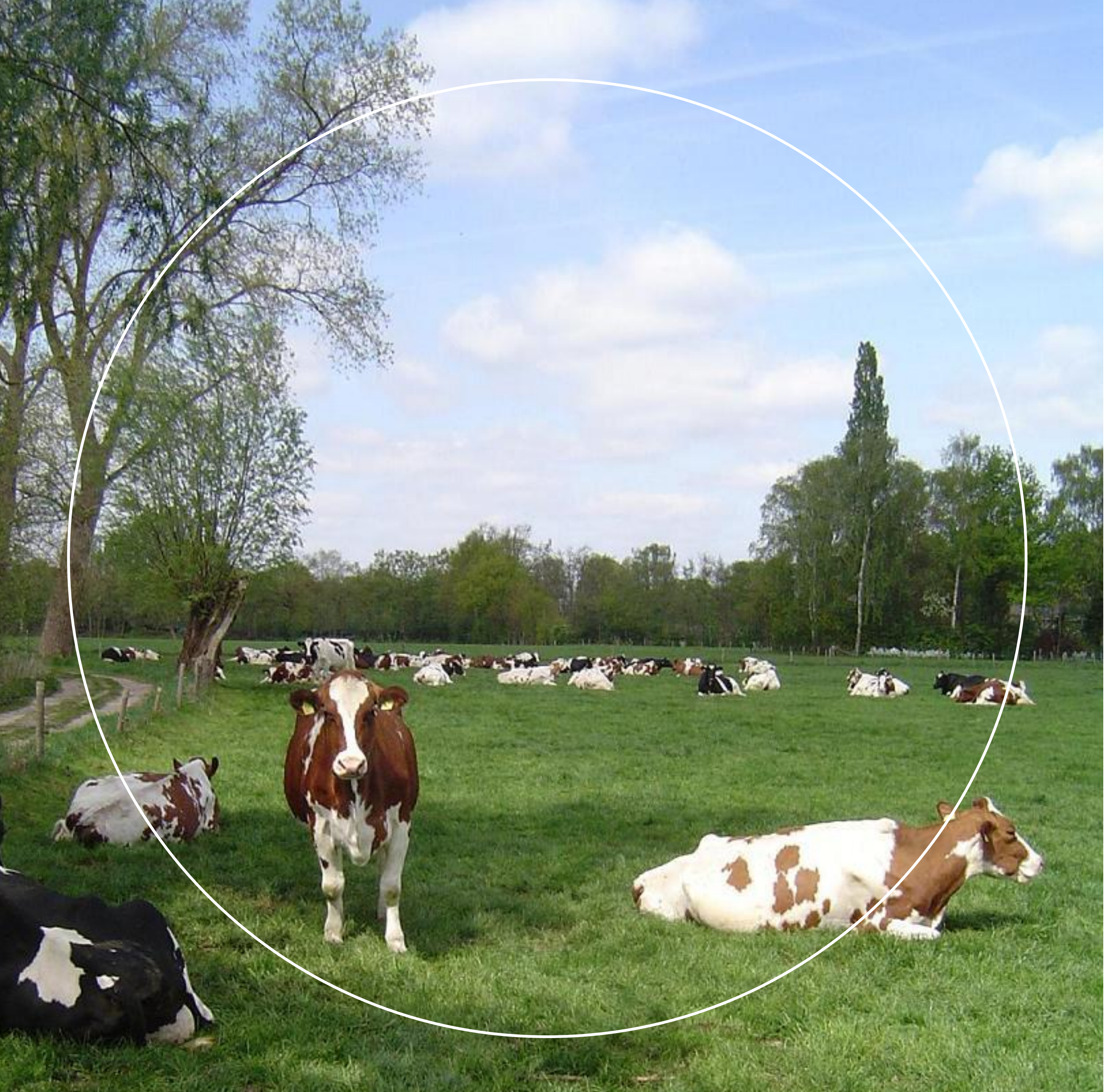

How to assess and improve nitrogen cycling in agricultural production

WAGENINGEN UNIVERSITY & RESEARCH

University of Antwerp

How to assess and improve nitrogen cycling in agricultural production

With examples from Flanders (Belgium) and the Netherlands

Key messages

1. **Nitrogen cycling can be assessed at farm and regional scale by construction of nitrogen balances**
2. **Synergy exists between nitrogen cycling and greenhouse gas emissions, but a trade-off with agricultural land use and productivity for Dutch dairy farms**
3. **There is more scope for improving nitrogen cycling on arable farms compared to dairy farms**
4. **Anaerobic digestion of manure leads to more regional nitrogen cycling**

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1. Introduction

Increased recycling of nutrients in agriculture may be a promising pathway to reduce environmental impacts and improve resource use efficiency at systems level. Improving the recycling of nutrients reduces the need for external inputs by mining (for phosphate) or energy consumption (to produce nitrogen fertilizer). In addition, increased recycling of nutrients may lead to less losses to the environment. In this policy brief, we focus on nitrogen (N). For N, reduced losses means less N deposition in nature areas and less greenhouse gas emissions. Currently, N efficiency is often assessed by relating nutrients in outputs (agricultural products) to those used as inputs (fertilizer, manure) (i.e., N output:N input). Assessing progress towards more nutrient cycling requires an additional indicator, here we propose the Cycle Count indicator to address this knowledge gap.

In this policy brief we explain how nutrient cycling within agricultural production can be assessed and explore how it can be improved. For this purpose, we focus on N cycling in the Netherlands and Flanders (Belgium). In the Netherlands and Flanders, agriculture has a high level of intensification with high N inputs and large N losses to the environment.

Using a N balance, we compare environmental, productivity and circularity performance of intensive and extensive Dutch dairy farms. In addition, we assess the potential of manure processing and digestion for improved N cycling at regional level in Flanders.

2. How to define a nutrient cycling indicator

To assess N cycling we use a recently developed indicator called Cycle Count (van Loon et al. 2023). Cycle Count indicates the number of cycles a nutrient, for example N, makes through an agricultural system before leaving the system (being either an agricultural field, a farm or a region; Figure 1). In agriculture, N can enter a system directly as synthetic fertilizer, externally sourced animal manure, feed, through deposition or through biological fixation. Nitrogen can leave a system as a loss or as a product. Finally, N can cycle in a system via re-use of manure, co-products or return of crop residues (Figure 1).

If N is cycled in an agricultural system instead of lost, it contributes to more product produced on a field, a farm or in a region. In this manner, a larger Cycle Count will go along with higher N use efficiency. In Figure 1, the blue arrows are direct flows while the green arrows indicate cycled flows.

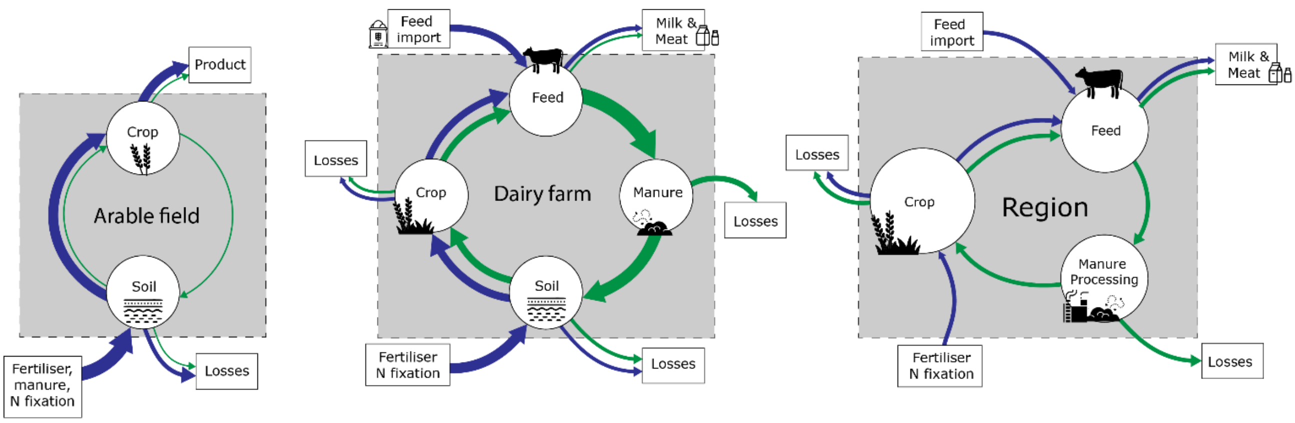

Figure 1. Conceptual overview of nitrogen cycling at three scales. Blue arrows indicate direct flows and green arrows indicate cycled flows.

3. How to assess nitrogen cycling: Benchmarking Dutch arable and dairy farms

Cycle Count is the number of cycles a nutrient, for example N, makes through an agricultural system before leaving the system (being either an agricultural field, a farm or a region).

Nutrient efficiency is the ratio between nutrients in outputs (agricultural products) and those used as inputs (fertilizer, manure) (i.e., N output:N input)

Dutch arable farms

Dutch arable fields show a wide variation in N efficiency and N cycling (Figure 2), depending on the crop composition and management of the field. Arable farmers who cultivate cover crops and return crop residues to their fields have higher N efficiency and higher N cycling as long as N delivery from crop residues is accounted for in the fertilisation. In addition, the choice of crop also matters. Cultivating crops with a low N uptake efficiency such as potatoes normally also leads to a high N surplus and less N cycling.

Here, Dutch arable farms with an average size of 160 ha were investigated, with crops including sugar beet, potato, winter wheat, and spring barley. On the arable farms, mineral N fertilizer contributions ranged from 0% to 60% of the total N inputs, with an average of 84 kg N//ha. Average organic fertilizer application was 132 kg N/ha. Crop residues and cover crops were considered cycled flows. System outputs consist of crop yields, along with removed co-products like straw and N losses such as nitrate leaching.

Dutch dairy farms

Dutch dairy farms have a smaller variation in N cycling compared to arable farms (Figure 2) and can reach less cycling because more N losses occur. At the same time, the lower range for N cycling is higher on dairy farms than on arable farms because there is always some degree of cycling through on-farm manure application.

The mean farm size of the Dutch dairy farms was 60 hectares with 77 young stock and 127 dairy cows, producing roughly 8,500 kg milk per cow per year. Total N inputs include feed for the cows (concentrates, roughages) and fertilizer for the soil. Nitrogen outputs are milk and meat, but also some manure export and gaseous losses of ammonia (NH_3) and nitrous oxide (N_2O) and nitrate (NO_3) leaching from soil.

The key message is that the farm structure matters: Dutch dairy farms which grow their own animal feed and those who use less N fertilizer have comparatively higher N cycling.

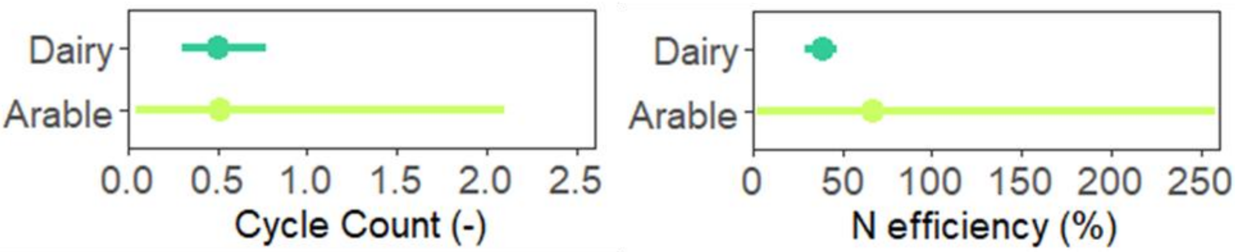

Figure 2. N efficiency and Cycle Count for Dutch arable fields (sample size 782 fields for the year 2022 obtained from 39 farms) and Dutch dairy farms (sample size 284 obtained from 27 dairy farms for the years 2006 – 2022).

4. Productivity, nitrogen cycling and greenhouse gas emissions

For Dutch dairy farms, we also studied the differences in productivity, N cycling and greenhouse gas emissions for extensive and intensive farms (Figure 3). On average, extensive dairy farms had more on-farm cycling, with a 93% higher Cycle Count and 54% less greenhouse gas emissions per hectare compared to intensive farms, but had similar greenhouse gas emissions per liter milk.

The extensive dairy farms had an average total N input of 233 kg/ha while the intensive dairy farms had an average total N input of 589 kg/ha. Extensive farms also produced 56% less milk per hectare (i.e. 16,439 kg milk/ha less). Thus, extensive dairy farms scored better on circularity indicators, while scoring lower on the productivity indicators compared to intensive farms.

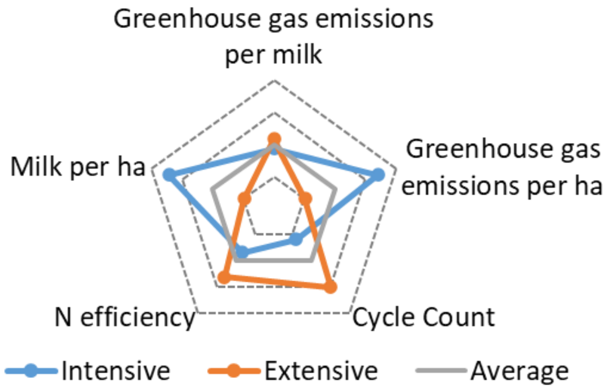

Figure 3. Productivity, N cycling and greenhouse gas emission on intensive (blue line; sample size 60, milk production above 24,000 kg/ha), extensive (orange line, sample size 88, milk production below 15,000 kg/ha) and average performance of all Dutch dairy farms (grey line; sample size 284).

5. How to improve nitrogen cycling at regional scale: The potential of manure digestion

One of the possible interventions to increase N cycling is anaerobic digestion of animal manure. Digestion of manure whether combined with further processing of digestate (e.g. separation/stripping) or not, leads to less gaseous emissions (e.g. NH_3) in the stable and improves the application efficiency, as N in digestate is more readily available for uptake than N in undigested manure. This will decrease demand for mineral fertilizer N and therefore increase N cycling.

Different scenarios were explored. For the Netherlands only the dairy sector was included in the analysis, while for Flanders, both the beef and dairy sector were included. In both cases, the impact of manure digestion was compared to a reference in which no manure is digested (business as usual or reference scenario), either with or without NH_3 stripping/scrubbing from the liquid fraction (with the N stripped used as mineral N fertilizer). For Flanders, the effect of treating the effluent from stripping/scrubbing with nitrification and denitrification (NDN) was also assessed. Note, that the results between the Netherlands and Flanders are not directly comparable as they are based on different system boundaries and assumptions.

The Netherlands

Anaerobic digestion of manure combined with separation/stripping/ scrubbing on Dutch dairy farms decreases N losses in the Netherlands, especially NH_3 emissions.

The national use of mineral fertilizer N can be reduced by 6-9% with this intervention (Table 1).

Table 1. For the Netherlands, changes in on-farm emissions, mineral fertilizer use and soil N balance when all manure from dairy farms is digested and stripped/scrubbed. Reference values refer to whole agricultural sector with emissions only from manure and fertilizer use.

	NH_3 emissions (kt/yr)	N_2O emissions (kt/yr)	Mineral fertilizer N use (kt/yr)	Soil N balance (kt/yr)
Reference	87.7	9.41	245	245
Manure digestion and separation + stripping/scrubbing	-11 to -19%	-2.4 to -2.9%	-6.3 to -8.8%	-3.0 to -3.1%

Flanders

Currently, 30% of N in manure applied in Flanders is lost through leaching and air emissions (mainly as N_2, NH_3, N_2O) (Figure 4). The use of anaerobic digestion with stripping (AD+SS) has the largest environmental benefits with 21% less N emissions, 17% less N leaching and 13% less N mineral fertilizer use in Flanders. In this scenario, N cycling improved with 13% and N efficiency with 13%. Treating the effluents with nitrification and denitrification (AD+SS+NDN) led to less leaching, but did not reduce emissions and not reduce N fertilizer use and is therefore not recommended.

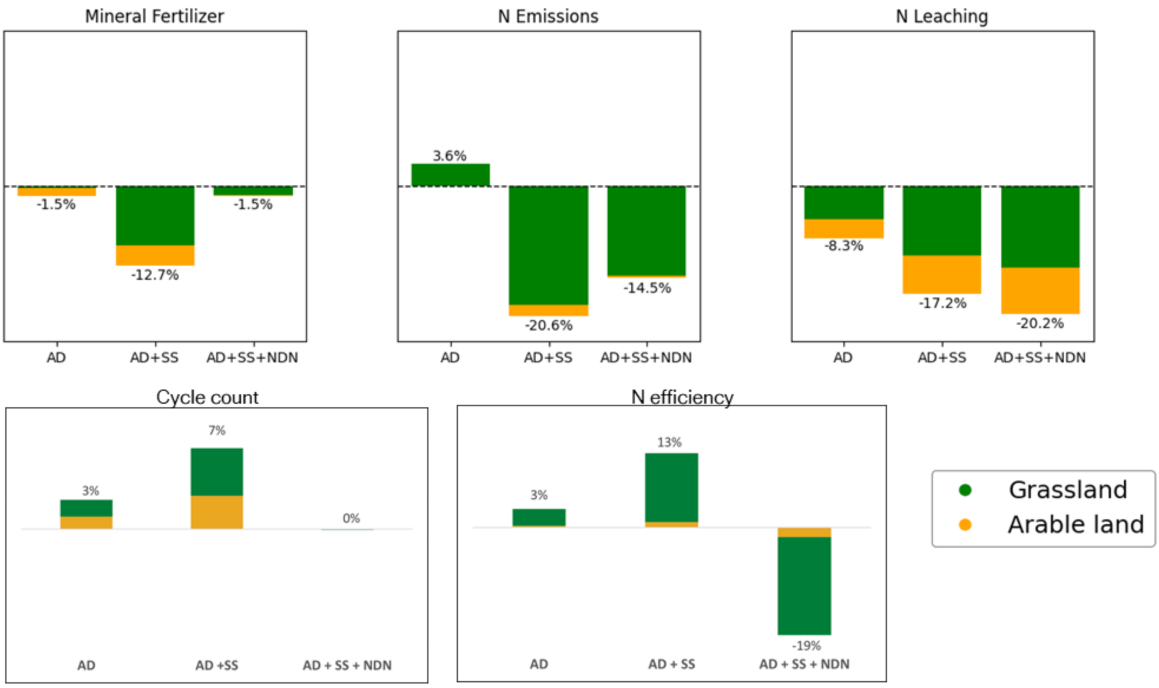

Figure 4. For Flanders, percentual changes when all manure from the dairy and beef sector is digested. Business as usual Cycle Count is 0.207 and N efficiency is 49.6%. N emissions include N_2, NH_3, N_2O and NO_2. AD = Anaerobic Digestion; SS = Stripper-Scrubber of NH_3 from the liquid fraction; NDN = Nitrification Denitrification treatment of effluent before land application.

6. Implications

Using different examples, we show how N cycling in agriculture can be assessed by constructing N balances and the Cycle Count indicator at farm and regional scale. Comparing extensive and intensive Dutch dairy farms, we see that extensive farms have more N cycling and less greenhouse gas emissions per hectare, but also a lower productivity per ha of land and the same emissions per kg milk. This indicates a synergy between N cycling and greenhouse gas emissions, but a trade-off with agricultural land use.

A more technical option to improve cycling and reduce emissions is the anaerobic digestion of manure. Using two modelling studies, we showed that stripping/scrubbing of manure leads to more regional N cycling, both in Flanders and the Netherlands. These findings will most likely be similar for other countries with intensive livestock systems. We illustrated how the combined use of efficiency, surplus and cycle count indicator provides a comprehensive assessment of nutrient cycling, environmental performance and productivity of different systems.

Acknowledgements

We would like to thank all the dairy farmers participating in the Koeien en Kansen project and all the arable farmers participating in the KPI project.

This research is funded by the GRA project Benchmarking nutrient circularity at different scales: using a food systems perspective

Date published April 2024

Main data sources used

General

Van Loon, M. P., Vonk, W. J., Hijbeek, R., van Ittersum, M. K., & ten Berge, H. F. M., 2023. Circularity indicators and their relation with nutrient use efficiency in agriculture and food systems. Agricultural Systems, 207, 103610. https://doi.org/10.1016/j.agsy.2023.103610

Picture cover page, Marloes van Loon

Dutch arable farms

KPI projects

Nutrient Balance Arable farming version 2.4

Dutch dairy farms

Kringloopwijzer (Koeien en Kansen farms)

Regional analysis for the Netherlands

CBS (Statline)

www.emissieregistratie.nl

Gollenbeek L.R., J.P.B.F. van Gastel, F.A.M. Casu, I. Huisman, N. Verdoes, 2022. Berekeningen emissies en economie voor verschillende scenario's voor verwaarding van rundveemest; NL Next Level Mestverwaarden. Wageningen Livestock Research, Openbaar Rapport 1372.

Schulte-Uebbing, G.L. Velthof and T. van der Zee, 2023. Emissies naar lucht uit de landbouw berekend met NEMA voor 1990-2021. Wageningen, The Statutory Research Tasks Unit for Nature and the Environment (WOT Natuur & Milieu), WOt-technical report 242.

Van Bruggen, C., A. Bannink, A. Bleeker, D.W. Bussink, H.J.C. van Dooren, C.M. Groenestein, J.F.M. Huijsmans, J. Kros, L.A. Lagerwerf, K. Oltmer, M.B.H. Ros, M.W. van Schijndel, L.

Regional analysis for Flanders

https://cdn.digisecure.be/vcm/2020115133544568_191572-brochure-oplossingen-mestoverschot-eng.pdf

Mălinaş, A., Vidican, R., Rotar, I., Mălinaş, C., Moldovan, C. M., & Proorocu, M. (2022). Current status and future prospective for nitrogen use efficiency in wheat (Triticum aestivum L.). Plants, 11(2), 217.

Vingerhoets, R., Spiller, M., De Backer, J., Adriaens, A., Vlaeminck, S. E., & Meers, E. (2023). Detailed nitrogen and phosphorus flow analysis, nutrient use efficiency and circularity in the agri-food system of a livestock-intensive region. *Journal of Cleaner Production*, *410*, 137278.