

# Nitrogen and phosphorus fluxes of grassland-based dairy production systems on mixed farms in Switzerland

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## Abstract

Farm gate balances for nitrogen (N) and phosphorus (P) were calculated for mixed crop-livestock farms in Switzerland for three types of dairy production systems: Partial grazing with indoor feeding of fresh grass with reduced (IF) and increased (IFplus) concentrate supplementation was compared with full-time grazing (FG). The aim was to identify the effects of the different systems on the N/P surplus per hectare and the N/P use efficiency (N/PUE). The mean values of the N surplus were 90.1 kg N ha<sup>-1</sup> (FG), 91.8 kg N ha<sup>-1</sup> (IF) and 133.6 kg N ha<sup>-1</sup> (IFplus). The NUE was highest in IF (53.2%) and comparable for IFplus and FG (46.1 and 44.6%). Phosphorus surpluses were 2.5, 9.6 and 10.8 kg P ha<sup>-1</sup> for FG, IF and IFplus, respectively. Some farms showed negative P balances. The PUE was 100.6, 76.5 and 70.0% for FG, IF and IFplus, respectively. Significant relationships were found between the N/P surplus and inputs of fertiliser, manure, concentrate and legume N fixation. NUE on IF and IFplus farms was significantly correlated with the percentage of arable land of the total farm land. An appropriate need-based feeding strategy and a low-loss use of fertiliser and manure might improve the N/P balances.

**Keywords:** nutrient use efficiency, nutrient surplus, system comparison, dairy farming

## Introduction

Surpluses of nitrogen (N) and phosphorus (P) in farming systems are indicators of negative environmental impacts and inefficient use of agricultural resources. Farm gate balances provide an effective tool for the quantification of nutrient surpluses (Oenema *et al.*, 2003) and the identification of the improvement potential, especially if applied regularly. Within the scope of a system comparison of grassland-based dairy production systems, farm gate balances were calculated for 31 pilot farms. The main objective of this study was to analyse differences between the systems and to identify the most important factors influencing nutrient surplus and nutrient use efficiency.

## Materials and methods

Farm gate balances were calculated for mixed crop-livestock farms practising one of the following three milk production systems: Partial grazing with indoor feeding of fresh grass with reduced (IF) and increased (IFplus) concentrate supplementation, and full-time grazing with reduced concentrate supplementation (FG) (Table 1). For the year 2014, all nutrient inputs and outputs of the farms were recorded. The inputs mainly consisted of mineral fertilisers, animal feeds, livestock and manure. Nutrient fluxes directly related to livestock production other than dairy cattle (pigs, poultry, horses, small ruminants, fattening cattle) were excluded. Manure applied to grassland from the other livestock sectors was accounted as input for after deducting 50% of the N losses from the total N content of the manure. Nitrogen input by biological N fixation of legumes was estimated based on the dry matter yields and legume contents of grassland according to Boller *et al.* (2003). Input from atmospheric nitrogen deposition was accounted for as 25 kg N ha<sup>-1</sup> for farms in the valley zone and 20 kg N ha<sup>-1</sup> for farms in the hill zone (BAFU, 2014). The nutrient outputs included milk, livestock, manure and products from arable farming (exported crops and other feedstuff). A clear demarcation of crop production was not possible. The nutrient surplus was

Table 1. Characteristics of the 31 analysed pilot dairy farms according to the three production systems, averages and range (in italics) for the year 2014.

Production system	Farmed area (ha)	Herd size (number of dairy cows)	Proportion of arable land (%)	Concentrate consumption (kg cow <sup>-1</sup> year <sup>-1</sup> )	Annual milk yield (kg ECM cow <sup>-1</sup> )
IF	26.6	35.7	28.1	425	7,125
n = 11	<i>11.0-60.2</i>	<i>16.2-70.3</i>	<i>0-70.4</i>	<i>111-718</i>	<i>6,367-8,349</i>
IFplus	29.7	44.3	29.6	991	8,225
n = 9	<i>14.3-59.6</i>	<i>28.5-76.0</i>	<i>5.8-52.2</i>	<i>623-1,534</i>	<i>6,893-9,619</i>
FG	31	36.8	13.9	115	6,444
n = 11	<i>19.3-42.5</i>	<i>21.0-60.5</i>	<i>0-43.4</i>	<i>0-347</i>	<i>5,024-8,535</i>

determined as the difference between inputs and outputs (Input-Output). From the ratio between the outputs and inputs, the nutrient efficiency could be calculated (Output/Input). Correlation coefficients were determined with R (R Core Team, 2013). After performing a Shapiro-Wilk test for normality, normally distributed parameters were computed using the Pearson method and non-normally distributed parameters using the Spearman method. Statistical significance was determined at  $P < 0.05$ .

## Results and discussion

Due to the different farm structures, the variability between the farms was high (Table 2). The average N surplus was highest on IFplus farms at 133.6 kg N ha<sup>-1</sup>. IF and FG farms were comparable to one another (91.8 and 90.1 kg N ha<sup>-1</sup>). The NUE was highest for IF farms (53.2%) and on a comparable level for IFplus and FG farms (46.1%, 44.6%). The P surplus was highest for IFplus farms (10.8 kg P ha<sup>-1</sup>,  $\pm 7.8$ ). IF farms showed a surplus of 9.6 ( $\pm 16.3$ ) and FG farms showed a surplus of 2.5 kg P ha<sup>-1</sup> ( $\pm 5.4$ ). The average PUE was 100.6% ( $\pm 48.3$ ), 76.5% ( $\pm 28.0$ ) and 70.0% ( $\pm 18.6$ ) for FG, IF and IFplus farms, respectively. Some farms showed a negative P balance due to low P inputs from feed and manure. The development of soil P reserves on these farms should be evaluated on a long-term basis. Significant relationships between the farm gate balance parameters could be found (Table 3). On IFplus farms, the

Table 2. N fluxes of the three dairy production systems in kg N ha<sup>-1</sup> farmland and percentages of total inputs and outputs.

	IF		IFplus		FG	
	$\bar{x} \pm SD$ kg N ha <sup>-1</sup>	%	$\bar{x} \pm SD$ kg N ha <sup>-1</sup>	%	$\bar{x} \pm SD$ kg N ha <sup>-1</sup>	%
<b>N inputs</b>						
Dairy livestock	6.1 $\pm$ 4.4	3.3	9.7 $\pm$ 6.6	3.9	6.3 $\pm$ 3.1	4.0
Mineral fertiliser	22.9 $\pm$ 21.8	12.3	43.9 $\pm$ 21.0	17.7	39.1 $\pm$ 31.4	24.7
Manure	44.4 $\pm$ 35.5	23.8	38.5 $\pm$ 19.7	15.5	26.8 $\pm$ 18.2	16.9
Roughage/succulent feed	22.8 $\pm$ 21.2	12.2	28.1 $\pm$ 15.8	11.3	11.1 $\pm$ 7.5	7.0
Concentrates	24.3 $\pm$ 15.6	13.0	56.5 $\pm$ 12.5	22.8	4.9 $\pm$ 5.8	3.1
Biological N fixation	39.4 $\pm$ 13.8	21.1	47.0 $\pm$ 9.0	19.0	46.7 $\pm$ 7.1	29.5
Atmospheric N deposition	24.1 $\pm$ 2.0	12.9	24.4 $\pm$ 1.7	9.9	23.2 $\pm$ 2.5	14.7
<b>N outputs</b>						
Milk	45.0 $\pm$ 13.7	47.4	63.1 $\pm$ 13.3	55.1	33.0 $\pm$ 5.8	48.5
Dairy livestock	9.5 $\pm$ 5.3	10.0	14.4 $\pm$ 6.3	12.6	11.2 $\pm$ 3.3	16.4
Plant products	35.4 $\pm$ 31.0	37.2	28.9 $\pm$ 17.7	25.3	23.9 $\pm$ 24.5	35.1
Manure	5.1 $\pm$ 13.5	5.3	8.1 $\pm$ 14.7	7.1	0.0 $\pm$ 0.0	0
N surplus kg N ha <sup>-1</sup>	91.8 $\pm$ 47.6		133.6 $\pm$ 25.3		90.1 $\pm$ 38.8	
N use efficiency (%)	53.2 $\pm$ 14.1		46.1 $\pm$ 6.8		44.6 $\pm$ 12.4	

Table 3. Correlation co-efficients between the parameters of the farm gate balances ( $P < 0.05$ ).

	IF	IFplus	FG
N surplus vs input concentrates	$r = 0.58^{n.s.}$	$r = 0.88^{P=0.002}$	$r = 0.09^{n.s.}$
N surplus vs input mineral fertiliser	$r = 0.08^{n.s.}$	$r = -0.15^{n.s.}$	$r = 0.8^{P=0.002}$
NUE vs output milk	$r = -0.49^{n.s.}$	$r = 0.14^{n.s.}$	$r = -0.15^{n.s.}$
NUE vs percentage arable land	$r = 0.70^{P=0.016}$	$r = 0.86^{P=0.003}$	$r = 0.34^{n.s.}$
N surplus vs N fixation	$r = 0.38^{n.s.}$	$r = 0.55^{n.s.}$	$r = 0.71^{P=0.014}$
N surplus vs input manure	$r = 0.69^{P=0.019}$	$r = 0.56^{n.s.}$	$r = 0.46^{n.s.}$
P surplus vs input concentrates	$r = 0.74^{P=0.013}$	$r = 0.79^{P=0.012}$	$r = 0.67^{P=0.025}$
P surplus vs input manure	$r = 0.65^{P=0.037}$	$r = 0.97^{P<0.001}$	$r = 0.71^{P=0.015}$
PUE vs output milk	$r = -0.62^{P=0.042}$	$r = 0.18^{n.s.}$	$r = 0.12^{n.s.}$

N surplus and the input of concentrates were significantly correlated ( $r = 0.88$ ,  $P = 0.002$ ). The impact of arable farming (proportion of arable land to total farm land) on the N exports can be demonstrated with its correlation to the NUE, especially on IF and IFplus farms. On IF farms, a significant correlation was observed between N surplus and manure input. These inputs of manure mainly refer to the calculated data of demarcated other livestock. In comparison to IFplus and FG farms, IF farms imported the lowest amounts of mineral fertiliser. FG farms had lower inputs via purchased feed but higher inputs via mineral fertilisers and biological N fixation by legumes compared to IF farms. Combined with the lowest outputs of milk and products from arable farming, the FG farms showed the lowest NUE. With regard to P fluxes, all the systems demonstrated significant relationships between P surplus and the input of concentrates and manure. A significant negative correlation between the output of milk and PUE only existed for IF farms.

## Conclusion

The results of the calculated farm gate balances showed considerable variability between farms. This demonstrates the need for individual farm analysis to develop adequate improvement strategies for each farm type as well as farm-specific recommendations. Concerning the different dairy production systems, IFplus farms showed the highest N and P surpluses. The highest NUE was found on IF farms while the highest PUE was on FG farms. To reduce surpluses and to improve the nutrient use efficiency, concentrate and fertiliser use should be optimised through an appropriate need-based feeding strategy and nutrient loss should be minimised in the use of fertiliser and manure. In most cases, better nutrient use efficiency will have benefits both for farm finances (reduced cost) and the environment (less emissions).

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