MODELLING OF FARM-GATE NITROGEN BALANCE IN DAIRY FARMING – CASE STUDY OF LATVIA

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Abstract. It is predicted that the demand for dairy products in the world will continue to grow in the next decade, and Latvian dairy products have growth potential in international markets. The European Green Deal aims to boost efficient use of resources by moving to a clean, circular economy and stop climate change, and revert biodiversity loss. The very significant element of it is the EU taxonomy for sustainable activities. The taxonomy stipulates that economic activity can qualify as environmentally sustainable only if it substantially contributes to one or more environmental objectives. In case of agriculture, especially dairy farming, there are limited options how to make substantial contribution. Although it is likely that several options will be available, ensuring sustainable farm-gate nitrogen balance could be the most realistic option, especially for intensive dairy farms. The Platform on Sustainable Finance has proposed several indicators how to measure farm-gate nitrogen balance, e.g. nitrogen surplus (also called nitrogen balance), nitrogen use efficiency (NUE). At present there is a lack of evidence based knowledge about farm-gate nitrogen balance in Latvia’s dairy farming. The aim of the study was to model the farm-gate nitrogen balance and examine nitrogen surplus and NUE for several types of dairy farms (depending on the herd size and management practice). The input data for modelling were derived from results of the previous research carried out by the authors. The criteria of maximum nitrogen surplus and minimum NUE proposed by the platform were applied to assess the results of the modelling. The results of the study indicate that it could be challenging for Latvia’s dairy farms to meet the maximum nitrogen surplus and especially the minimum NUE. These challenges are particularly considerable for dairy farms that have low productivity and that have high dependency on purchased feed.

Keywords: nitrogen balance, nitrogen use efficiency, dairy farming, modelling.

Introduction

As a response to demand trends, the world milk production is increasing, and it has been projected at 901.6 million tons in 2022 [1]. The European Union with approximately 155 million tons of milk per year [2] is one of the leading milk production regions in the world. Although Latvia contributes only 0.6% [3] of the total volume of milk to the European common market, it exceeds the level of self-sufficiency, and Latvia is among net milk exporting countries.

The increase in production worldwide has been mostly achieved by intensification activities – increased application rates of nutrients, particularly nitrogen (N), as biological or mineral fertiliser used for forage production to ensure the volume and the source of protein in animal feed [4], however, overuse of N fertilizers leads to various environmental problems [5], for the mitigation of which not only encouraging policy initiatives, but also legal requirements and restrictions are being introduced on international and national level.

The European Green Deal as a set of the EU’s policy initiatives aims to boost efficient use of resources by moving to a clean, circular economy and stop climate change, and revert biodiversity loss. The very significant element of it is the EU taxonomy for sustainable activities. The taxonomy stipulates that economic activity can qualify as environmentally sustainable only if it substantially contributes to one or more environmental objectives [6]: (i) climate change mitigation, (ii) climate change adaptation, (iii) sustainable use and protection of water and marine resources, (iv) transition to a circular economy, (v) pollution prevention and control, and (vi) protection and restoration of biodiversity and ecosystems. In case of agriculture, technical screening criteria have not been adopted yet. However, the proposals by the Platform on Sustainable Finance allow concluding that there will be limited options how to make the substantial contribution – substantial contribution to either climate objectives or the protection and restoration of biodiversity and ecosystems (B&E).

The Platform has developed several proposals on the technical screening criteria for the substantial contribution to B&E but the proposed technical criteria for the substantial contribution to climate objectives have been recalled for revising. Moreover, ensuring sustainable farm-gate N balance could be the most realistic option, especially for intensive dairy farms [7].

The evaluation of N balance on farm level, where total N inputs and outputs are estimated and the difference (N surplus) and ratio (N use efficiency) are quantified, is caried out worldwide to evaluate N use outcomes of an agricultural system and the risk of N losses in environment [8]. From the practical point of view, the N balance and NUE in different dairy systems, for example, depending on grazing intensity [4; 9] or farming scale [8] have been analysed. The latest studies have become more complex: De Klein *et al.* (2017), involving the case studies of several European countries, the USA and Oceania, outline the problematics on the assumptions used in the calculations of NUE and N surplus and the use of these indicators in setting realistic environmental policy goals [10], on the other hand, Hutchings *et al.* (2020) estimate the existing level of NUE of European agricultural production and model possibilities to increase it by technical measures [11]. Although the results of the studies are hardly comparable due to different system boundaries in the approaches, they provide new knowledge and possible solutions both for farmers and policy makers in the future. Simultaneously, there is scant knowledge about the farm-gate N balance in Latvia's dairy farms. Therefore, the aim of this study is to model the farm-gate nitrogen balance and examine nitrogen surplus and nitrogen use efficiency for several types of dairy farms (depending on the herd size and management practice) in Latvia.

Dairy farming is the most important livestock sector in Latvian agriculture (20% of total output in 2021, EUR 316.6 million) [12]. In 2021, a total of 10.1 thousand dairy farms were registered in Latvia with 131.2 thousand dairy cows. The structure of the milk production in Latvia is assessed to be fragmented: 78% of dairy farms held herds with 1-9 dairy cows, 16% of all dairy cows are concentrated in these farms, and this group of farms produces about 13% of the total milk per year. The largest number of dairy cows (30%) is concentrated in farms with the number of dairy cows exceeding 200 in the herd, in this group of farms 38% of the total tons of milk are produced, however, there are only 84 such farms in Latvia (~1% of the dairy community). Also, a small number of farms (126) are in the group with 100-199 dairy cows in the herd, in this group of farms there are 13% of all dairy cows concentrated and 14% of the total milk is produced [13]. Significant structural changes occurred in the dairy sector in Latvia in the period from 2015-2021: the number of farms and cows involved in milk production has significantly decreased; productivity and production efficiency are increasing; however, it is still lower than the EU average and significantly lower than in the leading EU milk producing countries. Thus, the issue of the better effectiveness of resource use, including N, is important for Latvian dairy sector not only in the context of the environmental sustainability, but also necessary to strengthen the economic competitiveness.

Materials and methods

The main data sources for the study are information and empirical data obtained within the research projects "Assessment of impact of EU framework promoting sustainable finance on agriculture" (2021, 2022) and "Development of the strategy for a sustainable and multifunctional dairy sector in Latvia" (2021). The typology of dairy farms used in the research "Development of the strategy for a sustainable and multifunctional dairy sector in Latvia" has been used to model a farm-gate nitrogen balance [14].

The types of Latvia's dairy farms and the main assumptions about them are presented in Table 1.

Table 1

Main assumptions about types of dairy farms in Latvia

Type	Number of dairy cows in herd, average	Milk sold, t per year	Utilized agriculture area, ha	Grazing as part of production system
Conventional farms				
1-9 cows:				
Milk yield 5.5 t per year	6	32.0	20	+
Milk yield 8 t per year	6	47.0	20	+
10-29 cows:				
Milk yield 5.5 t per year	16	85.5	50	+
Milk yield 8 t per year	16	125.5	50	+
30-49 cows:				
Milk yield 6.5 t per year	35	228.0	100	+
Milk yield 9 t per year	35	318.0	100	+

Table 2 (continued)

Type	Number of dairy cows in herd, average	Milk sold, t per year	Utilized agriculture area, ha	Grazing as part of production system
50-99 cows:				
Milk yield 6.5 t per year	62	402.0	170	+ *
Milk yield 9 t per year	62	562.0	170	+ *
100-199 cows				
Milk yield 8 t per year	130	1 043.0	300	-
Milk yield 11 t per year	130	1 448.0	300	-
≥ 200 cows:				
Milk yield 9 t per year	460	4 131.0	800	-
Milk yield 11 t per year	460	5 069.0	800	-
Milk yield 11 t per year**	460	5 069.0	800	-
Organic farms				
Milk yield 5 t per year	12	61.0	50	+
Milk yield 8 t per year	58	466.0	170	+

* the authors' assumption of partly grazing (pasture management) in production system is used
** the more efficient DDM of grass forage (increased from 67% to 69%) and thus less need for concentrated feed
Source: the authors' assumptions based on unpublished data of Latvian farm accountancy data network (FADN) and Agricultural Data Centre of Republic of Latvia, 2020

The methodology proposed by the Platform [15; 16] has been used to assess the farm-gate nitrogen balance of dairy farms in Latvia. According to this methodology, the following N inputs have been considered – seed, mineral fertilisers, imported feed, and biological N fixation. Exported animals and milk have been considered as N inputs. It is assumed that all livestock manure is used within the farm and there is no exported manure.

In order to assess and calculate N inputs and outputs for different types of dairy farms mentioned in Table 1, feed rations, feed requirements and requirements of mineral fertilizers have been modelled at relevant milk yield and herd size. The digital tool "NorFor Feed Ration Optimizer™" is applied to calculate feed rations. It is assumed that dry matter digestibility (DDM) of grass forage is 65% and 67% at the milk yield until 6.5 t and 8 t or more respectively. The Gross Margin Calculations for 2021 by the Latvian Rural Advisory and Training Centre (LLKC) have been used to calculate total feed requirements and total requirements of mineral fertilisers [17]. The standard assumptions of the digital tool "NorFor Feed Ration Optimizer™" are applied to calculate N outputs from milk and exported animals.

The Platform has proposed several indicators to measure farm-gate nitrogen balance. The main indicators are N surplus (also called nitrogen balance) and nitrogen use efficiency (NUE) [15; 16]. It should be mentioned that both terms "nitrogen surplus" and "nitrogen balance" have been used by scholars and institutions (including the Platform). However, the authors use the term "nitrogen surplus" (N-surplus) in the article because this term is more unambiguous than the term "nitrogen balance", which has several meanings (including a balance as an arrangement of N inputs and outputs).

The following formula is used to calculate N-surplus for each type of dairy farms:

$$N\_surplus_i = \frac{N\_seed_i + N\_mfert_i + N\_feed_i + N\_{fixi} - N\_anim_i - N\_milk_i}{UUA_i}, \quad (1)$$

where $N\_surplus_i$ – N-surplus for farm type *i*, kg N;
N_seed_i – nitrogen from seed for farm type *i*, kg N;
N_mfert_i – nitrogen from mineral fertilisers for farm type *i*, kg N;
N_feed_i – nitrogen from imported feed for farm type *i*, kg N;
N_fix_i – nitrogen from biological fixation for farm type *i*, kg N;
N_anim_i – nitrogen from exported animals for farm type *i*, kg N;
N_milk_i – nitrogen from exported milk for farm type *i*, kg N;
UAA_i – utilised agricultural area for farm type *i*, ha.

NUE for each type of dairy farms is calculated as the ratio of nitrogen output to nitrogen input by applying the following formula:

$$NUE_i = \frac{N\_anim_i + N\_milk_i}{N\_seed_i + N\_mfert_i + N\_feed_i + N\_fix_i}, \quad (2)$$

where NUE_i – NUE for farm type *i*.

In order to avoid the biased assessment of nitrogen input (in turn, N-surplus and NUE) for farms that import feed, the nitrogen input from imported feed is adjusted by applying nitrogen unit efficiency of the feed production. The Platform has proposed to use the nitrogen unit efficiency of 50% if is not known for imported feed [15; 16]. In addition, the authors have used the nitrogen unit efficiency of 70% because it corresponds to the minimum NUE criteria for crop production [15, 16]. The following formula is applied to calculate the adjusted N input from imported feed:

$$N\_feed\_adj_i = \frac{N\_feed_i}{NUE_{feed}}, \quad (3)$$

where $N\_feed\_adj_i$ – adjusted nitrogen from imported feed for farm type *i*, kg N;
NUE_{feed} – nitrogen unit efficiency of the feed production (either 50% or 70%).

$N\_feed\_adj_i$ is used in formulae (1) and (2) to calculate adjusted $N\text{-}surplus_i$ and NUE_i. Although the Platform proposes calculating N-surplus and NUE on a rolling three-year bases, the modelling is carried out on a year bases because the model assumes constant annual N inputs and outputs (see above).

According to the Platform's proposal of 2021, N-surplus limit was set in the range of 30 kg N per ha per annum (if only mineral fertiliser and no organic manure were applied) and 90 kg N per ha per annum (if organic manure was applied 120 kg per ha and more) [15]. However, the Platform has revised its proposal and substituted those flat limits with the regional and farm specific farm-gate nitrogen balance limit as well as maximum farm-gate nitrogen limit [16]. These recently proposed limits are not constant amounts but depend on the regional biodiversity related thresholds for nitrogen and the specifics of the farm (including nitrogen-manure prevalent at the farm). The Platform refers to the study by DeVries *et al.* (2021) and proposes to adapt the critical values from the data set of DeVries *et al* [16, 18]. However, the methodology of deriving limits for the farm is quite unclear. Therefore, at present it is hardly possible to set the benchmarks for the comparison and evaluation of the calculated $N\text{-}surplus_i$. The authors use the following indicative benchmarks – 90 kg N per ha (the maximum limit according to the Platform proposal of 2021 [15]) and 120 kg N per ha (the maximum limit proposed as an example by the Platform in 2022 [16]) in the current evaluation.

According to the Platform proposals of 2021 and 2022, the minimum NUE is set at 70% for crops, 40% for granivores and 30% for ruminants [15, 16]. Thus, the value of 30% is used as a benchmark against which NUE_i is assessed.

Results and discussion

Based on the methodology, the data and the assumptions described above, the indicators of the farm-gate N balance have been modelled for all the types of Latvia's dairy farms. The assessed N-surplus and NUE for conventional dairy farms with herd size up 99 cows are presented in Table 3.

Table 3

Assessment of nitrogen balance for dairy farms depending on herd size and milk yield (Part 1)

Indicators	1-9 cows		10-29 cows		30-49 cows		50-99 cows	
	5.5 t	**8 t**	**5.5 t**	**8 t**	**6.5 t**	**9 t**	**6.5 t**	**9 t**
N input								
Seed, kg	2	2	3	3	8	8	16	16
Mineral fertilisers, kg N	386	386	1 291	1 291	4 300	4 300	8 560	8 560
Imported feed, kg N	106	106	146	568	500	1 474	933	2 610
Biological N fixation, kg N	510	510	1 115	1 115	2 811	2 811	5 350	5 350
Total	**1 004**	**1 004**	**2 555**	**2 977**	**7 619**	**8 593**	**14 859**	**16 536**
Adjusted N input*								
If NUE of imp. feed 70%	1 049	1 049	2 618	3 220	7 833	9 225	15 259	17 655
If NUE of imp. feed 50%	1 110	1 110	2 701	3 545	8 119	10 067	15 792	19 146

Table 4 (continued)

Indicators	1-9 cows		10-29 cows		30-49 cows		50-99 cows	
	5.5 t	**8 t**	**5.5 t**	**8 t**	**6.5 t**	**9 t**	**6.5 t**	**9 t**
N output								
Exported animals, kg N	23	23	82	82	183	183	354	354
Milk, kg N	170	170	453	665	1 208	1 685	2 131	2 979
Total	**193**	**193**	**535**	**747**	**1 391**	**1 868**	**2 485**	**3 333**
N-surplus, kg per ha:								
Without adjustment	41	41	40	45	62	67	73	78
If NUE of imp. feed 70%	43	43	42	49	64	74	75	84
If NUE of imp. feed 50%	46	46	43	56	67	82	78	93
NUE								
Without adjustment	19.2%	19.2%	20.9%	25.1%	18.3%	21.7%	16.7%	20.2%
If NUE of imp. feed 70%	18.4%	18.4%	20.4%	23.2%	17.8%	20.2%	16.3%	18.9%
If NUE of imp. feed 50%	17.4%	17.4%	19.8%	21.1%	17.1%	18.6%	15.7%	17.4%

* adjusted by applying the nitrogen unit efficiency to imported feed
Source: the authors' calculations

The assessed N-surplus and NUE for conventional dairy farms with the herd size 100 and more cows as well as for organic dairy farms are presented in Table 5.

Table 5

Assessment of nitrogen balance for dairy farms depending on herd size and milk yield (Part 2)

Indicators	100-199 cows		≥ 200 cows			org. farms	
	8 t	**11 t**	**9 t**	**11 t**	**11 t***	**5 t**	**8 t**
N input							
Seed, kg	140	140	225	225	225	11	16
Mineral fertilizers, kg N	14 780	14 870	45 920	45 920	45 920	-	-
Imported feed, kg N	4 019	15 731	27 543	65 260	27 543	257	1 958
Biological N fixation, kg N	6 320	6 320	24 770	24 770	24 770	4 200	7 220
Total	**25 259**	**37 061**	**98 458**	**136 175**	**98 458**	**4 468**	**9 194**
Adjusted N input**							
If NUE of imp. feed 70%	26 981	43 803	110 262	164 144	110 262	4 578	10 033
If NUE of imp. feed 50%	29 278	52 792	126 001	201 435	126 001	4 725	11 152
N output:							
Exported animals, kg N	671	671	2 753	2 753	2 753	34	354
Milk, kg N	5 528	7 674	21 894	26 866	26 866	323	2 470
Total	**6 199**	**8 345**	**24 647**	**29 619**	**29 619**	**357**	**2 824**
N surplus, kg per ha							
Without adjustment	64	96	92	133	86	82	37
If NUE of imp. feed 70%	69	118	107	168	101	84	42
If NUE of imp. feed 50%	77	148	127	215	120	87	49
NUE							
Without adjustment	24.5%	22.5%	25.0%	21.8%	30.1%	8.0%	30.7%
If NUE of imp. feed 70%	23.0%	19.1%	22.4%	18.0%	26.9%	7.8%	28.1%
If NUE of imp. feed 50%	21.2%	15.8%	19.6%	14.7%	23.5%	7.6%	25.3%

* the scenario of the more efficient DDM of grass forage (see above)
** adjusted by applying the nitrogen unit efficiency (NUE) to imported feed
Source: the authors' calculations

The results of the current study indicate that conventional farms with the herd size 100 and more cows have quite high N-surplus, especially if the NUE of imported feed is low. The benchmark value of 90 kg N per year is exceeded in conventional farms with the herd size 50-99 cows (if the milk yield 9 t and NUE of imported feed 50%), herd size 100-199 cows (if the milk yield 11 t) and the herd size 200 and more cows (except the scenario of the milk yield 11 t and more efficient use of forage). Moreover, the benchmark value of 120 kg N is reached or exceeded in conventional farms with the herd size 100-199 cows (if milk yield 11 t and the NUE of imported feed 50%) and with the herd size 200 and more cows (if the milk yield 9 t and NUE of imported feed 50% and if the milk yield 11 t except the scenario of more efficient use of forage (NUE of imported feed above 50%)). Organic farms do not exceed selected N-surplus benchmark values.

The assessed values of NUE indicate that almost all types of farms cannot meet the minimum NUE of 30%. The only exceptions are conventional farms with the herd size 200 and more cows (under the scenario of more efficient use of forage) and organic farms, if the milk yield 8 t. However, these exceptions hold only if no adjustments on the N inputs from the imported feed are made. Thus, it could be challenging for Latvia’s dairy farms to meet the criteria of sustainable farm-gate nitrogen balance and, in turn, become taxonomy-aligned. This challenge probably is not relevant for organic dairy farms because it is likely that certified organic farms will automatically qualify as making substantial contribution to the climate objectives [7].

These challenges mentioned above are particularly considerable for dairy farms that have low productivity and that have high dependency on purchased (imported) feed. Nevertheless, high milk yields do not necessarily lead to lower N-surplus and higher NUE. If the increase in milk yield in not accompanied by efficient use of forage, then it can impair the fam-gate nitrogen balance. The very crucial factor is also the nitrogen unit efficiency in imported (purchased) feed. The use of the imported feed with low or unknown nitrogen unit efficiency impairs N-surplus and NUE substantially.

The results obtained in this study are alike to those other authors have published. For dairy production systems, de Klein *et al.* (2017) found a range of 21-39% for farm scale NUE and 124-259 kg N per ha of N-surplus for New Zealand [10]. The range found in Australia and the USA by Gourley *et al.* (2012) was wider still (15-35%) for NUE whereas Buckley *et al.* (2016) found a narrower range of NUE at 21–24% in Ireland [11]. Some latest publications report higher farm scale NUE and lower N-surplus, for example Low *et al.* (2020) reveal the average N-surplus tending to be from 179 to 259 kg N per ha, and farm gate NUE 40-50% in North-western Germany, Hutchings *et al.* (2020) estimate NUE at 46-53% in Northern European dairy production and Toda *et al.* (2020) show the mean value for N surplus at 40.5 kg N per ha and the NUE at 69.5% for Hokkaido dairy farms [8; 9; 11]. Other authors indicate that it is important to pay attention to the system boundaries and to whether the residual effects of fertiliser and manure N applications are included, when comparing NUE internationally. Estimates of NUE tend to be higher where the soil processes are taken fully into account and vice versa – the values for NUE of livestock production systems are much lower if the study does not take into account the extent to which excretal N is recycled through increased crop production [11].

In order to achieve further improvements in the nitrogen balance (N-surplus, NUE) of dairy farming and make it more sustainable, future studies will have to consider how to increase the nitrogen unit efficiency of feed production, improve the utilisation of manure, increase DDM of grass forage, etc. According to Hutchings *et al.* (2020), the upper limit of NUE varies from 46% to 52% for ruminants in Northern Europe [11].

Conclusions

1. The results of this study indicate that N-surplus is quite high and exceeds the level of benchmark 90 kg N per ha in the conventional dairy farms with the herd size 100 and more cows (varies from 64 to 215 kg N per ha). For these farms the import of feed is inherent and grassland management does not include grazing. Organic farms do not exceed selected N-surplus benchmark values.
2. Latvia’s dairy farms could face a challenge to meet the criteria of sustainable farm-gate nitrogen balance and, in turn, become taxonomy-aligned. The assessed values of NUE indicate that almost all types of farms cannot meet the minimum NUE of 30%. NUE varies from 14.7% to 30.1% for conventional farms and from 7.6% to 30.7% for organic farms. Although organic dairy farms may not be affected by this challenge, the current low productivity is a threat to the economic competitiveness of this type of farms; the improvement of productivity would also contribute to the improvement of NUE indicators in organic dairy farming.
3. Comparably higher N-surplus and lower NUE are particularly an issue for Latvian dairy farms that have low productivity and do not ensure the self-sufficient level of feed (depend on feed import). Nevertheless, higher milk yields do not necessarily lead to lower N-surplus and higher NUE. It must be accompanied by more efficient use of grass forage. Also crucial is the nitrogen unit efficiency of imported feed because it impairs both NUE and N-surplus substantially.

4. The NUE results reported in the previous studies by other authors are alike to the results of this study. However, in order to compare them properly, it is necessary to pay attention that the assumptions used in the calculations are comparable and the system boundaries are the same. Thus, standardisation of NUE calculations would be important for international comparisons, but may lead to situations where important local-level conditions are not taken into account.
5. Future studies are required to explore the possibilities how to achieve further improvements in the nitrogen balance (N-surplus, NUE) of dairy farming, e.g. increase the nitrogen unit efficiency of feed production, improve the utilisation of manure, increase DDM of grass forage.

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Author contributions

Conceptualization, A.A. and I.L.; methodology, A.A. and I.L.; validation, A.A. and I.L; data analysis, A.A., I.L. an S.D.; writing – original draft preparation, A.A. and I.L.; writing – review and editing, A.A., I.L. and S.D. All authors have read and agreed to the published version of the manuscript.

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