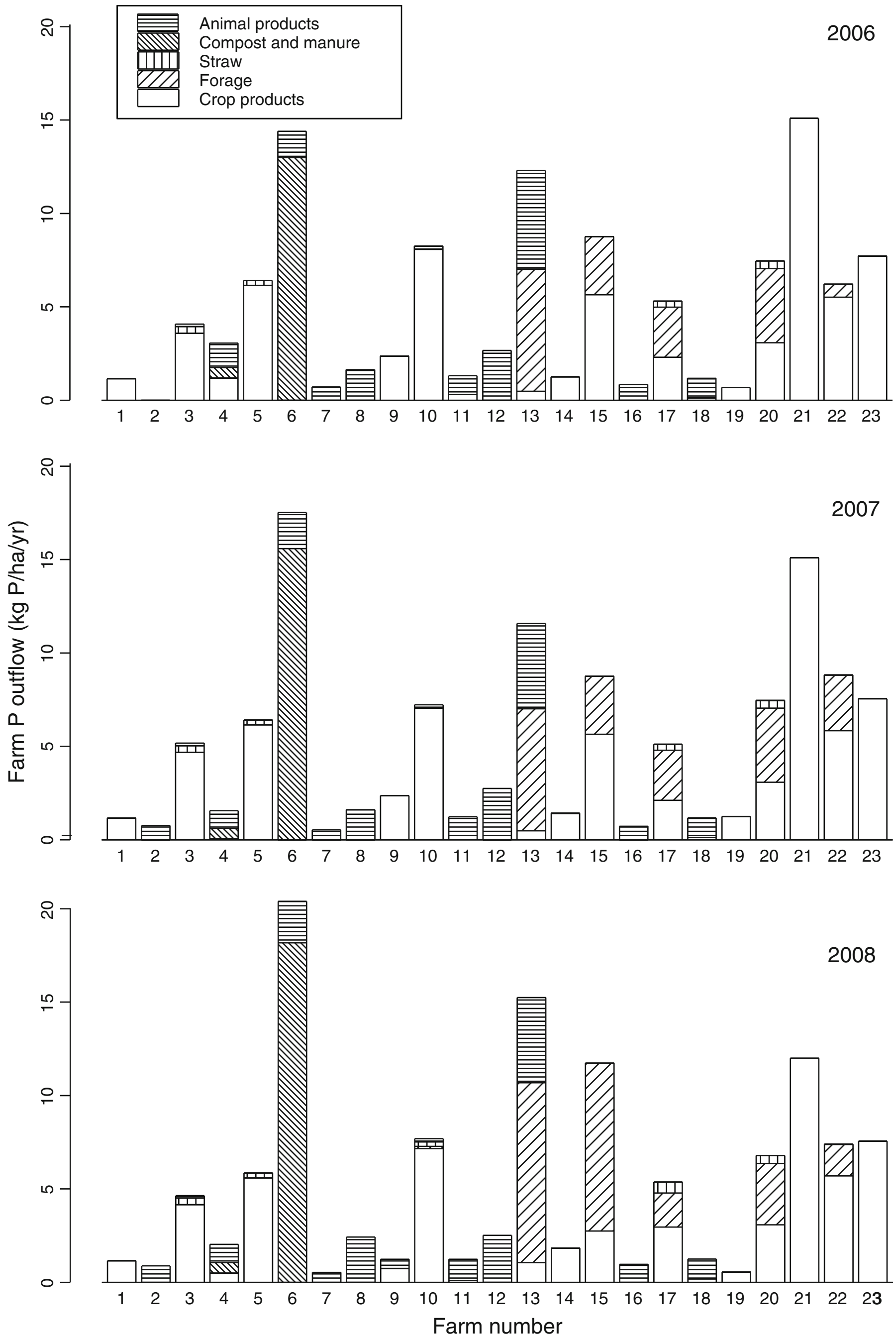

Fig. 2 Farm-gate P outflow for years 2006, 2007 and 2008

2009). Second, the farm-gate P budget did not depend on the farm livestock density in our sample (Table 6). This is in contradiction with previous studies that concluded that stockless organic farms had negative P budgets (Kirchmann et al. 2008; Watson et al. 2002a). Our result is due to the active strategy of compost, manure and organic fertiliser import of the farms considered (Fig. 1). This strategy was made possible due to exchanges of products containing P among farms: for example, farm no. 6 exported large quantities of manure to other organic farms, as did farms no. 13, 15, 17, 20 and 22 for forage (Fig. 2). Such exchanges were made possible by the diversity of agricultural production within the territory considered.

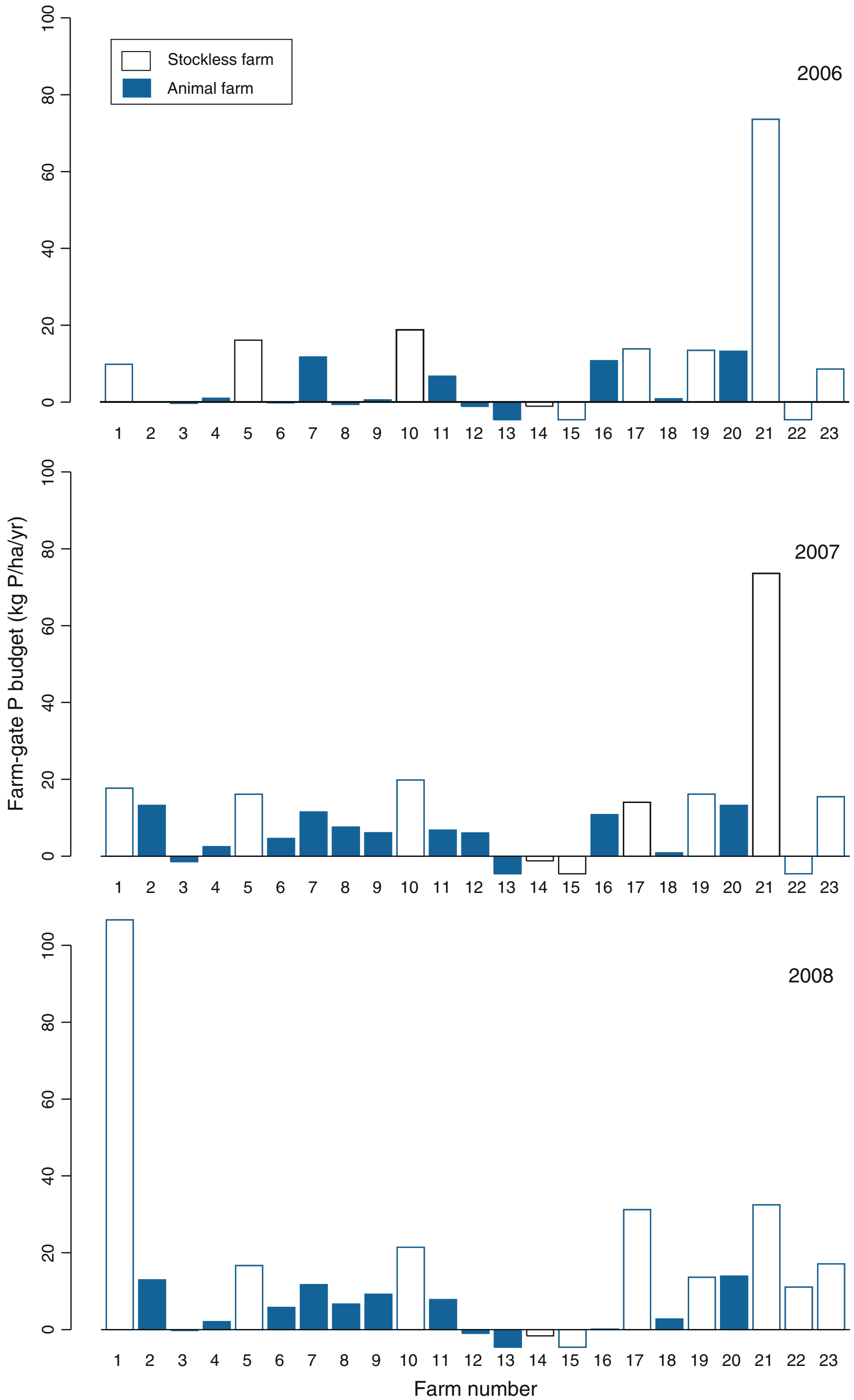

Fig. 3 Farm-gate P budget for years 2006, 2007 and 2008

Exchanges allowed a reasonable farm specialisation and, consequently, possible economies of scale (Woodhouse 2010). Nevertheless, exchanges were limited by their transaction cost, particularly for stock farms that imported large amounts of feed concentrates.

Table 6 Average (± standard error) 2002–2006 farm-gate P budget according to livestock density

Livestock density per total farm agricultural area (number of livestock unit/ha)	Farm-gate P budget (kg P/ha/year)
<0.1 ($n = 11$)	17.3 (± 4.2) *ns*
0.1–0.6 ($n = 4$)	2.4 (± 0.7) *ns*
>0.6 ($n = 8$)	4.3 (± 1.2) *ns*

ns no significant difference ($P > 0.1$)

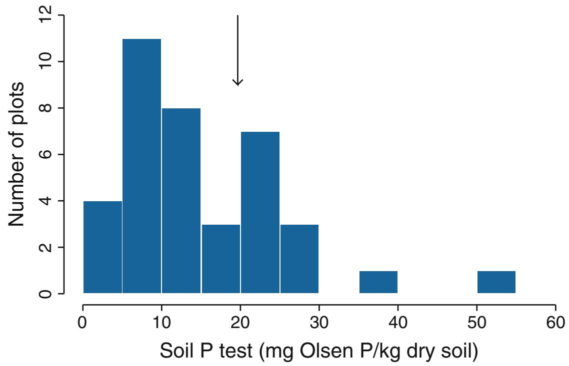

Fig. 4 Histogram of soil P test estimated by the Olsen method (in mg Olsen P/kg dry soil). The *arrow* indicates the limiting value for low-demanding crops in calcareous clay soils calculated using Regifert software (Denoroy et al. 2004)

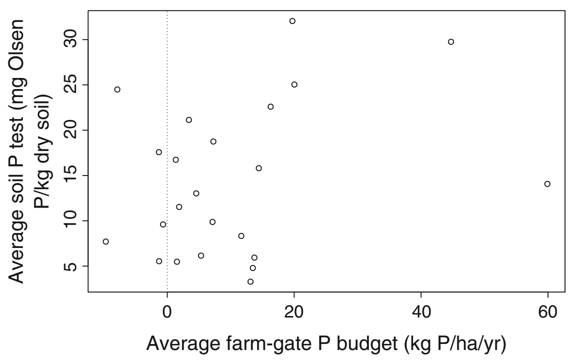

Fig. 5 Soil P test estimated by the Olsen method (averaged per farm, in mg Olsen P/kg dry soil) as a function of farm-gate P budget (averaged over the 2006–2008 period, in kg P/ha/year)

However, outputs of manure and forage from farms were far lower than compost, manure and forage inputs in our sample (Table 5). This suggests that other sources of products containing P were used

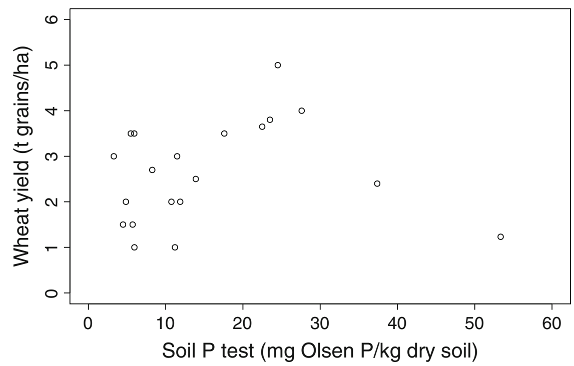

Fig. 6 Wheat yield as a function of soil P test estimated by Olsen method

within the region. First, conventional farms may supply composted manure, thus contributing to the nutrient supply of organic farms. This has already been suggested by Oelofse et al. (2010) for some farms in China. Second, urban areas may be a source of nutrients for organic farms, e.g., through green waste that contributes on average from 9 (in 2006) to 30% (in 2008) of farm P input (Section "Farm-gate P input and output"). Disentangling the contribution of the different sources would require further studies: nutrient cycling should be assessed at a larger scale (e.g., regional) to take into account exchanges between both organic and conventional farms, as well as those with urban areas. This would help to assess to what extent organic farming relies indirectly on conventional fertiliser, as already suggested (Oelofse et al. 2010; Gosling and Shepherd 2005). Moreover, this would help to go beyond farm-gate P budget results and to assess the actual regional nutrient cycling closure in organic farming systems.

Our study focused on farm-gate P budget. Such budget is interesting to assess the effect of farm characteristics but does not give direct insight into changes in soil P availability. Linking P budget and soil P availability would require mechanistic models that are valid under a large range of soil conditions. Such models exist (Stroia et al. 2007; Messiga et al. 2010), but they are soil-dependent and thus require complex parameterisation based on isotopic dilution methods. Moreover, these models can only account for mineral fertiliser as input, not organic materials such as manure, compost, etc. As a consequence, such models are not adapted to the organic farming context.

Therefore, our study could not offer conclusions about changes in soil P availability under organic farming. However, our results underlined a low to moderate soil P test (Fig. 4). Such results had already been reported under experimental conditions (Romanya and Rovira 2007; Oehl et al. 2002) and on representative organic farms (Gosling and Shepherd 2005; Cornish 2009). Such moderate soil P test may lead to moderate wheat yields (Fig. 6): the average yield of the sampled plots was 2.6 t grain/ha, whereas conventional wheat yield in the Dordogne Department (France) was 5.4 t/ha for the same period (http://acces.agriculture.gouv.fr/disar/faces/, access on July 25th 2011). Oehl et al. (2002) also mentioned the possibility that soil P availability may limit crop yield in organic farming systems. However, many easily confounding effects may apply on the plots considered due to N deficit, weeds, poor soil structure, etc. Disentangling such effects in order to highlight the P nutrition effect would require thorough regional agronomic diagnosis (Doré et al. 1997) and use of a model capable of simulating crop growth under P deficiency (Mollier et al. 2008; Greenwood et al. 2001). Moreover, the use of the Olsen P method for low soil P test is debatable, raising the question of whether other indicators may be more well suited to assess soil P dynamics in organic farming systems due to the supposedly higher contribution of soil organic matter mineralisation, rhizosphere activity and mycorrhiza contribution to plant nutrition (Oehl et al. 2002; Mäder et al. 2002; Hinsinger et al. 2011).

Conclusion

In opposition to several authors, our study demonstrated that farm P budget was not related to the stock versus stockless characteristics of the farms alone. On the contrary, the farm P budget depended more on the farmers' strategy about fertiliser and compost/manure import: these products contributed mostly to farm P input whereas crop products dominated farm P output. This calls for a better attention to the sources of organic products within agricultural regions, e.g., from organic or conventional farms or urban areas. The availability of such sources is probably highly dependent on the diversity of farming systems within the region due, for example, to the presence of animal breeding systems. This also suggests that options for achieving a better nutrient closing in organic farming systems exist, for example, through exchanges of organic products containing P within agricultural regions. Addressing the last two issues would require larger scale analysis of material exchange among farms and could help to design farming systems that better close nutrient cycles.

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