Assessment of the nitrogen use efficiency of Swiss farms based on a representative farm management survey

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Abstract
In Switzerland, representative stratified surveys on livestock and manure are regularly conducted as a basis for the official ammonia emission inventory. The data of the 2007 survey was also used to assess the nitrogen (N) use efficiency (NUE) of Swiss farms, expressed as N output in per cent of N input. Overall, Swiss farms export approximately 80% as much N in products as they import in form of concentrate feed and fertilizer (level 1 NUE). Looking at the full NUE also including atmospheric inputs in form of deposition and N fixation, the median NUE is about 40%. The difference between valley, hill and mountain zone is quite negligible, but the N turnover decreases with altitude. Clear differences exist between different farm types, with livestock farms achieving a median NUE 2 efficiency around 35% while arable farms are at about 65%. In general, the share of arable crops of the total farming surface showed a very clear positive correlation to the NUE.

Introduction
To estimate the nitrogen (N) use efficiency (NUE) of farms, detailed information on farm structure and management is needed. Such information is rarely available for larger representative groups of farms. Only a few publications exist which have calculated NUE for different farms (e.g. Jarvis and Menzi, 2005; Cuttle, 2002).

In Switzerland a stratified farm survey on farm management is regularly performed as a basis for the national ammonia (NH_3) emission inventory calculations (Kupper et al., 2013). The 2007 survey was used to study the NUE for different regions and farms types.

Material and Methods
Farm management survey
The random sample of the 2007 survey consisted of 6565 farms meeting defined minimum size criteria. All in all, 3133 questionnaires (48%) could be included in the data analysis (Kupper et al., 2013). For the NUE assessment farms with larger herds of fattening cattle, small ruminants, horses or with more than 10% of the agricultural area used for orchards, vegetable, vineyards had to be excluded because the N import to the farm could not be reliably estimated with the available information. Furthermore, farms with no N import in fertilizer were also excluded because the 30% of the questionnaires provided no information on mineral fertilizer use which indicates that many farms did not have this information readily available or hesitated to provide it because it might not be in full agreement with their nutrient balance. It is clear that with exclusion criteria organic farms were mostly omitted from our study. The sample retained for the NUE assessment finally contained 1430 farms. The data allowed a stratification of three geographical regions (East, Central, Western/Southern Switzerland), three altitude classes (valley, hill, mountain zone) and four main farm types (arable, dairy cattle, specialized, pig/poultry, mixed farms).

The twelve page questionnaire on livestock and manure management (Kupper et al., 2013) contained questions on livestock and manure management and fertilization. The contents of the questionnaire followed a guiding principle: "everything relevant for NH3 emissions and known on the farm without special queries". The survey data were anonymised and combined with structural data such as livestock numbers and crop areas by the Federal Office of Statistics. The data reported by the farms was extensively checked for plausibility. Eventually, data was available on livestock numbers (>30 categories), crop surfaces (>30 arable crops), milk yield, concentrate use for dairy cows, protein content of pig feed, N fertilizer use etc.

N balance calculations
NUE, the balance between N inputs and N outputs in form of exported farm products, was individually calculated for each of the farms used for the assessment. Two levels were considered, without inputs from fixation and deposition (level 1; "farmers view balance")) and with these N inputs (level 2; full N balance). For further data interpretation, the dependency of NUE on farm size, livestock density, share of arable land etc. was studied for the whole data set as well as for different sub-classes.

Assumptions on N inputs and outputs
For additional data on harvested crop yields and protein content, amount and N content of livestock products etc., the assumption used by the authors of the Swiss fertilizer recommendations (Agroscope, 2009) were used. For N in atmospheric deposition 25, 20 and 15 kg/ha were assumed for valley, hill and mountain zone, respectively (estimate derived from Rihm and Kunz (2001)). For N fixation by legumes of different types of meadows standard yields according to Agroscope (2009) and 4 and 8.75 kg N per ton dry matter yield for natural and artificial meadows (derived from Boller (2003), respectively, were assumed. For ammonia emissions, the farm specific emission factors from the modelling done for the emission inventory (Kupper et al., 2013) were available. The export of manure from farms with high density (surpassing the nutrient balance criteria) was not considered calculations, because such information was not available.

Selected results
Per hectare agricultural surface, N inputs in form of feed (concentrate), mineral fertilizer, biological fixation and deposition as well as N in livestock and crop products leaving the farm decrease from valley, to hill, to mountain zone. This reflects the decreasing production intensity with rising altitude that is due to the shorter vegetation period, lower temperatures and higher precipitation, less intensive grassland etc.

On average Swiss farms export as much as 88% N in products as they import in form of concentrate feed and fertilizer (level 1 NUE; Tab. 1). In nearly all classes the median value is about 10% lower, which indicates that a few farms with very high values have a considerable influence on the result. It might therefore be advisable to consider median rather than average values. The maximum values reflect that some rather unrealistically high values exist. They are generated by farms with very low inputs. The difference of the level 1 NUE between valley, hill and mountain zone is negligible (Tab. 1). However, clear differences exist between different farm types (Tab. 2). While the median value is around 90% for arable, cattle and mixed farms it is at 57% for pig/poultry farms.

Looking at the full NUE including atmospheric inputs (level 2), the median NUE is 39% (outputs in % inputs). Contrary to the level 1 NUE there is a gradient between altitude zones with highest values (42%) in the valley zone. Apparently this is not due to shorter vegetation period or harsher climate in higher areas, as for cattle farms there is practically no difference in the NUE between zones. It must therefore be due mainly to the higher proportion of arable land. The importance of the proportion of arable land for the NUE is reflected by the results for different farm types. While cattle and pig/poultry farms reach about the same level (median 34% and 37%), arable farms achieve 65%.

Factors influencing the NUE
There was practically no difference in NUE (level 2) between the three geographical regions. The farm size also had practically no influence on the NUE. However, there was a clear dependency between the proportion of agricultural land with arable crops and NUE (Fig. 1). This is not surprising, as it is known that the efficiency of crop systems is better than that of livestock systems where crops that are fed to livestock have to be produced first, which results in a relatively low NUE.

Over all, Swiss farms export approximately 80% N in products as they import in form of concentrate feed and fertilizer (median value level 1 NUE). Looking at the full NUE (including atmospheric inputs), the median NUE is about 40% (outputs in % inputs). The difference between valley, hill and

mountain zone is quite negligible, but the N turnover decreases with altitude. Clear differences exist between different farm types, with livestock farms achieving a median NUE 2 efficiency around 35% while arable farms are at about 65%. In general, the share of arable crops of the total farming surface showed a very clear positive correlation to the NUE. There was practically no difference in NUE (level 2) between the three geographical regions.

Table 1. N use efficiency (NUE) in different zones at level 1 (without atmospheric inputs trough deposition and fixation) and level 2 (with atmospheric inputs)

zone		NUE: N export in % of N input	
		level 1	level 2
all zones	average	88%	41%
	median	78%	39%
	minimum	11%	4%
	maximum	1017%	172%
valley	average	90%	44%
	median	79%	42%
	minimum	12%	9%
	maximum	1017%	172%
hill	average	84%	38%
	median	76%	37%
	minimum	11%	4%
	maximum	425%	99%
mountain	average	88%	33%
	median	74%	34%
	minimum	23%	7%
	maximum	376%	68%

Table 6. N use efficiency (NUE) for different farm types at level 1 (without atmospheric inputs trough deposition and fixation) and level 2 (with atmospheric inputs)

farm type		NUE: N export in % of input	
		level 1	level 2
arable	average	114%	69%
	median	92%	65%
	minimum	33%	28%
	maximum	1008%	172%
cattle	average	99%	34%
	median	90%	34%
	minimum	15%	4%
	maximum	425%	72%
pork/poultry	average	56%	37%
	median	57%	37%
	minimum	11%	9%
	maximum	153%	77%
mixed	average	102%	46%
	median	91%	46%
	minimum	27%	13%
	maximum	1017%	112%

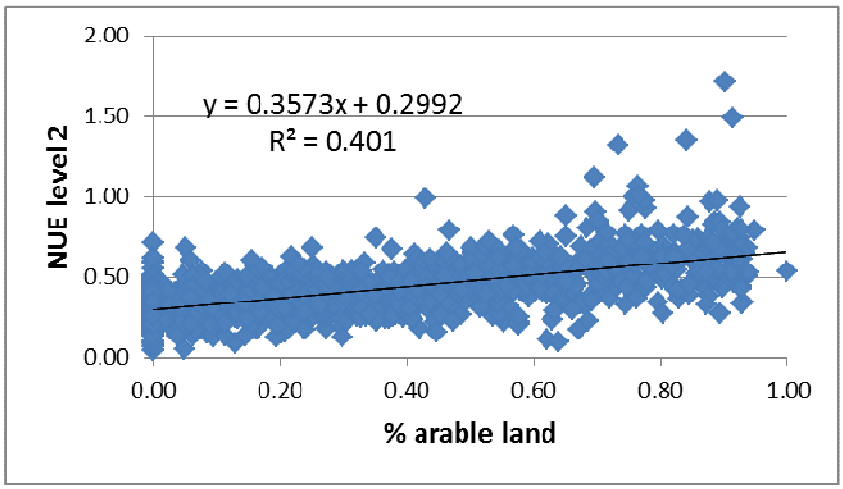

Figure 4: Dependency and correlation between N use efficiency (NUE; level 2, with atmospheric inputs) and percentage of agricultural land with arable crops for all zones and farm types.

Conclusion and perspectives

The range of values for NUE is very large. This indicates that NUE is part of a very complex system with a wide range of influencing factors and interactions. This makes it difficult to make a clear interpretation of the NUE and to judge what is good or bad or how much NUE could be improved. On the other hand it also means that for most farms there certainly is a potential for improvement.

The most severe weakness of our approach was, that yields (crops and livestock products except milk) could not be gathered from the survey. Thus, conclusions about the effect of good or bad farming practice (e.g. level of NH_3 emissions) on NUE are hardly possible with this approach. Nevertheless, the study provides valuable insights about the influence of structural factors on NUE.

For the farmer, level 1 is more informative because it corresponds with the flows he knows and controls. From the environmental point of view, level 2 is probably more significant because it shows the actual N surplus in the system which is prone to be emitted to the environment through leaching or volatilization.

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