

# Variation in nitrogen use efficiencies on Dutch dairy farms

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## Abstract

**BACKGROUND:** On dairy farms, the input of nutrients including nitrogen is higher than the output in products such as milk and meat. This causes losses of nitrogen to the environment. One of the indicators for the losses of nitrogen is the nitrogen use efficiency. In the Dutch Minerals Policy Monitoring Program (LMM), many data on nutrients of a few hundred farms are collected which can be processed by the instrument Annual Nutrient Cycle Assessment (ANCA, in Dutch: Kringloopwijzer) in order to provide nitrogen use efficiencies.

**RESULTS:** After dividing the dairy farms (available in the LMM program) according to soil type and in different classes for milk production  $\text{ha}^{-1}$ , it is shown that considerable differences in nitrogen use efficiency exist between farms on the same soil type and with the same level of milk production  $\text{ha}^{-1}$ .

**CONCLUSION:** This offers opportunities for improvement of the nitrogen use efficiency on many dairy farms. Benchmarking will be a useful first step in this process.

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**Keywords:** nitrogen use efficiency; dairy farms; variation; efficiency

## BACKGROUND

In dairy farming systems, four major components can be distinguished, i.e. herd, manure, soil and crop (Fig. 1). Nitrogen cycles through these components: output from one component is input into another, but losses are incurred in these transfers.<sup>1–3</sup> The major commercial output of dairy farms is milk, though some meat is produced because of replacements in the dairy herd and sales of surplus calves. To compensate for the output and the losses, conventional dairy farms in the Netherlands buy at least concentrates and nitrogen fertiliser as inputs. The input of nitrogen from outside the farm is nearly always higher than the amount of nitrogen leaving the farm in output,<sup>4,5</sup> resulting in a surplus of nitrogen.

Losses in the nitrogen cycle, or in other words the surplus of nitrogen, are a threat to the quality of groundwater and surface water.<sup>6–9</sup> They also influence air quality<sup>10,11</sup> because of ammonia emissions and the amount of greenhouse gases (GHGs)<sup>12</sup> due to emissions of nitrous oxide (laughing gas, the most potent GHG emitted from agriculture). Much effort has been put into decreasing the losses,<sup>4,5</sup> but for instance a level of at most 50 mg nitrate  $\text{L}^{-1}$  groundwater, as required by the EU Nitrates Directive, is still not achieved on all soils in the Netherlands.<sup>13</sup>

The nitrogen surplus is calculated as the output (milk, animals, exported manure, exported crops) in kg nitrogen subtracted from the input (fertilisers, feed, imported manure, deposition, fixation<sup>†</sup>) in kg nitrogen, generally expressed in  $\text{kg ha}^{-1}$  to show the pressure on the cropping area. A comparable measure is the nitrogen use efficiency where the output is divided by the input and expressed as a percentage. The efficiency better shows which share of the

inputs is captured in outputs than the surplus does. Changes in stocks are taken into account when calculating surpluses and efficiencies.<sup>†</sup>

More efficient use of feed and fertilisers results in a better cycling of nitrogen and thus in lower losses to the environment and less costs for purchases. Efficiency is partly governed by conditions that the dairy farmer cannot affect, such as soil type or weather conditions. However, management generally is the most dominant factor.<sup>4,5</sup>

The instrument Annual Nutrient Cycle Assessment (ANCA, in Dutch: Kringloopwijzer) has been developed and introduced to monitor and stimulate improvement in nitrogen use efficiency.<sup>1</sup> Indicators calculated by ANCA enable dairy farmers to optimise their farm management as well as to justify this management to authorities and the dairy processing industry. The instrument ANCA does not consider externalities, so losses in the production of crops, used for feed that is imported on the farm, and losses during transport and application of manure, exported off farm, are not taken into account. A cradle to farm gate approach or a

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<sup>†</sup>Nitrogen fixation concerns the fixation by leguminosae. Nitrogen mineralisation (except from grassland on peat soils) and other nitrogen fixation are supposed to balance each other out.

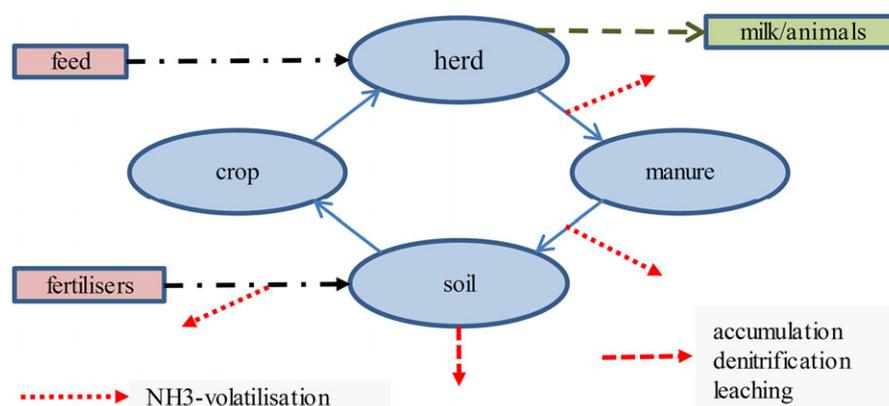


Figure 1. Nitrogen cycle for dairy farm.

cradle to cradle approach is more holistic but requires more data and assumptions. Yet the developers of ANCA have not included such externalities.

Dairy farmers hence need to know their position concerning the nitrogen use efficiency. The objective of this study is to show the variation in nitrogen use efficiency at farm level, even if soil type and intensity (ton milk ha<sup>-1</sup>) are more or less the same, and to discuss the potential for further improvement in nitrogen use efficiency. Different sources consider soil type and intensity as important factors for differences in nitrogen use efficiency.<sup>4,5</sup>

Since 1991, the Dutch Minerals Policy Monitoring Program (LMM) has collected data on farm practice and water quality for both a representative sample of conventional farms in the Netherlands and some pilot farms such as the participants in the Dutch project Cows and Opportunities (dairy farms that are progressive in terms of nutrient management).<sup>14</sup> The LMM program collects many data, including the necessary data for the aforementioned instrument ANCA.

The calculation procedure within the instrument ANCA cannot be applied to all farms yet. On dairy farms with a significant arable branch and/or a significant intensive livestock branch, it is often difficult to clearly separate the product flows between different production units. The instrument is therefore only used on farms that satisfy the following criteria:<sup>15</sup> (1) the farm is a specialised dairy farm according to the Standard Output classification; (2) the dairy herd accounts for at least 67% of the total quantity of phosphate livestock units<sup>‡</sup> for grazing livestock; (3) no pigs or poultry are present on the farm; (4) at least 80% of the acreage is used for the cultivation of fodder crops. Also, the pilot farms were removed to get a more representative picture. Averages per farm over a three-year period were taken to smooth year effects. The eventual analysis in this study included 275 dairy farms in the period 2009–2011.

The representativeness of these 275 dairy farms for the Dutch dairy sector is highly supported by the fact that farms within the LMM program are basically farms participating in the Farm Accountancy Data Network (FADN) of the European Union.<sup>16</sup> The FADN delivers a representative picture of structural and financial data on different farm types and uses farm size, measured in financial output, and farm type for stratification: stratification is applied to reduce the standard error of results. For an even better representation in the LMM program concerning water quality,

<sup>‡</sup>Sum of the multiplications of the number of animals per animal category and the respective phosphate production standard per animal.

some additional farms are chosen above those within the FADN.<sup>14</sup> The additional stratification for the LMM program concerns the number of hectares in different regions in the Netherlands.

The farms were divided into four soil types: clay, peat, dry sand and wet sand. Dry sand means a sandy soil with a groundwater level of about 1 m or more below ground level; other sandy soils fall under wet sand. Soil type is one of the determinants of nitrogen use efficiency and is confounded with e.g. fertiliser nitrogen rates (consult tables). Within these soil types, the farms were divided based on their milk production ha<sup>-1</sup>: <13, 13–16 and >16 ton. Milk production ha<sup>-1</sup> turns out to be an important structural aspect for the level of nitrogen use efficiency.<sup>4,5</sup> Owing to the limited number of farms on peat soil, only two classes in milk production ha<sup>-1</sup> were distinguished there: <13 and ≥13 ton.

Relevant data of these farms on farm practice were processed through the ANCA instrument to obtain figures on nitrogen use efficiency. Farmers can use the ANCA instrument to calculate these outcomes for their own farm; then the average results of the corresponding group of LMM farms are presented to the farmer as a benchmark. A detailed description of the nitrogen inputs and outputs (for the calculation of the nitrogen use efficiency) is given in the yearly derogation monitoring report which is one of the products of the LMM program.<sup>13</sup>

## RESULTS

Table 1 shows average results per group of dairy farms on clay and peat soils for some indicators in the period 2009–2011. Table 2 shows these results for dairy farms on sandy soils.

For every soil type, it applies that the farms with a higher milk production ha<sup>-1</sup> have a higher total milk production. Within a soil type, the area of agricultural land shows no relation with total milk production or milk production ha<sup>-1</sup>. At a higher milk production ha<sup>-1</sup>, the milk production per cow is generally higher and the number of young stock per cow tends to be lower.

To achieve savings on the purchase of roughage, the more intensive dairy farms with a higher milk production ha<sup>-1</sup> use more nitrogen from chemical fertilisers but nevertheless buy much more roughage, expressed in kg nitrogen in purchased feed ha<sup>-1</sup>.

Also, in most cases, both the nitrogen soil surplus ha<sup>-1</sup> and the nitrogen use efficiency are higher if the milk production ha<sup>-1</sup> is higher. The higher amount of nitrogen ha<sup>-1</sup> in purchased feed on more intensive dairy farms is not compensated by a comparable amount of nitrogen ha<sup>-1</sup> in the outputs milk and meat plus export of animal manure. That explains the higher nitrogen soil surplus

**Table 1.** Averages for some indicators on Dutch dairy farms on clay and peat soils in period 2009–2011. Farms divided by soil type and ton milk production ha<sup>-1</sup>

Soil type	Clay			Peat	
	< 13	13–16	> 16	< 13	≥ 13
Ton milk ha <sup>-1</sup>					
No. of observations	36	21	16	29	21
Farm size in ha	77.3	66.7	76.0	52.0	62.2
Farm size in ton milk	754	922	1358	533	931
Ton milk ha <sup>-1</sup>	9.8	13.8	17.9	10.3	15.0
Kg milk per cow	6899	8163	8734	7270	8026
LSU young stock per cow	0.27	0.25	0.25	0.26	0.23
Kg N chemical fertiliser ha <sup>-1</sup>	114	160	187	86	96
Kg N in purchased feed ha <sup>-1</sup>	96	160	279	112	175
Kg N soil surplus ha <sup>-1</sup>	121	176	188	111	127
N-efficiency farm (%)	29.6	27.1	31.8	32.4	34.0

LSU, livestock unit based on phosphate production standards per animal.

**Table 2.** Averages for some indicators on Dutch dairy farms on sandy soils in period 2009–2011. Farms divided by soil type and ton milk production ha<sup>-1</sup>

Soil type	Dry sand			Wet sand		
	< 13	13–16	> 16	< 13	13–16	> 16
Ton milk ha <sup>-1</sup>						
No. of observations	22	12	27	46	25	20
Farm size in ha	54.0	57.4	48.1	54.8	47.8	48.1
Farm size in ton milk	534	811	1002	533	673	955
Ton milk ha <sup>-1</sup>	9.9	14.1	20.8	9.7	14.1	19.8
Kg milk per cow	7363	8221	8563	7044	8455	8764
LSU young stock per cow	0.33	0.27	0.21	0.25	0.25	0.25
Kg N chemical fertiliser ha <sup>-1</sup>	104	118	113	99	128	135
Kg N in purchased feed ha <sup>-1</sup>	95	127	231	103	138	223
Kg N soil surplus ha <sup>-1</sup>	123	132	145	111	137	150
N-efficiency farm (%)	31.6	33.8	39.5	32.6	32.3	36.9

LSU, livestock unit based on phosphate production standards per animal.

on more intensive dairy farms. Because more intensive dairy farms rely more on purchased feed, they avoid the nitrogen losses that would accompany the cultivation of forage crops on their own farms. Moreover, they can better tune the total feed mix. If, for example, own roughage contains too much crude protein, they can compensate not only with concentrates with low crude protein content but also with roughage containing little crude protein. Both factors increase their nitrogen use efficiency.

Besides the variation between the groups, there is also variation within the group as Fig. 2 expresses. The boxes show the 25–75% interval and the whiskers depict the 10–90% interval. To avoid the visibility of individual observations, the 10–90% interval has been chosen instead of the more common minimum and maximum values for the lengths of the whiskers.

In most groups, the 10% farms with the highest nitrogen use efficiency at farm level achieve at least a 1.5-fold higher nitrogen use efficiency than the 10% lowest. In many groups, the distance between the 25% highest and the 25% lowest in nitrogen use efficiency is more than a factor of 1.2. Thus a considerable number of farms, being in the same circumstances (soil type and intensity),

have room to improve their nitrogen use efficiency. No group differs significantly from another group at a confidence level of 90%: all groups have observations with a nitrogen use efficiency of (or close to) 30%.

## CONCLUSION

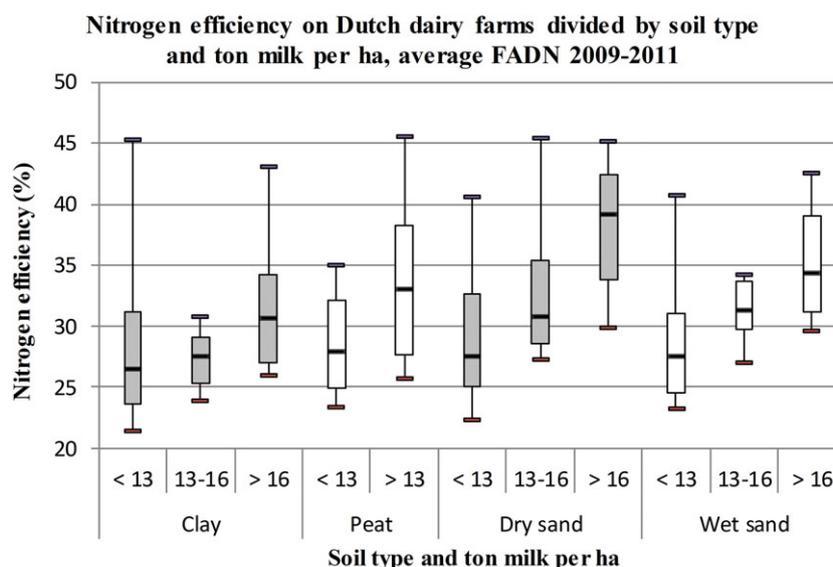
Milk production at farm level and milk production ha<sup>-1</sup> are positively related on Dutch dairy farms as Tables 1 and 2 show. Land is a very limiting factor in the Netherlands, so a higher total milk production generally requires a more intensive farming system.<sup>17</sup> Both indicators also have a positive relation with the nitrogen surplus ha<sup>-1</sup> as well as the nitrogen use efficiency. Thus a farm with a higher nitrogen use efficiency can yet be locally more polluting because of the higher nitrogen surplus ha<sup>-1</sup>.

As already mentioned, the bigger dependence on purchased feed in intensive dairy farms can improve efficiency, because the farmer has more choice in the composition when buying roughage. If a dairy farm is (more than) self-sufficient for roughage, the composition of the roughage is more determined. Moreover, when purchasing roughage, intensive dairy farms avoid the nitrogen losses that inevitably accompany the cultivation of crops. By exporting manure off farm, intensive dairy farms also avoid losses during application of that manure. Currently, the instrument ANCA does not calculate these losses outside the farm; however, the developers of ANCA have started to implement the calculations for the calculations of GHG emissions. Those calculations, based on Life Cycle Assessment, will at least contain the losses that accompany the cultivation of crops, imported on the farm in a cradle to farm gate approach.

When correcting for milk production ha<sup>-1</sup> and soil type by division into groups, considerable variation in nitrogen use efficiency occurs within the different groups. These variations offer possibilities for many dairy farmers to improve the nitrogen use efficiency, starting with benchmarking and followed by suitable improvement measures.

Benchmarking with nitrogen use efficiency could be useful but must be done with caution.<sup>18</sup> A considerable part of this caution concerns the intensity, expressed in kg milk ha<sup>-1</sup>. It is recommended to take intensity into account, which strongly supports the division into groups by intensity in this study. Nevertheless, some differences in nitrogen use efficiency cannot be attributed to farmers' management alone. Describing and presenting the underlying processes such as the conversion from available nitrogen in harvested feed into animal products (milk and meat) or the conversion from nitrogen, available in manure, into nitrogen added to the soil (see Fig. 1) can provide very useful additional information, also for the benchmarking. The instrument ANCA provides this additional information.<sup>1</sup>

The nitrogen use efficiency as calculated by the instrument ANCA includes the import of nitrogen in animal manure from another farm on the input side. Accordingly, nitrogen in animal manure exported off farm is part of the output, which in the Dutch circumstances is nearly always the case for dairy farms with a milk production ha<sup>-1</sup> above about 16 tons. A dairy farm with no agricultural land would then be able to achieve a nitrogen use efficiency close to 100%. The only nitrogen input is by feed, and all that nitrogen leaves the farm in milk, meat or manure, except a limited amount of nitrogen in ammonia volatilisation from barns and manure storage. Therefore it is sometimes recommended<sup>19,20</sup> to leave the nitrogen in the manure, exported off farm, outside the calculation of the nitrogen use efficiency. As Fig. 2 shows, the



**Figure 2.** Nitrogen efficiency on Dutch dairy farms. The boxes show the 25–75% interval and the whiskers depict the 10–90% interval.

highest 10% of the nitrogen use efficiencies is below 50%, far below 100%, so the problem of including nitrogen in manure exported off farm in the calculation of the nitrogen use efficiency is negligible in this study.

Benchmarking remains a useful method to improve nutrient management and will work better if reference values can be corrected for important factors (e.g. milk production  $\text{ha}^{-1}$ ); then the reference values become more custom-made. Study groups of farmers to discuss the results of the benchmarking are a good next step, since farmers take up more from their colleagues than from others. However, insight into the efficiencies of the separate processes on dairy farms, as depicted in Fig. 1, and excluding nitrogen from manure exported off farm in the calculation of the whole farm nitrogen use efficiency can further improve the insights for farmers.

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## REFERENCES

- Oenema J, Transitions in nutrient management on commercial pilot farms in the Netherlands. *PhD thesis*, Wageningen University (2013).
- Öborn I, Edwards AC, Witter E, Oenema O, Ivarsson K, Withers PJA, *et al.*, Element balances as a tool for sustainable nutrient management: a critical appraisal of their merits and limitations within an agronomic and environmental context. *Eur J Agron* **20**:211–225 (2003).
- Bassanino M, Grignani C, Sacco D and Allisardi E, Nitrogen balances at the crop and farm-gate scale in livestock farms in Italy. *Agric Ecosyst Environ* **122**:282–294 (2007).
- Daatselaar CHG, Reijis JW, van Leeuwen TC, de Hoop DW, Boumans LJM and Fraters B, Relations between management, economics and environmental quality of dairy farms, in *Proceedings of the 16th Nitrogen Workshop – Connecting Different Scales of Nitrogen Use in Agriculture, 28th June–1st July 2009, Turin, Italy*, ed. by Grignani C, *et al.* Faculty of Agriculture, University of Turin, Turin, pp. 469–470 (2009).
- Ondersteijn CJM, Nutrient management strategies on Dutch dairy farms: an empirical analysis. *PhD thesis*, LUW, Wageningen (2002).
- Baumann RA, Hooijboer AEJ, Vrijhoef A, Fraters B, Kotte M, Daatselaar CHG, *et al.*, Agricultural practice and water quality in the Netherlands in the period 1992–2010. *RIVM Report 680716008*, National Institute for Public Health and the Environment, Bilthoven (2012).
- Cartwright N, Clark L and Bird P, The impact of agriculture on water quality. *Outlook Agric* **20**:145–152 (1991).
- Erisman JW, Bleeker A, Galloway J and Sutton MS, Reduced nitrogen in ecology and the environment. *Environ Pollut* **150**:140–149 (2007).
- Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai Z, Freney JR, *et al.*, Transformation of nitrogen cycle: recent trends, questions, and potential solutions. *Science* **320**:889–892 (2008).
- Van Bruggen C, Groenestein CM, de Haan BJ, Hoogeveen MW, Huijsmans JFM, van der Sluis SM, *et al.*, Ammonia emissions from animal manure and inorganic fertilisers in 2009. Calculated with the Dutch National Emissions Model for Ammonia (NEMA). *WOt Working Document 302*, Wettelijke Onderzoekstaken Natuur & Milieu (2012).
- Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M and de Haan C, *Livestock's Long Shadow; Environmental Issues and Options*. Food and Agricultural Organization of the United Nations, Rome (2006).
- Dolman MA, Sonneveld MPW, Mollenhorst H and de Boer IJM, Benchmarking the economic, environmental and societal performance of Dutch dairy farms aiming at internal recycling of nutrients. *J Cleaner Prod* **73**:245–252. (2014).
- Hooijboer AEJ, van den Ham A, Boumans LJM, Daatselaar CHG, Doornwaard GJ and Buis E, *Agricultural Practice and Water Quality on Farms Registered for Derogation: Results for 2011 in the Derogation Network*. National Institute for Public Health and the Environment, Bilthoven (2013).
- Fraters B, Boumans LJM, van Leeuwen TC and de Hoop DW, Results of 10 years of monitoring nitrogen in the sandy regions in The Netherlands. *Water Sci Technol* **51**(3/4):239–247 (2005).
- Aarts HFM, Daatselaar CHG and Holshof G, Bemesting, meststofbenutting en opbrengst van productiegrasland en snijmaïs op melkveebedrijven. *Report 208*, Plant Research International, Wageningen (2008).
- Van der Meer RW, van der Veen HB and Vrolijk HCJ, Sample of Dutch FADN 2011. *LEI Report 2013-064*, LEI Wageningen UR, The Hague (2013).
- Gourley CJP, Dougherty W, Weaver DM, Aarons SR, Awty IM, Gibson DM, *et al.*, Farm-scale nitrogen, phosphorus, potassium and sulfur balances and use efficiencies on Australian dairy farms. *Anim Prod Sci* **52**:929–944 (2012).
- Schröder JJ, Aarts HFM, ten Berge HFM, van Keulen H and Neeteson JJ, An evaluation of whole-farm nitrogen balances and related indices for efficient nitrogen use. *Eur J Agron* **20**:33–44 (2003).
- Kohn RA, Dou Z, Ferguson JD and Boston RC, A sensitivity analysis of nitrogen losses from dairy farms. *J Environ Manag* **50**:417–428 (1997).
- Halberg N, Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. *Agric Ecosyst Environ* **76**:17–30 (1999).