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RESEARCH

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Survey of farm-gate N and P balances on arable and dairy organic and conventional farms in Sweden—basis for improved management

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Abstract About half of all N and P loads to Swedish waters originate from agriculture and must decrease to reach environmental goals. Studying nutrient management at farm level can provide an understanding of nutrient recycling and the risk of losses. In a survey of organic and conventional dairy and arable farms in three southern counties of Sweden, farm-gate N and P balances and N use efficiency (NUE) were analysed. Crop distribution differed significantly between organic and conventional farms, with organic dairy farms having higher proportions of ley and pulse crops and organic arable farms having a much higher proportion of N-fixing crops than corresponding conventional farms. Conventional dairy and arable farms had on average 70% and 40% higher N surplus than corresponding organic farms. Farm-gate P surplus was larger on conventional dairy farms and much larger on organic arable farms, mainly due to purchase of P-rich organic fertilisers. Organic dairy farms had higher NUE than corresponding conventional farms, but the opposite was true for arable farms. However, in the southernmost county Skåne, where soil fertility and yield potential are high, NUE was similar on all arable farms. Total inputs of N and P were positively correlated with N and P surpluses, especially on dairy farms. Improved manure and crop residue management, reduced use of purchased mineral N fertilisers coupled to more uniform within-farm distribution of manure, use of catch crops, intercropping and organic fertilisers with appropriate N:P ratio are measures that can reduce farm nutrient surpluses and improve nutrient management on both organic and conventional farms.

Keywords Nutrient management · Farm-gate N and P balances · Dairy farms · Arable farms · Organic farms · Conventional farms

Introduction

Eutrophication is a severe environmental problem at local and regional scale. Around half the total nitrogen (N) load and almost half the total phosphorus (P) load reaching surface waters in southern Sweden in 2014 originated from agriculture (SAMVM 2019). Losses from agriculture occur through leaching and surface run-off from agricultural land. Nitrogen is also lost as ammonia (NH_3) emissions, predominantly from manure management, and through emissions of different N oxides from arable and pasture land. Thus, N and P losses leading to eutrophication

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originate from both crop and animal production systems. Although N and P loads have been reduced in recent decades, there is an urgent need to further lower the loads by improving farm nutrient management, to achieve good ecological status in Swedish inland and marine waters (HELCOM 2018).

Organic farming aims at recycling nutrients and minimising negative environmental impacts. Some studies have shown that organic farming has the potential to reduce N losses (Seufert and Ramankutty 2017; Reganold and Wachter 2016), but these findings have also been questioned (Kirchmann and Bergström 2001). Reported reductions show large variation, e.g. depending on type and intensity of production and the actual design of the farming systems studied (Jespersen et al. 2017; Seufert and Ramankutty 2017).

Calculation of nutrient balances for a large number of farms with a particular production system in different regions could be a way to improve understanding of N and P dynamics, the risk of unwanted losses/build-ups and the long-term sustainability in different agroecosystems (Reimer et al. 2020; Öborn et al. 2005). In a study by Dalgaard et al. (2012) of farm-gate N balances and surpluses on farms in different European landscapes, farm N surpluses were positively correlated with measured N losses in the study areas, i.e. concentrations of ammonia (NH_3) in air and nitrate in soil and groundwater. De Notaris et al. (2018) found a consistent relationship in long-term crop rotation field experiments in Denmark between N leaching and N input or N surplus for both organic and conventional crop rotations. However, management factors, such as catch crops, influenced N leaching more than N surplus in those experiments, leading De Notaris et al. (2018) to conclude that strategies to retain N in the crop production system are of crucial importance for reducing N leaching and that N field balances can act as a proxy for potential N losses. No such relationship has been identified for P, as P losses to water correlate more strongly with soil type and specific field activities (Ulén and Jakobsson 2005). However, long-term build-up of P in the soil may increase P losses to water (Ulén and Jakobsson 2005). In summary, plant nutrient balances have gained widespread acceptance as indicators of the risk of nutrient losses from agriculture, and are also used as a regulatory tool to decrease this risk (Bauer and Sweers 2015).

However, there are some shortcomings of using nutrient balance calculations as a management tool to optimise N and P management. The two main constraints are lack of a standardised method (Bleken et al. 2005; Reimer et al. 2020) and use of simple input-output accounting where the farm is regarded as a 'black box', neglecting internal farm structures, nutrient fluxes and management practices (Watson et al. 2002; Öborn et al. 2003). In the present survey, we applied farm-specific information collected by farm advisors within a Swedish environmental advisory project (Focus on Nutrients 2011), which increased the potential to identify management practices that influence farm-gate N and P surpluses and N use efficiency (NUE). A further weakness with the farm-gate system boundary could be that it does not take the nutrient balances of off-farm inputs into account, such as purchased feed for livestock (Koesling et al. 2017). A wider system boundary such as in chain nutrient budgets will give better information about the overall risk of nutrient losses associated with a product (Einarsson et al. 2018). However, the farm-gate N and P surpluses per unit area provide information of the local nutrient load where the farm is situated.

In order to draw valid conclusions about the risk of losses based on farm nutrient balances and NUE for different production systems, it is most important to compare systems with similar types of products sold from the farm and consider difference in the proportions of animal and crop produce, as nutrient surpluses and NUE are strongly influenced by these two output categories (Bleken et al. 2005).

In this broad Swedish survey of 2550 dairy and arable farms, organic as well as conventional, we analysed farm N and P balances in the three southern counties (Skåne, Halland, Västra Götaland), where most high-intensity agricultural production in respect of nutrient inputs and flows is situated. About 40% of total arable land, 37% of cattle and 59% of pigs in Sweden are situated in these counties (SS 2015; SS 2016), and thus, they have a major influence on nutrient loads in coastal waters in southern Sweden (HELCOM 2018).

Specific objectives of this study were to (i) analyse N and P flows and balances for organic and conventional dairy and arable farms in Skåne, Halland and Västra Götaland; and (ii) examine surpluses of N and P and NUE in relation to farming system (organic vs. conventional), regional location and farm management practices.

Materials and methods

Study area characteristics

Locations and climate conditions

Skåne county lies within 55°20′–56°26′N and 12°46′–14°23′E, Halland county within 56°21′–57°33′N and 12°18′–13°26′E and Västra Götaland county within 57°17′–59°08′N and 11°21′–14°41′E. On average, the climate in Skåne is characterised by mean temperature of 7 °C (typically 15 to 17 °C in July, 0 to −2 °C in January), with a growing season (number of days with mean temperature above 5 °C) of 190–210 days. Average precipitation in the main agricultural areas in Skåne is 500–700 mm per year. The climate in Halland is characterised by slightly lower temperature than in Skåne (15 to 16 °C in July, −1 to −3 °C in January), but the growing season is similar in length to that in Skåne. Average precipitation in different areas of Halland ranges from 700 to 1200 mm per year. In Västra Götaland, temperatures are slightly lower than in Halland, leading to a growing season of 180–200 days, and average precipitation varies from 500 to 1000 mm per year.

Farms in the survey (Fig. 1)

The national advisory project Focus on Nutrients, run since 2001 by the Swedish Board of Agriculture, aims to improve plant nutrient management at farm level and reduce losses of N and P (Focus on Nutrients 2011). Here, we used farm-gate N and P flows and balance data for arable land on 2550 farms collected by farm advisors between 2001 and 2006. If balances were made for more than 1 year on a farm, the most recent balance from each farm was included. The farms comprised 124 organic and 2426 conventional dairy and arable farms in Skåne, Halland and Västra Götaland (Table 1), where the production system on the farms was defined based on the type and number of animal units per hectare. Dairy farms were defined as having 75% or more of total animal units as dairy cows, while arable farms were defined as having less than 0.2 animal units per hectare. Most arable farms had no animals, but some had small herds of beef cattle up to 0.2 animal units per hectare. The organic dairy farms had significantly larger area arable land than corresponding conventional farms, but the opposite was true for arable farms. There were also significant

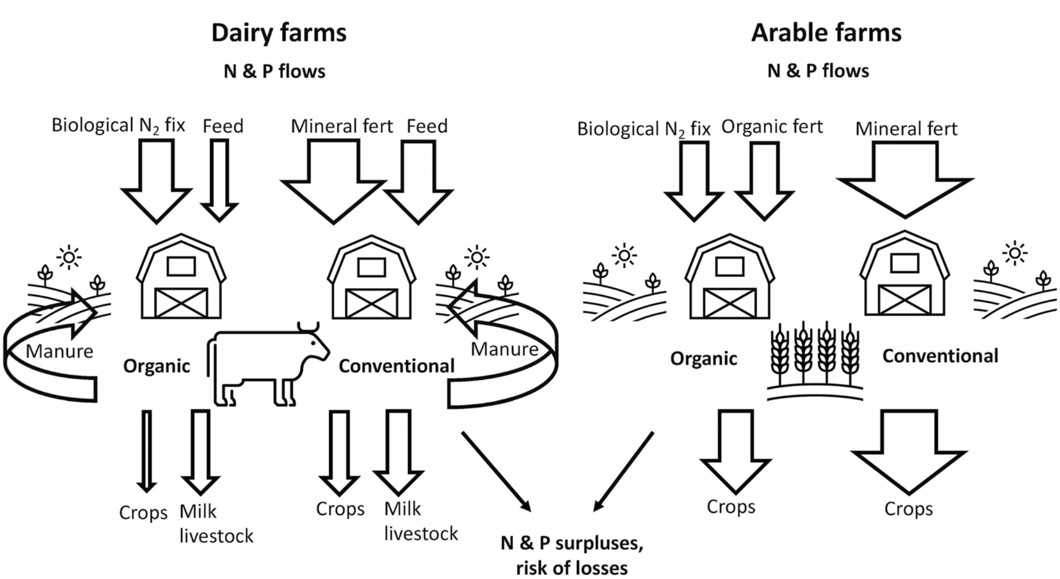

Fig. 1 N and P flows on organic and conventional dairy and arable farms in three southern counties in Sweden

Table 1 Characteristics of farms in the survey between year 2001 and 2006

County	Organic production			Conventional production			*p*-value[1]
	Skåne	Halland	Västra Götaland	Skåne	Halland	Västra Götaland	
Dairy farms							
Number of farms	19	14	35	662	159	335	
Average arable land, ha	100	100	148	78	74	92	s 0.0002, c 0.0062
Arable land in survey, ha	1900	1400	5200	51,900	11,800	30,700	
Animal units ha^{-1} [2]	0.95	0.77	0.71	0.95	1.10	0.89	s 0.0005, c 0.0030
kg milk cow^{-1}	6740	7460	7730	8070	8680	8350	s <0.0001, c <0.0001
Arable farms							
Number of farms	31	10	15	1015	66	189	
Average arable land, ha	79	52	98	132	91	119	s 0.0202, c 0.0281
Arable land in survey, ha	2500	520	1500	134,500	6000	22,600	

[1] *p*-values ≤ 0.05 are given; *s* system (organic/conventional), *c* county

[2] Area-weigthed data

differences between the counties. Animal density and milk yield were both lower on the organic dairy farms.

Data sources

The data required for calculating farm-gate balances of N and P were recorded by an advisor visiting the farm. The advisor entered data into a database developed within the project Focus on Nutrients called STANK in MIND (named VERA from 2015) (Focus on Nutrients 2021). The data were sorted by farming system, organic or conventional, county and production system. The types and amounts of products were based on purchase and sales documents where it was possible to specify the N and P content in some products precisely, e.g. mineral fertilisers, sold milk and crops (not always) using exact figures in filed documents. For other products, e.g. animal manures, that are heterogeneous in dry matter, N and P contents, and which were only occasionally sampled and analysed, standard values of N and P contents available in the tool STANK in MIND were used. These values were average values based on compilation of available Swedish publications of analysed nutrient concentrations of different kinds of manure on both organic and conventional farms (SBA 2021).

The empirical model proposed by Høgh-Jensen et al. (2004) was used for estimating symbiotic N fixation in the legume crops. The amount of fixed N was calculated by estimating the proportion of clover in clover/grass leys and under-sown clover-grass catch crops by visual observations by the farmer or by the advisor, while yields per hectare were based on farm records. The ley used as green manure constituted a minor proportion of the ley area on arable farms (see below), and the yields of green manure leys were visually estimated. The proportion of N derived from the atmosphere by legume crops was based on parameters for different legumes in the empirical model. The amounts of N fixed in below-ground biomass, immobilised in soil and transferred below-ground to grass roots were included in the model.

Representativeness of soil types

On all farms, soil type was recorded in four soil texture categories defined by the proportion of clay: sand <5%; silt 5–15%; clay loam 15–25%; clay >25%. There were significant differences in the proportions of sand soils between organic and conventional arable farms, with more sand soils under organic production. There was also a tendency for dairy farms to be situated on lighter soils than arable farms. Furthermore, the soil type on farms in the survey had a somewhat finer texture (more clay) than soils on total arable land in the three counties (Eriksson et al. 2010). Overall, it was concluded that these differences in soil type did not affect the accuracy of comparisons between organic and conventional farms in this study.

Crop distribution and manure management

Complementary information was collected from each farm about crop distribution on arable land and, for dairy farms, about manure management. Organic dairy farms had a significantly larger proportion of ley, green fodder and pulses, mainly peas and faba beans (67–78% of total arable land in the different counties) than conventional dairy farms (52–59% of total arable land) (Table 2). On the other hand, conventional dairy farms had a significantly larger proportion of both winter and spring cereals in their crop rotations than organic farms. Other minor crops grown on the dairy farms were maize and potatoes.

On organic arable farms, most ley was grown for forage, for sale or for own use (some arable farms had small herds of beef cattle), and a minor part was grown for seeds and green manure. Green manure corresponded to about 8% of the ley area (data not shown). Conventional arable farms grew significantly larger proportions of cereals, sugar beet and potatoes than organic arable farms. Vegetables were also grown on some farms, both organic and conventional. Furthermore, organic arable farms occasionally had black fallow in their rotations. Both organic and conventional farms grew catch crops, between main crops, under environmental subsidies, corresponding to 13% of total arable area in both farming systems.

On both organic and conventional dairy farms, liquid manure systems dominated, which was in accordance with national statistics showing that about 80% of dairy manure in Sweden was handled in liquid form due to increased use of loose housing systems (SS 2008). Based on farm records of animal manure distribution over time, larger proportions of the total of both liquid and solid manure (59% and 65%, respectively) were spread in spring on organic dairy farms than on conventional dairy farms (50% and 56%, respectively). Consequently, a larger proportion of the total manure collected for storage was spread in early or late autumn on conventional farms than on organic farms.

Farm N and P balances and NUE

Farm-gate balances were calculated as the difference between N and P inputs (*i*) and N and P outputs (*o*) per hectare arable land where symbiotic N fixation and atmospheric N deposition were included as farm inputs (Eqs. 1 and 2).

Table 2 Distribution of main crops, % of total arable land on organic and conventional dairy and arable farms in the three different counties included in the survey

	Organic production			Conventional production			
	Skåne	Halland	Västra Götaland	Skåne	Halland	Västra Götaland	*p*-values[1]
	% of total arable land on the farms						
Dairy farms							
Grass-clover ley	64	61	54	50	58	53	s 0.0295
Green fodder, pulses	14	8	13	2	1	4	s <0.0001, c 0.0007
Winter cereals	4	4	11	12	6	10	s 0.0342, c 0.0107, s*c 0.0299
Spring cereals	9	22	16	19	24	24	s <0.0001, c<0.0001
Oilseed	4	1	2	1	0.5	2	s 0.0017, c 0.0103
Arable farms							
Grass-clover ley	21	26	29	4	9	9	s<0.0001, c<0.0001
Pulses	17	8	11	3	4	3	s<0.0001
Winter cereals	11	18	18	34	26	33	s<0.0001
Spring cereals	29	30	21	27	38	32	s 0.0317, s*c 0.0095
Oilseed	3	7	11	7	4	10	c 0.0019
Sugar beet	4	1	-	14	2	-	s 0.0218, c<0.0001, s*c 0.0004
Potatoes	2	1	-	3	9	2	s 0.0257

[1] *p*-values ≤ 0.05 are given; *s* system (organic/conventional), *c* county, s*c interaction

As the types and amounts of products of crop and animal origin differed on conventional and organic farms, it was not appropriate to compare NUE between these farming systems for total outputs in relation to total inputs (Dalgaard et al. 1998). This was especially true for the dairy farms, where conventional farms exported considerable amounts of crops and manure, besides milk and livestock. On the organic dairy farms, sales of milk and livestock were the major outputs. Hence, NUE was defined and calculated for animal products on dairy farms and NUE for crop products on arable farms (Eqs. 3 and 4). For animal products, the NUE was computed as net N output of animal products (milk and livestock) divided by net N input of different categories. For crop products, NUE was computed as net N output of crop products (output of crops minus feed inputs) divided by net N input of different categories.

The calculations were made according to Dalgaard et al. (2012) for the dairy farms (Eq. 3) and adjusted to reflect NUE in crop produce for the arable farms (Eq. 4).

$$\begin{aligned}\textit{Input products} =& \textit{feed}\ (i1) + \textit{seeds}\ (i2) + \textit{straw}\ (i3) + \textit{fertilisers}\ (i4)\\ &+ \textit{manure}\ (i5) + \textit{livestock}\ (i6)\\ &+ \textit{deposited atmospheric N}\ (i7) + \textit{symbiotic fixed N}\ (i8)\end{aligned} \tag{1}$$

$$\textit{Output products} = \textit{milk}\ (o1) + \textit{livestock}\ (o2) + \textit{manure}\ (o3) + \textit{straw}\ (o4) + \textit{crops}\ (o5) \tag{2}$$

$$\begin{aligned}&\textit{N use efficiency of animal products}, \%_{\textit{dairy farms}} =\\ &\left[(o1 + o2 - i6) * [(i1 + i2 + i3 - o4 - o5) + (i4 + i5 - o3) + (i7 + o8)]^{-1}\right] * 100\end{aligned} \tag{3}$$

$$\begin{aligned}&\textit{N use efficiency of crop products}, \%_{\textit{arable farms}} =\\ &\left[(o5 - i1) * [(i2 + i3 - o4) + (i4 + i5 - o3) + (i6 - o2) + (i7 + i8)]^{-1}\right] * 100\end{aligned} \tag{4}$$

Statistical analysis

The farm-gate N and P balance values, for dairy and arable farms separately, were analysed by variance analysis for statistical significance in JMP 8.0.1 (Cary, NC: SAS Institute Inc. 2009), using a linear fixed-effect model consisting of main effects (farming system (organic or conventional) and county (Skåne, Halland or Västra Götaland)), and their interactions. The data were area-weighted, which meant that the results corresponded to the total area with, e.g. organic production. Linear regression analyses were performed to evaluate the correlation between total inputs of N and P on each farm, and individual farm N and P surpluses. All statistical differences were tested at $p \leq 0.05$. Separate statistical analyses were performed for dairy and arable farms.

Analysis of NUE for animal and crop products was performed by log transformation of the ratios described by Eqs. 3 and 4, thus comparing geometric mean differences in the variance analysis, since the ratios had skewed distributions. Least square means were back-transformed and presented in the original scale.

Results

N and P balances and NUE on dairy farms

Organic dairy farms had significantly lower N and P surpluses than conventional dairy farms (41% and 33% lower, respectively) (Tables 3 and 4). Significantly lower feed and fertiliser N and P inputs to the organic farms contributed to the lower N and P surpluses, especially much lower farm input of N fertilisers, which was on average only 12% of the input on conventional farms. Some organic farms imported N and P through farm-yard manure as complement to the manure produced on the farm.

Table 3 Nitrogen flows, farm N balances (kg N ha^{-1}) and N use efficiencies of animal products (%) on organic and conventional dairy farms in three counties in Sweden (area weighted values)

County	Organic dairy farms				Conventional dairy farms				*p*-values [1]
	Skåne	Halland	V. Götaland	All farms	Skåne	Halland	V. Götaland	All farms	
	kg N ha^{-1}								
Farm N inputs									
Fertiliser	5	14	13	11	95	96	84	92	s 0.001
N_2 fixation	58	65	61	61	18	24	26	21	s 0.001
Atm dep	10	10	6	8	10	10	6	9	c 0.001
Seed	3	5	4	4	2	3	2	2	s 0.007
Straw	3	3	1	2	2	2	1	2	c 0.037
Feed	26	20	31	28	77	86	65	74	s 0.001s*c 0.044
Livestock	0.2	1.2	0.3	0.4	0.5	1.3	0.6	0.6	c 0.001
Sum	105	118	116	114	205	225	186	201	s 0.001, s*c 0.045
Farm N outputs									
Crops	2	2	9	6	27	11	12	20	s 0.001, s*c 0.001
Straw	0	0.4	0	0.1	0.3	0.1	0.3	0.2	
Manure	4	0	0.4	1.1	10	9	3	8	s 0.007
Milk, livestock	29	27	26	27	38	46	36	39	s 0.001
Sum	35	30	36	35	76	67	52	67	s 0.001, c 0.018, s*c 0.003
Farm N balance	70	88	80	79	129	158	133	134	s 0.001, c 0.014
N use efficiency of anim. prod, %	30	23	25	26	21	22	20	21	s 0.001, c 0.011, s*c 0.030 [2]

[1] *p*-values ≤ 0.05 are given at 5 per cent significance level; *s* system (organic/conventional), *c* county

[2] N use efficiency statistical evaluation was performed by log transformation of the ratio farm N net outputs/farm N net inputs = log N net output − log N net input (Eq. 3). The table values were obtained by re-transformation from log values

On the other hand, the input of N through symbiotic N fixation was up to three times higher on organic farms, due to higher proportions of legume crops in the rotation. The higher amount of purchased feed on conventional farms corresponded to the average higher stocking density (Table 1). The different flows of N and P revealed considerably lower feed import on organic farms in relation to output of animal products, indicating a higher self-sufficiency with more home-grown feed in the organic dairy systems. The N and P outputs also showed distinct farming system differences, with the outputs of N and P in animal products on organic farms being on average 69 and 75%, respectively, of the outputs on conventional farms. At the same time, crop and manure N and P outputs were much higher on conventional farms. All together, the results showed considerably higher land area intensity, of both N and P inputs and outputs, on conventional dairy farms, and also higher surpluses of both these nutrients. The dataset showed large variations between farms within the compared systems (Table 5). Despite that, clear differences were found between farming systems in average numbers of balance components and surpluses.

The NUE of animal products differed significantly between farming systems, with on average higher efficiency on organic than on conventional dairy farms, despite higher N outputs per hectare on the latter (Table 3).

The N and P surpluses differed significantly between counties, with the lowest surpluses on farms in Skåne (Tables 3 and 4). There was also a tendency for lower N and P inputs on organic farms in Skåne than on organic farms in the other two counties, despite similar or higher outputs. These findings reflected the high NUE on Skåne organic dairy farms. Conventional dairy farms in Skåne had

Table 4 Phosphorus flows and farm P balances (kg P ha^{-1}) on organic and conventional dairy farms in three counties in Sweden (area weighted values)

County	Organic dairy farms				Conventional dairy farms				*p*-values [1]
	Skåne	Halland	V. Götaland	All farms	Skåne	Halland	V. Götaland	All farms	
	kg P ha^{-1}								
Farm P inputs									
Fertiliser	0.6	3.4	3.2	3.2	3.7	3.0	4.7	3.9	s 0.052, c 0.054
Seed	0.5	0.8	0.5	0.5	0.3	0.5	0.4	0.4	s 0.032
Straw	0.4	0.2	0.2	0.2	0.3	0.2	0.1	0.2	c 0.034
Feed[2]	6.2	5.2	6.2	5.5	12.8	15.3	11.0	12.4	s 0.001
Livestock	0.1	0.4	0.1	0.1	0.1	0.4	0.2	0.2	c 0.001
Sum	7.8	10.0	10.2	9.5	17.2	19.4	16.4	17.1	s 0.001
Farm P outputs									
Crops (incl straw)	0.4	0.4	1.3	0.9	4.9	1.9	2.1	3.6	s 0.001, s*c 0.001
Manure	0.5	0.0	0.1	0.2	2.1	1.6	0.8	1.6	s 0.005
Milk, livestock	5.9	5.6	5.4	5.6	7.9	9.6	7.4	7.9	s 0.001
Sum	6.8	6.0	6.8	6.7	14.9	13.1	10.3	13.1	s 0.001, c 0.009, s*c 0.004
Farm P balance	1.0	4.0	3.4	2.8	2.3	6.3	6.1	4.0	s 0.01, c 0.001

[1] *p*-values ≤ 0.05 are given at 5 per cent significance level; *s* farming system (organic/conventional), *c* county

[2] Mineral supplement is included in feed

the highest total farm N and P outputs, but not the highest output of animal products. Instead, almost half of all N and P outputs were on average sold as crops and manure. However, the variation of both crop and manure outputs was large on the conventional farms where most farms did not export, e.g. manure and a small part exported large amounts (Table 5).

Significant interactions between farming system and county were obtained for some N and P flows (Tables 3 and 4). For example, organic farms in Halland had the lowest feed N input, while conventional farms in Halland had the highest. Concerning total farm N and P outputs, organic farms in Halland had the lowest levels, but amongst conventional farms those in Västra Götaland had the lowest outputs. Total N and P inputs showed significant positive correlations with farm N and P surpluses (Figs. 2a, b and 3a, b). However, the correlation was weaker for P due to wider variation in P inputs at a certain P surplus, especially on conventional farms. The highest N and P surpluses were found on several conventional farms, so they could not be ignored as outliers. A statistically significant positive but weak linear correlation was found between N surplus (kg ha^{-1}) and animal units ha^{-1} on both organic farms (R^2 = 0.130289, p=0.0025) and conventional farms (R^2 = 0.299685, p<0.0001).

N and P balances and NUE on arable farms

Organic arable farms had on average a significantly lower N surplus and a higher P surplus (mean 35 kg N ha^{-1} and 5 kg P ha^{-1}) compared with conventional farms (mean 49 kg N ha^{-1} and −2 kg P ha^{-1}) (Tables 6 and 7). The negative average P balance for conventional farms was caused by a negative balance on Skåne farms. The main inflows of N and P were bought fertilisers and, on organic farms, also N input through symbiotic N fixation. The large difference between the farming systems in terms of symbiotically fixed N was caused by dramatic differences in crop distribution, with a significantly higher proportion of legume crops on organic than on conventional farms (Table 2). The fertiliser N input was around 70% lower on organic than on conventional farms, while there was a much smaller difference for P fertiliser inputs. On conventional farms, input of mineral

Table 5 Descriptive statistics of N and P balance components on organic and conventional dairy farms that shows the variation in the dataset. Columns Q1 and Q3 present the 1st and 3rd quartile

	Organic dairy farms, kg ha^{-1}						Conventional dairy farms, kg ha^{-1}					
	Min	Q1	Median	Q3	Max	Stdv	Min	Q1	Median	Q3	Max	Stdv
Farm N inputs												
Fertiliser	0	0	0	8	153	22	0	63	86	103	298	36
N_2 fixation	14	38	58	77	183	33	0	10	19	28	124	18
Atm dep	4	5	9	10	14	2	4	8	9	10	14	2
Seed	0	1	1	3	7	2	0	1	1	2	9	1
Straw	0	0	1	2	19	3	0	0	0	2	48	4
Feed	0	12	29	51	211	38	0	46	70	105	321	48
Livestock	0	0	0	0	7	1	0	0	0	0	23	2
Total inputs	37	83	116	149	251	49	24	156	193	228	483	67
Farm N outputs												
Crops	0	0	0	6	68	13	0	0	4	17	117	21
Straw	0	0	0	0	2	<1	0	0	0	0	16	1
Manure	0	0	0	0	48	9	0	0	0	5	335	22
Milk, meat	0	21	28	36	92	15	0	29	39	51	107	18
Total outputs	15	25	33	41	141	21	7	41	55	70	390	35
Farm N balance	−1	58	78	107	196	42	9	103	134	157	291	50
Farm P inputs												
Fertiliser	0	0	0	2	22	4	0	0	1	4	53	5
Seed	0	0	0	0	2	<1	0	0	0	0	2	<1
Straw	0	0	0	0	2	<1	0	0	0	0	7	1
Feed[1]	0	4	7	11	39	7	0	9	13	20	59	9
Livestock	0	0	0	0	2	<1	0	0	0	0	7	1
Total inputs	1	4	8	13	35	6	<1	11	16	20	62	9
Farm P outputs												
Crops (incl straw)	0	0	0	1	7	2	0	0	1	3	19	4
Manure	0	0	0	0	7	1	0	0	0	1	50	5
Milk, meat	2	4	6	8	19	3	1	6	8	11	22	4
Total outputs	3	5	7	8	26	4	2	8	11	15	64	7
Farm P balance	−8	−2	2	5	19	5	−31	<1	4	7	48	7

[1]Mineral supplement is included in feed

N and P fertilisers strongly dominated, while different kinds of organic fertilisers, e.g. animal manure, meat/meat-bone meal and biogas digestate, were imported to organic farms. The inputs through feed to both organic and conventional farms were small, reflecting the definition of arable farms used in this study (less than 0.2 animal units per hectare). The main N and P products consisted of almost entirely crops, and organic farms had significantly lower crop N output, approximately half that of conventional farms, 47 and 99 kg N ha^{-1} respectively. As for dairy farms, the dataset showed large variations between farms within the compared systems (Table 8).

The NUE was highest in Skåne, where organic and conventional arable farms performed equally well (NUE 67–68%) (Table 6). In Halland and Västra Götaland, the NUE was lower, and lower on the organic farms (NUE 44–45%) than on the conventional farms (NUE 56–59%).

The N and P surpluses on both organic and conventional farms were significantly lower in Skåne than in the other counties, which was related to

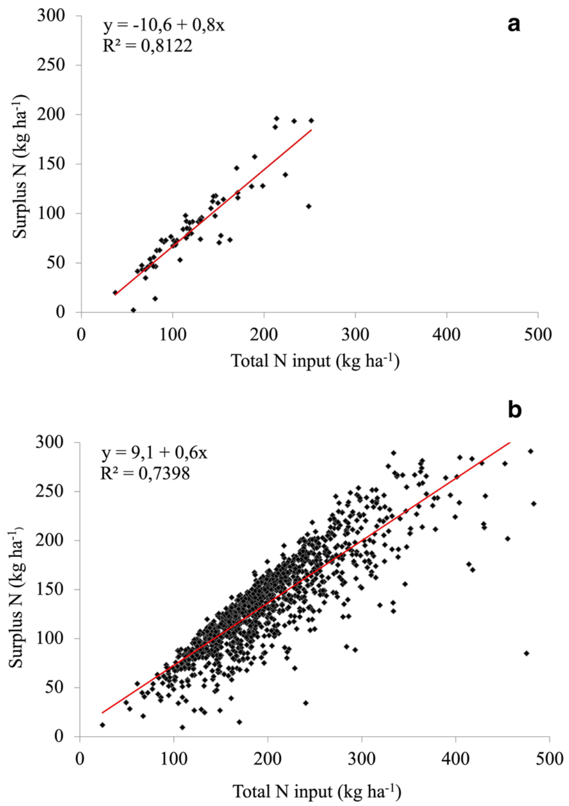

Fig. 2 The relationship between surplus N (kg ha^{-1}) and total N input (kg ha^{-1}) on **a** organic dairy farms and **b** conventional dairy farms

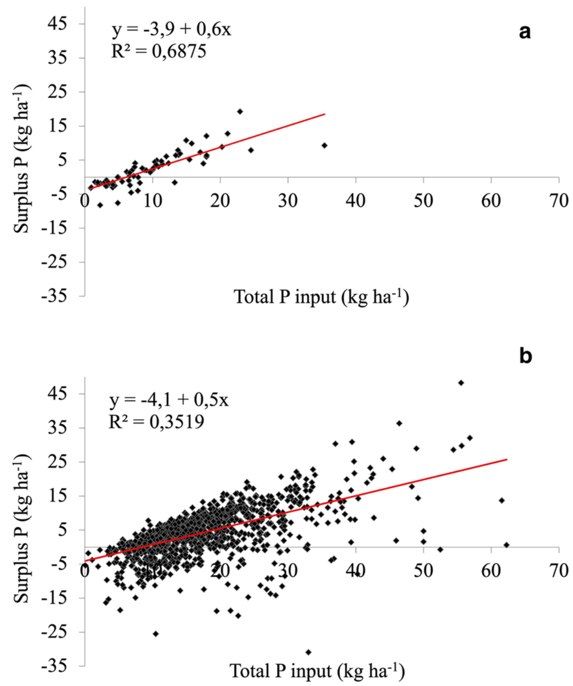

Fig. 3 The relationship between surplus P (kg ha^{-1}) and total P input (kg ha^{-1}) for **a** organic dairy farms and **b** conventional dairy farms

higher production than in the other counties, and also the lower N and P input in the case of organic farming. Organic farms in Halland had the highest fertiliser N inputs, mainly manure but also to some extent meat/meat-bone meal and biogas digestate, while inputs through symbiotic N fixation were lowest, leading to significant interactions between farming system and county concerning fertiliser N inputs.

The N and P surplus per hectare were positively correlated with the estimated per-area N and P inputs for both forms of farming system (Figs. 4a, b and 5a, b). At a given total N input, the N surplus seemed to vary more on conventional farms, which explained the weaker correlation compared with organic farms. A larger proportion of conventional farms had a negative P surplus (i.e. P deficit), compared with organic farms. Both organic and conventional farms were within the same range concerning amounts of total P input at a certain surplus P.

Discussion

Overall, N and P inputs were lower on organic farms than on conventional farms in this broad study of actual Swedish farms. The forms of inputs were also different, e.g. with more N from biological N fixation, no supply of mineral N fertilisers and some purchased organic fertilisers on organic arable farms, while conventional arable farms relied solely on purchased mineral N inputs. This confirms findings in previous studies (Reimer et al. 2020; Röös et al. 2018; Seufert and Ramankutty 2017). This clear system difference, together with the complexity of nutrient fluxes within farming systems, demands caution when comparing nutrient balances and using them as indicators of sustainable nutrient management (Chmelíková et al. 2021; Reimer et al. 2020; Öborn et al. 2003). When comparing

Table 6 Nitrogen flows, farm N balances (kg N ha^{-1}) and N use efficiencies of crop products (%) on organic and conventional arable farms in three counties in Sweden (area weighted values)

County	Organic arable farms				Conventional arable farms				*p*-values [1]
	Skåne	Halland	V. Götaland	All farms	Skåne	Halland	V. Götaland	All farms	
	kg N ha^{-1}								
Farm N inputs									
Fertiliser	35	58	34	37	136	123	111	132	s 0.001, c 0.034, s*c 0.022
N_2 fixation	28	26	40	30	8	10	8	8	s 0.001
Atm dep	10	10	6	8	9	11	6	9	c 0.001
Seed	2.7	3.1	2.6	2.7	2.3	2.5	2.3	2.3	
Straw	0.2	0	0.1	0.1	0.1	0	0	0.1	
Feed	0.8	1.3	0.8	0.9	1.5	4.4	2.5	2.8	
Livestock	0	0.2	0.4	0.2	0.1	0.3	0.1	0.1	c 0.051
Sum	79	99	89	85	153	146	127	149	s 0.001, s*c 0.005
Farm N outputs									
Crops	55	40	37	47	104	79	74	99	s 0.001, c 0.001
Straw	0	0.2	0.5	0.2	0.7	0.7	0.3	0.6	
Manure	0	0	0	0	0	0.1	0.3	0.1	
Livestock	1.2	2.6	1.9	1.6	0.7	2.8	2.0	1.0	
Sum	56	43	40	49	105	83	77	100	s 0.001, c 0.001
Farm N balance	23	56	49	35	48	64	50	49	s 0.052, c 0.001
N use efficiency of crop prod., %	67	44	45	51	68	56	59	61	s 0.001, c 0.001, s*c 0.011[2]

[1]*p*-values ≤ 0.05 are given at 5 per cent significance level; *s* system (organic/conventional), *c* county

[2]N use efficiency statistical evaluation was performed by log transformation of the ratio farm N net outputs/farm N net inputs = log N output − log N input (Eq. 4). The table values were obtained by re-transformation from log values

Table 7 Phosphorus flows and farm P balances (kg P ha^{-1}) on organic and conventional arable farms in three counties in Sweden (area weighted values)

County	Organic arable farms				Conventional arable farms				*p*-values [1]
	Skåne	Halland	V. Götaland	All farms	Skåne	Halland	V. Götaland	All farms	
	kg P ha^{-1}								
Farm P inputs									
Fertiliser	9.3	13.5	15.7	11.8	15.6	16.7	15.4	15.8	
Seed, straw, livestock	0.4	0.5	0.5	0.4	0.4	0.5	0.4	0.4	
Feed	0.4	1.4	0.2	0.4	0.4	1.2	0.4	0.4	
Sum	10.1	15.4	16.4	12.6	16.4	18.3	16.2	16.6	
Farm P outputs									
Crops	7.9	5.5	5.2	7.0	19.1	13.4	13.2	18.1	s 0.001, c 0.001
Straw, livestock, manure	0.3	0.6	0.6	0.4	0.3	0.7	0.3	0.3	
Sum	8.2	6.1	5.8	7.4	19.4	14.1	13.5	18.4	s 0.001, c 0.001
Farm P balance	1.9	9.3	10.6	5.2	−3.0	4.2	2.7	−1.8	s 0.010, c 0.001

[1]*p*-values ≤ 0.05 are given at 5 per cent significance level; *s* farming system (organic/conventional), *c* county

Table 8 Descriptive statistics of N and P balance components on organic and conventional arable farms that shows the variation in the dataset. Columns Q1 and Q3 present the 1st and 3rd quartile

	Organic arable farms, kg ha^{-1}						Conventional arable farms, kg ha^{-1}					
	Min	Q1	Median	Q3	Max	Stdv	Min	Q1	Median	Q3	Max	Stdv
Farm N inputs												
Fertiliser	0	10	30	60	164	43	0	110	129	145	351	32
N_2 fixation	0	12	30	50	94	27	0	0	0	6	115	9
Atm dep	5	7	9	10	14	2	4	8	9	10	14	2
Seed	0	1	3	4	6	2	0	2	2	3	13	1
Straw	0	0	0	0	8	1	0	0	0	0	14	1
Feed	0	0	0	0	47	7	0	0	0	0	92	8
Livestock	0	0	0	0	4	1	0	0	0	0	1	1
Total inputs	17	64	84	114	214	41	16	128	146	162	361	33
Farm N outputs												
Crops	6	34	49	61	126	23	5	81	100	115	219	26
Straw	0	0	0	0	3	1	0	0	0	0	22	2
Manure	0	0	0	0	0	0	0	0	0	0	36	2
Livestock	0	0	0	0	24	4	0	0	0	0	66	5
Total outputs	10	34	49	62	126	23	11	83	101	116	219	26
Farm N balance	−36	15	36	66	152	40	−40	31	43	58	275	28
Farm P inputs												
Fertiliser	0	0	10	21	39	11	0	12	16	21	238	11
Seed, straw, livestock	0	0	0	0	2	<1	0	0	0	0	10	<1
Feed	0	0	0	0	21	3	0	0	0	0	69	3
Total inputs	0	4	11	21	39	11	0	12	16	21	238	11
Farm P outputs												
Crops	2	5	7	9	21	3	1	15	18	21	86	5
Straw, livestock, manure	0	0	0	0	5	1	0	0	0	0	18	1
Total outputs	2	5	6	7	9	3	3	15	19	22	87	5
Farm P balance	−9	−2	2	12	29	10	−77	−7	−2	3	213	12

N balances and NUE with respect to farming system, it is especially important to consider the relationship between the amounts of animal and crop products generated on farms (Bleken et al. 2005). Specifically, arable farming results in higher NUE in farm-gate balance calculations compared with farms with animal production (Watson et al. 2002; Reimer et al. 2020), as animal production is at a higher level in the trophic chain.

The relationship between sold animal and crop products can also differ considerably within farm types, as in the present study. The Swedish organic dairy farms we studied tended to specialise solely in dairy production, while the conventional dairy farms also sold large amounts of crop products. We overcame the difference in product composition by taking import of feed and export of crops into account when calculating NUE, according to Dalgaard et al. (1998). As the methodology used for N balance and NUE calculations can differ between studies and as there is generally high variation in the farm types included, comparisons between studies are difficult. However, Watson et al. (2002) found similar NUE on organic dairy farms (30%) as in our study (26%) and, as found by Dalgaard et al. (1998), NUE was higher in organic than in conventional dairy production (25–28% and 18–20% respectively). Chmelíková et al. (2021) found very high NUE in soil-surface balances for crop production on organic and conventional dairy farms (95% and 80%, respectively). This reflects the fact that soil-surface balances are analyses of the crop production sub-system with crop production within a

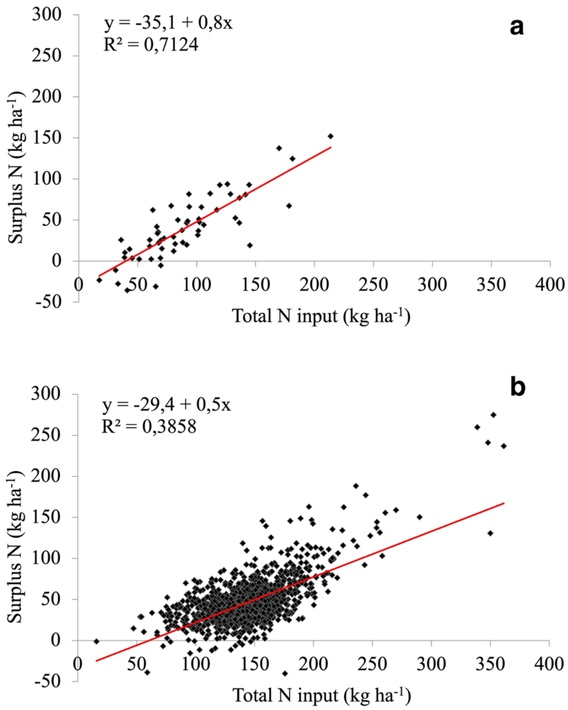

Fig. 4 The relationship of surplus N (kg ha^{-1}) against total N input (kg ha^{-1}) on **a** organic arable farms and **b** conventional arable farms (2 outliers excluded)

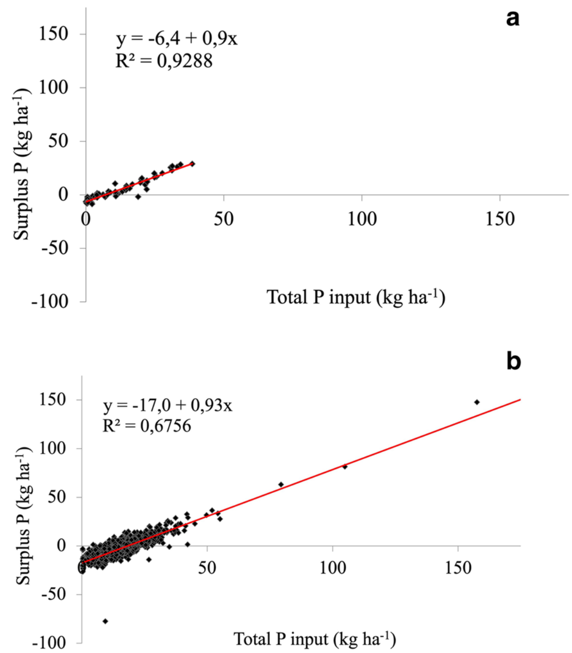

Fig. 5 The relationship of surplus P (kg ha^{-1}) against total P input (kg ha^{-1}) on **a** organic arable farms and **b** conventional arable farms (2 outliers excluded)

dairy farm, and thus do not include inputs and losses from the livestock sub-system.

Furthermore, N and P surpluses generated off-farm, i.e. inputs of feed and livestock, were not included in our analysis of dairy farms. Koesling et al. (2017) found that the contribution of off-farm N inputs to N surpluses was of the same magnitude for both organic and conventional dairy farms in a study of Norwegian farms and did not affect the comparison between the two farming systems. However, including N surpluses on off-farm areas increased N surpluses on both organic and conventional dairy farming systems. As conventional dairy farms in our study had a larger proportion of off-farm N inputs related to total N inputs than organic dairy farms, inclusion of the N cost of off-farm inputs would not change our conclusion, but strengthen the implication that conventional farms had significantly higher N surplus than organic farms. This statement is in line with Einarsson et al. (2018) who compared farm-gate N with chain N (including off-farm areas) surpluses on organic and conventional Swedish dairy farms. The implication of using chain N surplus calculations would be an increased difference between N surplus on organic and conventional dairy farms in this study.

The farm-gate N surplus was 70% larger on conventional than on organic dairy farms in our study, 134 and 79 kg N ha^{-1} respectively. In an analysis of organic and conventional dairy farms in Sweden with more recent data than used in this survey, the farm-gate N surpluses were very similar, 138 and 82 kg N ha^{-1}, indicating data robustness over time (Einarsson et al. 2018). The finding in this study of considerably higher N surplus on conventional dairy farms is also in accordance with findings in other countries (Barataud et al. 2015; Koesling et al. 2017; Chmelíková et al. 2021; Dalgaard et al. 1998).

A more efficient use of manure is, amongst other N management improvements, of main importance to increase NUE and reduce N surpluses on both organic and conventional dairy farms. Feeding strategies and an efficient use of N and P in the feed are also of importance for surpluses on dairy farms, but we do not have access to the data needed to explore this further in our analysis. Possible measures for improved manure management are new spreading techniques, immediate incorporation into the soil and reduced losses of ammonia from storage (Webb et al. 2013). The organic and conventional dairy farms in this study both mainly had liquid manure systems and there are no reports elsewhere of differences in manure management between the farming systems. However, manure was more frequently spread in spring than in autumn on organic compared with conventional dairy farms, which is favourable for reducing N losses (Webb and Archer 1994; Webb et al. 2013). One reason for this difference could be the larger proportion of winter cereals grown on conventional dairy farms.

It is also important to increase awareness of the value of N in manure and to analyse the N content before spreading, in order to apply optimal rates (Sindhöj and Rodhe 2013). The amount of N in manures can be underestimated due to uncertainties about the mineralisation rates of organic N, leading to application of N in excess, irrespective of whether the manure is combined with purchased fertilisers or not (Aarts et al. 2000). Non-uniform distribution of manure N within farms also poses a risk of high N surpluses and low NUE. This can be a particular problem on conventional farms, where above-optimal rates of manure may have been applied to fields close to the farm centre, while purchased mineral N fertilisers are applied to fields farther away. This could be one explanation for the lower NUE on conventional than on organic dairy farms in this study, as large amounts of mineral N fertilisers were purchased on conventional farms despite higher animal densities, and consequently, larger amounts of manure were produced per hectare, compared with organic farms. The same reasoning could be applied to P management, i.e. with potential for better utilisation of manures with more uniform distribution of these manures on the farm to replace purchased P fertilisers (Dalgaard et al. 2012).

The farm-gate P surplus on Swedish organic dairy farms was within the same order of magnitude as that in an earlier study by Watson et al. (2002), but higher than that in a recent meta-analysis by Reimer et al. (2020). One explanation for this difference in results could be management differences, such as the level of feed import. On the organic dairy farms in our study, P surpluses were mainly caused by imports of feed, even though feed import contributed a smaller part of both N and P inputs on organic compared with conventional farms.

Purchased feed contributed 46% and 25% of total N inputs on conventional and organic dairy farms respectively. The corresponding figures for P were 73% and 58%. The large feed import, especially on the conventional farms, could intensify the dairy production on the farms above the level supported by soil productivity, leading to a larger N and P losses through greater manure production (Bleken et al. 2005). However, the export of manure from conventional dairy farms in this study could have lessened the on-farm nutrient losses and consequently exported possible losses to other farms. In order to reduce the risk of creating a large on-farm pollution load, dairy production with a coupling to local crop feed production needs to be encouraged.

The farm-gate N surplus was 40% larger on conventional than on organic arable farms, 49 and 35 kg N ha^{-1} respectively, which was a much smaller difference than for the corresponding system difference on dairy farms, which was 134 and 79 kg N ha^{-1} respectively. Similar differences between farm-gate N surpluses on organic arable and dairy farms as those in our study were found by Watson et al. (2002), 26 and 82 kg N ha^{-1} respectively, and by Reimer et al. (2020), 20 and 80 kg N ha^{-1} respectively. Anglade et al. (2015) compared conventional and organic arable farms in France using soil surface N balances and found similar differences as in our study, N surpluses of 51 and 38 kg N ha^{-1} respectively. In updated Swedish data (2010–2016) on N flows and N farm-gate surpluses on conventional and organic Swedish farms within the project Focus on Nutrient (SBA 2020), the average results recorded for arable farms were in the same range to those in this study, 40 and 28 kg N ha^{-1} respectively.

NUE was on average considerably lower on the organic than on the conventional arable farms, 51% and 61% respectively. One explanation could be a larger soil N accumulation on the organic farms caused by a high proportion of clover-grass ley in the rotations and also use of organic fertilisers instead of mineral fertilisers (Gattinger et al. 2012). Also, the risk of N losses that can lower NUE may increase with a large proportion of legumes in the crop rotation, as in the case of organic arable farms in this survey, as it can be difficult to synchronise timing of these N sources with crop requirements (Olesen et al. 2009). Climate and soil conditions, and thereby yield potential, also affect N and P balances and NUE. Higher standard yields in the southernmost county, Skåne, than in all other counties in Sweden have been reported in Swedish statistics (SS 2020b). In this study, organic and conventional farms in Skåne (both dairy and arable) had the highest N and P outputs of products and, at the same time, the lowest N and P surpluses. The favourable climatic conditions with a longer growing period combined with good average soil fertility in Skåne may have enhanced the NUE. Higher NUE was found for organic and conventional arable farms and for organic dairy farms in Skåne compared with the other counties. In particular, organic arable farms in Skåne had a much lower N surplus, 23 kg N ha^{-1}, and much higher NUE, 67%, in comparison with the same type of farms in the other two counties. Favourable soil and climate conditions for N mineralisation from organic fertilisers and crop residues may be one explanation. Only a few results of NUE based on farm-gate N balances on organic arable farms are reported in the literature. An NUE of 77% was reported in a review of farm-gate balances by Watson et al. (2002), but it was based on calculations on two farms only.

Appropriate management practices, such as growing catch crops between main crops and appropriate timing of soil tillage, can reduce the risk of N losses and improve NUE (Plaza-Bonilla et al. 2015). Catch crops were grown on about 13% of the arable land on both organic and conventional arable farms in the present study, but this measure to reduce N leaching could be expanded further. Other measures could focus on intercropping of legumes and non-legumes, which has been shown to increase the use efficiency of N resources (Hauggaard-Nielsen et al. 2009). Crop protection issues (weed, disease and pest control) also have considerable effects on N management and should be taken into consideration to increase NUE and N output, especially in organic arable production (Panday et al. 2018).

In our survey, the input of fertiliser-P on organic arable farms, in form of, e.g. animal manure, meat/meat-bone meal and biogas digestate, during the study period was on average high in relation to P output from these farms. In Swedish official statistics for organic farms, the P application rate varies over time depending on both price and access to certified fertilisers for organic production. In the first decade of the twenty-first century, the P application rate on organic arable farms in Sweden was high (SS 2008), due to access to a cheap P-rich bone-meal approved for organic farming. However, more recent official statistics show much lower P fertiliser use on organic farms (SS 2020a) and, accordingly, a recent data compilation by the project Focus on Nutrients found that the P surplus on organic arable farms was half of the value in our study (SBA 2020). At that period of time, the meat-bone meal with high P concentration was not available on the market. Other studies have reported a negative P surplus, which could pose a threat to long-term soil fertility, especially on organic arable farms (Korsaeth 2012; Ohm et al. 2017). The differences in results between studies are mainly caused by differences in management factors within organic systems, such as fertilisation strategy. On Swedish organic arable farms today, mining of soil P is on average not the main challenge. Instead, more balanced P fertiliser management is needed in order to supply optimal amounts of N without causing too high P balance surpluses. On the organic arable farms in this study, different kinds of organic fertilisers were used, often rich in P. Besides the P-rich meat-bone meal, different kinds of manure were applied, which also often have high concentrations of P in relation to N. It is not possible to decouple N and P inputs when using organic fertilisers, which may lead to over-application of P (Maltais-Landry et al. 2016). This was well illustrated by our data on the organic arable farms, with positive P balances. Möller (2018) also reported imbalanced fertiliser management with slow-release N organic fertilisers, often too rich in P, in specialist organic vegetable and fruit production. This indicates a need to develop fertilisation strategies combining available organic amendments and N fixation or new N-rich fertilisers that are in accordance with organic standards.

The negative P balances found on conventional farms in Skåne indicated that the farms relied on soil P delivery capacity, instead of compensating for P in sold crops with purchased P fertilisers. Build-up of soil P in arable soils in Skåne has been observed in the Swedish soil monitoring program (Eriksson et al. 2010). A Finnish meta-analysis showed that soil P delivery capacity can be maintained for decades on clay soils without P fertilisation (Valkama et al. 2009). However, there are farms in southern Sweden with sandy soils that would need regular monitoring of soil P status to avoid crop P deficiency.

Organic farms in this study had a significantly higher proportion of grass-clover fodder leys or green manures and pulses in their crop rotation. The large proportion of grass-clover leys grown on organic dairy farms corresponds well to results by Gustafson et al. (2007) that the forage dry matter part of the feed ration has been shown to be significantly higher for organic than for conventional dairy cows. Together with higher ley clover proportions under organic management (SS 2017) and more home-grown pulse crops, these factors explain the on average three-fold higher amount of biological fixed N seen on organic compared with conventional dairy farms in this study. On the arable farms studied, the proportion of fixed N was nearly four times as high as on the corresponding conventional farms. However, model quantification of this N flow was rough and can have influenced the N surplus values significantly. Einarsson et al. (2018) concluded that uncertainties in N fixation estimates could lead to misleading conclusions, especially when symbiotic N fixation constitutes a high proportion of N inputs and differences in farm N surpluses between the systems compared are small. This is especially valid for the comparison between conventional and organic arable farms in this study, where the N surplus difference was only 14 kg N ha^{-1}. The uncertainty in N fixation estimates was partly overcome by using farm records of grass-clover ley and green manure yields and their legume content.

While N and P surpluses per hectare were on average lower on organic than on conventional farms, the N and P outputs per hectare in products were considerably lower on organic farms. This yield gap is well documented in the literature (Röös et al. 2018) and should be taken into account when evaluating the sustainability of farming systems.

The value of farm N surplus related to land area as an indicator for N losses and sustainable N management has been thoroughly investigated and discussed within the scientific community. Many authors regard farm-gate N balances as an important tool if the dataset is not too small and if the analyses cover several years (Blicher-Mathiesen et al. 2014; Dalgaard et al. 2012; Reimer et al. 2020; Watson et al. 2002; Öborn et al. 2005). However, to achieve long-term sustainable N management, farm-gate N balances need to be used in combination with other management tools that reduce N losses and increase NUE (De Notaris et al. 2018; Panday et al. 2018; Öborn et al. 2003). The large variation of N and P surpluses in our dataset within the respective farming systems reveals considerable potential for improvements. Follow-ups of farm-gate balances on individual farms, which is done in the Swedish advisory program Focus on Nutrients, pose opportunities for implementing measures that reduce losses to the environment and produce a more sustainable N and P management.

The uncertainties that arose due to quality of data in the present study were reduced by the number of farms included, corresponding to 2550 farms in total. However, organic farms represented a minor proportion, in total 124 farms, meaning that results for organic farms are less generalisable compared with those for the group of conventional farms. Furthermore, our data were from 2001 to 2006, although we found that the results were consistent over time for both dairy and arable organic and conventional farms when compared against more recent Swedish data (2010–2016) (SBA 2020). One exception was P balances on organic arable farms, as discussed above.

Klages et al. (2020) concluded that the main value of N balances in optimising nutrient management is dependent on having farm-specific actual data, which to a large extent was fulfilled in this survey. The N and P budgets for the different farms were established by advisors in the three Swedish counties together with farmers during farm visits, and were based on a detailed inventory by these trained advisors. Although table values on N and P contents were often used for some commodities, e.g. imported or exported manure, these values corresponded well with N and P contents in other Swedish studies in which products were sampled and analysed on both organic and conventional farms (Gustafson et al. 2007; Salomon et al. 2006; Steineck et al. 2000).

Conclusions

Calculation of N and P surpluses over time and for groups of farm types can be used to identify trends in farm nutrient management with environmental impacts. In this survey, conventional dairy farms in three southern Swedish counties had on average significantly higher N surplus (134 N ha^{-1}) than corresponding organic farms (79 kg N ha^{-1}). The largest inputs of N were mineral fertilisers and feed on conventional farms and biological N fixation and feed on organic farms. On conventional dairy farms in particular, a more uniform supply of manure on all farmland could increase manure N use, decrease N mineral fertiliser inputs and reduce N surpluses. Good on-farm management of manure to achieve higher NUE is most important on both organic and conventional farms. Organic dairy farms in the survey had lower N and P surpluses, by having a higher degree of feed self-sufficiency with clover/grass ley as major crop, but with the consequence that milk yield per cow was up to 10% lower than on the conventional dairy farms. We suggest policy work to encourage dairy production to establish a coupling to local feed production, on-farm or in cooperation with neighbours, which could increase the efficiency in use of manure on conventional farms but also on organic dairy farms, which on average import considerable amounts of feed.

The N surpluses were also higher on conventional than on organic arable farms (on average 49 and 35 kg N ha^{-1} respectively), but the magnitude of the difference and the number of organic arable farms were smaller, which increased the uncertainty in the results. On conventional arable farms, optimisation of mineral N fertiliser supply is crucial, while on organic arable farms management of organic fertilisers and use of fixed N in legume crop residues in the crop rotation need to be tailored to match crop needs and increase yields. Catch crops, which are proven to be effective in reducing leaching losses, were used equally often on the Swedish conventional and organic arable farms surveyed here. However, the winter-green portion of the farm area was on average higher on organic arable farms due to the clover-grass leys on these farms, which mostly were under-sown in a preceding crop. This implies that there is less room for increasing the area of catch crops on organic than on conventional arable farms. There is also scope for other management measures, such as intercropping and timing of soil tillage, to reduce N losses on arable farms.

The P surplus per hectare of farmland on conventional dairy farms was higher than on organic dairy farms (4.0 kg ha^{-1} and 2.8 kg ha^{-1} respectively). Furthermore, ten times more P per hectare was exported as manure from conventional dairy farms compared with organic dairy farms. This indicated a potentially excessive P load on conventional dairy farms, caused by P feed imports to intensify milk production per cow. The P surplus on conventional and organic arable farms, corresponding to −1.8 and 5.2 kg P ha^{-1}, indicated quite different fertilisation strategies. The large P surplus on organic arable farms in this study was caused by temporary availability of cost-effective P-rich meat-bone meal, and cannot be seen as sustainable in the long run. The P surpluses on Swedish organic arable farms have decreased in recent years, but there is still a risk of oversupply of P through organic fertilisers in relation to crop needs. If soils have a high P content due to historically high P supply, as in the Skåne county in Sweden, running a negative P balance could be an optimal strategy. In summary, to interpret P balances and suggest appropriate measures for improved P management, a broad historical and site-specific perspective need to be applied.

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Authors contribution Maria Wivstad and Eva Salomon set up and made the data analysis and prepared all figures and tables. Maria Wivstad was a major contributor in writing the manuscript. All authors contributed to writing, reading and approving the manuscript.

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Data availability The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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