Effectivity of measures on dairy farms to improve nitrogen balance and nitrogen use efficiency

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Abstract
The aim of this study is to evaluate the effects of measures taken on dairy farms to reduce nitrogen (N) losses in the framework of a national initiative improving agricultural N use efficiency (NUE). Farm gate N balances were assessed to determine the N surplus and the NUE of 11 dairy farms (6 specialized with >65% grassland of total agricultural land and 5 mixed with >40% arable land of total agricultural land). The farmgate N balances were assessed in 2019 and 2020 and compared to the baseline (2015 to 2017) in order to evaluate the effects of the measures taken on the farms. Individual measures were taken on each farm to reduce the N surplus and to increase the NUE. On all farms N input via concentrates was reduced and manure composition was analysed to improve fertilisation. Additional measures consisted of the optimisation of animal management, manure application and crop rotation. The mean N surplus was reduced from 146 to 106 kg N/ha and NUE increased from 44 to 53% on average in the years where measures were taken. These results show an improvement regarding N surplus when measures were taken and indicate a general potential for improvement in N use on dairy farms.

Keywords: Nitrogen, dairy, farmgate balance, grassland, measures

Introduction

The farm gate N balance is considered a useful tool to identify the sustainability of nutrient use and the potential for N losses into the environment (Oenema et al. 2003). Nitrogen inputs from concentrates and mineral fertiliser have been identified as important N inputs (apart from biological N_2 fixation and atmospheric N deposition) (Akert et al. 2020). Different technical measures have been proposed to farmers to reduce N surplus and to improve N use efficiency (NUE) at the field and farm level of arable and livestock farms (Hutchings et al. 2020).
The aim of this study is to analyse the effectivity of measures introduced to reduce N losses and improve the NUE on Swiss dairy farms.

Materials and methods

Farmgate N balances were calculated for 11 dairy farms based on the data obtained from the national nutrient budgeting tool "Suisse-Bilanz" and from the farm records. Six dairy farms were specialised grassland farms (SF) with >65 % grassland of total agricultural land and five farms were mixed arable farms (MF) with >40 % arable land of total agricultural land (Table 1). Nitrogen inputs such as animals, fertilizers, manure, feed, seed and plant material, biological N_2 fixation and atmospheric N deposition were accounted for. Biological N_2 fixation by legumes was calculated assuming legume shares of 0.1, 0.15 and 0.2 of the annual dry matter yield for extensively managed meadows, pastures and intensively managed leys respectively with an average N Input of 30 g N kg^{-1} of dry matter legume yield according to Boller et al. (2003). Atmospheric N deposition was calculated based on the amount of deposited N published by the Federal Office for the Environment for the corresponding region of each farm. Animals, milk, eggs, manure, plant products and forage were considered as farm N outputs. Nitrogen surplus per hectare of farmland for each farm was calculated annually as N inputs minus N outputs. Nitrogen use efficiency was referred to as the relation of N outputs to N inputs per hectare of farmland. For each farm, individual measures were defined to reduce N surplus and increase NUE in 2019 and 2020 compared to the baseline of 2015 to 2017. Measures taken on all farms consisted of reducing or abandoning the N supply from off-farm feed and analysing chemical manure composition before application on the fields. Further planning of mineral fertilizer manure management on the farmland, optimising crop rotation, using nitrification or urease inhibitors for manure, optimising livestock husbandry or management and low emission manure application techniques were measures taken on individual farms. Statistical analysis was performed on the mean for the baseline and period with measures implemented. The baseline was compared to the period with measures on each farm applying a mixed model with period as fixed factor and the farm as random factor accounting for repeated measurements. The farm type (SF or MF) was excluded from the model as the factor was not statistically significant. When model assumptions for analysis of variance were not met (no normal distribution of residuals), the analysis of variance was performed on the square root transformed parameter. Comparisons between means for the two periods were performed with Tukey's method at a significance level of $P < 0.05$.

Table 1: Farm characteristics of all farms and grouped according to farm type for the specialized grassland farms (SF) and the mixed arable farms (MF) presented as mean of the baseline (2015 to 2017) and the years 2019 and 2020 with individual measures taken.

			Farmland area (ha)	**Arable crops (ha)**	**Total Livestock units (LU)**	**cattle (LU)**	**stocking rate (no of LU ha^{-1})**	**concentrate (kg cow^{-1}a^{-1})**	**milk yield [a] (kg cow^{-1}a^{-1})**
baseline	all farms	n=11	42.9	11.3	66.2	58.6	1.60	1244	7937
	SF	n=6	44.4	5.1	71.2	61.9	1.64	1153	7623
	MF	n=5	41.0	19.2	59.8	54.5	1.55	1359	8497
2019/20	all farms	n=11	43.8	11.7	69.1	60.0	1.65	1099	8022
	SF	n=6	46.3	5.0	73.9	61.2	1.64	920	7892
	MF	n=5	40.9	19.7	63.4	58.5	1.66	1314	8238

[a] all farms n=8; SF n=5; MF n= 3

Results and discussion

The farm N surplus was reduced in 2019/20 compared to the baseline by 28% (Table 2). According to the ideal pathways of Quemada et al. (2020) to improve the N use, the farms in this study have improved by extensification and sustainable intensification. Total N inputs were reduced in the period with measures taken to reduce N surplus on the farms. Significant reduction of mineral fertiliser input and roughage input were made compared to the baseline. Interestingly N outputs did not show a significant reduction compared with the level of the baseline, even though N inputs were reduced. The large range of N inputs indicate a potential for optimisation on individual farms. When measures were applied on the farms, NUE was increased on average of all farms from 43.5 to 53.3% and the minimum NUE increased from 31.0% to 37.7%. Even though NUE on arable farms have been found to exceed NUE on dairy farms (Quemada et al. 2020), no difference was found on the farms investigated probably due to the similar N output via milk (56.1 and 65.1 kg N ha^{-1} a^{-1} for SF and MF in 2019/20 respectively, data not shown) and the relatively small difference of arable production on MF (50% vs. 14% open arable land of total farmland of MF and SF respectively).

Table 2: Annual nitrogen (N) inputs and outputs (arithmetic mean, minimum and maximum in kg N ha^{-1} a^{-1}, share of total in %), N surplus and N use efficiency of 11 dairy farms calculated for the

baseline years and for 2019/20 where measures on farms were taken to reduce N surplus and increase N use efficiency.

	Baseline (n=11) 2015/16/17			2019/20 (n=11)			2019/20 vs. Baseline	p-value
	mean	min	max	mean	min	max		
Total farm N inputs	258	133.9	450.0	229	96.6	361.5	-29.0	*
Mineral fertiliser	47.1	5.4	113.7	30.8	5.4	104.8	-16.3	**
Animal manure	17.2	0	54.9	19.6	0	62.2	2.4	NS
Livestock	15.7	2	47.2	15.8	1.8	55.6	0.1	NS
Plant material	0.5	0	1.3	0.5	0	1.3	0.0	NS
Feed pigs/chicken	15.3	0	110.8	12.7	0	101.5	-2.6	NS
Feed rearing	1.5	0	5.0	1.4	0	4.5	-0.1	NS
Roughage	24.5	4.2	65.8	21.2	0	67.3	-3.3	*
Concentrates dairy cows	78.7	5.3	236.6	67.1	0	158.8	-11.6	NS
Biological N fixation	32.7	21.6	58.2	34.8	19.2	63.4	2.1	NS
Atmospheric deposition	25.0	19.2	29.9	25.2	19.3	29.8	0.2	NS
Total farm N outputs	111.7	45.8	172.9	123.5	48	210.7	11.8	NS
Milk protein	55.5	24.7	115.1	59.3	28.4	137.4	3.8	NS
Livestock	27.7	8.6	91.6	27.4	7.7	88.3	-0.3	NS
Egg protein	0	0	0.2	0	0	0.4	0.0	NS
Plant product	16.4	0	56.6	16.5	0	74.9	0.1	NS
Roughage	5.7	0	26.3	6.9	0	35.1	1.2	NS
Animal manure	6.8	0	23.6	13.3	0	40.7	6.5	NS
Farm N balance	146.3	84.5	302.5	105.5	43.7	208.3	-40.8	*
Farm N use efficiency	43.5	31.0	63.4	53.3	37.7	72.5	9.8	***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; [a] parameter was square root or log10 transformed for statistical analysis

Conclusion

With the application of specific measures, the N surplus could be reduced and the NUE increased compared to the baseline on the individual farms. Reducing N input via mineral fertiliser seems to be an effective way for reducing N surplus and increasing NUE on dairy farms. Short-term effects such as reduced N output due to substantially reduced crop yields could not be observed. To account for the interannual variance three years of baseline have been included and two years of measures taken. Nevertheless, additional years with measures taken will be included to account for short-term effects but also for long-term effects such as mineral N stock changes in the soil.

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