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Expert workshop on re-evaluating the potential nitrogen recovery of different manure categories

Workshop summary

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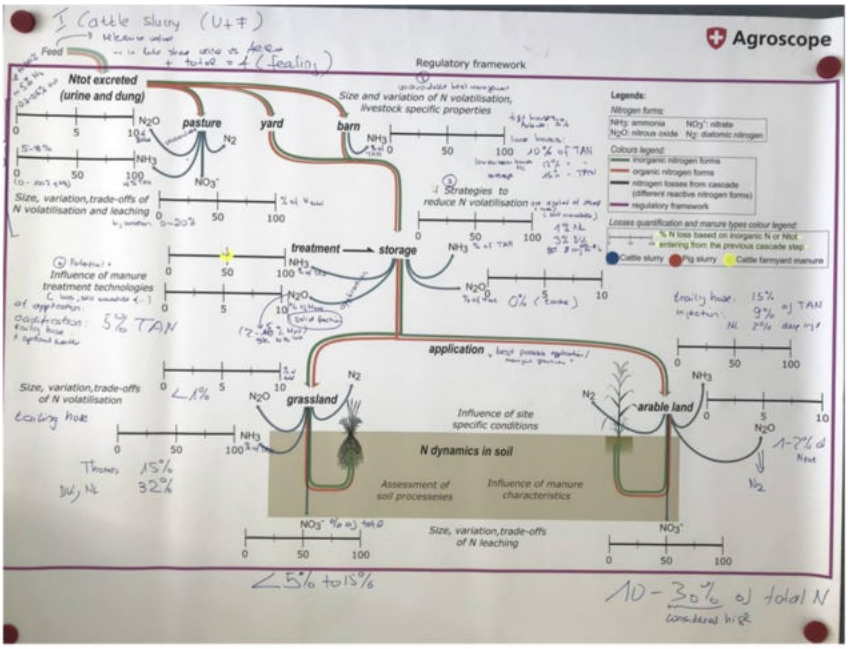

Workshop structure: via keynotes, short-inputs and group works we followed the different nitrogen forms along the manure cascade and after application.

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A key information the farmer needs to know for fertiliser planning is, how much of the total nitrogen (N) excreted and transformed into organic fertilizers can potentially be taken up by the crops. This requires bundling the available scientific knowledge on animal nutrition, the potential N losses along the manure cascade, i.e. from excretion to and including application, and the potential long-term N recovery after field application. During the expert workshop Re-evaluating the potential nitrogen recovery of different manure categories, held on 4 – 6 May 2022 at Agroscope in Switzerland, we identified ranges of reactive N losses reduction potentials along the manure cascade, which can be achieved through the implementation of specific agricultural practices. Subsequently, we discussed possible strategies to assess the potential N recovery after application of manure in the field (Fig. 1). Thanks to the different perspectives, based on country and specialisation, we were able to collect a broad spectrum of knowledge. Additional to this workshop summary, an in-depth review on the potential of N recovery of selected manure categories in livestock systems will be prepared in a follow up.

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Objectives of the workshop

The main objective of the workshop was to re-evaluate the N recovery concepts and assessment strategies along the manure cascade from animal excretion to crop N recovery.

Four main thematic blocks were discussed:

1. Defining the manure quality according to livestock and manure management choices along the manure cascade: Drivers and levers to reduce ammonia (NH_3) and nitrous oxide (N_2O) emissions and nitrate (NO_{3-}) leaching.
2. Manure treatment strategies: potentials to reduce NH_3 and N_2O emissions and NO_{3-} leaching and effects on manure characteristics and scaling potentials.
3. Assessing the potential manure N recovery after application: current knowledge and challenges of the N dynamic assessment in the soil.
4. Regulatory fertilisation measures in selected countries: Obstacles and opportunities of fertilisation laws adaptations on manure management strategies.

The current knowledge was retrieved from nine keynote (KN) and 12 short-input (SI) talks (List at page 6) and complemented with plenary and additional notes. The first three topics were associated with a particular location along the manure cascade.

Workshop topic blocks

Animal nutrition

While the specific subject of animal nutrition was excluded from the workshop program, it entails a very important information for the assessment of the overall system efficiency. It was mentioned as highly important by several participants and was introduced in the short-inputs on animal housing and pasture. A balanced energy-protein feed ration markedly decreases the potential N emissions (SI1_A, slides 13-14: Schrade), as less N, with a lower ammonium: total N (Ntot) ratio is included in the system from the start. Achieving this is particularly complicated within part time grazing systems (example on feeding with grazing in SI1_B, slide 9-14: Ammann).

Animal housing

Animal housing, slurry/manure storage and slurry application are key contributors to ammonia (NH3) emissions at the farm level (KN1_1: Kupper). The presentation in the workshop focused on mitigation measures investigated in the experimental dairy housing for emission measurements (SI1_A: Schrade). Further measures and other animal categories (pigs, poultry or small ruminants) were not mentioned. Preliminary results from the experimental dairy housing for emission measurements in Tänikon show that by floors with 3% gradient and urine-collecting gutter cleaning reduces the NH_3 emissions by 23-37% compared to solid floors without slope (SI1_A, slides 5-6: Schrade). Furthermore, first results of feeding stalls (i.e. raised standing surface with partitions) were presented and showed 8-16% NH_3 reduction compared to a housing system without feeding stalls (SI1_A, slides 7-8: Schrade). However, animal housing facilities last for several decades, which means that adaptations at the housing level are less rapidly implemented.

Manure storage

Livestock category, diet, livestock holding system and dilution are important factors influencing manure quality (SI2_B, slide 3: Williams) and subsequently the potential for gaseous losses from manure in form of NH_3 and/or N2O. While the effects of manure quality changes on NH_3 storage emissions can be predicted fairly well, potential changes in N_2O volatilisation and total denitrification to di- N (N_2) are more difficult to quantify, because in this case there are several processes involved (KN2_1, slide 11, Velthof). Measures to reduce N losses at the storage level can roughly be divided in construction measures and manure treatment strategies. Through both, building measures and treatment the manure properties are changed, which can potentially change the N dynamics during and after application, causing pollution shifts (e.g. decreased NH_3 emissions during storage, and then increased NH_3 emissions during application when using a broadcast slurry spreader). During the workshop, the presenters focused on the following measures at the storage level: slurry tank coverage, crust formation (SI2_A, slides 3 - 7: Kupper), anaerobic digestion (SI2_A, slide 8: Kupper), solid-liquid separation (SI2_A, slide 8: Kupper; SI2_B, slide 7: Williams), and slurry acidification prior or during field application (see section application; SI2_A, slide 8: Kupper, SI2_B, slide 9: Williams; SI2_C, slide 11: Krol, WS2_Notes_Plenum, slide 11: Krol).

Impermeable structural covers can reduce the NH_3-Emissions by approximatively 80%, impermeable synthetic floating covers by approximatively 48% and natural crust by approx. 43% (SI2_A, slides 4 - 5: Kupper). In contrast, N_2O emissions tend to increase with structural changes. However, particularly for N_2O, robust experimental data are somewhat sparse, particularly depending on slurry type (pig vs. cattle) and construction measure (SI2_A, slide 4: Kupper). Therefore, the results must be treated with caution and need further evaluation.

Based on the available experimental data, anaerobic digestion, solid-liquid separation and dilution have the opposite effect than construction measures, i.e. tendency to increase the potential NH_3 emissions and decrease N_2O emissions (SI2_A, slide 8: Kupper), which is caused by the changes in slurry quality. The solid-liquid separation enables a more targeted and precise application of different plant nutrients (SI2_B, slide 7: Williams). The liquid fraction has a similar fertiliser N recovery as the original slurry, while the solid fraction can be used as soil conditioner (organic fraction) with a similar N effect as solid manures (KN2_2: Möller). Still, reduction of N losses, from the remaining N in the solid fraction is a major challenge. The fertiliser N recovery is significantly higher in a crop with a long crop cycle (maize) than in spring wheat with a short growth cycle. Transportation volumes and weight can be reduced and through the utilisation as substrate for digestion in biogas plants energy can be obtained (KN2_1, slide 5: Velthof). Even though N_2 itself is harmless, considerable N_2 losses may be produced from solid manure or farmyard manure, but are difficult to quantify, because they cannot be measured directly.

Manure application

The dilemma of pollution shifts is also evident at the application stage. Numerous factors influence NH_3 emissions during field application, and include manure and soil properties, meteorological conditions, method and rate of application as well as crop structure (SI2_C, slide 2: Krol). Initial direct NH_3 emissions can be markedly reduced through the utilisation of low-emission application techniques (e.g. trailing hose, injection; SI2_C, slide 5: Krol), even though the NH_3 emissions differences with the splash-plate seem to be reduced over time (SI2_C, slide 6: Krol). A reduction of the NH_3 emissions during application simultaneously leads to reduced indirect N_2O emissions, as less N derived from NH_3 is translocated and deposited on land (SI2_D, slide 8: Richards). However, through improved manure management and treatment at the storage level, highly concentrated slurry applications through injection may cause a hotspot for increased N_2O emissions (KN2_1, slide 19, Velthof). The N_2O emissions hotspot is by trend lower compared to the reduced indirect N_2O emissions, but may lead to increased NO_3^- leaching even though detailed evidence was not identified during the workshop. In order to counteract the N_2O emissions from slurry application in the field, soil liming represents a possible soil management opportunity (SI2_D, slide 6: Richards), which however leads to potentially increased NH_3 emissions (SI2_C, slide 11: Krol). Another, somewhat disputed measure to decrease N_2O emissions is through addition of nitrification inhibitors. This addition may simultaneously increase NH_3 emissions and needs accurate handling in practice (SI2_D, slide 5: Richards). Moreover, its long-term effects on soil biology are still unclear.

Slurry acidification is a known slurry treatment procedure, which can reduce the risk of NH_3 losses by over 70% (SI2_B, slide 9: Williams; SI2_C, slide 11: Krol). Slurry acidification requires specific knowledge on concentrated acid handling, and has to be maintained by specialists (WS2_Notes_plenum, slide 5). Acidification can be applied in the midterm storage of the barn or the seasonal storage capacities. However, due to high buffer capacities of the manure that requires much larger acid quantities than acidification prior to application.

On arable land the total potential N emissions reduction is mostly based on a meticulous fertilisation plan, including low-emission application techniques, split fertilisation (where possible) and a crop rotation including cover crops. Fertilisation planning should integrate local conditions such as yield expectations, climate, growing patterns of crops and their N response and particularly the release of N from plant residues, soil and different fertiliser types (SI1_D_Knigge-Sievers, KN1_2_Frick). Especially on sandy soils, NO_3^- leaching, as well as N_2O emissions, are clearly linked to fertilisation exceeding the actual plant uptake. On clay-rich soils these effects can be masked by immobilisation, but nevertheless, contribute strongly to leaching by subsequent release, if the inputs repeatedly exceed the crop requirements.

Pasture and permanent grassland

The small surface exposure, as well as the fast urine penetration, which reduces it's contact with air before contact with the urease enzyme and urea hydrolysis, lead to a reduction of NH_3 emissions during grazing (SI1_B, slide 8: Ammann). At the same time, the heterogeneous and preferential spatial distribution leads to low N recovery potentials of the excreta (SI1_B, slide 8: Ammann), because the crops cannot take up the high amounts of N. Between regions (country) and farms we find diverging pasture management and fertilisation strategies (notes from final plenary discussion), which is reflected in the broad ranges of NH_3 emission amounts in literature (between 2.7 – 23% of excreted total ammoniacal N; SI1_B, slide 8: Ammann). This also means that the risk of N_2O emissions and NO_3- leaching under urine patches is not necessarily the same for each region and differences also exist among farms (notes from final plenary discussion). A particular knowledge gap in pasture systems remains in the N_2 losses. Available results can therefore only partially be scaled or applied to other pasture management systems.
Permanent grasslands can be managed at different intensities, and through fertilisation after each forage cut, crop nutrient requirements and availability can be better synchronized. Through the establishment of multispecies swards, including grass, clover and herbs, a deep rooting system can be developed and consequently the NO_3- leaching potential reduced. This can potentially also lead to an overall decrease of N_2O emissions (SI2_D, slide 4: Richards).

Long-term manure nitrogen recovery

In most cases, manure is applied repeatedly, year by year, on the field. A series of factors influence the potential N losses during the year of application as well as the soil biological activity, and therefore how much of the N applied can potentially be recovered during the year of application, and thereafter. The long-term N recovery is usually estimated by long term field experiments or through scientific models. Essential model inputs include manure properties (dry matter, total N content, C:N-ratio, type of C molecules), soil characteristics (type and particularly clay content, moisture, pH, SOM content, C:N-ratio), climate (temperature fluctuations, rainfall, evapotranspiration), soil management practice (tillage, manure application method, incorporation method, mechanical weed control, time of application, fertilising history), as well as crop type (annual or permanent as well as legumes or non-legumes) (compiled from different slides of KN3_2 Sørensen, KN3_1 Epper, SI3_A: Thuriès, SI3_B: Zavattaro, SI3_C: Bhogal, SI3_D: Cavalli). This extensive list of parameters highlights the difficulty of uniquely defining the potential N recovery. Indeed, in literature we find tailored definitions, based on the study aim and the available information. In this case, the potential N recovery is defined as the sum of readily plant available N and N mineralized from the organic N fraction, assuming a steady state after repeated, regular application and spreading according to best agricultural practice, over a period of time. In other instances it is defined as a mineral fertiliser equivalent, i.e. the sum of N taken up by the plant from the applied organic fertiliser compared to the sum of N taken up by the plant from applied inorganic fertiliser.
The MANNER-NPK tool, for instance, uses a series of influential manure characteristics (nutrients and dry matter content), management practices (application and incorporation method, including timing), soil characteristics (volumetric moisture content) and climate data (rainfall) to estimate the crop available nutrient supply for the year of application and the following year (SI3_C, slides 9 – 12: Bhogal). This tool represents an excellent example of how scientific knowledge can be brought into practice. It focusses on the application year and the following year, which seem to correspond to the highest N mineralisation period (SI3_C, slide 7: Bhogal), while it might still neglect part of the overall N recovery. The evaluation of long-term experiments and the calculation of specific indicators highlighted that particular climatic and soil conditions promote N mineralisation of the applied organic fertiliser, and play an important role in yield and N uptake (SI3_B: Zavattaro; KN_3_2: Sørensen). Therefore, by combining short- and long-term N recovery potentials, the overall N recovery can be estimated.
Laboratory and incubation data can be used to calculate manure characteristics indicators and typologies, to better estimate the N dynamics in the soil (e.g. potential N mineralisation rate based on the Carbon speciation abundance; SI3_A, slide 4: Thuriès). The utilisation of manure subgroups to calibrate N dynamic models is, however, not always applicable. Manures of the same group can differ in characterisation (SI3_A, slides 10 – 11: Thuriès), which is influenced amongst others by different feeding and manure management strategies. Therefore, laboratory analysis

and incubation experiments can give useful insights on the initial manure N dynamics after application, but should ideally be used individually for model calibration (SI3_A, slide 13: Thuriès). Additionally, because of the reactive nature of N, it remains difficult to precisely assess the N contents in manures under farm conditions (e.g. sensitivity to gaseous losses; SI3_A, slide 21: Thuriès).

Implementation in practice and at the policy level

Farmers need robust estimates of how much of the N applied in the manure is potentially available for crops to ensure productivity. Legal enforcement needs robust evidence in combination with controllable information to maintain or regain environmental quality or services. Decision support tools are often based on scientific models or real farm data and play an important role in mediating the complex knowledge between farmers and legislation. Making local and timely information available for fertiliser planning, decision making and prognosis are key elements to increase acceptance and implementation in practice and to support environmental monitoring as well as legal enforcement reports (SI3_D_Cavalli, and discussion). However, whatever tools are used, they should be accompanied by measures of knowledge transfer and by extension services helping the farmers to access the latest information and adopt new farm management measures and methods. Additionally, methods of precision farming using sensors or remote sensing may be implemented in such tools and further increase their reliability with respect to local adaptation of crop production and fertilisation efficiency (SI3_D_Cavalli and discussion/notes).
In the workshop, three examples of policy frameworks were presented including their basis, main problems and advantages, as well as possible future development of the legal enforcement. Keynote 4_1 "The current fertilizer regulatory system in Switzerland: strengths, weaknesses and future adaptations" highlighted that current numbers used for nutrient balancing and the paper-based accounting system are insufficient to fulfil the current demand for legal nutrient enforcement (KN4_1: Hunkeler). The vision of a national digital farm-based accounting system for nutrients was presented in "The Regulatory framework in Denmark, - Successes & challenges of the Danish fertilization reports" (KN4_2: Christel). The Danish nutrient accounting system is based on the relative utilization of manure N compared to using mineral N fertilisers (low ammonia emission N fertiliser as reference) and having norms for mineral N fertiliser application for each crop type. Decades of feedback driven adaptation of the regulatory system lead to the main drivers being efficient for nutrient surplus and loss reduction on national scale. Finally, the German contribution "Dealing with NO_{3^-} vulnerable zones: regulatory tools to complement the general fertilizer decree" showed the actual regulation in the Nitrate vulnerable zones, their development and integration in the European nitrate directive (KN4_3: Hofmeier). From the talks and the plenum discussion important parameters that should be part of a successful regulatory framework reducing N and phosphorus surplus and losses were derived as follows:

- obligatory and digital field scale fertilizer plan and accounting (eventually accompanied by a farm nutrient balance),
- up to date and strict fertilisation standards (reflecting best practice to foster innovation),
- restrictions and bans during certain periods of time or conditions of land (winter, frozen or saturated soil etc.),
- obligatory use of catch crops and buffer strips,
- regulations for infrastructure (sufficient storage volume) and
- regulations for machinery (e.g. no broad spread tech for slurry).

These measures should be accompanied by a clear and consistent communication integrating all stakeholders from farmers, farm advisory and extension services, water suppliers and managers to federal decision makers.

Conclusions

The workshop highlighted possible ranges of action based on different measures to reduce the N losses along the manure cascade. It also emphasised trade-offs between different N forms and their loss potentials, which have to be kept at the back of one's mind when implementing a new reduction measure. Therefore, when assessing the potential N recovery of manure, there is no 'one value fits all'. The aim should rather be to give a set of tools, which farmers can implement and the legislation should promote, in order to reduce the N losses to the environment. Additionally, the country specific regulatory frameworks underlined different approaches in accounting for N in fertilisers, and serve as inspiration for further development of the Swiss regulatory framework and to foster future exchange between farmers, extension, regulatory authorities and research.

The workshop as a starting point for a scientific review paper

National regulations and reduction measures are ultimately implemented at farm level. The final workshop synthesis session highlighted differences among countries regarding the regulations along the feed, manure to crop cascade. Participants integrated their knowledge on the potential to improve N recovery along the manure cascade for different animal and manure categories. At each level of the manure cascade, we can define a 'solution space', which describes the potential to improve the N recovery at the respective level.

For the review, we thus aim to first summarise and visualise the different 'solution spaces' along the manure cascade from animal nutrition to long-term recovery based on results available from literature, as well as for already implemented values in different countries at the legislation level. This way we want to make a dual comparison, among regions / countries and their actual potential to improve N recovery. Another important output of the review is aimed to be the comparison and critical discussion of well-established and new techniques to reduce N losses, and particularly on the influence on the long-term N recovery of the new methods, which will be related to the amount of reduction of N losses in the long term.

In order to assess the overall N recovery of organic fertilisers, and therefore to be able to advice farmers, we follow a system approach, where animal nutrition, housing and manure management are optimised and integrated with the scientific findings on long-term N recovery after manure application. When combining the different 'solution spaces', we obtain a farm-level apparent N recovery, which varies among farms implementation of 'bad' to 'best' agricultural practice. This final result will help us discussing the overall action potential at the farm level to reduce N losses and simultaneously increase the overall farm N use efficiency.

In the review, we will also comment on the added soil fertility value that can be achieved by the regular application of organic fertilisers, as well as highlight the limitations of manure N cycling assessment (e.g. total denitrification, inclusion of additional parameters). Finally, we will contextualise the results at the legislation (What is achievable?) and farm implementation level (e.g. consideration of site specific characteristics, fertilisation history, increase acceptance and implementation in practice).

List of keynote and short-input talks

Keynote / short-input abbreviation	Talk title (link to the presentation)	Presenter	Affiliation
KN1_1	Ammonia and nitrous oxide emissions along the manure cascade	T. Kupper	Department of Agronomy, School of Agricultural, Forest and Food Sciences (HAFL), Switzerland
KN1_2	Nitrate leaching after continuous manure application	H. Frick	Agroscope and FiBL, Switzerland
KN2_1	Effects of manure treatment on ammonia and nitrous oxide emissions	G. Velthof	Sustainable Soil Research, Wageningen University, The Netherlands
KN2_2	Potentials of manure treatment technologies on nitrogen availability and plant uptake	K. Möller	Agricultural Technology Centre, Augustenberg / Fertilization and soil matter dynamics, University of Hohenheim, Germany
KN3_1	Nitrogen recovery after manure application: concepts, challenges and modelling approach	C. Epper	Agroscope, Switzerland
KN3_2	Long-term manure N dynamics in the soil: long-term field trials as information base	P. Sørensen	Department of Agroecology - Soil fertility, Aarhus University (AU), Denmark

KN4_1	The current fertilizer regulatory system in Switzerland: strengths, weaknesses and future adaptations	J. Hunkeler	Department of Direct Payment Programmes, Federal Office for Agriculture, Switzerland
KN4_2	Regulatory framework in Denmark: Successes and challenges of the Danish fertilization reports	W. Christel	Ministry of Food, Agriculture and Fisheries of Denmark, Denmark
KN4_3	Dealing with nitrate vulnerable zones: regulatory tools to complement the general fertilizer decree	M. Hofmeier	German Environmental Agency, Germany
SI1_A	Ammonia emissions from naturally ventilated dairy housings and mitigation measures	S. Schrade	Agroscope, Switzerland
SI1_B	Ammonia emissions on pasture	C. Ammann	Agroscope, Switzerland
SI1_C	Quantity and drivers of nitrous oxide emissions during storage (or application)	D. Bretscher	Agroscope, Switzerland
SI1_D	Strategies to minimise nitrate leaching in vulnerable zones: N-Fertilisation and Intercropping:Effects on Nitrat Leaching, Results of field trials in Lower –Saxony	A. Knigge-Sievers	Chamber of Agriculture Lower Saxony, Germany
SI2_A	Strategies and technologies to reduce volatilisation during manure storage	T. Kupper	Department of Agronomy, School of Agricultural, Forest and Food Sciences (HAFL), Switzerland
SI2_B	How do we maximise nutrient value of manures	J. Williams	ADAS Helsby, United Kingdom
SI2_C	Strategies and technologies to reduce volatilisation during manure application	D. Krol	Department of Crops, Environment & Land Use, Teagasc, Ireland
SI2_D	Technologies to reduce ammonia and nitrous oxide emissions on pasture and grassland	K. Richards	Department of Crops, Environment & Land Use, Teagasc, Ireland
SI3_A	Estimation of manure N recovery based on measurable & affordable characteristics for model parameterization: field and lab data	L. Thuriès	Departement Persyst, The French agricultural research and international cooperation organization(cirad), France
SI3_B	Influence of external factors on manure N recovery	L. Zavattaro	Department of Veterinary sciences, University of Turin, Italy
SI3_C	Predicting manure N availability	A. Bhogal	ADAS Helsby, United Kingdom
SI3_D	Implementation of manure N use efficiency for farmers	D. Cavalli	Ministry of Agricultural, Food and Forestry Policies / Department of Agricultural and Environmental Sciences, University of Milan, Italy

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Berner Fachhochschule

Expert Workshop on Nitrogen recovery in manure
4 - 6 May 2022

Ammonia and nitrous oxide emissions along the manure cascade

Thomas Kupper

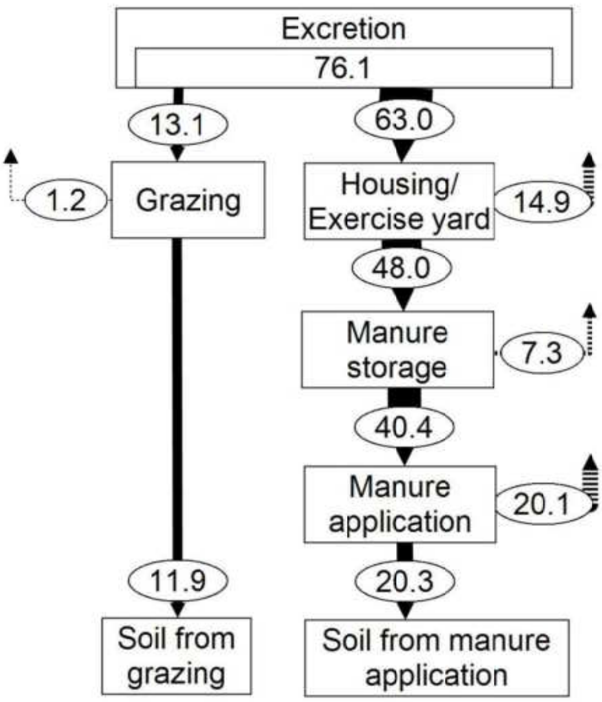
- Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften HAFL

Overview

- Introduction manure cascade/mass flow model
- Use and outcome of mass flow models exemplified by the Agrammon model
- Principles and bases of mass flow models: critical evaluation
- Emission mitigation / achievable emission reduction at individual farms
- Conclusions

- Focus on ammonia

Manure cascade:
Individual farm level or region/country level



Introduction

- Ceilings on the annual NH_3 emissions included in the Gothenburg Protocol United Nations Convention on Long-Range Transboundary Air Pollution
- Member states are obliged to regularly report emissions and achieve emission goals

Introduction

- It is impractical to measure emissions from all the sources that, together, comprise an emission inventory.

  ➔Thus, model calculations are applied by combining information on human activity (called activity data, AD) with coefficients that quantify the emissions per unit activity (denoted emission factors, EF).

  Emissions = AD x EF

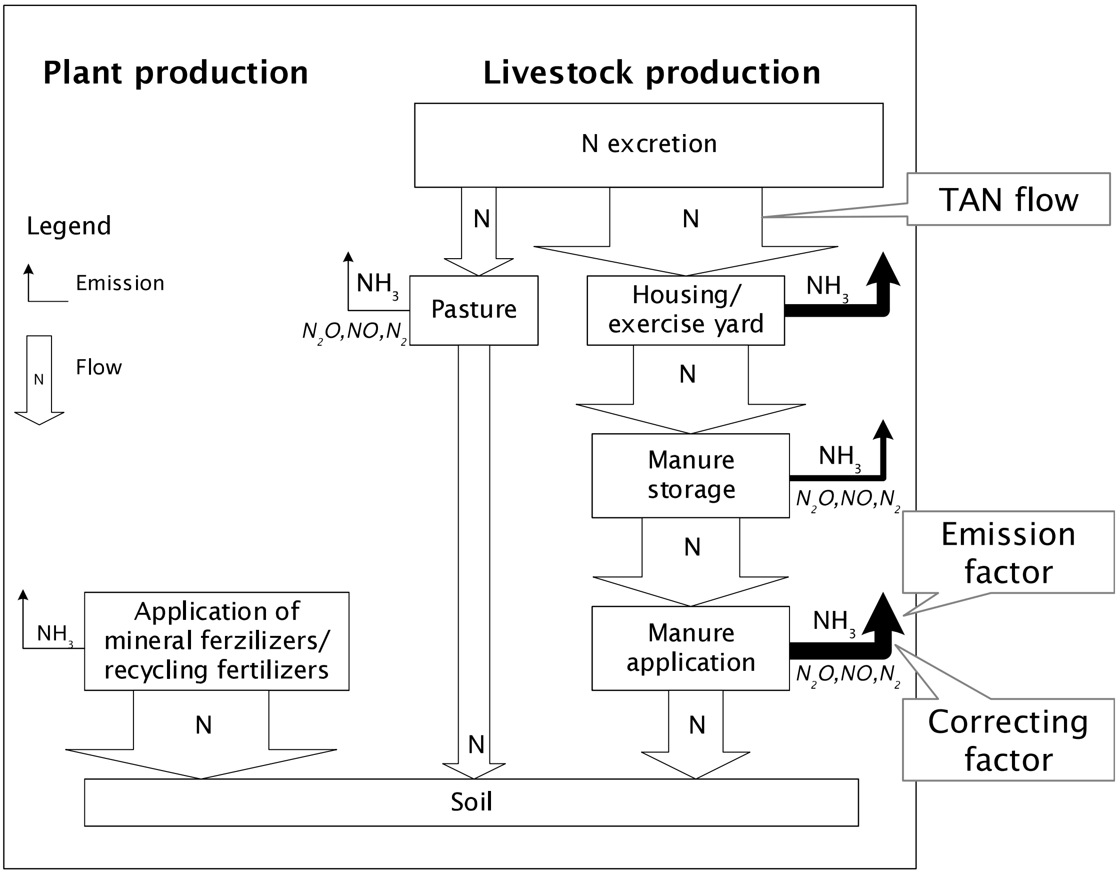
  ➔Mass flow model

Emission calculations

- State of the art for emission reporting:
  Mass flow models using a tier 1, 2 or 3 level approach
- Tier 1 methods apply a simple linear relationship between activity data and emission factors
- Tier 2 methods use the same or similar activity data to Tier 1 methods, but apply country-specific emission factors
- Tier 3 methods go beyond tier 2; these may include using facility level data and/or sophisticated models

EEA. 2019. EMEP/EEA air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. Luxembourg: European Environment Agency. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (accessed on 2022/04/25)

Tier 3 model to calculate ammonia emissions Agrammon (Switzerland)



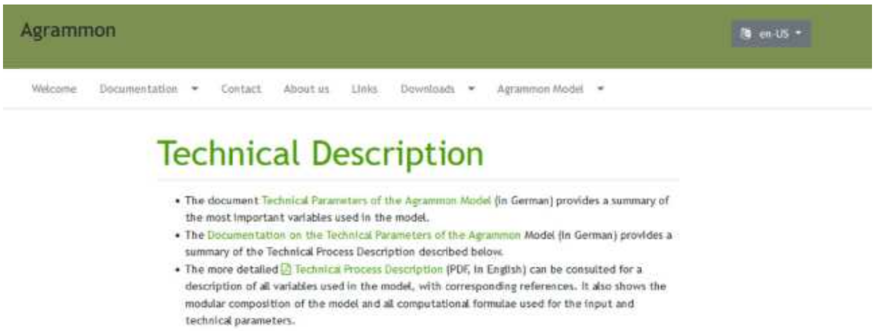
TAN = Total Ammoniacal Nitrogen ($NH_{3,L}$ + NH_4^+)

Principles of the Agrammon model

- Excretion of livestock animals, emission factors, correcting factors (in total approx. 200 parameters):
  - Based on data obtained from experiments under farm-scale conditions, farm-scale measurements in Switzerland wherever possible.
  - If not available, such data from other countries are used.
    - Where appropriate they are matched with UNECE (United Nations Economic Commission for Europe)* recommended values.
    - Data from other countries are, where necessary, adapted to suit conditions in Switzerland.
  - Where specific information was not available from the literature, expert judgement is used.

*UNECE. 2014. Guidance document for preventing and abating ammonia emissions from agricultural sources. Paper ECE/EB.AIR/120, February 7, 2014. Geneva, Switzerland: United Nations Economic Commission for Europe (UNECE).

Bases of the Agrammon model



Agrammon

en-US

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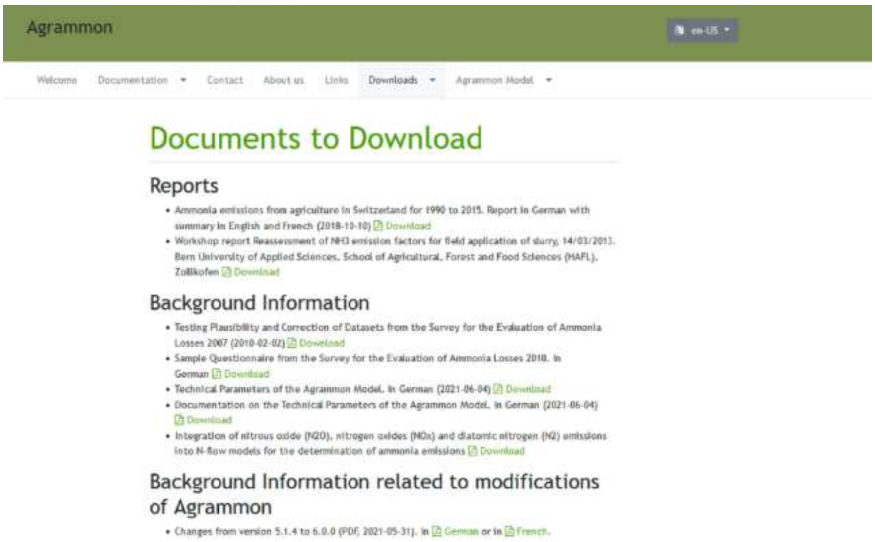
Technical Description

- The document Technical Parameters of the Agrammon Model (in German) provides a summary of the most important variables used in the model.
- The Documentation on the Technical Parameters of the Agrammon Model (in German) provides a summary of the Technical Process Description described below.
- The more detailed Technical Process Description (PDF, in English) can be consulted for a description of all variables used in the model, with corresponding references. It also shows the modular composition of the model and all computational formulae used for the input and technical parameters.



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Documents to Download

Reports

- Ammonia emissions from agriculture in Switzerland for 1990 to 2015. Report in German with summary in English and French (2018-10-10) Download
- Workshop report Reassessment of NH3 emission factors for field application of slurry, 14/03/2013. Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences (HAFL), Zollikofen Download

Background Information

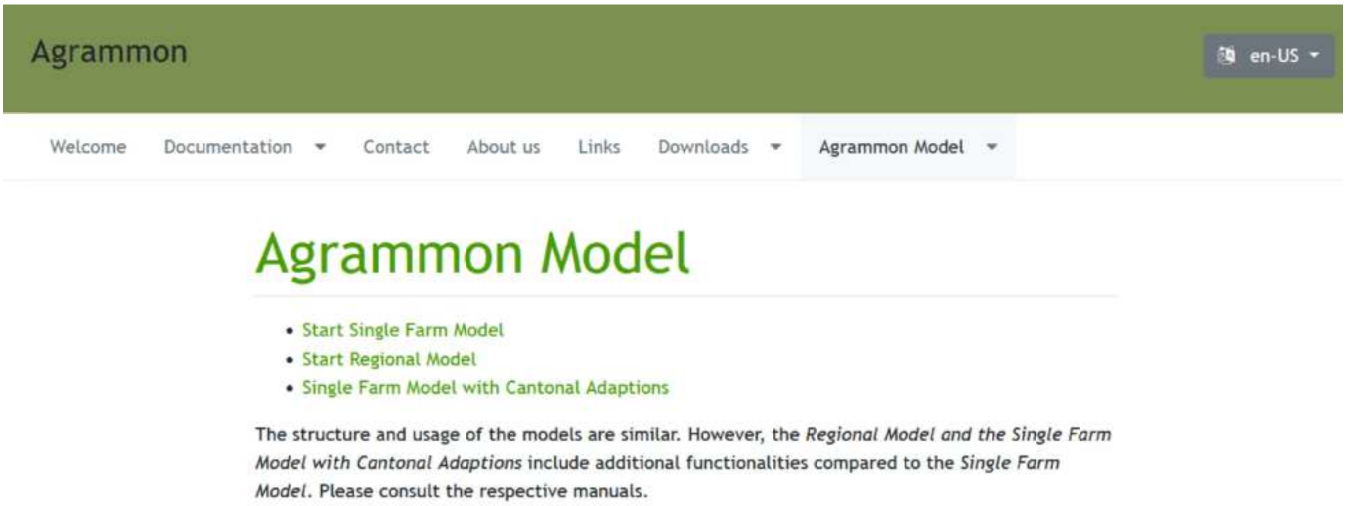
- Testing Plausibility and Correction of Datasets from the Survey for the Evaluation of Ammonia Losses 2007 (2010-02-02) Download
- Sample Questionnaire from the Survey for the Evaluation of Ammonia Losses 2010. In German Download
- Technical Parameters of the Agrammon Model. In German (2021-06-04) Download
- Documentation on the Technical Parameters of the Agrammon Model. In German (2021-06-04) Download
- Integration of nitrous oxide (N2O), nitrogen oxides (NOx) and diatomic nitrogen (N2) emissions into N-flow models for the determination of ammonia emissions Download

Background Information related to modifications of Agrammon

- Changes from version 5.1.4 to 6.0.0 (PDF, 2021-05-31). In German or in French.

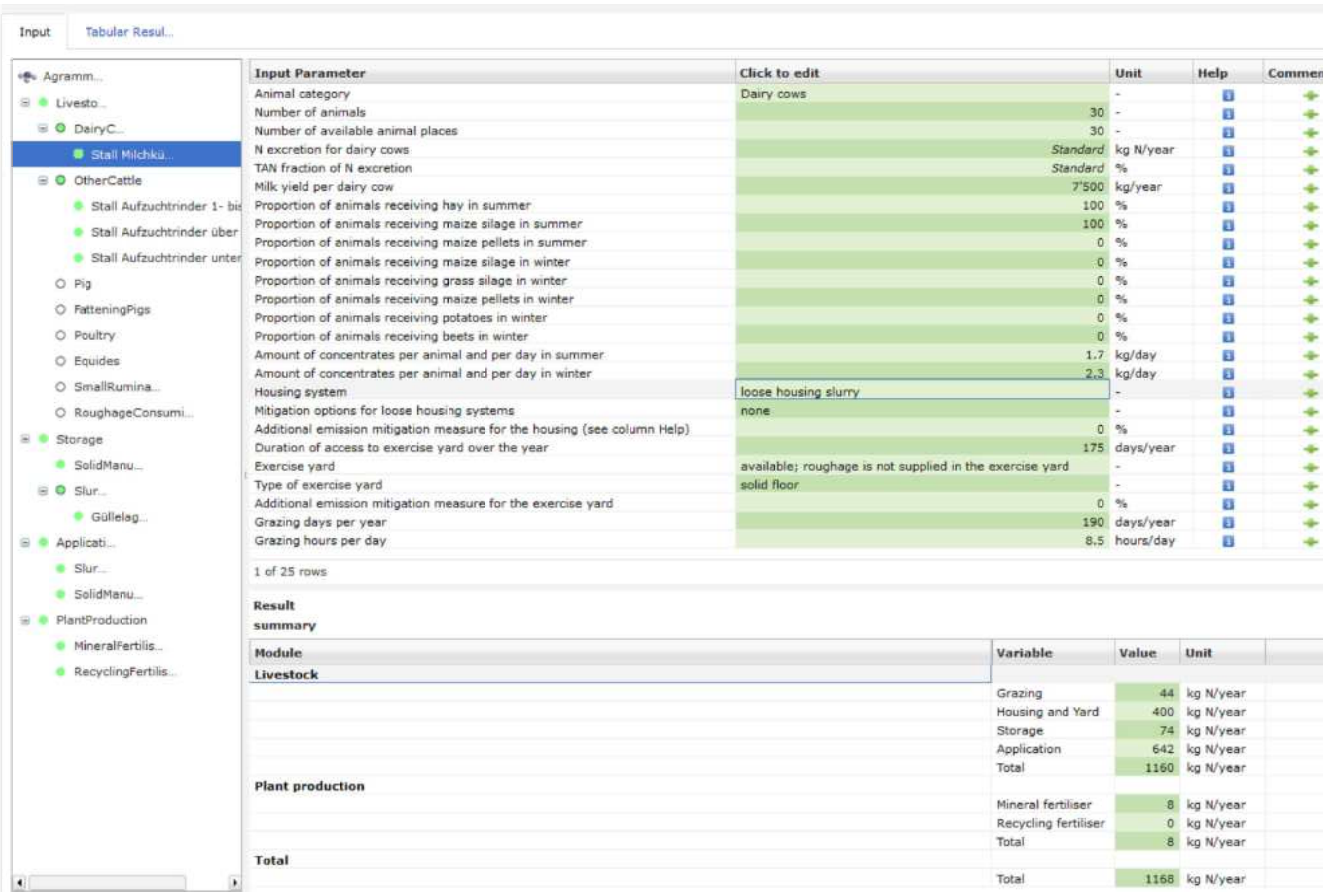
https://agrammon.ch/en/dokumentation-zum-modell/technical-description/
https://agrammon.ch/en/downloads/

Access to the Agrammon model



https://agrammon.ch/en/agrammon-model/

Agrammon model output for an individual farm

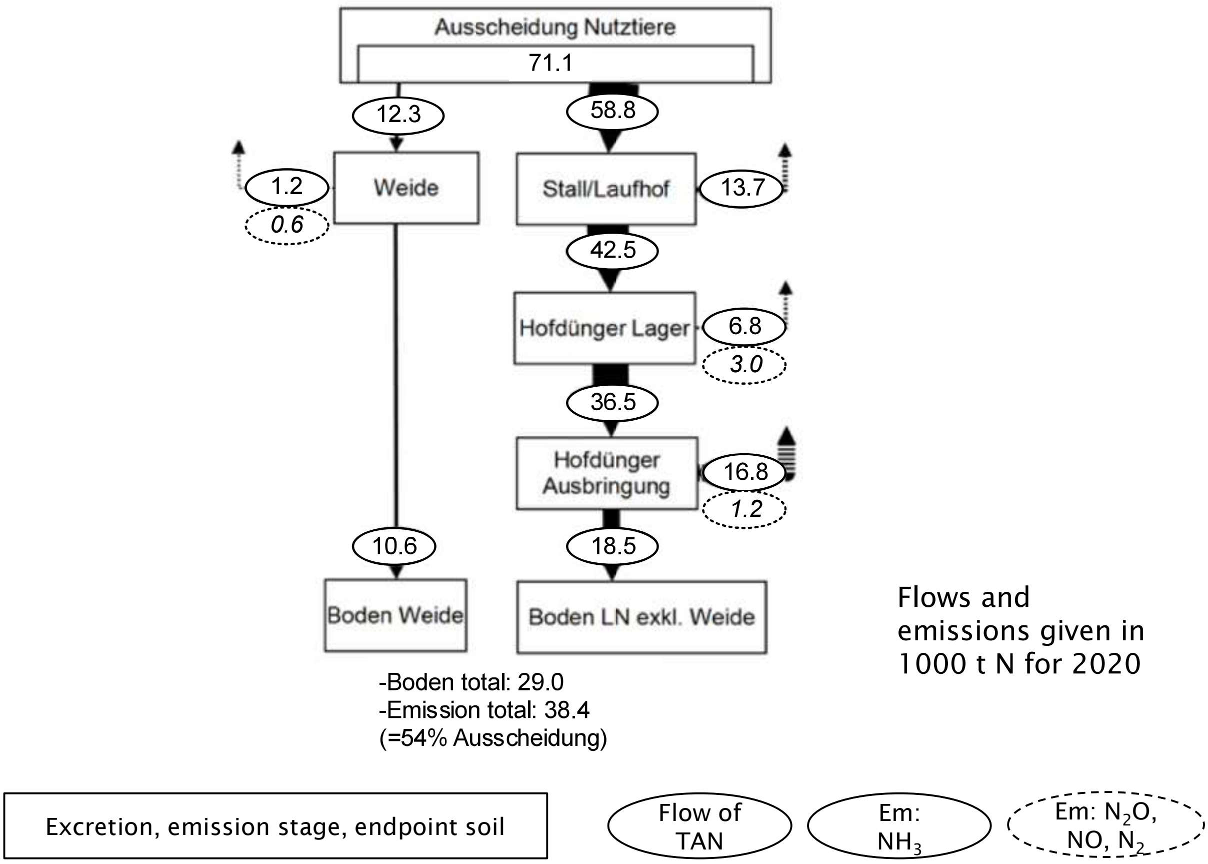


Input Parameter	Click to edit	Unit	Help	Comment
Animal category	Dairy cows	-		
Number of animals	30	-		
Number of available animal places	30	-		
N excretion for dairy cows	*Standard*	kg N/year		
TAN fraction of N excretion	*Standard*	%		
Milk yield per dairy cow	7'500	kg/year		
Proportion of animals receiving hay in summer	100	%		
Proportion of animals receiving maize silage in summer	100	%		
Proportion of animals receiving maize pellets in summer	0	%		
Proportion of animals receiving maize silage in winter	0	%		
Proportion of animals receiving grass silage in winter	0	%		
Proportion of animals receiving maize pellets in winter	0	%		
Proportion of animals receiving potatoes in winter	0	%		
Proportion of animals receiving beets in winter	0	%		
Amount of concentrates per animal and per day in summer	1.7	kg/day		
Amount of concentrates per animal and per day in winter	2.3	kg/day		
Housing system	loose housing slurry	-		
Mitigation options for loose housing systems	none	-		
Additional emission mitigation measure for the housing (see column Help)	0	%		
Duration of access to exercise yard over the year	175	days/year		
Exercise yard	available; roughage is not supplied in the exercise yard	-		
Type of exercise yard	solid floor	-		
Additional emission mitigation measure for the exercise yard	0	%		
Grazing days per year	190	days/year		
Grazing hours per day	8.5	hours/day		

Module	Variable	Value	Unit
Livestock			
	Grazing	44	kg N/year
	Housing and Yard	400	kg N/year
	Storage	74	kg N/year
	Application	642	kg N/year
	Total	1160	kg N/year
Plant production			
	Mineral fertiliser	8	kg N/year
	Recycling fertiliser	0	kg N/year
	Total	8	kg N/year
Total			
	Total	1168	kg N/year

https://model.agrammon.ch/single/?lang=en

Agrammon model output: emissions of NH_3 (N_2O, NO, N_2), flows of N, TAN



Flows and emissions given in 1000 t N for 2020

Why focus on ammonia emissions?

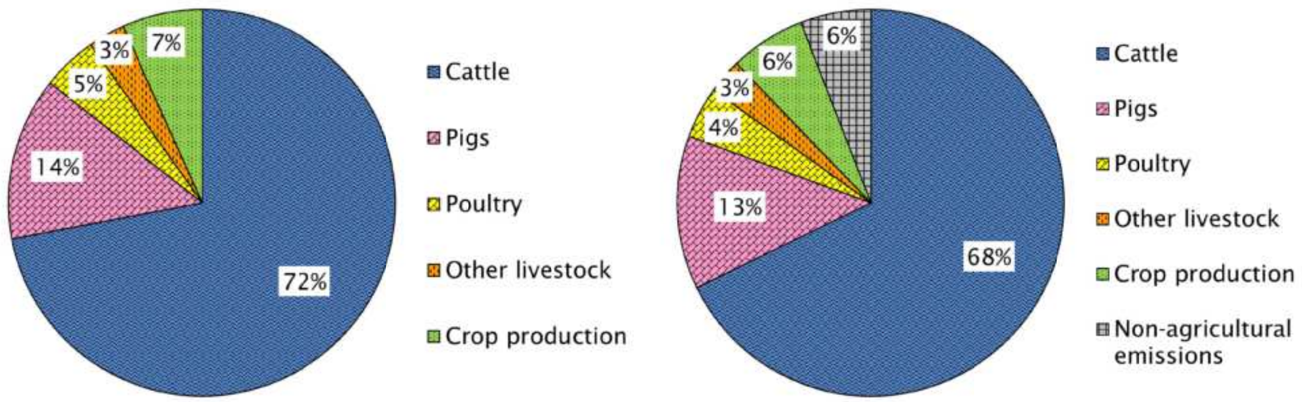
- Emissions of reactive nitrogen species and flow of N_2 from agriculture in Switzerland (2005)

	Amount in kt N	Proportion of N	Proportion of Nr
Ammonia	**47**	**41%**	**54%**
Nitrate	34	30%	40%
Nitrous oxide	4	3%	5%
Nitrogen oxides	1	1%	2%
Diatomic nitrogen N_2	28	25%	
Total nitrogen (N)	114		
Total reactive nitrogen (Nr)	86		

Emissions of ammonia:
approx. 25% of the total N in manure, recycling- and mineral fertilizer used in agriculture.

Heldstab, J., Leippert, F., Reutimann, J., Schwank, O. 2010. Stickstoff-Flüsse der schweizerischen Landwirtschaft. Evaluation von Wissenslücken in der Forschung. Schlussbericht. Zurich: Infras.

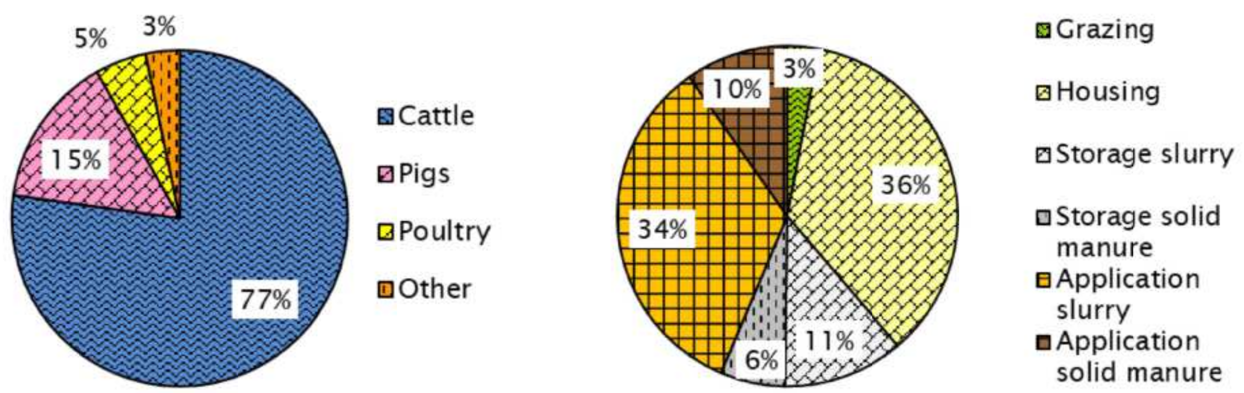
Agrammon model: output for Switzerland



Percentage contributions of the main livestock categories, crop production and non-agricultural emissions to the total ammonia emissions in Switzerland for 2020

Kupper, T., Häni, C., Bretscher, D., Zaucker, F. 2022. Ammoniakemissionen der schweizerischen Landwirtschaft 1990 bis 2020. Berner Fachhochschule. Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften, Zollikofen.

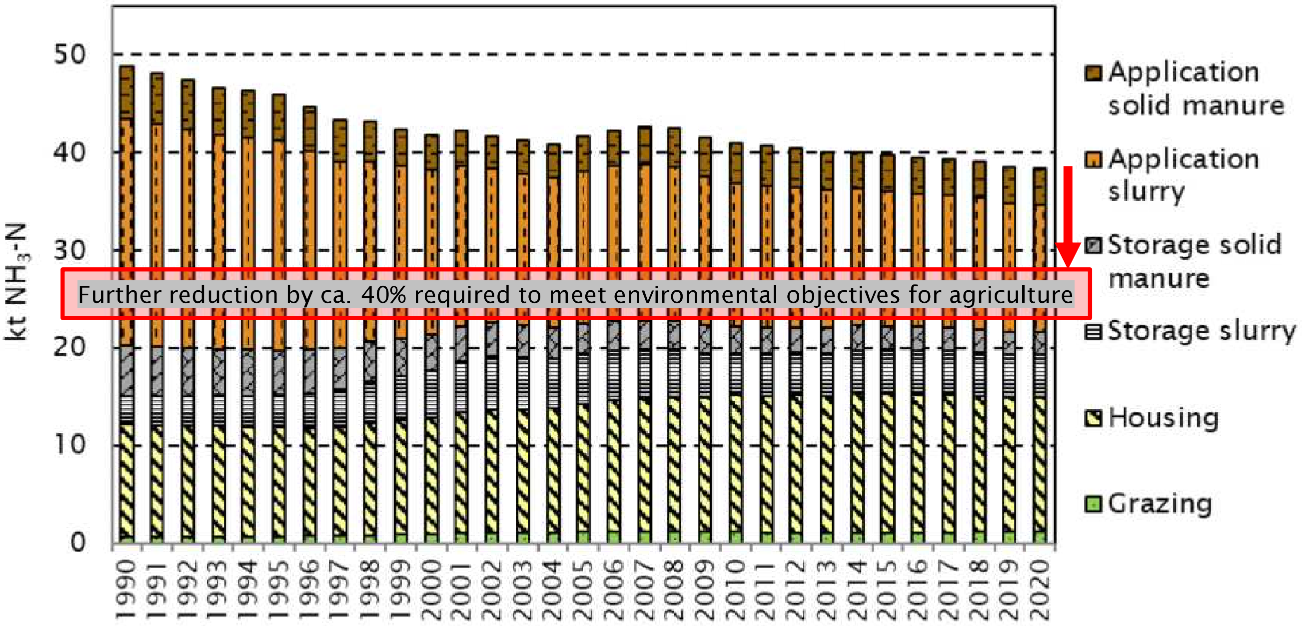
Agrammon model: output for Switzerland



Percentage contributions of the main livestock categories to the livestock emissions, and (b) percentage contributions of the different emission stages to the livestock emissions in Switzerland for 2020

Kupper, T., Häni, C., Bretscher, D., Zaucker, F. 2022. Ammoniakemissionen der schweizerischen Landwirtschaft 1990 bis 2020. Berner Fachhochschule. Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften, Zollikofen.

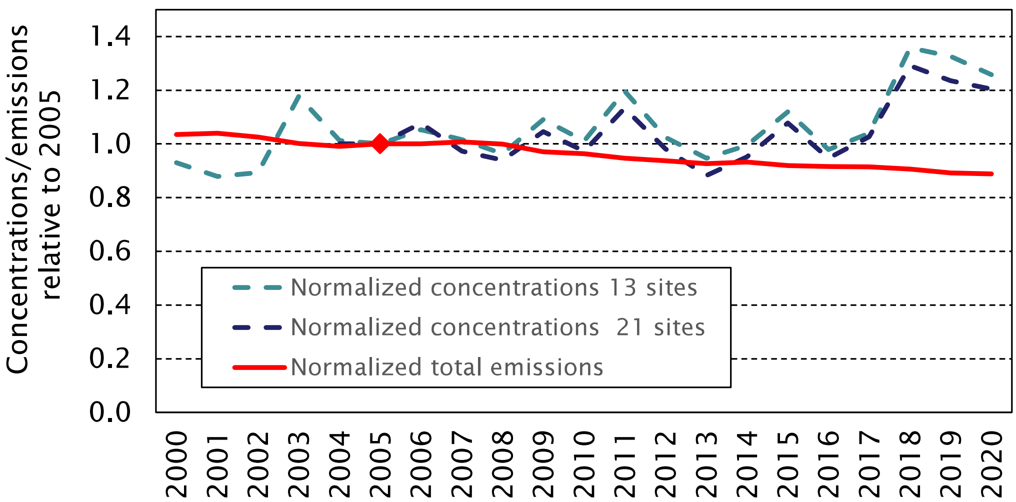
Agrammon model: output for Switzerland



Evolution of the ammonia emissions from livestock production between 1990 and 2020 from the emission stages grazing, housing/exercise yard, manure storage and manure spreading in kt NH_3-N

Kupper, T., Häni, C., Bretscher, D., Zaucker, F. 2022. Ammoniakemissionen der schweizerischen Landwirtschaft 1990 bis 2020. Berner Fachhochschule. Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften, Zollikofen.

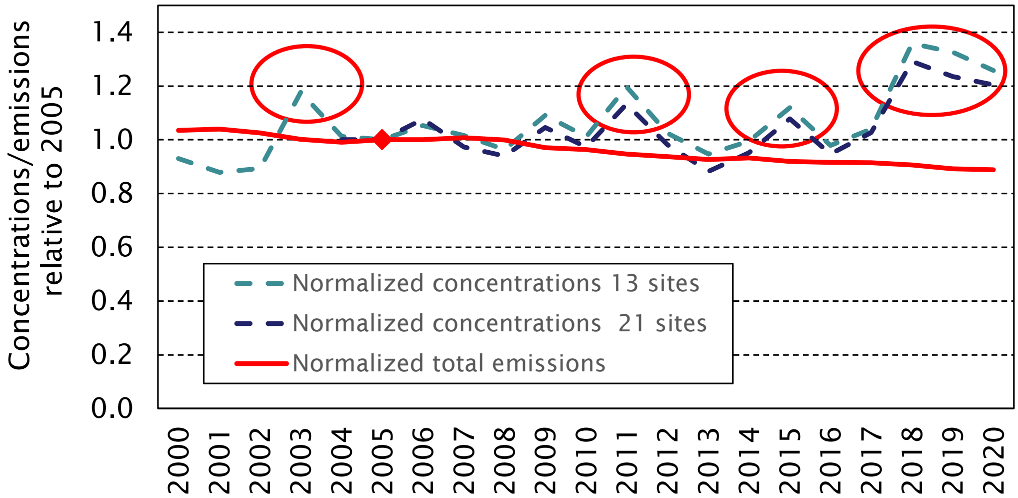
Agrammon model: accuracy of the output



Evolution of ambient ammonia concentrations derived from measurement data from a monitoring network based on passive samplers and modeled emissions in Switzerland between 2000 and 2020

Kupper, T., Häni, C., Bretscher, D., Zaucker, F. 2022. Ammoniakemissionen der schweizerischen Landwirtschaft 1990 bis 2020. Berner Fachhochschule. Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften, Zollikofen.

Agrammon model: accuracy of the output



Peaks of ambient ammonia concentrations are due to high annual temperatures which are not seen in emission data (addition of a correction in Agrammon would be possible but not intended for emission inventories)

Kupper, T., Häni, C., Bretscher, D., Zaucker, F. 2022. Ammoniakemissionen der schweizerischen Landwirtschaft 1990 bis 2020. Berner Fachhochschule. Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften, Zollikofen.

Principles of the Agrammon model

- The application of Agrammon has been expanded in recent years beyond emission inventory reporting:
  - Building permits
  - Agri-environmental monitoring
  - Manure nitrogen recovery assessment for application at the legislation level
- Different requirements according to the scope:
  - Emission inventory reporting: consistency (e.g. preferably no changes of model parameters over time)
  - Other applications: continuous adaptation of model parameters according to the state of the art

Bases of the Agrammon model (examples)

- Emission factors at the housing level for dairy cows

	Winter	Spring/fall	Summer	Average over year	
	kg NH_3-N cow^{-1} year^{-1}				% TAN
Tied housing (literature)*					
n	2	5	8	15	
Average	2	3	5	4	7%
Median	2	2	5	3	5%
Min	2	2	2	2	2%
Max	3	4	10	10	17%
Loose housing (literature)*					
n	15	61	34	110	
Average	10	14	18	**15**	**24%**
Median	7	12	12	**12**	**19%**
Min	2	1	0.5	0.5	1%
Max	34	56	75	75	121%
Data from EVS Tänikon (data from Agroscope and HAFL)					
1	14	15	16	**15**	**24%**
2	10	12	18	**13**	**21%**
3	8	13	17	**13**	**21%**
4	7	12	-	-	-
Tied housing Agrammon model					
Modeled value				**3.9**	**6.7%**
Loose housing Agrammon model					
Modeled value				**13.5**	**23%**

*Mostly based on Poteko, J., Zähner, M., Schrade, S. 2019. Effects of housing system, floor type and temperature on ammonia and methane emissions from dairy farming: A meta-analysis. Biosyst. Eng. 182: 16-28.

Bases of the Agrammon model (examples)

- Emission factors for slurry storage tanks (untreated slurry stored uncovered)

Slurry type	Study type	n	Avg	l95	u95	Reference values*	Reference values**	**Agrammon**
Kupper et al. (2020)								
			g NH_3 m^{-2} h^{-1}					
Cattle	Farm-scale	11	0.09	0.05	0.13	0.11***		
	Pilot-scale	34	0.08	0.07	0.09			
	Baseline	**45**	**0.08**	**0.07**	**0.09**	0.11-0.19	0.20	**0.30**
Pig	Farm-scale	8	0.23	0.13	0.37	0.40	0.30	
	Pilot-scale	15	0.24	0.15	0.38			
	Baseline	**23**	**0.24**	**0.17**	**0.34**	0.12-0.40	0.11-0.30	**0.40**

Kupper, T., Häni, C., Neftel, A., Kincaid, C., Bühler, M., Amon, B., VanderZaag, A.C. 2020. Ammonia and greenhouse gas emissions from slurry storage - a review. Agr. Ecosyst. Environ. 300(106963): 1-18.

*VanderZaag A., Amon B., Bittman S., Kuczynski T., 2015. Ammonia abatement with manure storage and processing techniques, in: Reis, S., Howard, C., Sutton, M.A. (Eds.), Costs of ammonia abatement and the climate co-benefits. Springer Netherlands, pp. 75-112.

**Sommer S.G., Zhang G.Q., Bannink A., Chadwick D., Misselbrook T., Harrison R., Hutchings N.J., Menzi H., Monteny G.J., Ni J.Q., Oenema O., Webb J., 2006. Algorithms determining ammonia emission from buildings housing cattle and pigs and from manure stores. Advances in Agronomy 89, 261-335.

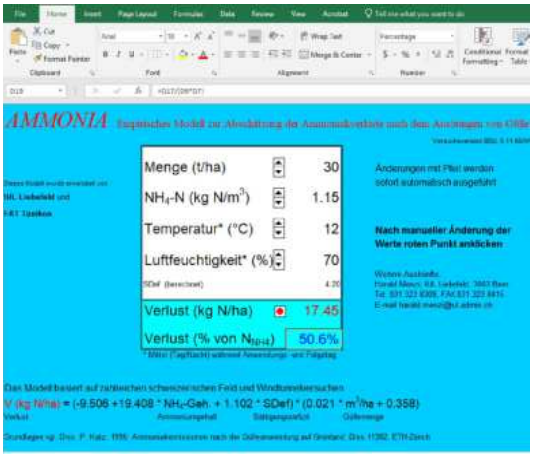
***for a crusted slurry surface

Bases of the Agrammon model (examples)

Emission factor (EF) implemented in Agrammon for slurry application based on the model of Menzi et al. (1998):

- Average temperature from March to November: 12°C (Data SMA Station Bern Liebefeld 1993-2002)
- TAN content slurry: 1.15 kg/m^3 (cattle slurry, dilution 1:1)
- Relative humidity: 70%
- Application rate: 30 m^3/ha

➔**Calculated EF: 50.6% TAN**



Menzi, H., Katz, P.E., Fahrni, M., Neftel, A., Frick, R. 1998. A simple empirical model based on regression analysis to estimate ammonia emissions after manure application. Atmos. Environ. 32(3): 301-307.

Bases of the Agrammon model (examples)

Emission factor (EF) for slurry application:

- "Are ammonia emissions from field-applied slurry substantially over-estimated in European emission inventories?" (Sintermann et al., 2012)
- ALFAM2 project:
  - Collecting emission data from field-applied slurry from many studies conducted over the last decades and organizing them in the ALFAM2 database (most complete database worldwide on this topic)
  - Building a semi-empirical dynamic model for predicting ammonia volatilization from field-applied slurry
  - ALFAM2 model: large data set of emission measurements using micrometeorological (i.e. non-intrusive) methods from cattle and pig slurry application (490 field plots in 6 countries from the ALFAM2 database)

Hafner, S.D., Pacholski, A., Bittman, S., Burchill, W., Bussink, W., Chantigny, M., Carozzi, M., Genermont, S., Häni, C., Hansen, M.N., Huijsmans, J., Hunt, D., Kupper, T., Lanigan, G., Loubet, B., Misselbrook, T., Meisinger, J.J., Neftel, A., Nyord, T., Pedersen, S.V., Rochette, P., Sintermann, J., Vermeulen, B., Vestergaard, A., Voylokov, P., Williams, J.R., Sommer, S.G. 2018. The ALFAM2 database on ammonia emission from field-applied manure: Description and illustrative analysis. Agric. For. Meteorol. 258: 66-78.

Hafner, S.D., Pacholski, A., Bittman, S., Carozzi, M., Chantigny, M., Genermont, S., Häni, C., Hansen, M.N., Huijsmans, J., Kupper, T., Misselbrook, T., Neftel, A., Nyord, T., Sommer, S.G. 2019. A flexible semi-empirical model for estimating ammonia volatilization from field-applied slurry. Atmos. Environ. 199: 474-484.

Sintermann, J., Neftel, A., Ammann, C., Häni, C., Hensen, A., Loubet, B., Flechard, C.R. 2012. Are ammonia emissions from field-applied slurry substantially over-estimated in European emission inventories? Biogeosciences 9(11): 1611-1632.

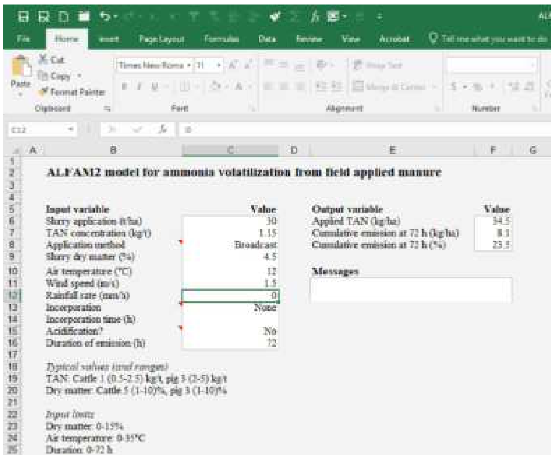
Bases of the Agrammon model (examples)

Emission factor (EF) for slurry application based on the ALFAM2 model (Hafner et al., 2019):

- Emission estimate with the same parameters used on the previous slide

  ➔**Calculated EF: 23.5% TAN**

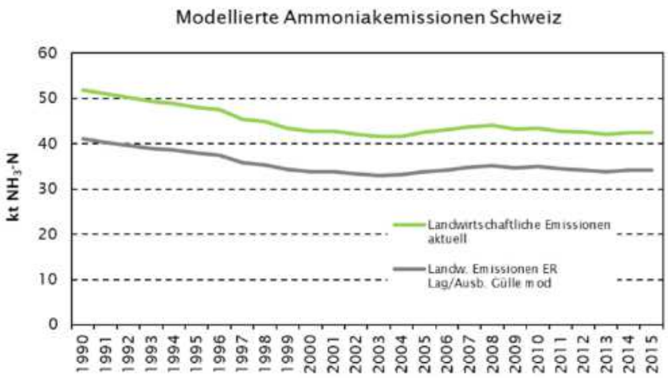
- Actual state of the art

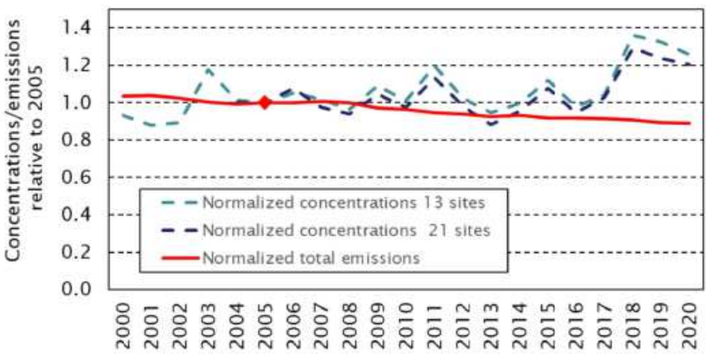


Hafner, S.D., Pacholski, A., Bittman, S., Carozzi, M., Chantigny, M., Genermont, S., Häni, C., Hansen, M.N., Huijsmans, J., Kupper, T., Misselbrook, T., Neftel, A., Nyord, T., Sommer, S.G. 2019. A flexible semi-empirical model for estimating ammonia volatilization from field-applied slurry. Atmos. Environ. 199: 474-484.

How to cope with differing model parameters?

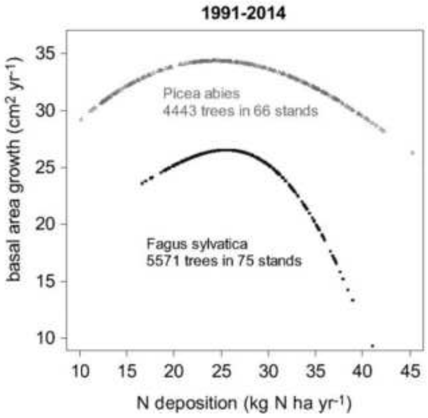
- Swiss ammonia emission inventory calculated with actual and revised EFs for slurry storage and application: the emissions trend remains almost unchanged



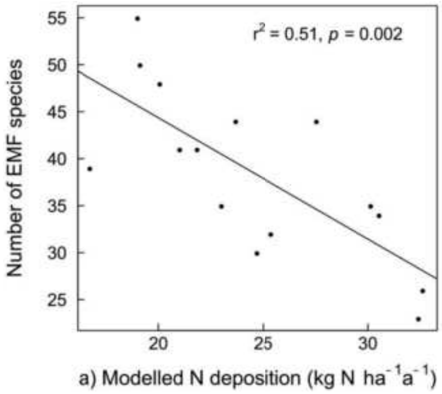


How to cope with differing model parameters?

- Swiss ammonia emission inventory: the emissions trend remains almost unchanged
  ➔If negative impacts for natural ecosystems due to high N deposition an emission reduction is required whatever method for emission reporting is used



Relationship between basal area growth and N deposition for beech and Norway spruce



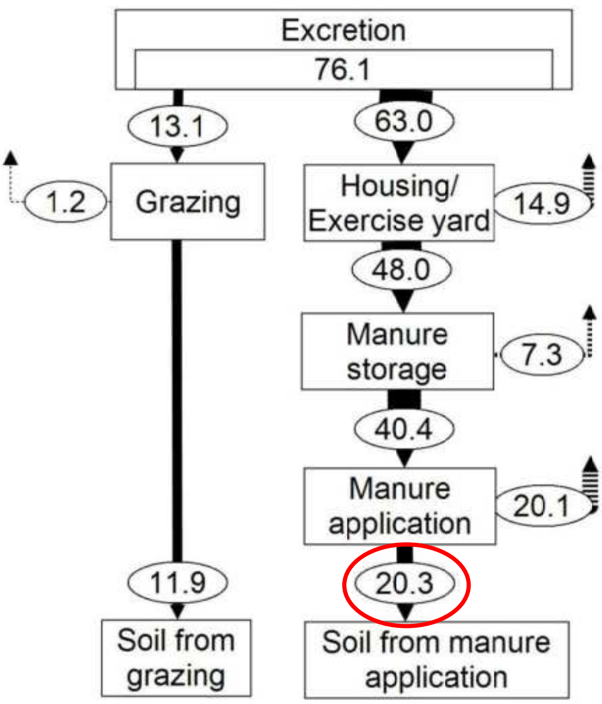
Relationship between ectomycorrhizal (EMF) species richness on root tips and N deposition

Braun, S., Schindler, C., Rihm, B. 2017. Growth trends of beech and Norway spruce in Switzerland: The role of nitrogen deposition, ozone, mineral nutrition and climate. Sci. Total Environ. 599: 637-646.

de Witte, L.C., Rosenstock, N.P., van der Linde, S., Braun, S. 2017. Nitrogen deposition changes ectomycorrhizal communities in Swiss beech forests. Sci. Total Environ. 605: 1083-1096.

How to cope with differing model parameters?

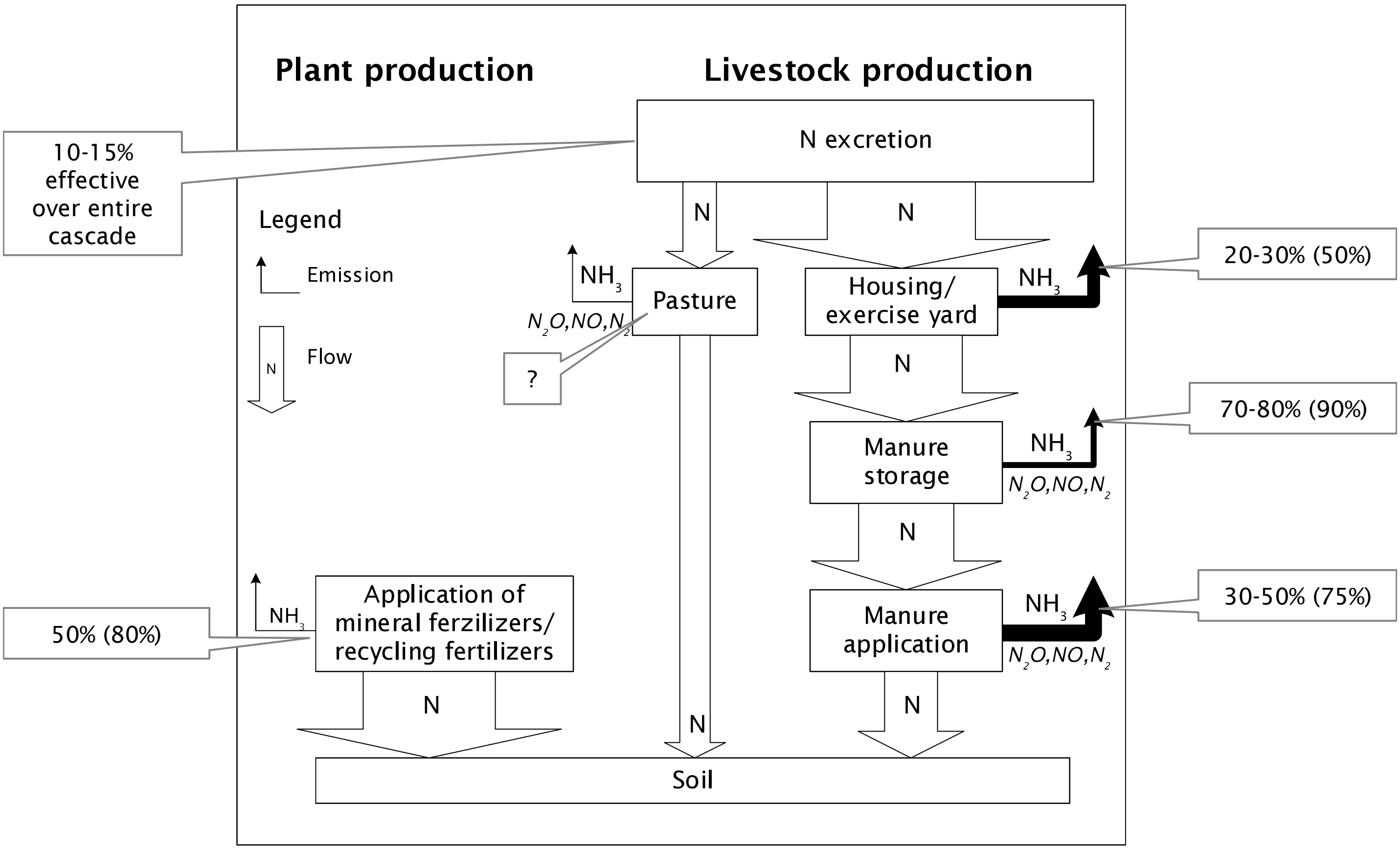
- If absolute numbers are relevant, e.g. for manure nitrogen recovery assessment, differing model parameters such as emission factors matter



Where to implement emission mitigation techniques?

- At emission stages with high emissions: housing/exercise yard; manure application
- At emission stages with high emissions high emission reductions can be achieved: e.g. slurry storage
- Tradeoffs with other issues, e.g. increase of greenhouse gas emissions, must be avoided

Achievable emission reductions for NH_3 based on readily applicable techniques



For higher emission reductions: more sophisticated techniques are required

Achieved modeled emission reduction for NH_3

	Farm with 40 dairy cows plus heifers, loose housing, covered slurry storage, slurry application with trailing hose	As Initial situation but further emission mitigation techniques for housing and slurry application	As Emission reduction 1 but less N-excretion due to optimized feeding
	Initial situation Emission in kg N	Emission reduction 1	Emission reduction 2
Grazing	33	0%	-8%
Housing and Yard	689	-17%	-28%
Storage	494	0%	0%
Application	724	-23%	-34%
Total farm	1619	-18%	-27%
Excretion	3116	0%	-13%
Into pasture	402	0%	-8%
Into housing/exercise yard	2714	0%	-14%
Into storage	2025	6%	-9%
Into application	1960	6%	-9%
Input soil from application	1174	24%	6%
Input soil from grazing	350	0%	-8%
Input soil total	1524	19%	3%

How to link achieved (modeled) emission reductions to nitrogen recovery in manure?

Conclusions

- A mass flow model representing the manure cascade is a valuable tool to estimate emissions as a basis for
  - Reporting/monitoring of emissions
  - Implementation of measures to reduce emissions
  - Demonstrating the potential to mitigate emissions along the manure cascade
  - Optimize the use of N included in manure
- Challenges due to differing requirements of the various applications of the model
- Link between modeled emissions and nitrogen recovery in manure
- Model bases need to be improved and more detailed model parameters based on experimental data/in the model integrated sub-models
- Improvement of model bases require knowhow in emission measurement methods/modeling and funding of the appropriate activities

Nitrate leaching after manure application

Hanna Frick[1,2,(*)], Else Bünemann[1]

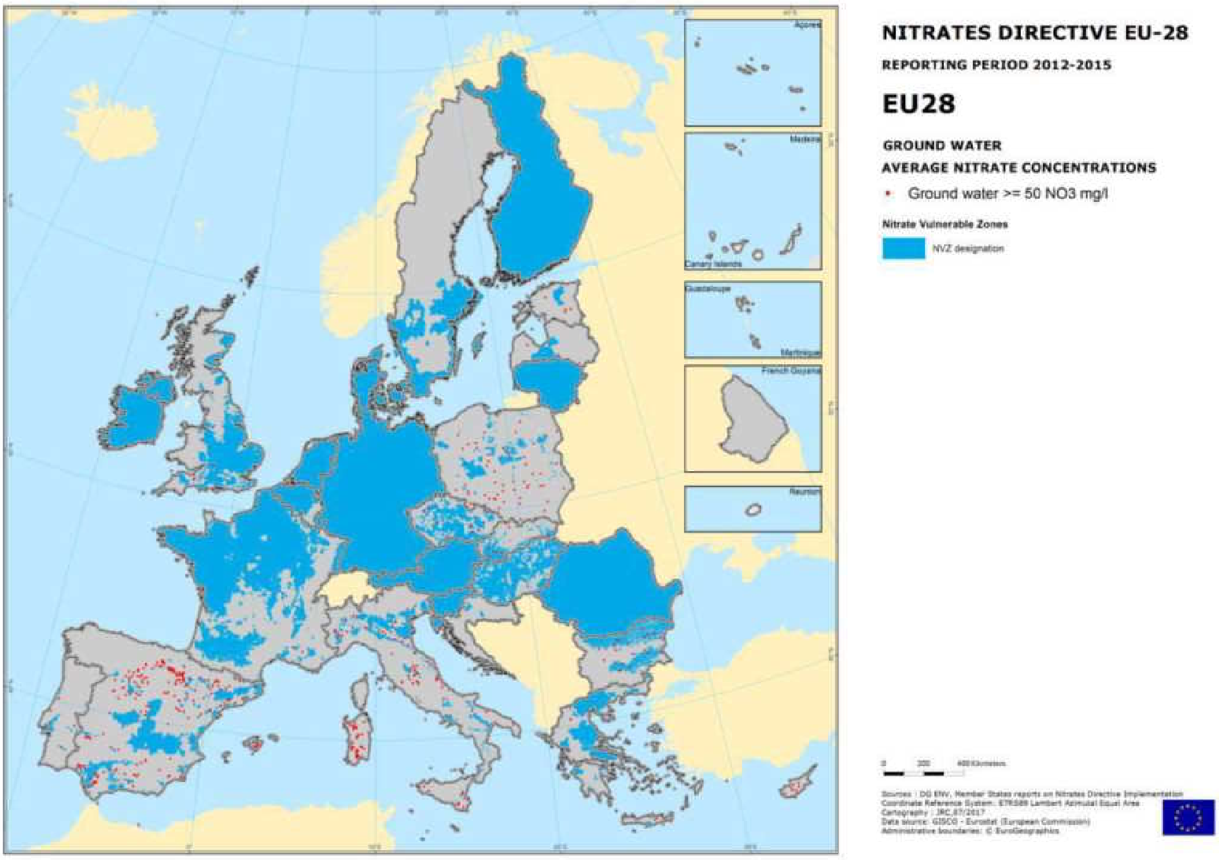
Manure Workshop, Agroscope, 4th of May 2022

[(*)]hanna.frick@agroscope.admin.ch

[1]Department of Soil Sciences, Research Institute of Organic Agriculture (FiBL), CH-Frick

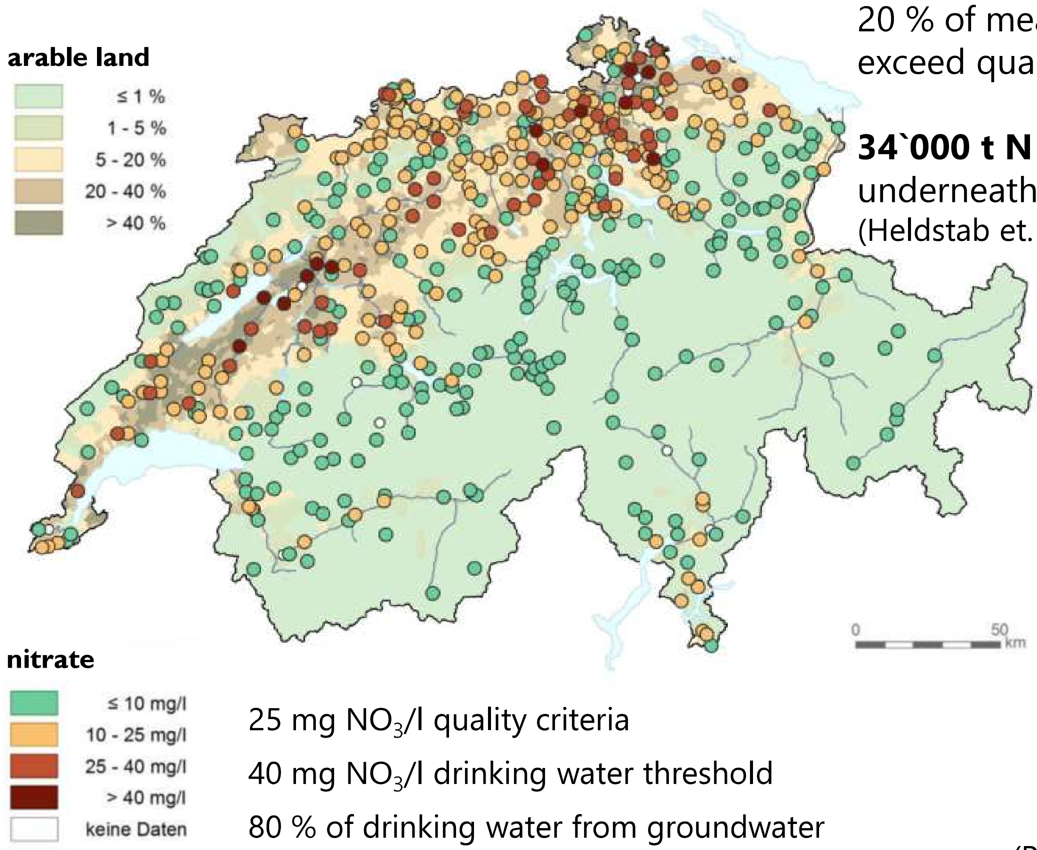
[2]Water Protection and Substance Flows, Agroscope, CH-Zürich

Groundwater nitrate levels in EU



(EC 2018)

… and Switzerland



20 % of measuring wells exceed quality criteria

34`000 t N per year leached underneath agricultural land (Heldstab et. al 2013)

25 mg NO_3/l quality criteria

40 mg NO_3/l drinking water threshold

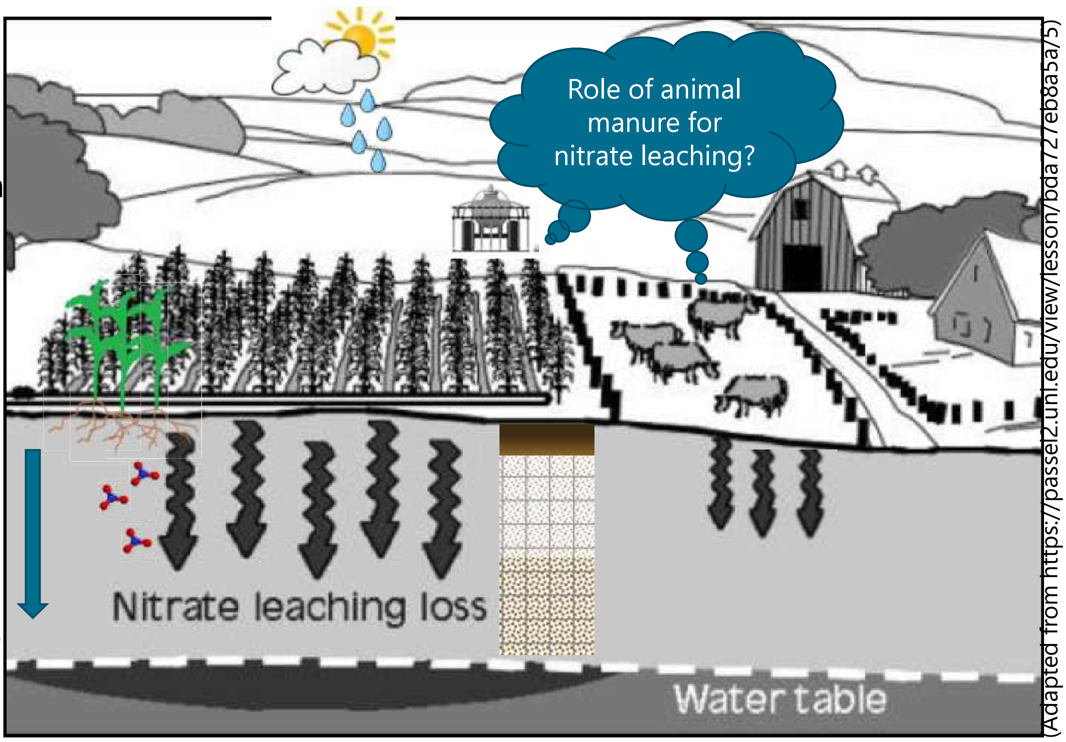
80 % of drinking water from groundwater

(BAFU, 2019) 3

Nitrate leaching losses are a function of…

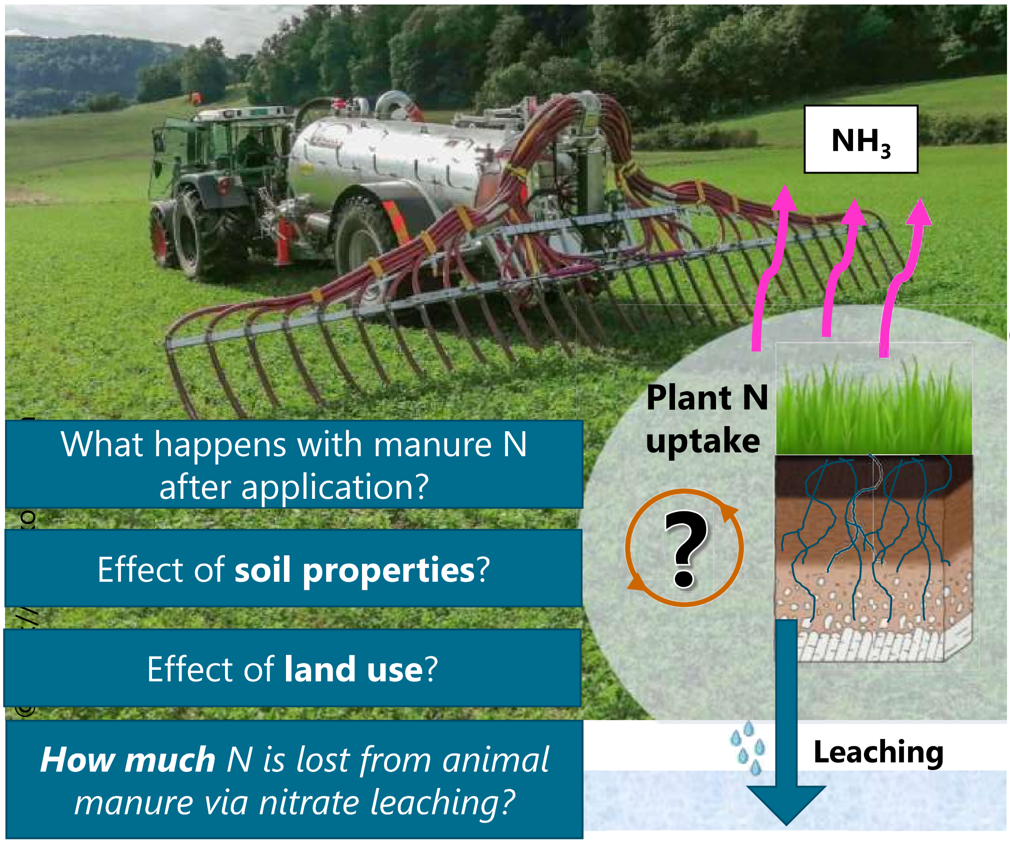
Drainage
- Precipitation (amount & distribution)
- Evapotranspiration (weather & crop)
- Water holding capacity of soil

Mineral N in soil
- Plant N uptake
- Mineralization of SOM (SOC content, tillage)
- Fertilization (amount, timing & type)



(Goulding 2000; Spiess et al. 2011)

N losses upon and after manure application



What happens with manure N after application?

Effect of **soil properties**?

Effect of **land use**?

***How much** N is lost from animal manure via nitrate leaching?*

NH$_3$ emissions

hours - days

Depend on

- Manure composition
- Weather
- Application technique

NO$_3$ leaching

years - decades

In addition depends on

- Soil properties & processes
- Land use/plant N uptake

Fate of cattle slurry N after application to soil – A case study from Switzerland

^{15}N cattle slurry

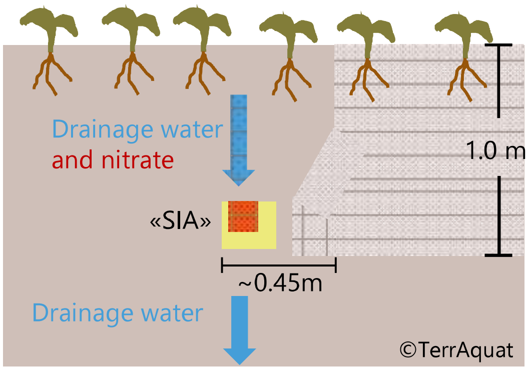
Year	Field A	Field B
2018	Maize	Grass-clover
2019	Winter wheat	Maize
2020	Grass-clover	Winter wheat

NitroGäu

Aim: full balance of cattle slurry N during 3-year crop sequence under field conditions

Treatments: Control (**Con**), ^{15}N mineral fertilizer (**Min**), ^{15}N cattle slurry (**Slu**); same rate of **mineral N** (**Min 37**; **Slu 60** [kg Ntot ha^{-1} application^{-1}])

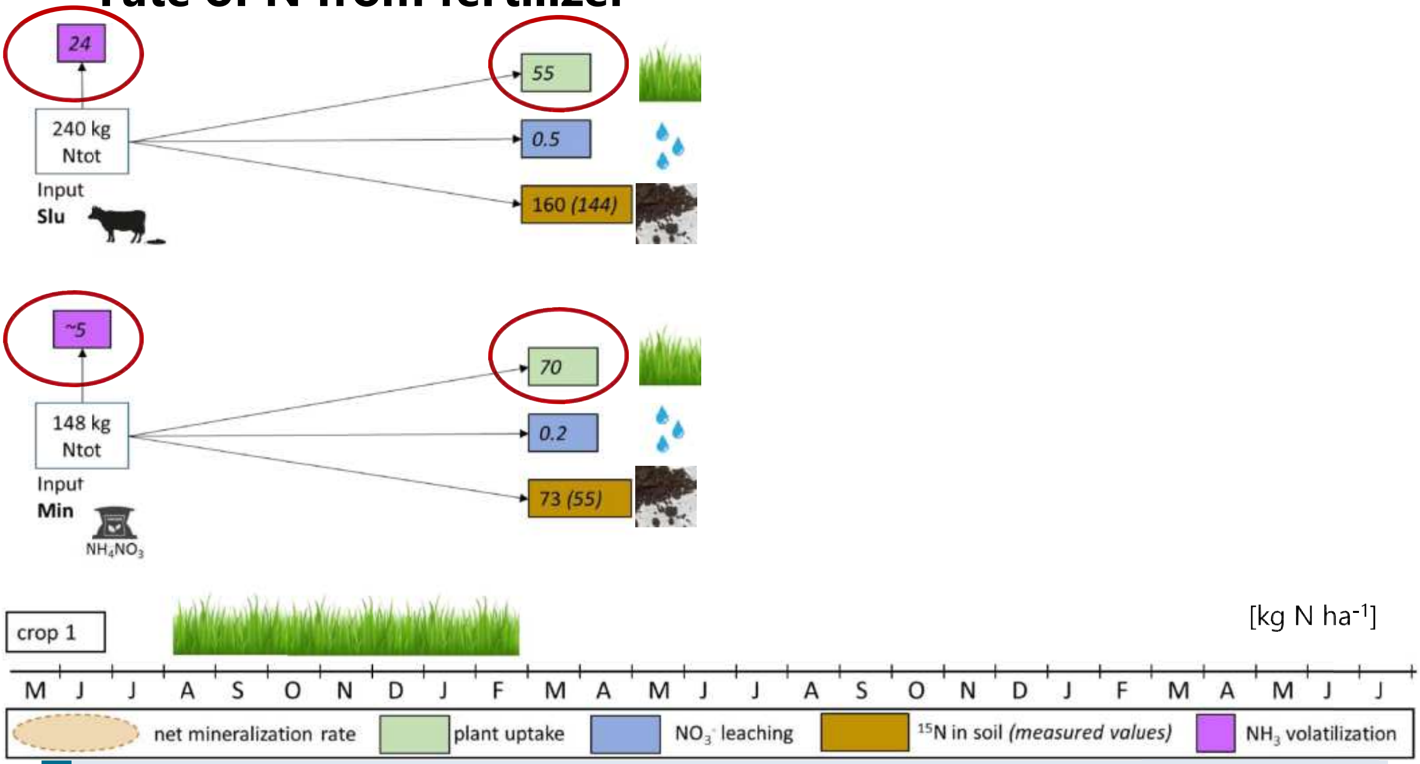
Installation of SIAs in the field



Self-integrating accumulators (SIAs)

Fate of N from fertilizer

(Data from Frick et al., under revision)

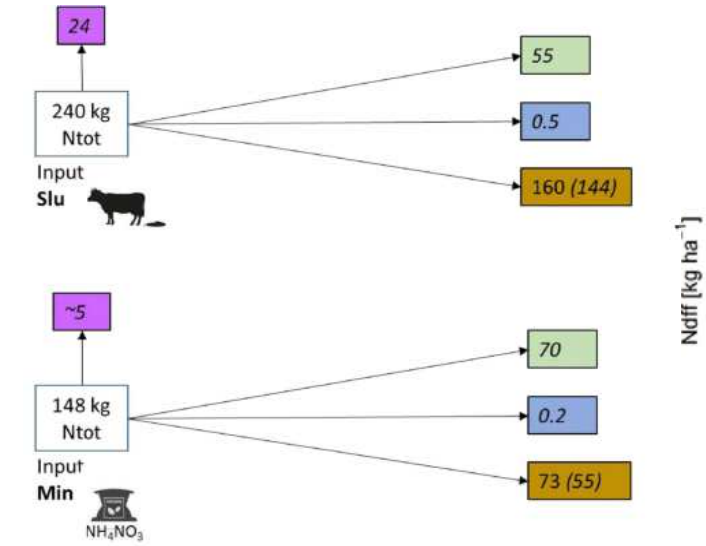


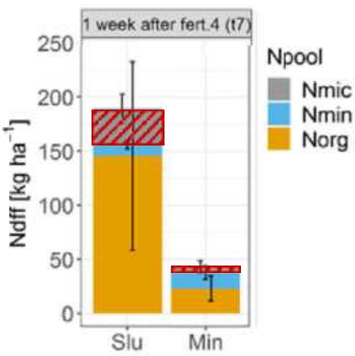
Fertilizer N uptake by crop Min > Slu, although both applied at same rate of mineral N

→ NH_3 emissions Slu > Min

Fate of N from fertilizer

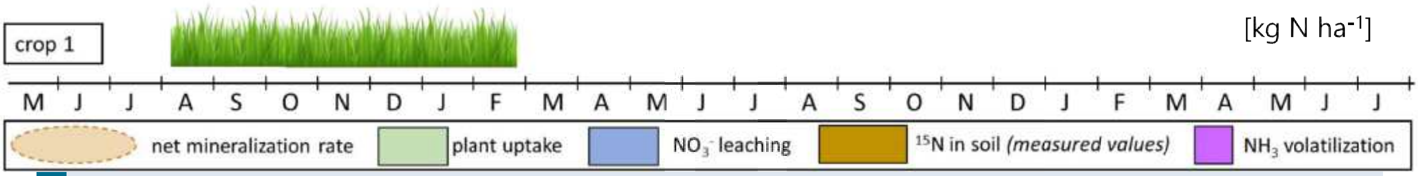
(Frick et al., 2022; Frick et al., under revision)





Rapid incorporation of slurry NH_4-N in Nmic
(e.g. Jensen et al. 2000)

Net immobilization of slurry N during the first 3 months
(Sørensen 2004)



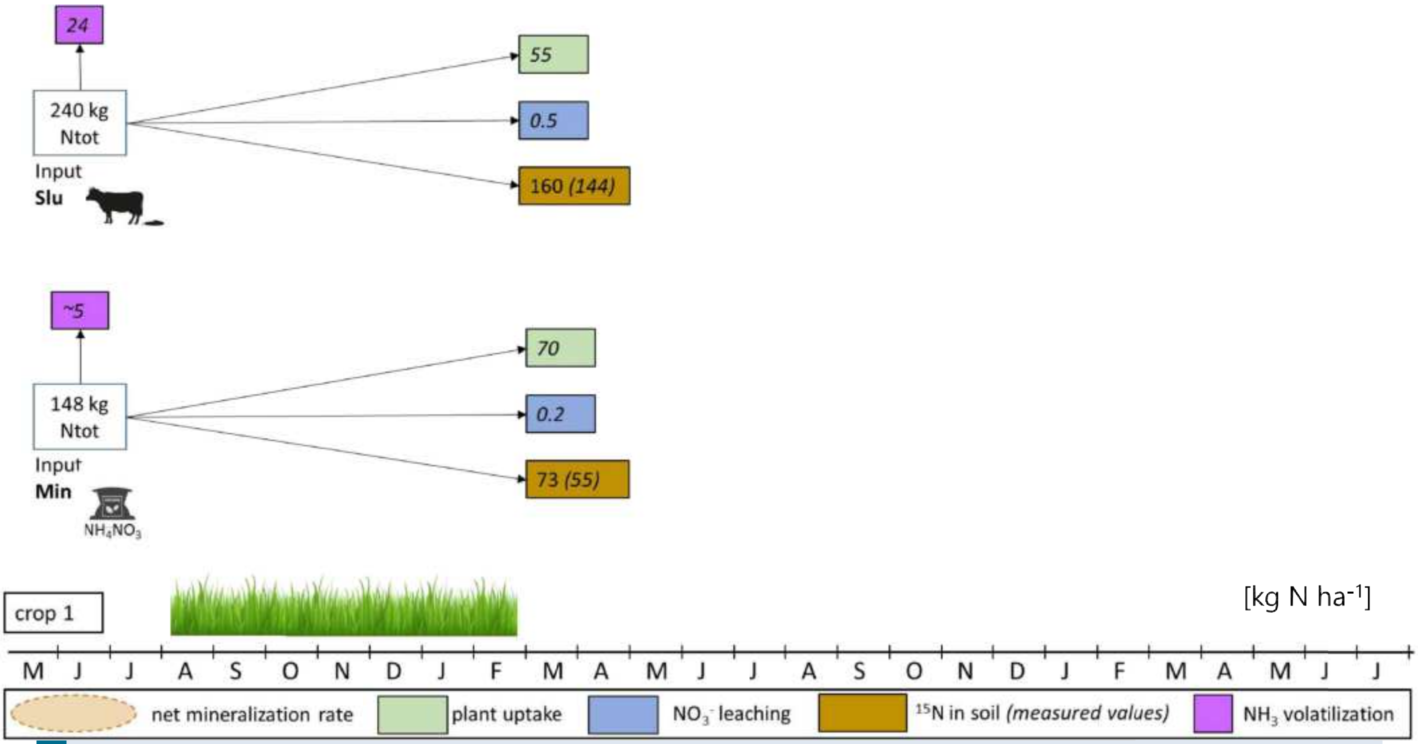
Fertilizer N uptake by crop Min > Slu, although both applied at same rate of mineral N

→ NH_3 emissions Slu > Min

→ Microbial immobilization Slu > Min

Fate of N from fertilizer

(Frick et al., 2022; Frick et al., under revision)



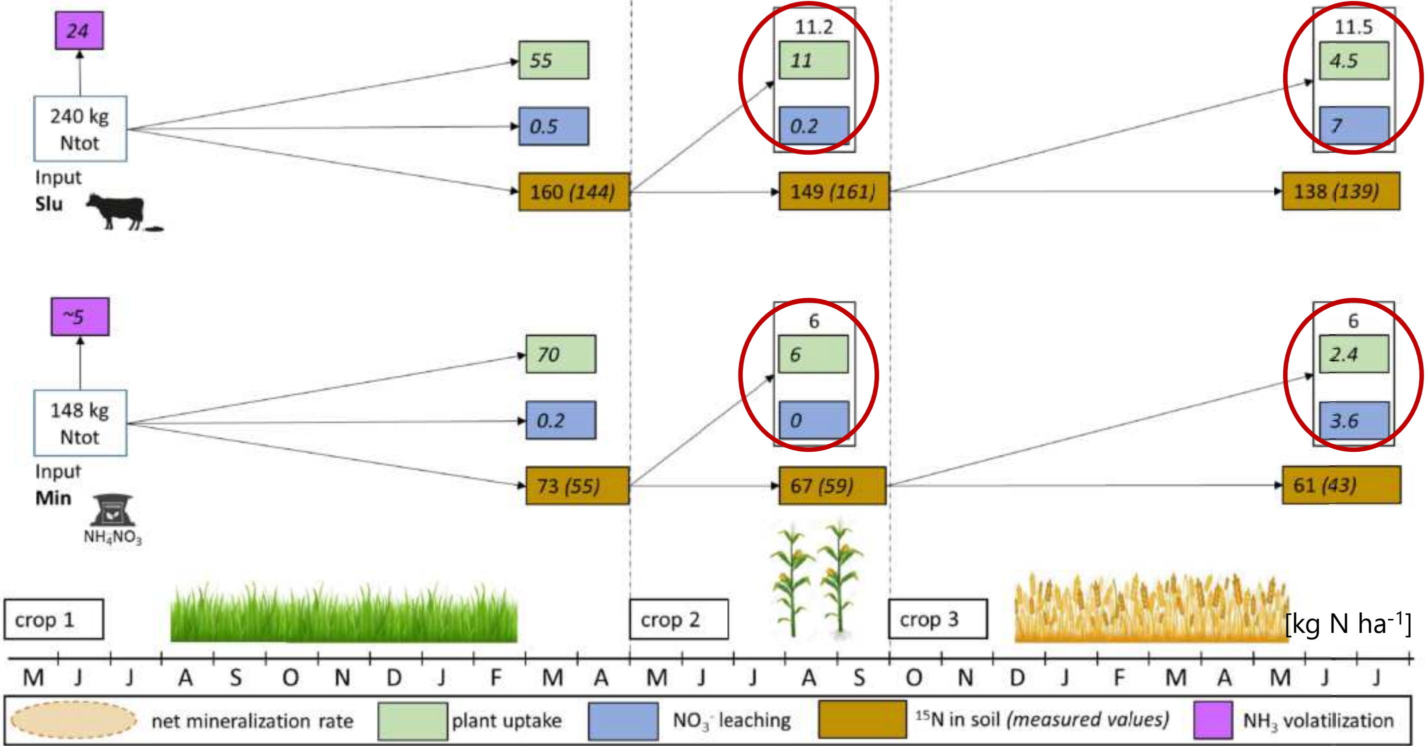
Fertilizer N uptake by crop Min > Slu, although both applied at same rate of mineral N

→ NH_3 emissions Slu > Min

→ Microbial immobilization Slu > Min

Fate of N from fertilizer

(Data from Frick et al., under revision)

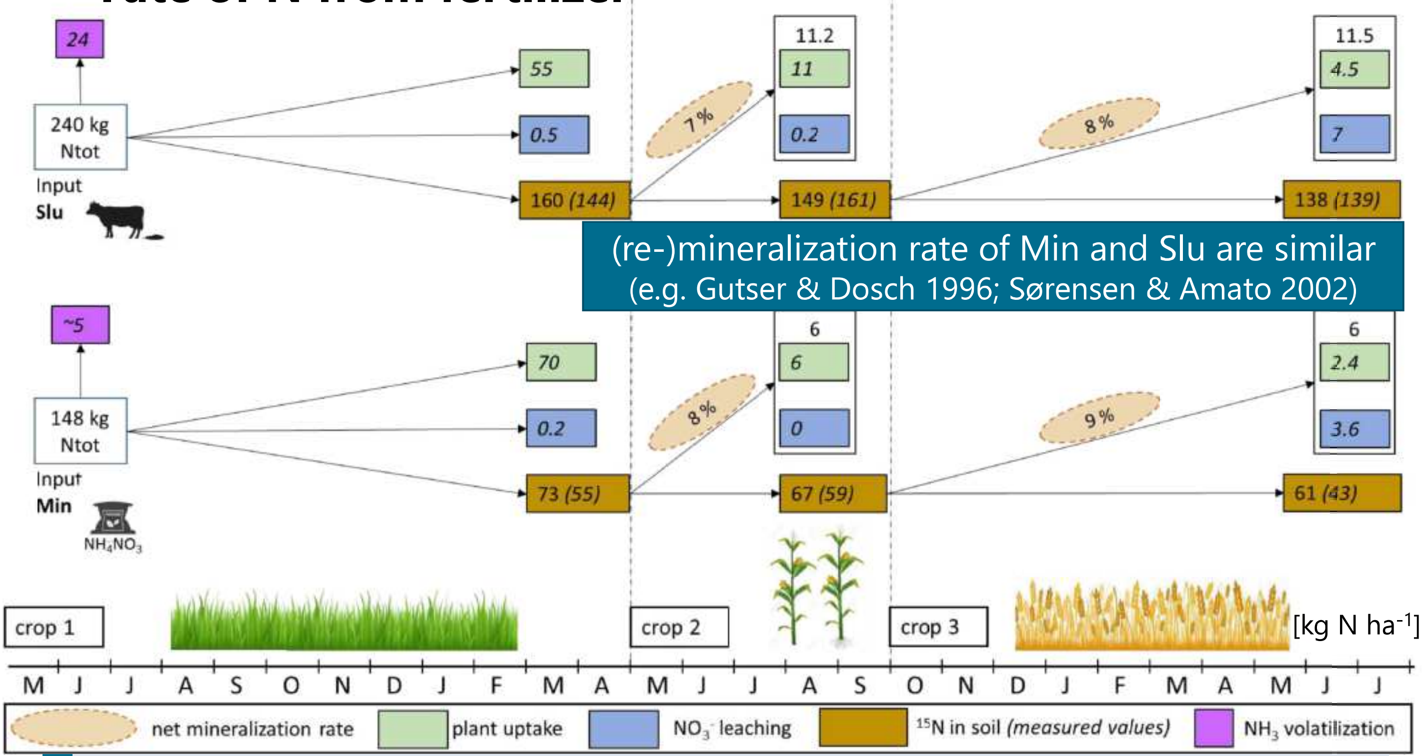


Fertilizer N uptake by crop Min > Slu, although both applied at same rate of mineral N

Residual N effect, but also **nitrate leaching**, Slu > Min

Fate of N from fertilizer

(Data from Frick et al., under revision)



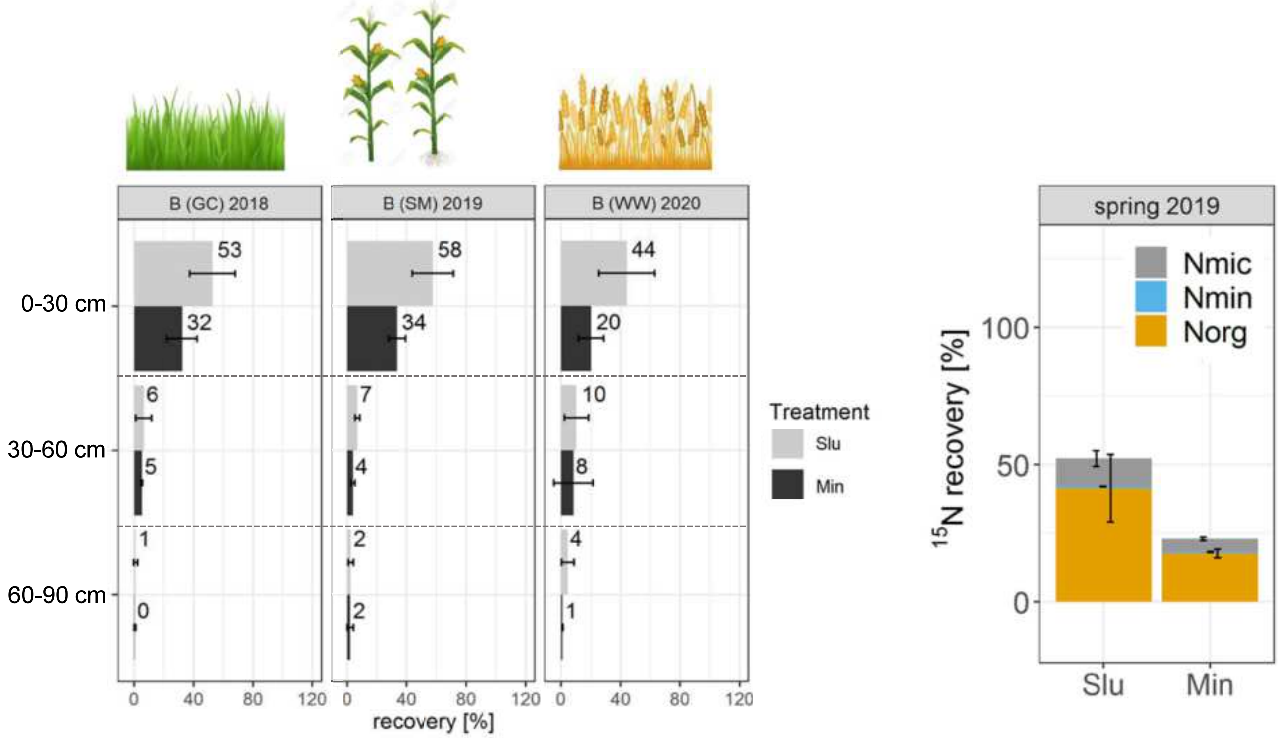
Fertilizer N uptake by crop Min > Slu, although both applied at same rate of mineral N

Residual N effect, but also **nitrate leaching**, Slu > Min

Mineralization rate similar for Min and for Slu

^{15}N recovery in soil

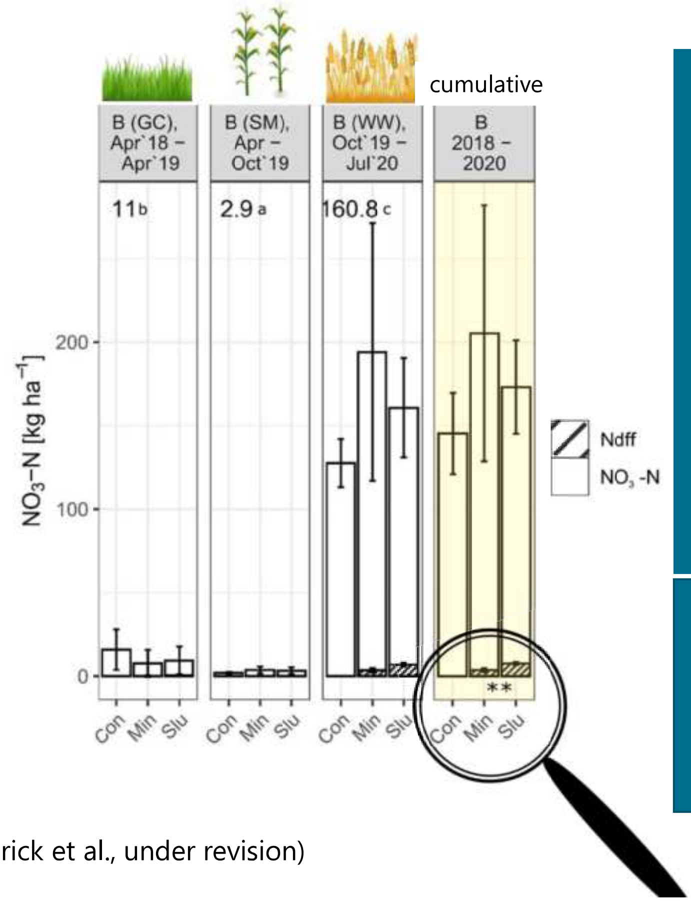
(Frick et al., 2022; Frick et al., under revision)



Minor depth translocation of fertilizers

Most fertilizer N in the **non-microbial organic N pool** in spring after application

How much nitrate is leached from manure?



(Frick et al., under revision)

Highest nitrate leaching under winter wheat (**after ley termination**)

Less than 5 % of leached nitrate orginated from ^{15}N labelled fertilizers

Cumulative nitrate leaching **greater for Slu** (7.6 kg ha^{-1}) **than for Min** (3.7 kg ha^{-1}) → 3 % of added N leached during 2.5 years

55 – 70 % of leached N derived from **mineralization of soil N** (Gilbert 2021)

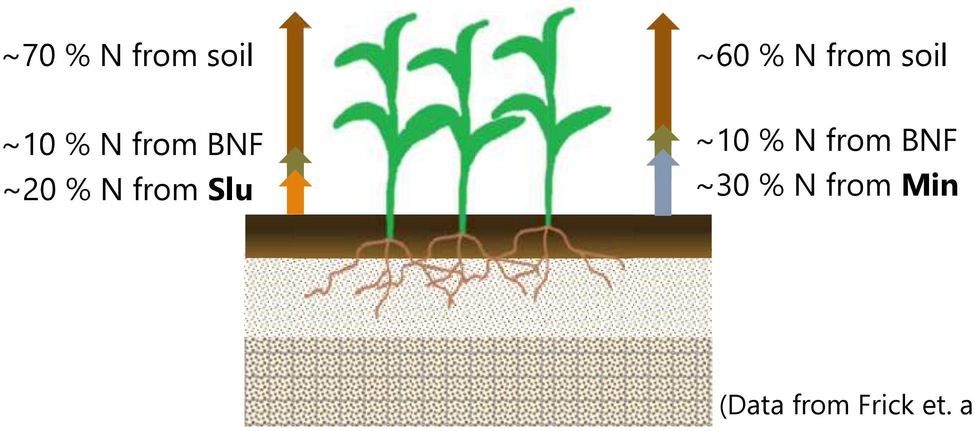
Leached nitrate originates mostly from mineralization of SOM
(e.g. Gutser & Dosch 1996; MacDonald et al. 1989)

Soil N mineralization is also the main source for plant N uptake

No differences in yield or N uptake between Min and Slu

In the year of application, plants took up **less than a third** of their N demand from fertilizers (see Yan et al. 2020)

Plant N uptake

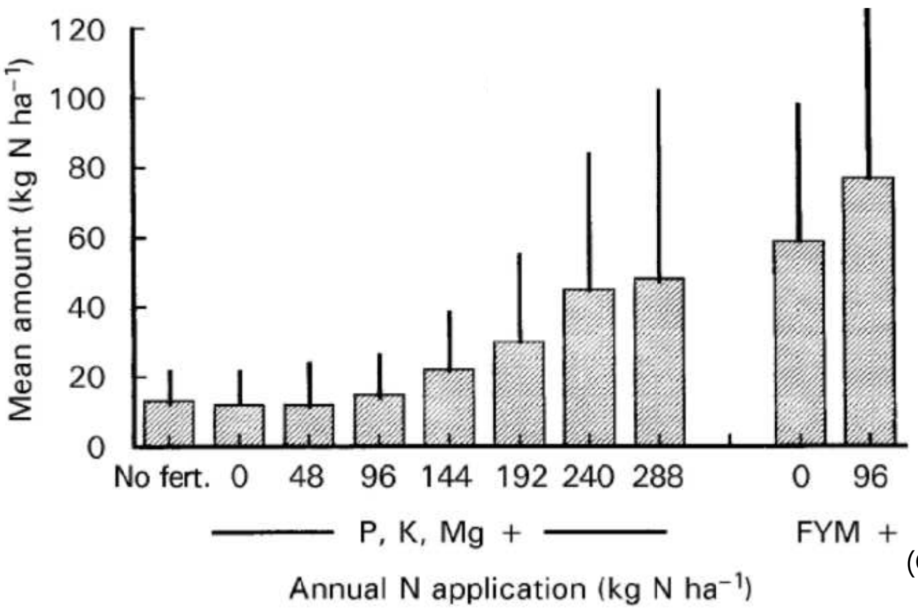


(Data from Frick et. al., 2022)

60 % of Slu-N and 30 % of Min-N remained in soil after 2.5 years

→ Fertilizer N refills soil N-resources

Trade-off between soil fertility and nitrate leaching?

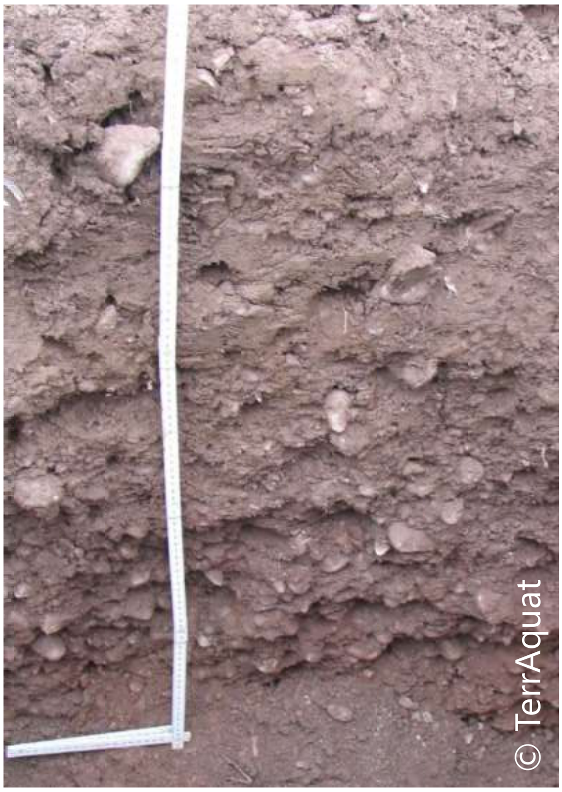


Annual nitrate leaching during 1990 – 1998 at Broadbalk long-term trial;
FYM = 35 t farmyard manure with 265 kg N

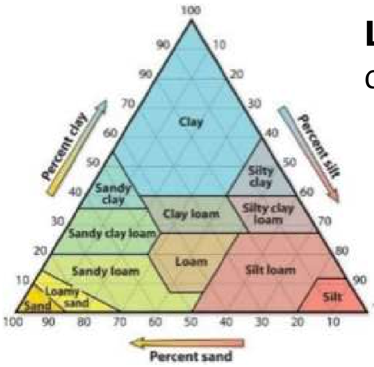
(Goulding et al. 2000)

> Repeated manure application can lead to **increasing soil-N stocks** and an increased leaching potential (Edmeades 2003)
>
> However, **SOM stocks** under cultivated land show **declining trend** (Charles et al. 2018)

How does soil texture influence nitrate leaching?



How does soil texture influence nitrate leaching from manure?



Loam: **3 %** of cattle slurry-N leached during 2.5 years (Frick et al., under revision)

Clay [%]	Silt [%]	Sand [%]
22	43	33

Silt loam: **3-5 %** of pig manure-N leached during 2 years
Sandy loam: **8-15 %** (Jayasundara et al. 2009)

Clay [%]	Silt [%]	Sand [%]
12	46	42
15	36	49

Loamy sand: **13-21 %** of FYM-N leached during 3 years (strong influence of application timing!) (Thomsen 2005)

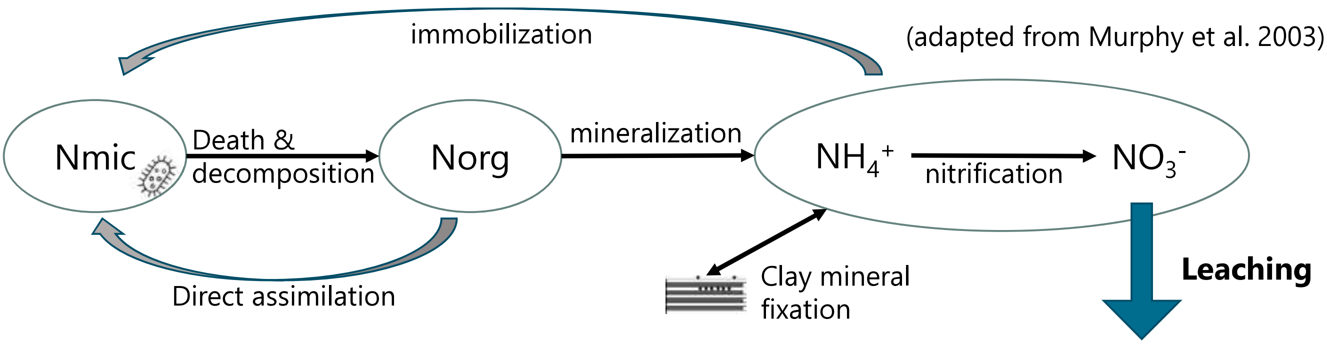
Clay [%]	Silt [%]	Sand [%]
9	11	80

Soil texture influences

→ **water drainage**

→ **N cycling and retention**

Soil texture influence N cycling and retention in soil on multiple levels – physical, biological, chemical



(adapted from Murphy et al. 2003)

	C% (fresh)	N immobilization (% of fertil. dose)	
		Sand	Loess
Slurry	4.4	24	44
Slurry	2.0	16	34
Slurry	0.6	13	30
CAN	-	7	13

(Gutser & Dosch 1996)

Immobilization higher in fine textured soil than in coarse soil (Gutser & Dosch 1996)

Remineralization rate lowest in soil that contained most clay (Sørensen & Amato 2002)

→ N retention and accumulation highest in fine textured soil

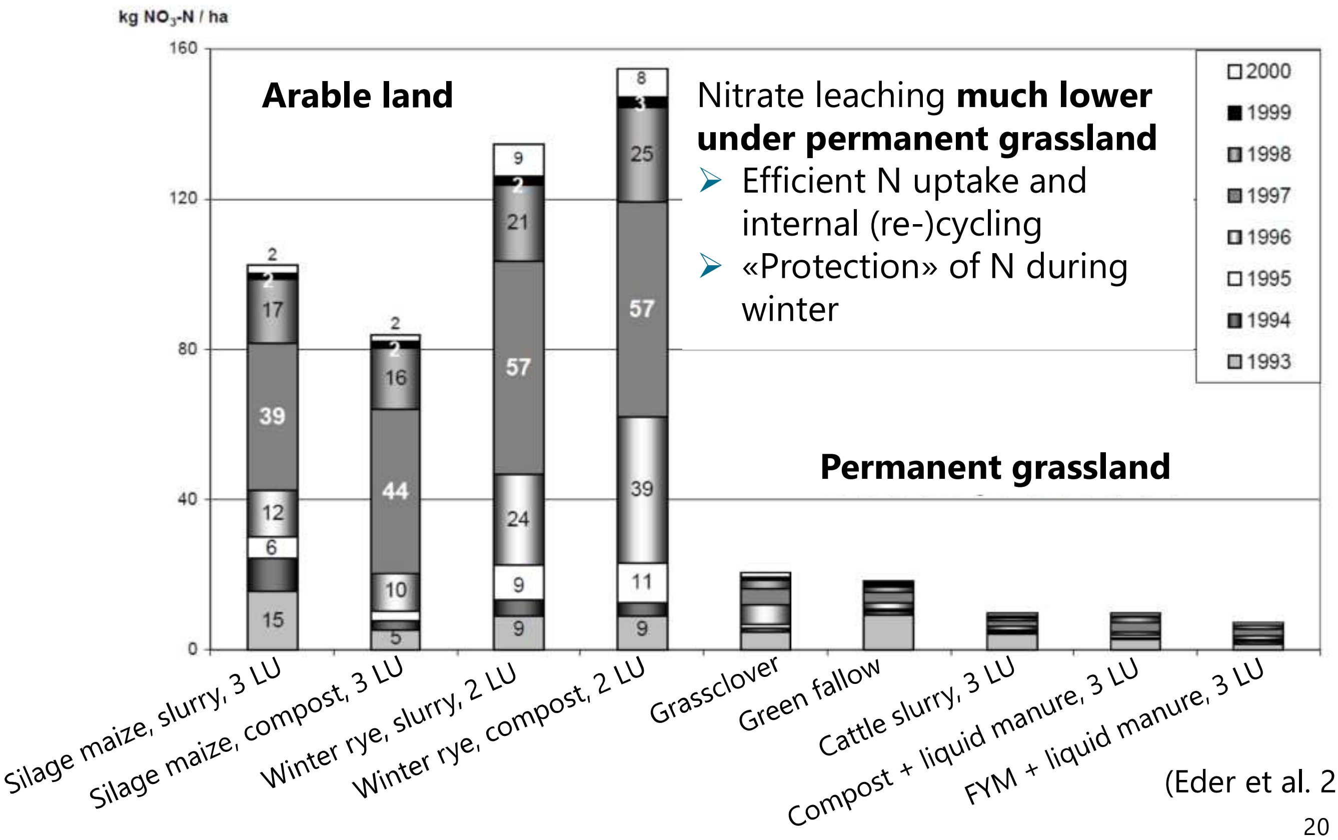
What does that mean for nitrate leaching? Protection or time bomb?

How does land-use influence nitrate leaching from manure?

vs

(permanent) grassland | **Arable land**

Effect of land-use on nitrate leaching from manure



(Eder et al. 2001)

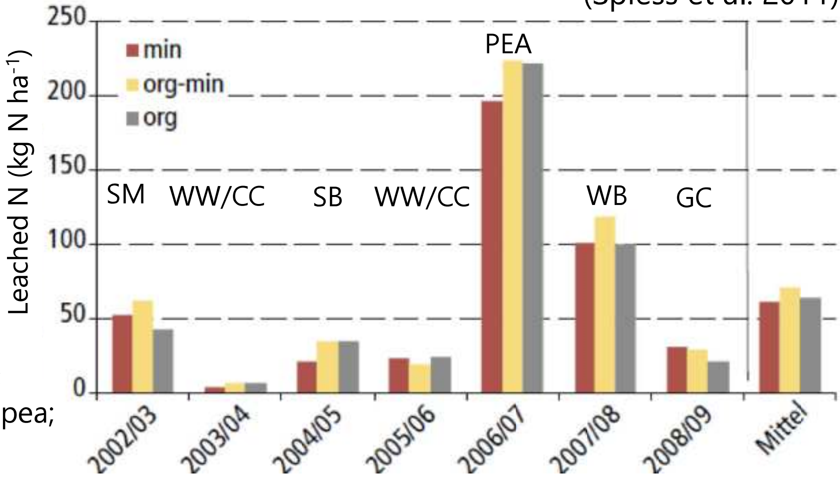
Nitrate leaching is influenced by crop sequence

7 year lysimeter trial; **min vs. org-min vs. org** (Spiess et al. 2011)

No effect of fertilization on nitrate leaching

Strong effect of **crop-sequence** (Stauffer & Spiess 2001)

(Spiess et al. 2011)



SM=silage maize; WW=winter wheat; CC=cover crop; SB=sugar beet; PEA=pea; WB=winter barley; GC=grass-clover

Grass-clover termination is a «hot moment»

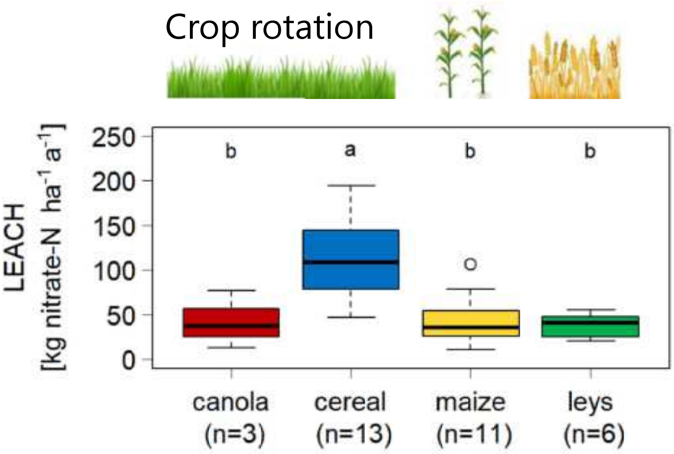
- High accumulation of SOM during grass-clover cultivation (high inputs + BNF)
- Mineralization «boost» upon/after termination of grass-clover

Maize after grass specifically risky (Børgesen et al. 2022)

Grass-clover termination causes **prolonged mineralization (>2 years)** (e.g. Helfrich et al. 2020)

Management **after** grass-clover termination important (e.g. Kayser et al. 2008)

➔ Cover crops/perennials!



(Wey 2021)

Composition and origin of manure – does it matter?

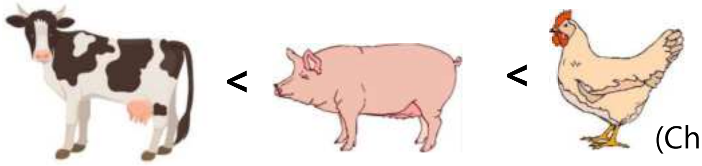
Yes and No!

Manure composition is relevant in the **short-term**; increased leaching risk for manure with **high NH_4 to total N ratio**; importance of

- Application rate (e.g. Goulding et al. 2000)
- Timing (e.g. Webb et al. 2013)

Most manure N rapidly **incorporated into SOM by microbes** → further mineralization is little affected by original composition.

BUT: mineralization of (undigested) **organic manure N** differs between animal categories (monogastric vs. ruminant)



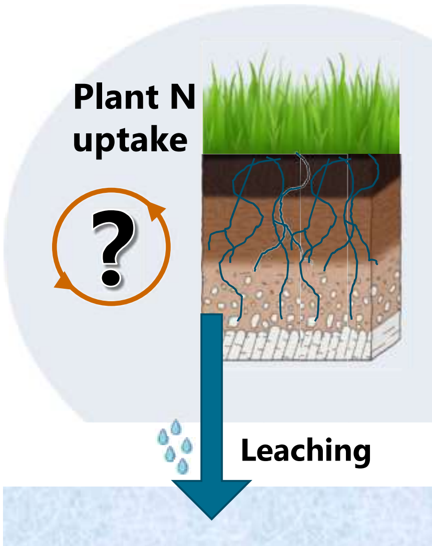
Mineralization of organic N

(Chadwick et al. 2000)

How much N is lost from animal manure via nitrate leaching?

Clear quanitification is challenging:

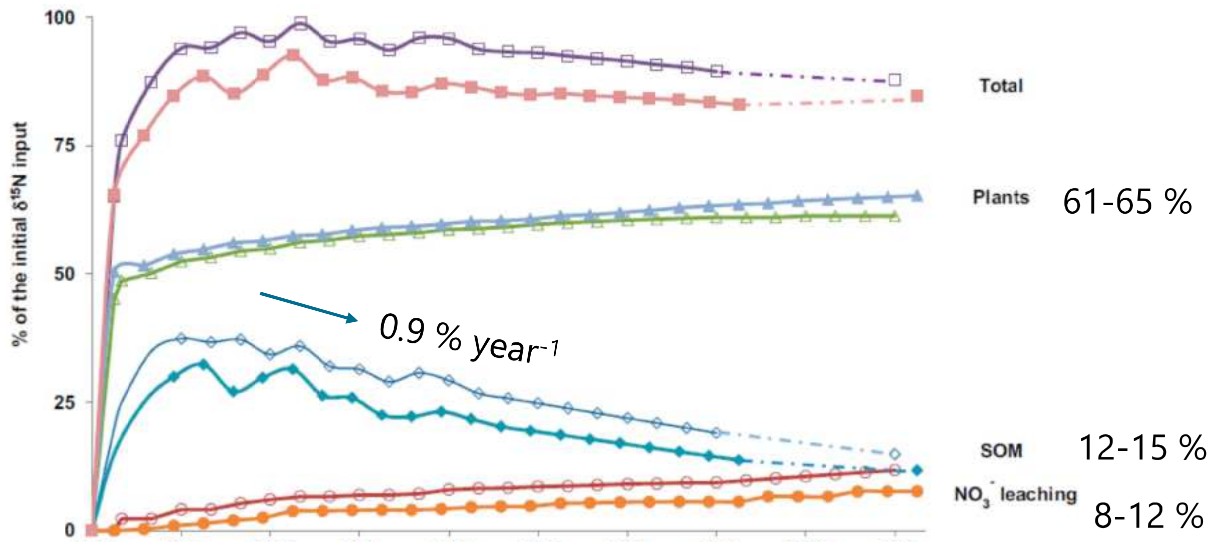
- Most manure N is not leached directly, but incorporated in SOM from where it can get leached (or taken up by crops) over a **long time**
- **Several (interlinked) factors** influence the amount of nitrate leached
- In general: **asynchrony** between plant N uptake and mineral N release from soil/manure makes N prone to leaching



How much?

Nitrate leaching from mineral fertilizer continues over decades

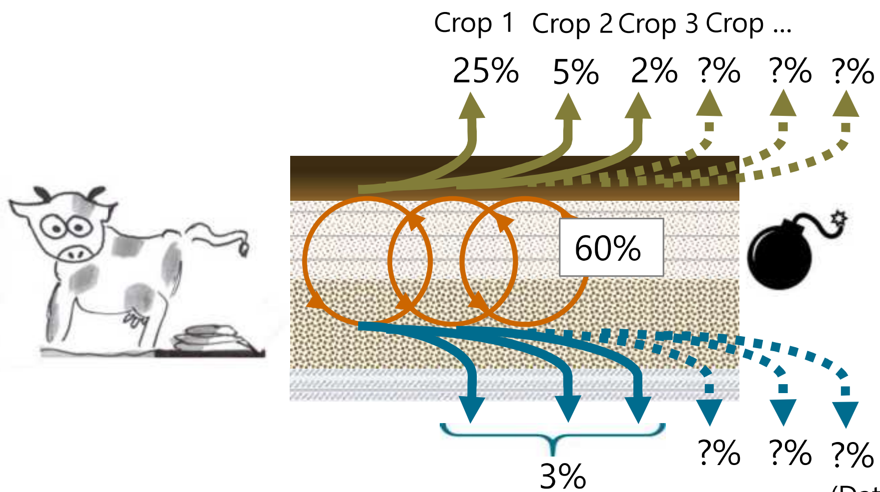
^{15}N tracer study on two lysimeters with arable crop rotation



Cumulative budget of ^{15}N-labeled fertilizer nitrogen based on mass and isotope balances for plants, soil organic matter (SOM), and nitrate

(Sebilo et al. 2013) 25

Let`s discuss!



(Data from Frick et. al., under revision)

Understanding and predicting **mineralization of residual manure N** over years – decades is key

Assessing «only» long-term supply to plants, disregards **nitrate leaching!**

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Effects of manure treatment on ammonia and nitrous oxide emissions

Gerard Velthof

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Content of the presentation

- Manure treatment: why and how?

- Factors controlling NH_3 and N_2O emissions from manure treatment
    - Emissions during the treatment process
    - Changes in manure properties
    - Emissions during manure storage
    - Emissions from applied manure

- Conclusions: challenges and potentials

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Manure treatment: why and how?

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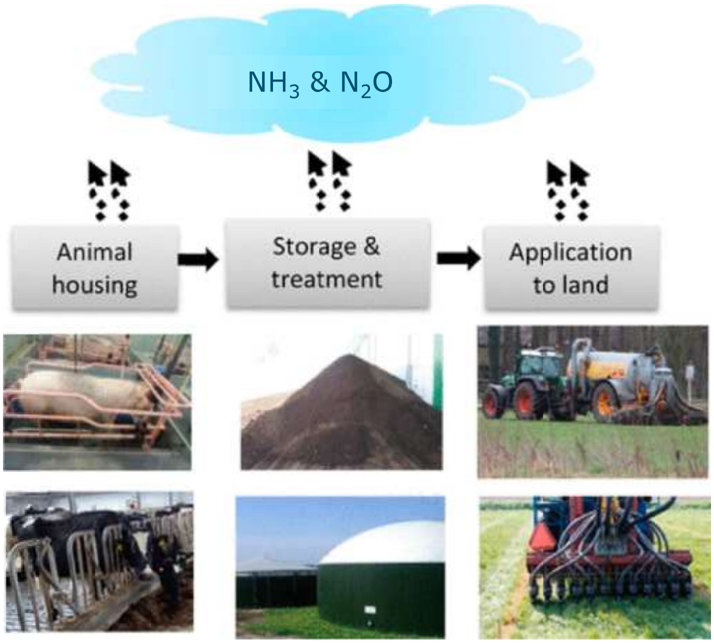
Manure treatment in the manure cascade

Manure treatment: "*A controlled biological, chemical or physical process that changes the properties of manures.*"

Source: RAMIRAN Glossary of terms on manure management

(http://ramiran.uvlf.sk/doc11/RAMIRAN%20Glossary_2011.pdf)



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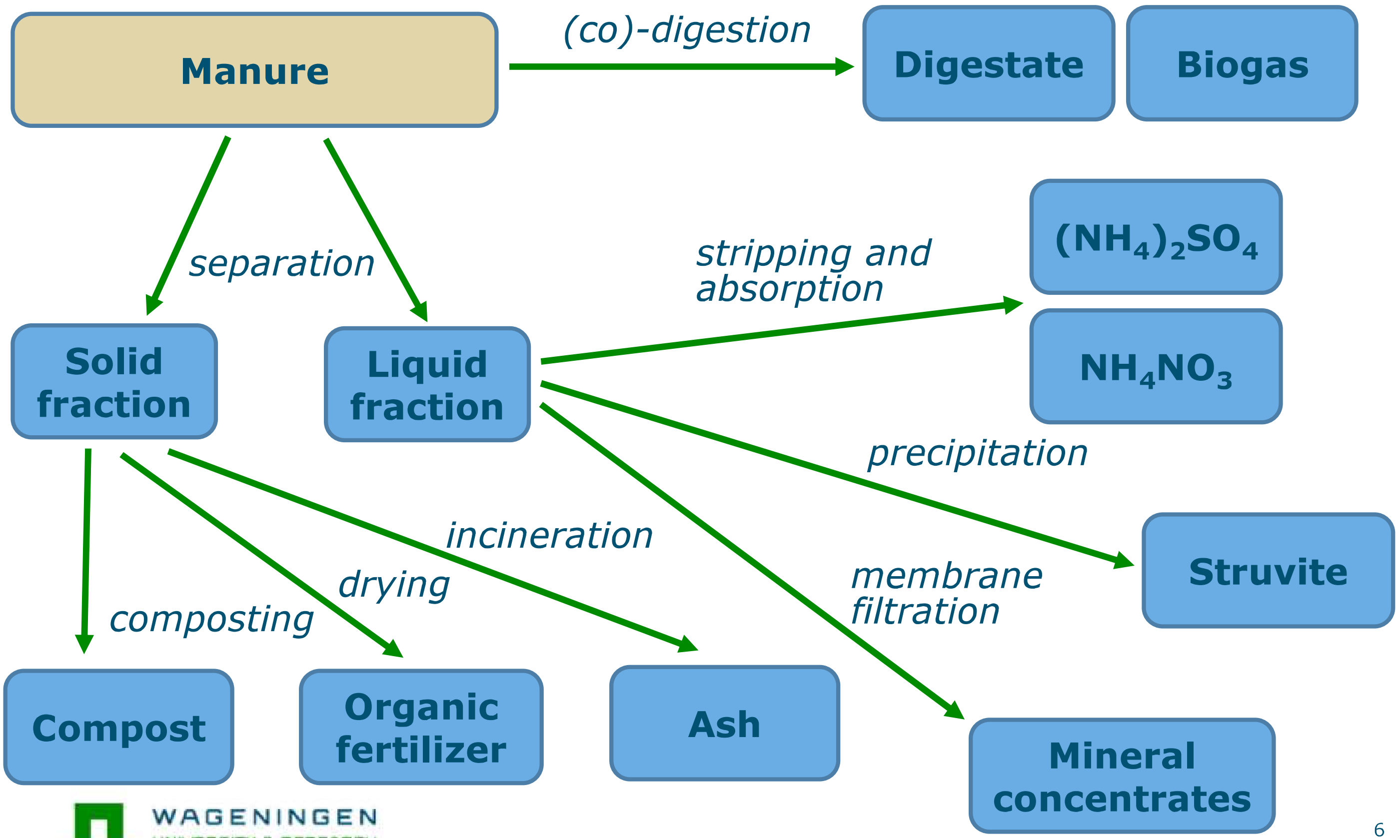
Why is manure treated?

- Increase nutrient use efficiency (N, P, K)
- Use as soil improver (organic matter)
- Reduction of volume for transport/export
- Energy generation
- Reduction of emissions of NH_3, CH_4 and N_2O
- Production of RENURE (REcovered Nitrogen from manURE)
  - Products considered as mineral N fertilizer in the Nitrates Directive, e.g. mineral concentrates, ammonium sulphate and ammonium nitrate

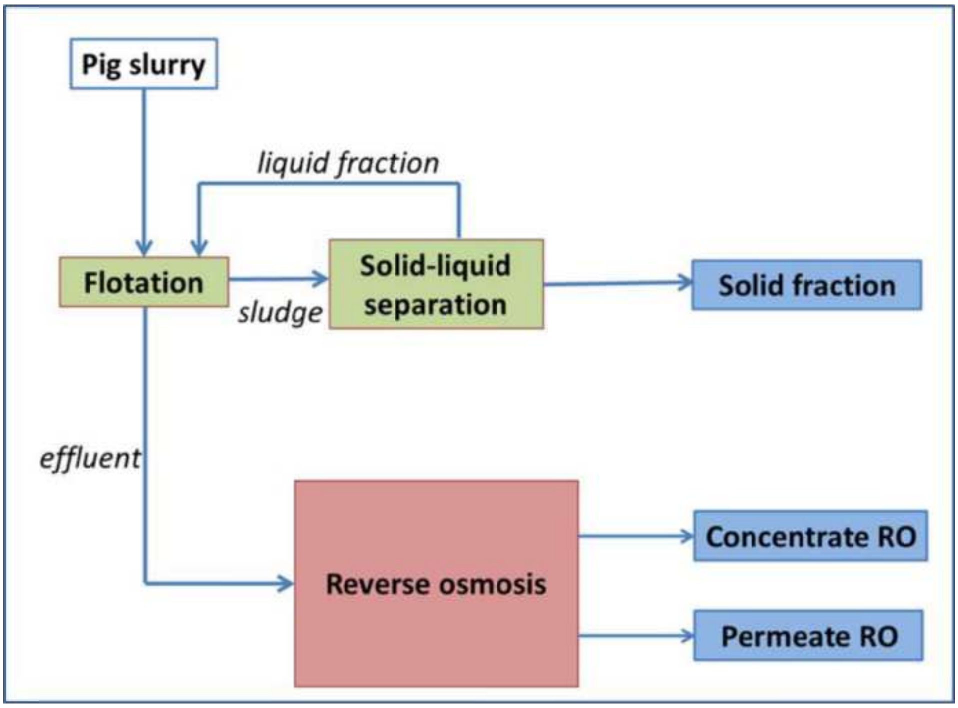




Many techniques and products



Example: production of mineral concentrate



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Factors controlling NH_3 and N_2O emissions from manure treatment

Emission during the treatment process

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N losses during manure treatment

Low risk in closed systems, e.g. digestion, ultra-filtration, reverse osmosis

- N loss < 5%

Higher risk in open systems, e.g. composting, belt separation

- N losses composting >> 25%

No experimental data on magnitude of NH_3 and N_2O emissions during treatment (except for composting)?

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Factors controlling NH_3 and N_2O emission from manure treatment

Changes in manure properties

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Effects of manure composition on NH_3 and N_2O emissions

NH_3 emission: NH_4 (TAN), pH, dry matter

→ effects on NH_3 can reasonably be predicted

N_2O emission: NH_4, NO_3, pH, degradable organic matter, dry matter, contaminants

→ effects on N_2O are difficult to predict:

- two biological processes involved: nitrification and denitrification
- ratio N_2O/N_2 also affected by these factors

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Effect manure treatment on manure properties

Average contents of 65 samples from 9 treatment plants

Parameter	Untreated	Solid fraction	Mineral concentrate
Dry matter, g/kg	61	283	35
Organic matter, g/kg dm	654	753	296
Ratio TAN/Total N	0.59	0.22	0.86
pH	7.8	8.4	7.9
NO_2-N + NO_3-N, mg/kg	neglibible	negligible	negligible

Hoeksma et al. (2021)

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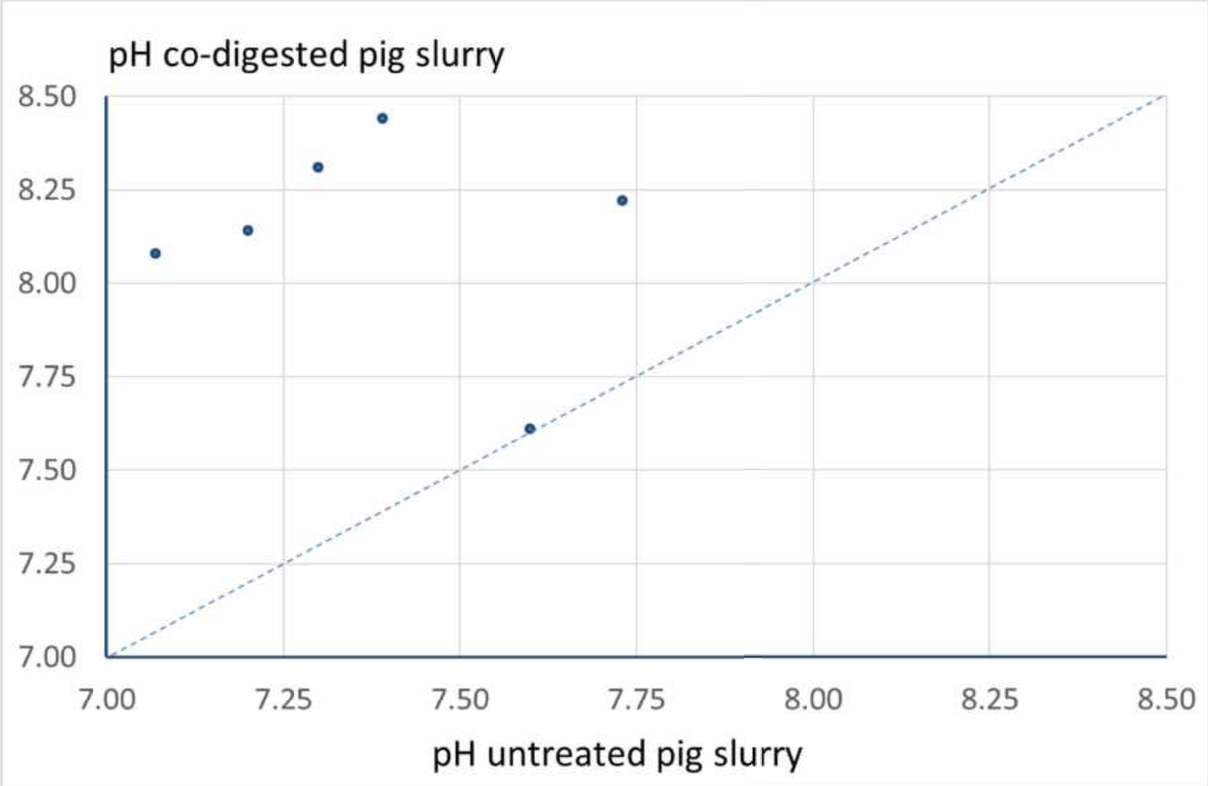
Effect co-digestion on pH



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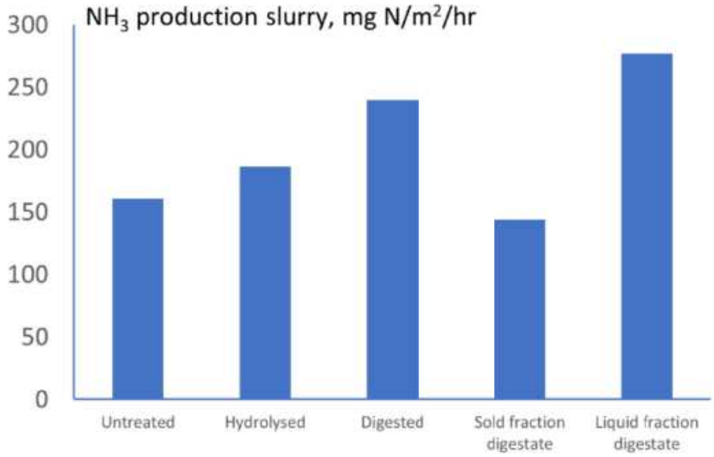
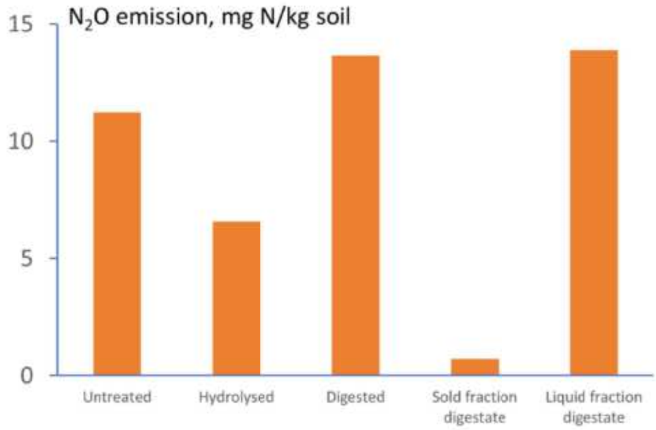
Manure treatment dairy farm

Cattle slurry	Dry matter g/kg	Organic matter g/kg	NH4/total N	pH
Untreated	84	72	0.49	6.8
Hydrolysed	81	68	0.61	7.4
Digested	77	59	0.59	7.9
Sold fraction digestate	218	205	0.28	8.5
Liquid fraction digestate	51	33	0.72	7.8

Velthof (unpublished)





Factors controlling NH_3 and N_2O emissions from manure treatment

Emission from stored treated manure

Housing and storage of untreated manure

Manure treatment affects the storage time and emissions of untreated manure in the housing and storage

- emissions of untreated manure decrease when storage time decreases

N losses during storage

Nitrogen losses during storage (literature review)			
Manure type		**N loss during storage, %**	**n**
Pig slurry	Untreated	23	8
	Solid fraction; centrifuge	32	8
	Liquid fraction; centrifuge	19	8

- Slurry systems: NH_3 emission >> N_2O emission
- N_2O emission: solid manure storage >> slurry storage
- Mitigation of NH_3 emission by covering storage

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Mosquera et al. (2010)

Factors controlling NH_3 and N_2O emissions from manure

Emission of applied manure

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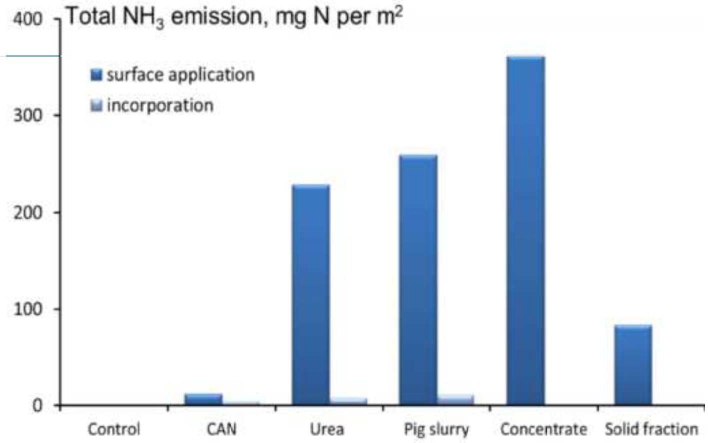
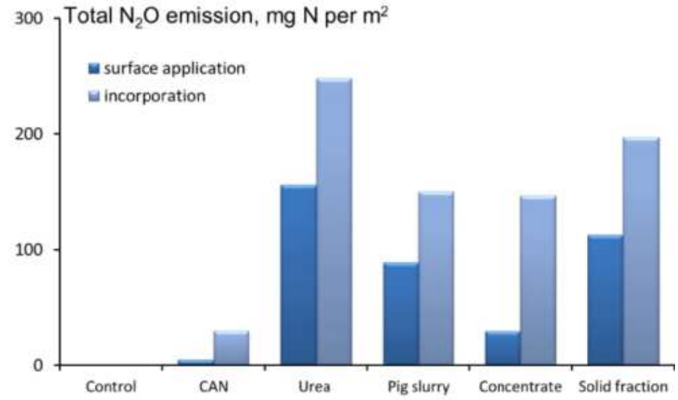
NH_3 and N_2O emission under controlled conditions





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Velthof et al. (2020)

Ongoing experiment on silage maize

Preliminary results 2021 (Van 't Hull)

Fertilizer	N_2O emission factor, % of N applied
Mineral N fertilizer (CAN)	1.9
Cattle slurry; sod injection	0.6
Liquid fraction separated cattle slurry; sod injection	1.2
Solid fraction separated cattle slurry; incorporation	0.7
Mineral concentrate; sod injection	3.1
Mineral concentrate + nitriifcation inhibitor; sod injection	1.3
Liquid ammonium sulphate of acid trap; injected	3.6

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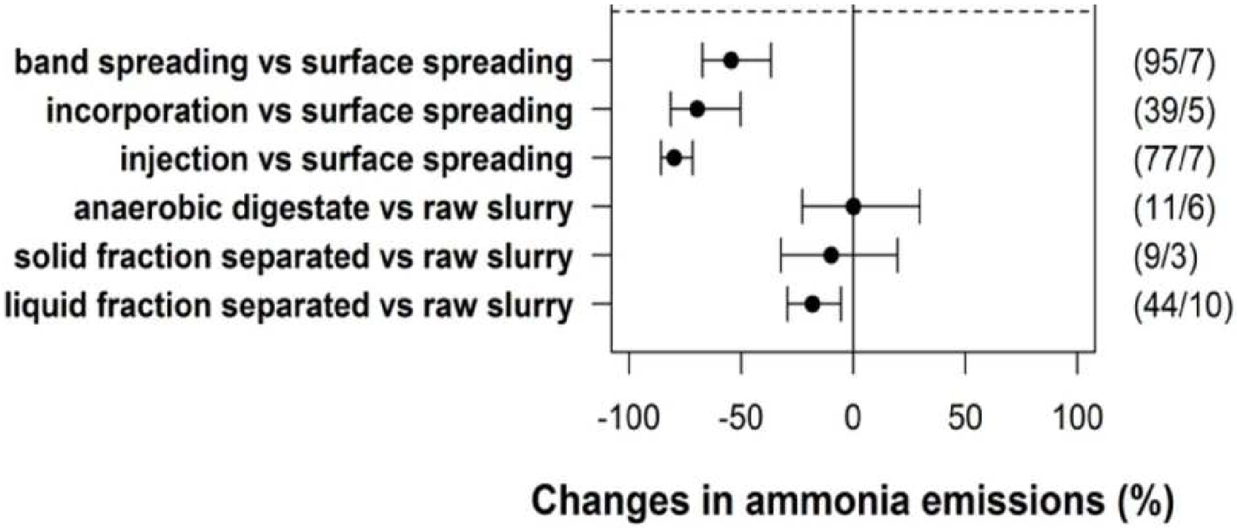
Manure treatment and ammonia abatement techniques



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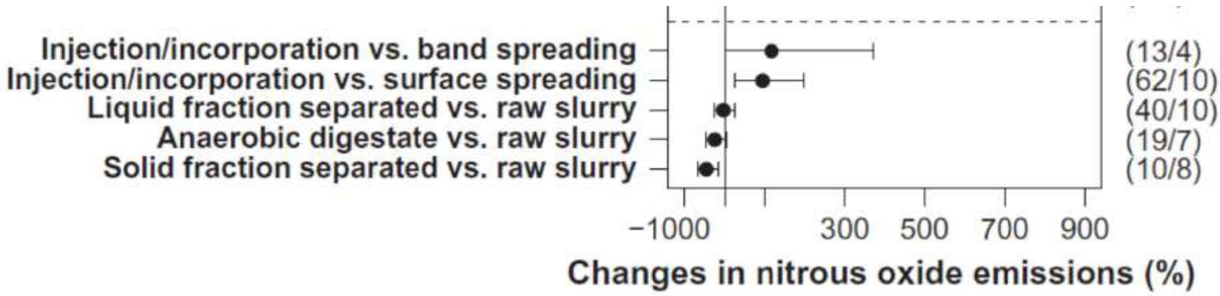
Meta-analysis of Hou et al. (2015)

Manure treatment and ammonia abatement techniques



Meta-analysis of Hou et al. (2015)

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Use of mineral N fertilizers

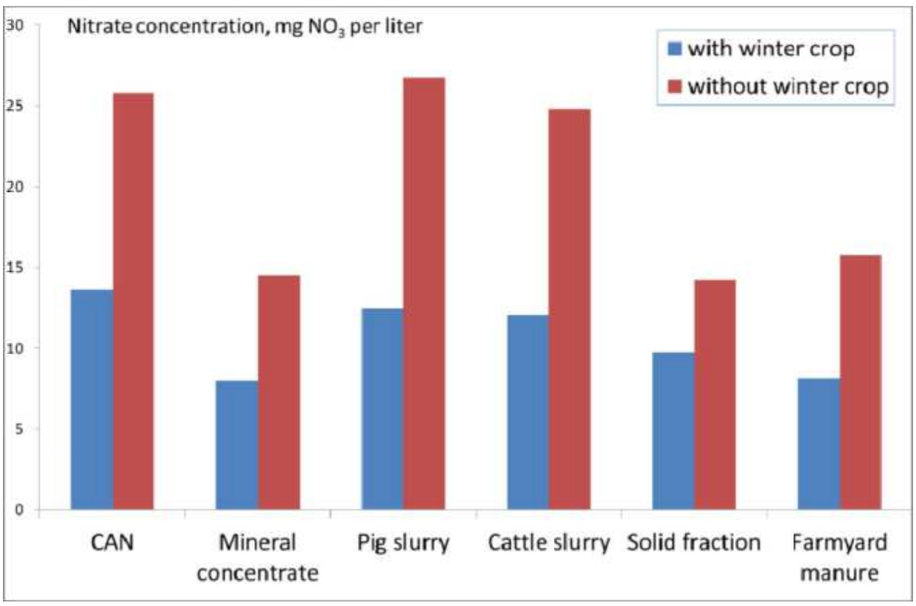
- Losses through NH_3 and N_2O emissions by manure treatment affect the amount of plant-available N in the end product of treatment

- To obtain the same application of plant-available N, mineral N fertilizer application rate has to be adjusted

  → emission of NH_3 and N_2O from mineral N fertilizer

Indirect nitrous oxide emissions

For a complete evaluation of N_2O emissions, changes in **indirect N_2O emissions** caused by NH_3 emissions and NO_3 leaching have to be considered as well



Schröder et al. (2012)

Conclusions

- Many treatment techniques and products are available
- Treatment can largely change the manure composition and the risk on NH_3 and N_2O emissions
- Treatment mostly results in two or more products -> N losses from all products have to be considered
- Direction of change in NH_3 emission by treatment can be predicted reasonably well
- Direction of change in N_2O emission by treatment is difficult to predict
- Manure treatment may cause pollution swapping between housing and field application, and between NH_3 and N_2O emission

Challenges and potentials

- A system approach is needed to quantify the potential effects of manure treatment
  - All untreated and treated manures
  - Housing – storage – field
  - NH_3 – N_2O, but also N_2 and NO_x
  - GHG: N_2O and CH_4

- High potential to decrease N losses by a combination of manure treatment and emission mitigation techniques
  - NH_3: covered storage; low emission application
  - N_2O: N fertilization of the crop; nitrification inhibitor

Thank you

Potentials of manure treatment technologies on nitrogen availability and plant uptake

Kurt Möller
University of Hohenheim, Stuttgart, Germany
LTZ Augustenberg, Karlsruhe, Germany

Expert Workshop on Nitrogen recovery in manure, Reckenholz, 5th May 2022

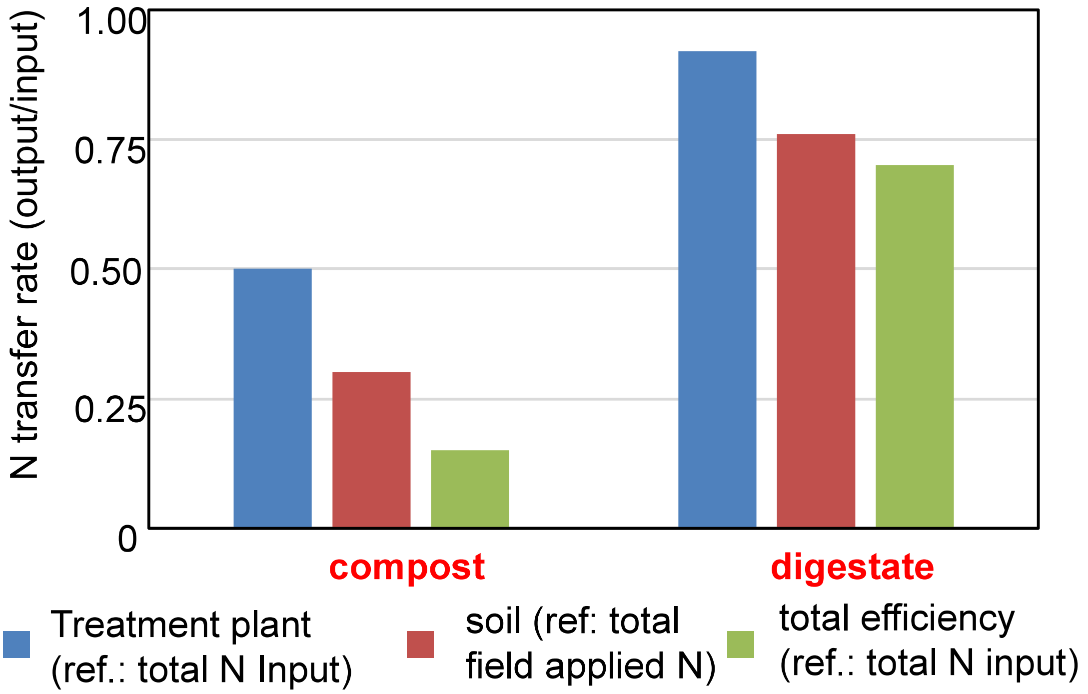
Outline

- Introduction
- Overview treatment technologies
- Anaerobic digestion vs. composting
- Post treatment of liquid fertilizers/digestates on composition and fertilizer value
- Conclusions

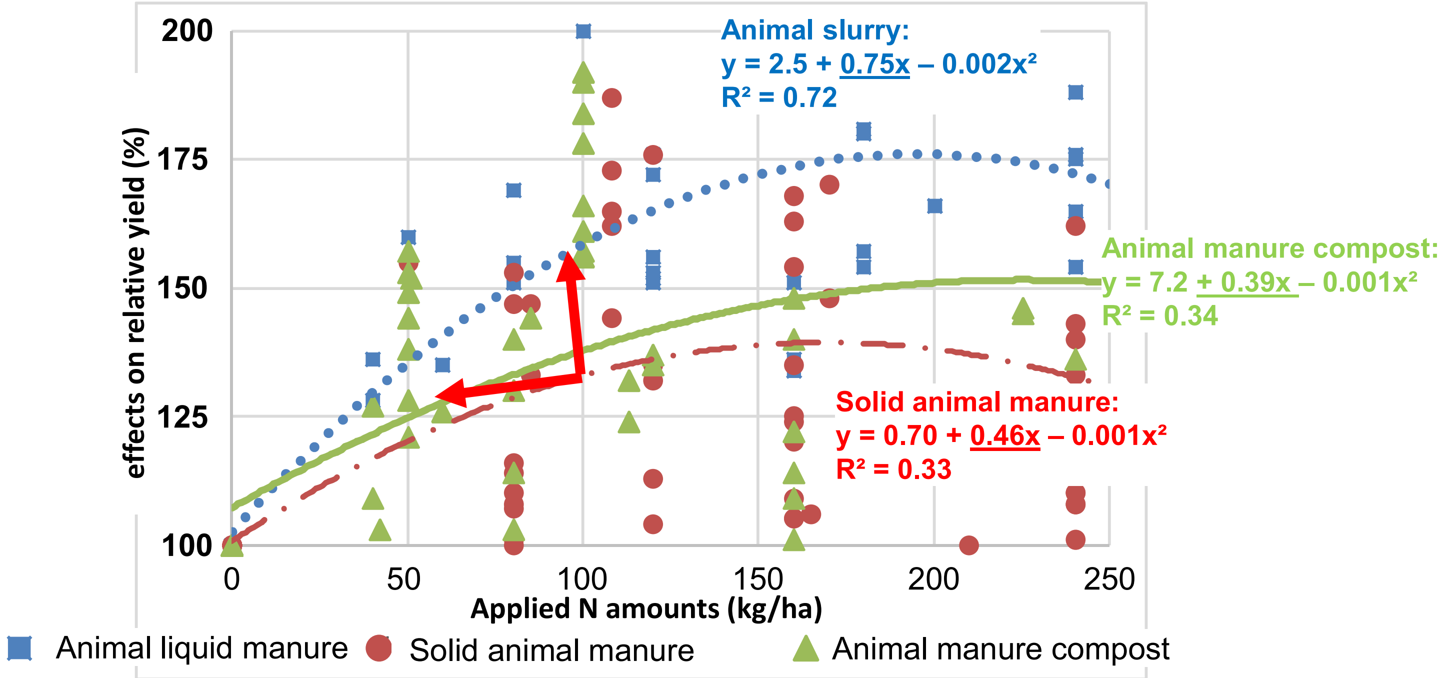
Overview of methods of manure treatment

Biological approaches	• Composting (solids) • Anaerobic digestion (liquid and solids)
Physical methods	• Solid-liquid separation (liquids) • Drying, pellet production (solids) • Evaporation, membrane technologies (liquids)
Physico-chemical methods	• Ammoniac stripping
Chemical methods	• Struvite crystallization (liquid) • Ca-Phosphate-precipitation (e.g. P-Roc) (liquid)
Thermal methods	• Incineration, pyrolysis, etc. (liquid and solids)

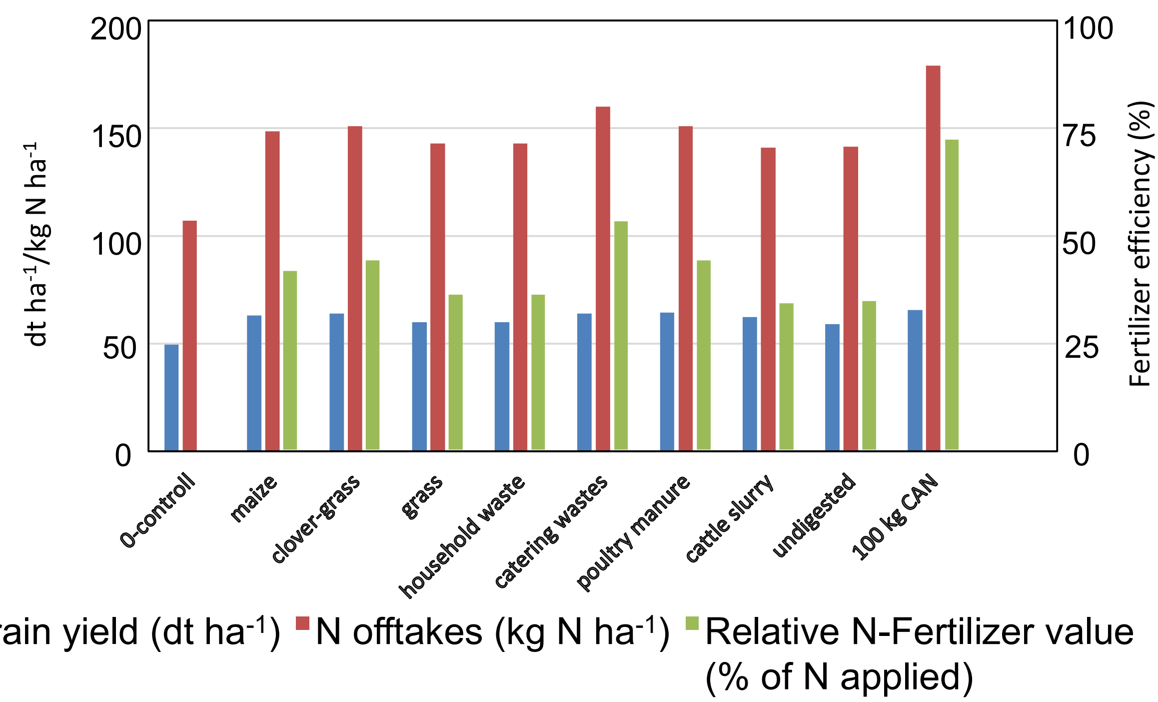
N transfer efficiencies of N rich feedstocks during manure treatment and in the soil, and total N transfer efficiency (rate = output/input) (Benke et al. 2017)



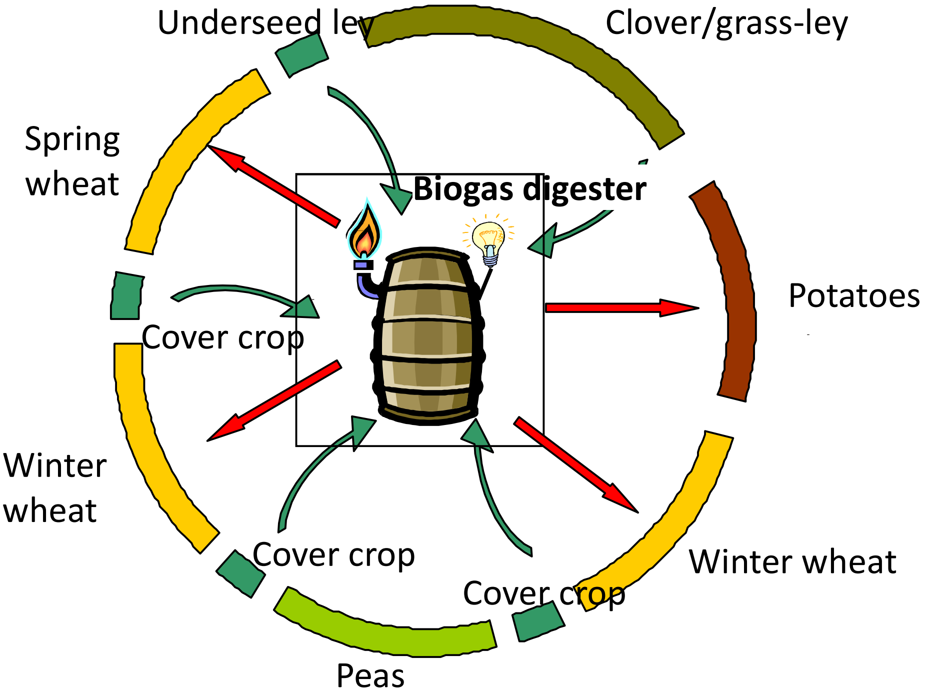
Relationship between applied N amounts and potato yields depending on the organic fertilizer type (Möller and Kolbe 2003)



Effect of different feedstocks on grain yield of winter wheat in field experiment (Häfner et al., in prep.)



Reallocation of nutrients of crop residues via AD: example from a stockless System with digestion



Digestion of crop residues: Effects on the organic matter and nutrient flows (Stinner et al. 2008, Möller 2009)

Crop	Stockless without AD	Stockless with AD
Total amount of N (kg ha^{-1})	128	126
Amounts of „mobile“ N (kg N ha^{-1})	0	104
N supplied to non-legume crops (kg N ha^{-1})	150	180
N supplied to legumes (kg N ha^{-1})	83	10
C/N ratio of organic residues/manures	25.2	11.0
Total ammoniacal N (kg N ha^{-1})	0	43.2

Effect of anaerobic digestion of residues in a stockless organic crop rotation on relative crop yields (Stinner et al. 2008)

Crop	Stockless without AD	Stockless with AD
Clover grass	100	100
Potatoes	100	100
Winter wheat	100	**117**
Peas	100	100
Winter wheat	100	**130**
Spring wheat	100	**117**
Sum non legumes	**100**	**116**
Sum cereals	**100**	**122**

Treatment options for liquid feedstocks

Anaerobic digestion

- Anaerobic digestion
- Solid-liquid separation

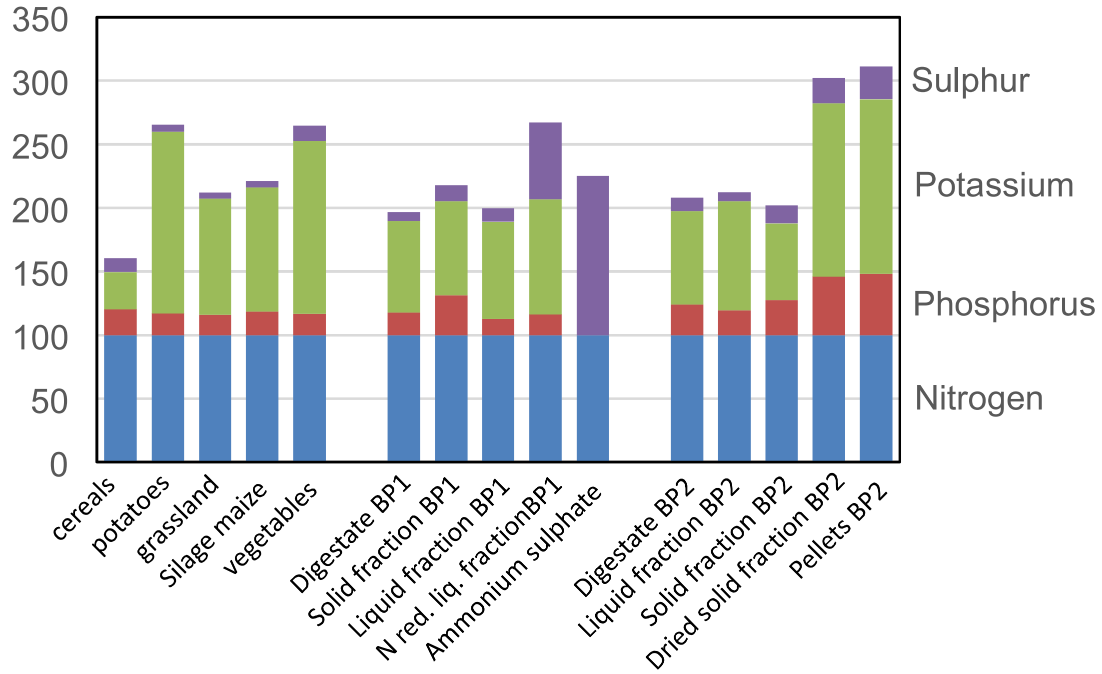
More sophisticated approaches

- Separation combined with post treatment approaches, e.g.:
  - Drying and pellet production
  - Dewatering, ammonia stripping
  - Membrane technologies
  - Many others (struvite crystallization, etc.)

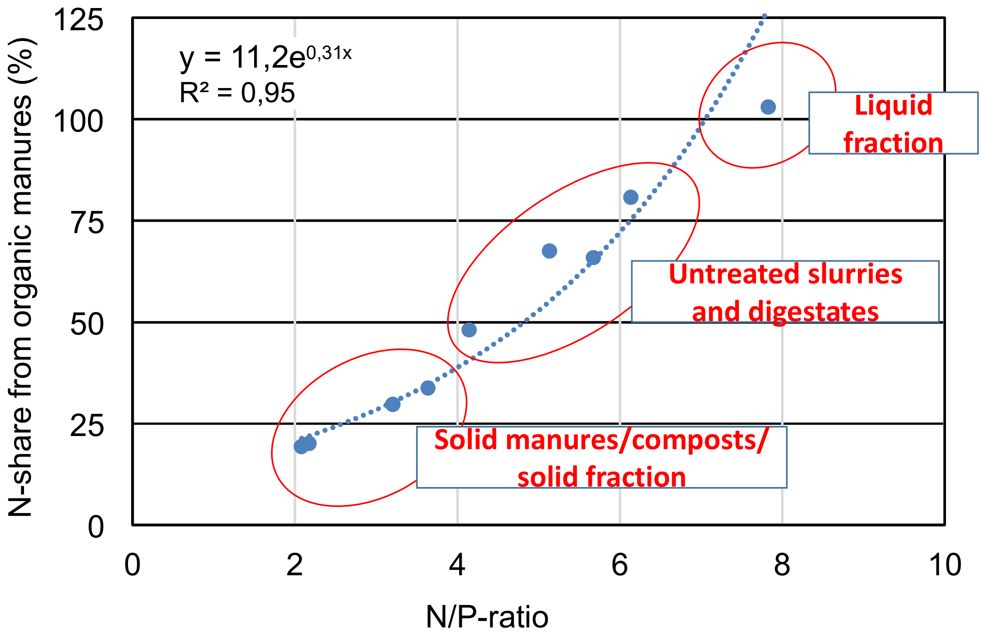
Digestate composition after treatment of the solid fraction (Petrova et al. 2017)

Treatment	Product	N_t % FM	N_t % TM	NH_4-N % N_t	C/N ratio
no	Digestate untr.	0,59	6,41	47	5,4
Separation	Liquid fraction	0,55	8,65	50	4,1
	Solid fraction	0,67	2,52	25	17,1
Belt dryer	Solid fraction	1,69	2,56	7	16,2

Nutrient stoichiometry of harvested products and of the obtained fertilizer products (without corrections for differences in long term fertilizer efficiency)



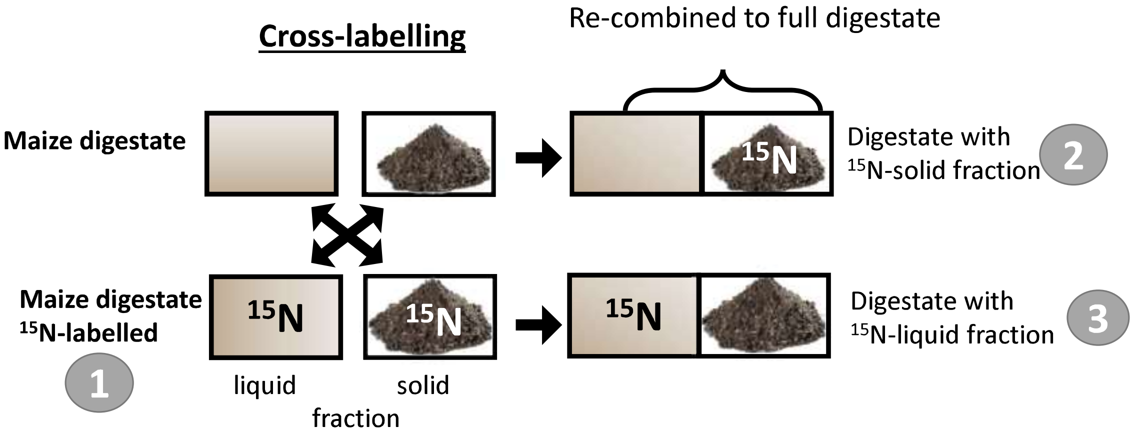
Maximal N-share from organic amendments (%) as function of the N/P-ratio



Mineral fertilizer equivalents of treated digestate fertilizers (Petrova et al. 2017)

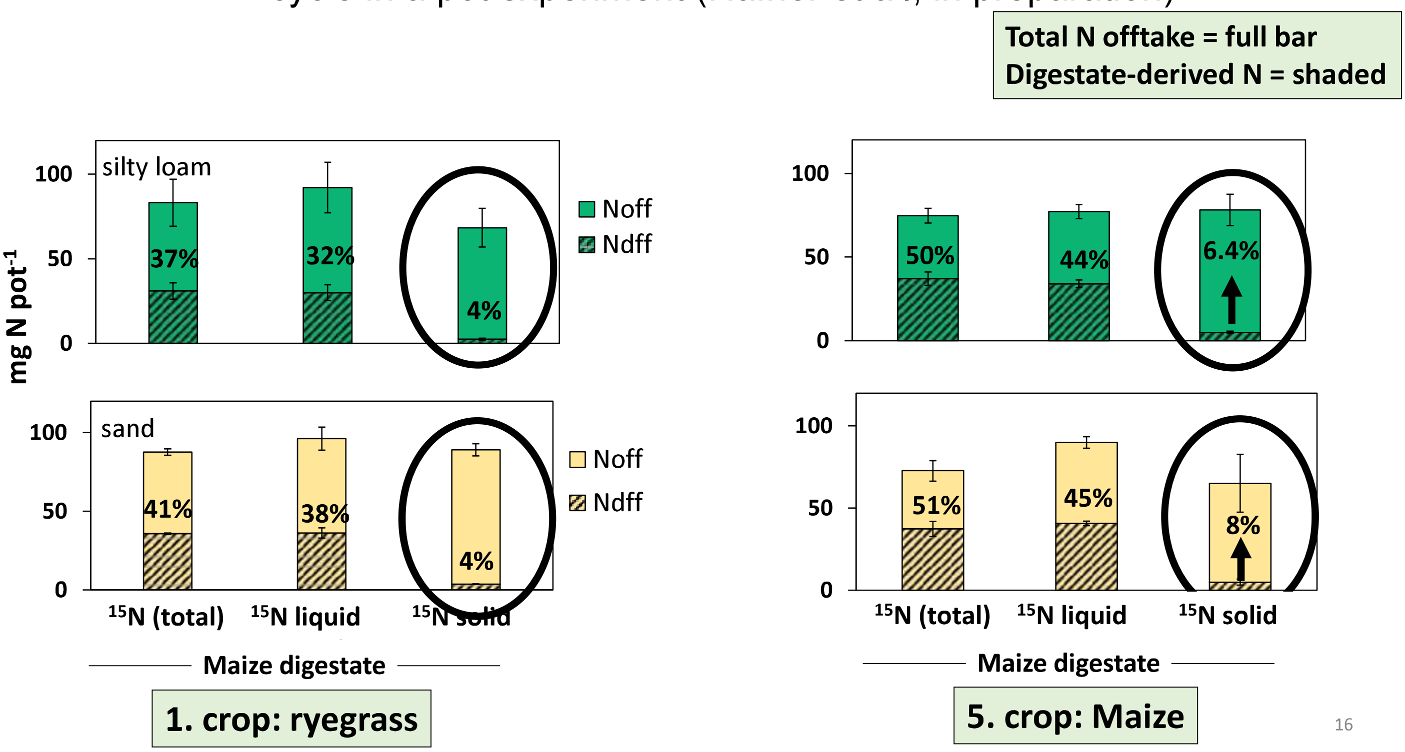
Treatment	Product	MFE (%)	
		Silage maize	Spring wheat
no	digestate	61	62
Separation	liquid fraction	68	50
Separation	solid	38	4
Belt dryer	solid	-6	13

^{15}N-cross-labeling of digestates for the pot experiment (Häfner et al., in prep.)



→Three maize digestate variants

N release of ^{15}N labelled maize digestate at the beginning and after the 5th crop cycle in a pot experiment (Häfner et al., in preparation)



Long term NPK-fertilizer efficiency of organic amendments (Benke et al. 2017, Möller 2020)

- Phosphorus and potassium: 100 %: Schröder et al. 2011, Frossard et al. 2015, Schnug und Haneklaus, 2016

Amend-ment	Long term N fertilizer efficiency	References
composts	20 – 40 %	Amlinger et al., 2003; Diez and Krauss, 1997; Gutser and Claasen, 1994
Solid animal manure	50 – 70 %	Russels, 1937; Körschens, 1987; Asmus, 1995; Chang and Janzen, 1996; Albert and Grunert, 2013; Gutser and Claasen, 1994
Slurry, digestates	70 – 80 %	Gutser and Claasen, 1994; Schröder et al., 2005; Möller and Müller, 2012
Liquid separates	80 – 90 %	Gutser et al., 2005
N-Mineral-fertilizer	80 – 90 %	Körschens, 1987; Asmus, 1995; Gutser et al., 2005

Conclusions

- The stoichiometry of nutrients with liquid fertilizers matches much better crop offtakes than with solid (solid manures, separated solids)
- Composting of N rich feedstocks are related to large N losses and a reduction of the availability of the remaining N
- Anaerobic digestion does increase the N availability mainly when solid feedstocks are digested (e.g. crop residues, solid animal manures, etc.), digestion of liquid animal manures have only minor agronomic effects
- The digested feedstock have only minor effects on the N availability
- Treatment of liquids by solid-liquid separation
  - Liquid fraction: similar N fertilizer value as the unseparated liquid
  - Solid fraction high in Norg: low N fertilizer value, minor carry-over effects
- The overall long term N fertilizer value of organic fertilizers is often driven by their short-term (direct) effects

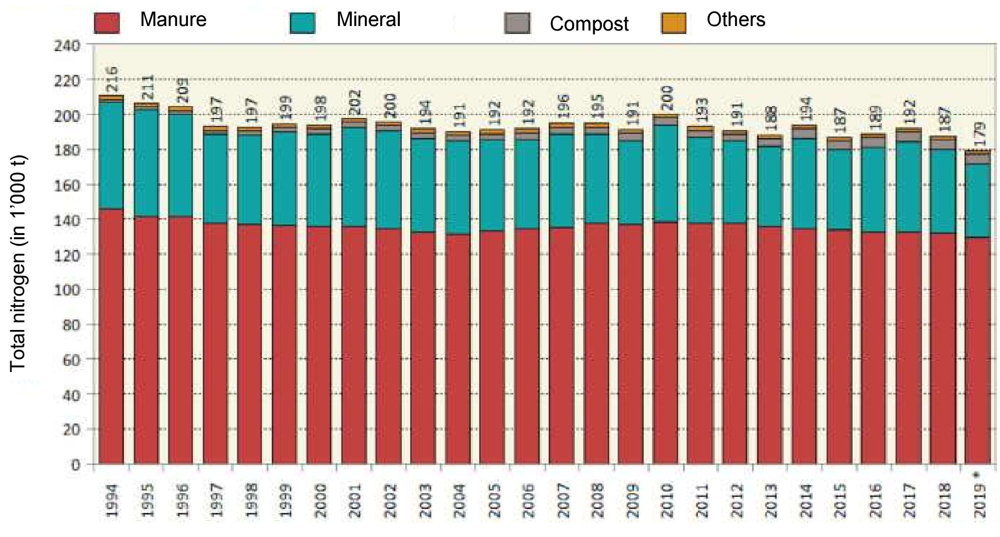
Nitrogen recovery after manure application: concepts, challenges and modelling approach at the farm level

CA Epper, J Mayer and F Liebisch

Reckenholz, 5th of May 2022

Importance of manure as nitrogen source in Switzerland

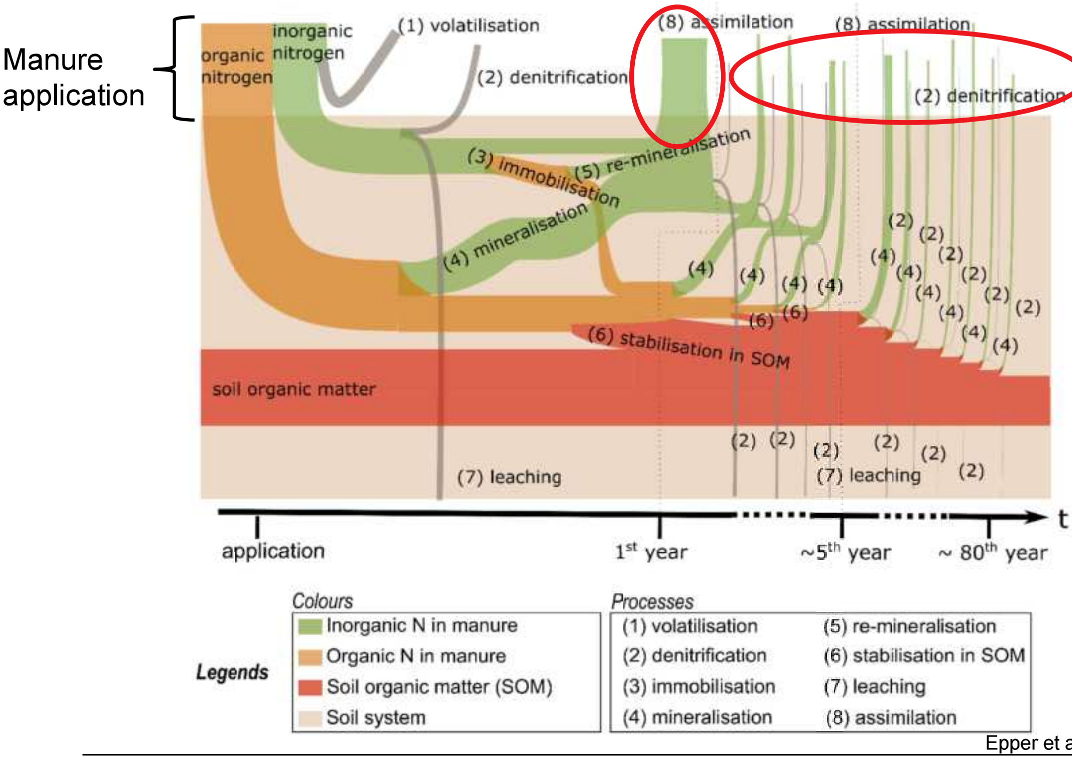
agristat Nitrogen sources and their N_{tot} quantities in Switzerland



* Provisory data

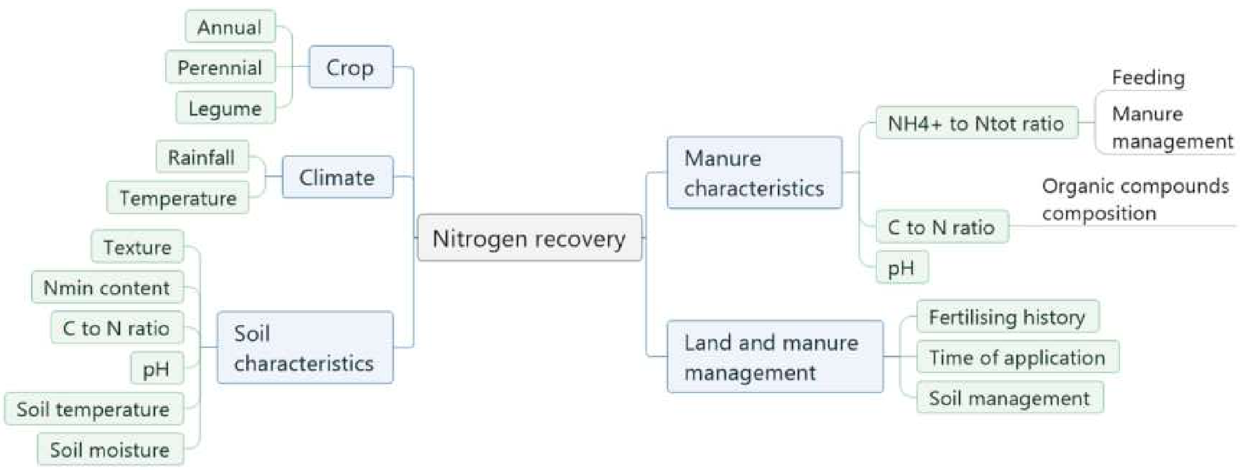
(translated and directly retrieved from Agristat 2022)

Processes involved in the nitrogen recovery assessment



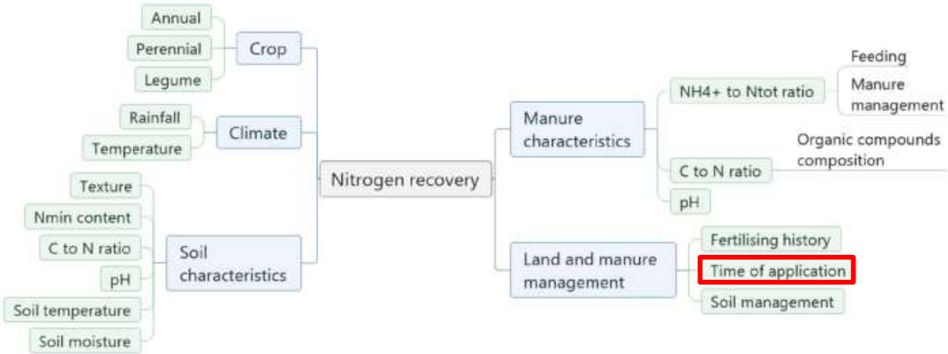
Epper et al. 2021, unpublished

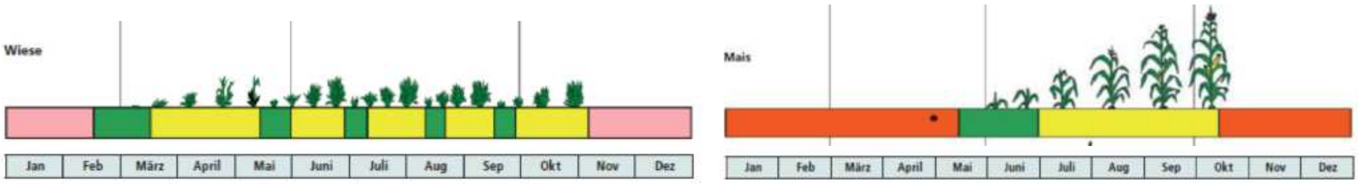
Factors influencing the nitrogen recovery assessment



(compiled based concepts in Boxberger et al. 2020, no guarantee of completeness)

Factors influencing the nitrogen recovery assessment





Time of application:

- Ideal application time
- Ideal application time (application potentially technically difficult)
- High negative environmental impact risk
- Low negative environmental impact risk
- Application technically difficult

Retrieved, modified and translated from Richner et al. 2017

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Processes and factors involved in the nitrogen recovery assessment

ELSEVIER European Journal of Agronomy 16 (2002) 81–95
European Journal of Agronomy
www.elsevier.com/locate/eja

Remineralisation and residual effects of N after application of pig slurry to soil

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Received 19 January 2001; received in revised form 15 May 2001; accepted 18 June 2001

Factors considered:

- Soil type
- Application method
- Till / no-Till

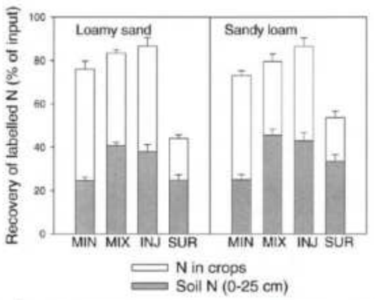
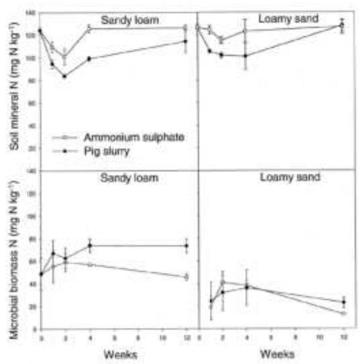


Fig. 4. Total recovery of ^{15}N applied as ammonium-N in pig slurry and mineral fertiliser (MIN) and retained in soil or removed in harvested barley and ryegrass cover crops after three growing seasons. The pig slurry was either applied by soil mixing (MIX), direct injection (INJ) or surface-banding (SUR). Bars indicate standard deviation (n = 4).

Systems :

- Field
- Pot incubation



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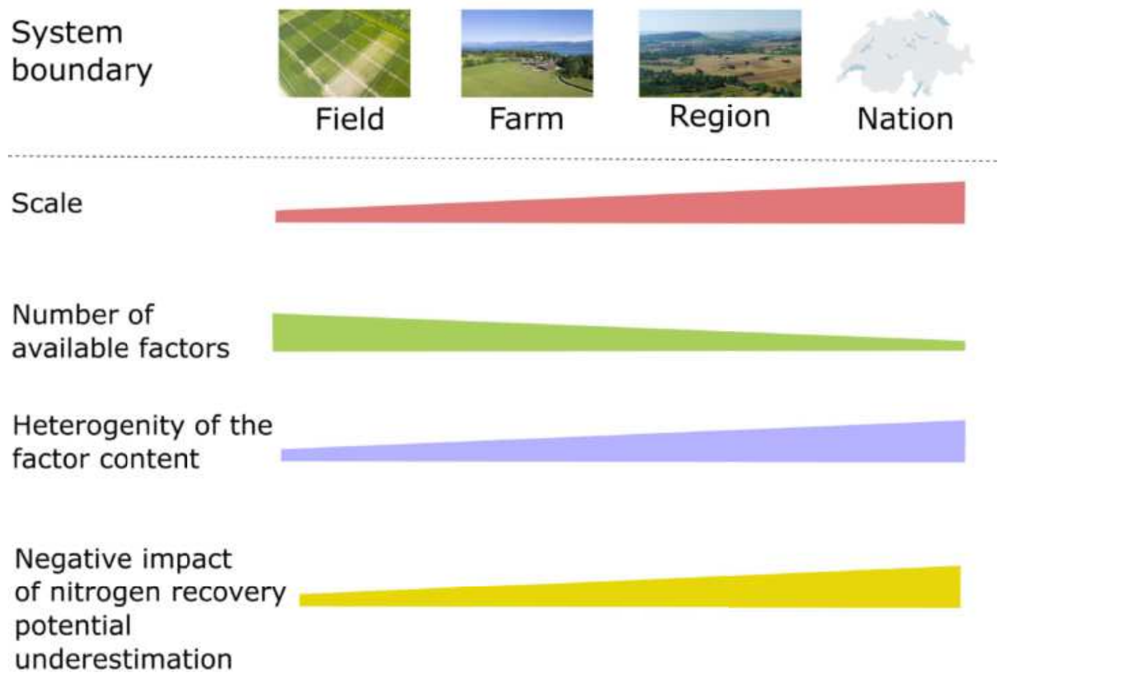
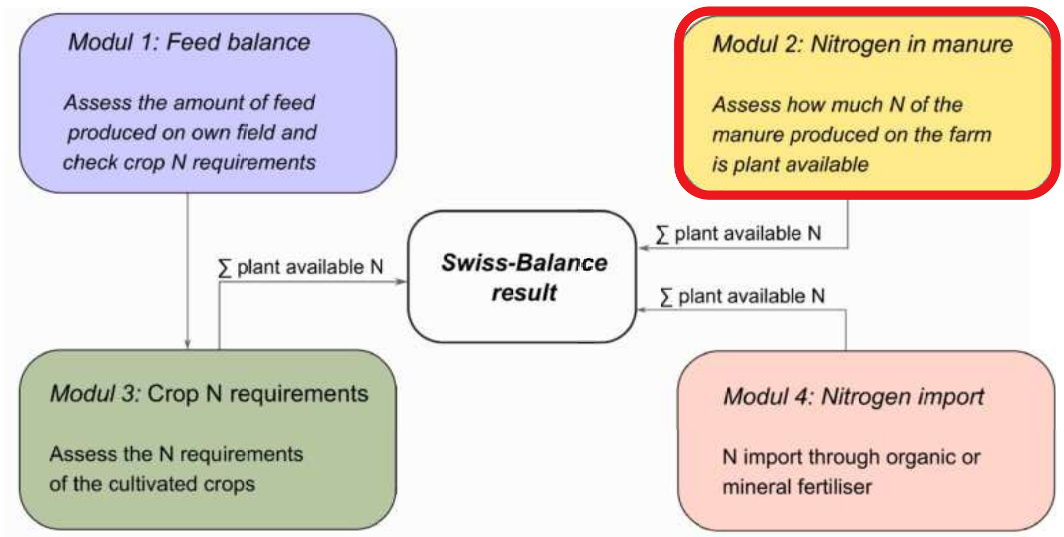
Assessing the nitrogen recovery in the Swiss-Balance



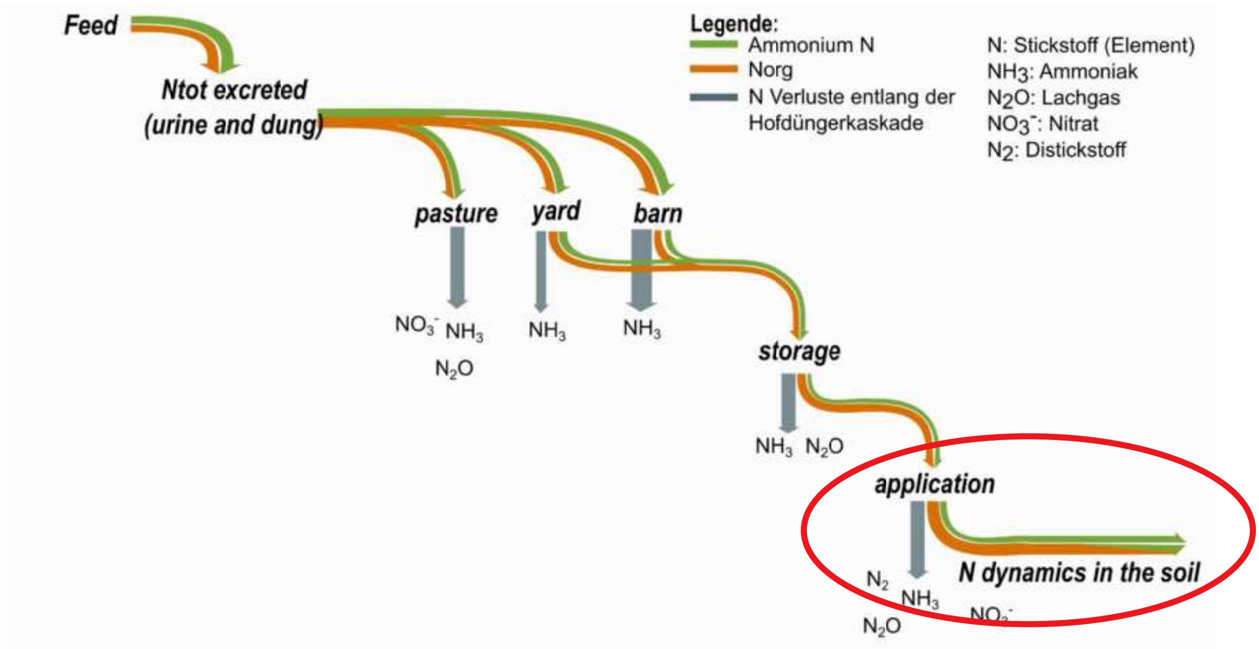
Plot, farm and nation images retrieved from the Agroscope photo archive
Region image retrieved from piyabay.com, curtesy of MonikaP

Assessing the nitrogen recovery in the Swiss-Balance

- No excessive N application → crop N requirement ≈ N applied
- Plant N requirements and economic optimum as central elements
- Plant available N instead of total N → Factors for organic fertilizers



Assessing the nitrogen recovery in the Swiss-Balance



Assessing the nitrogen recovery in the Swiss-Balance – Current state

Current nitrogen recovery factors (%N_{tot} applied) :

Cattle and pig slurry: 60 %N_{tot} applied

Cattle farmyard manure: 48 %N_{tot} applied

Hofdüngerart	Mid-term N availability (% of Ntot applied)
Cattle slurry	50–70
Rindviehgülle, kotarm	65–85
Stapelmist	20–40[3]
Laufstallmist	25–50[3]
Pferdemist	10–25[3]
Schaf- und Ziegenmist	40–60[3]
Pig slurry e	50–70
Schweinemist	40–60[3]
Hennenkot (Kotband)	40–60[3]
Hennenmist (Kotgrube, Bodenhaltung)	40–60[3]
Geflügelmist (Mast), Poulet, Truten	40–60[3]

Richner et al. 2017

Assessing the nitrogen recovery in the Swiss-Balance – Current state

Current nitrogen recovery factors (%N_{tot} applied) :

Cattle and pig slurry: 60 %N_{tot} applied

Cattle farmyard manure: 48 %N_{tot} applied

TABLE 4 | Requirement for N utilization (RNU) of N in animal manure.

Manure category	Requirement for utilization of N in animal manure (RNU), % of manure N
Pig slurry	80
Cattle slurry	75
Mink slurry	75
Poultry slurry	80
Liquid fraction after slurry separation (i.e., permeate)	85
Deep litter and other solid manure from poultry	60
Deep litter from non-poultry animals	50
Solid manure (in-house separation by scraping or from separation of liquid manure, i.e., retentate)	65

Sommer, S. G., & Knudsen, L. (2021)

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Assessing the nitrogen recovery the Swiss-Balance – Modelling approach

- **Model development**
  - Applicable at the policy level
  - Based solely on the manure characteristics information NH_4^+ to N_{tot} ratio
  - Farm specific N recovery rate based on information on manure management

- **Method**
  - Simple empirical model, which congregates mathematical functions describing different selected processes
  - Nitrogen turnover rates retrieved from literature based on field and pot experiments
  - First order kinetic mineralisation of the N stabilised in SOM based on Parton 1987

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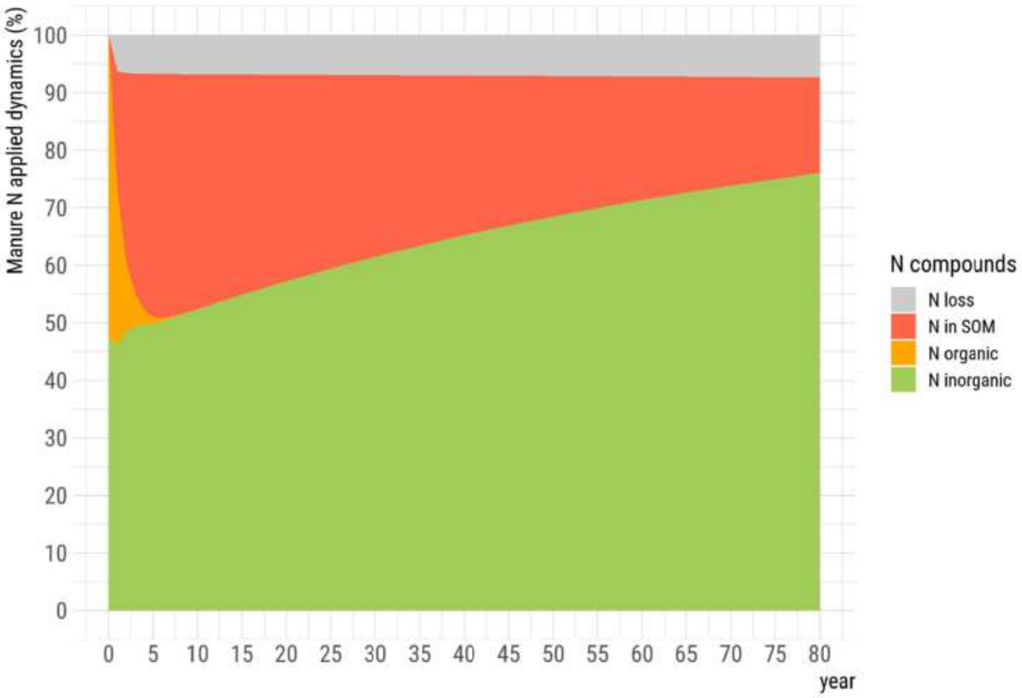
Assessing the nitrogen recovery in the Swiss-Balance – Model output



Epper et al. 2021, unpublished

Modelling the potential nitrogen recovery – Conclusions and outlook

- Helps visualise and better understand what are the processes, factors and time-frames taken into consideration
- Farm-specific nitrogen recovery factors
- Limitations in characterisation certain manure categories

Crucial points of our future model validation

- Field studies at different locations
  - Necessary manure characteristics
  - Site specific characteristics
  - Precise assessment of certain soil microbiological processes (e.g. immobilisation – remobilisation) and nitrogen losses

→ Long-term field experiments

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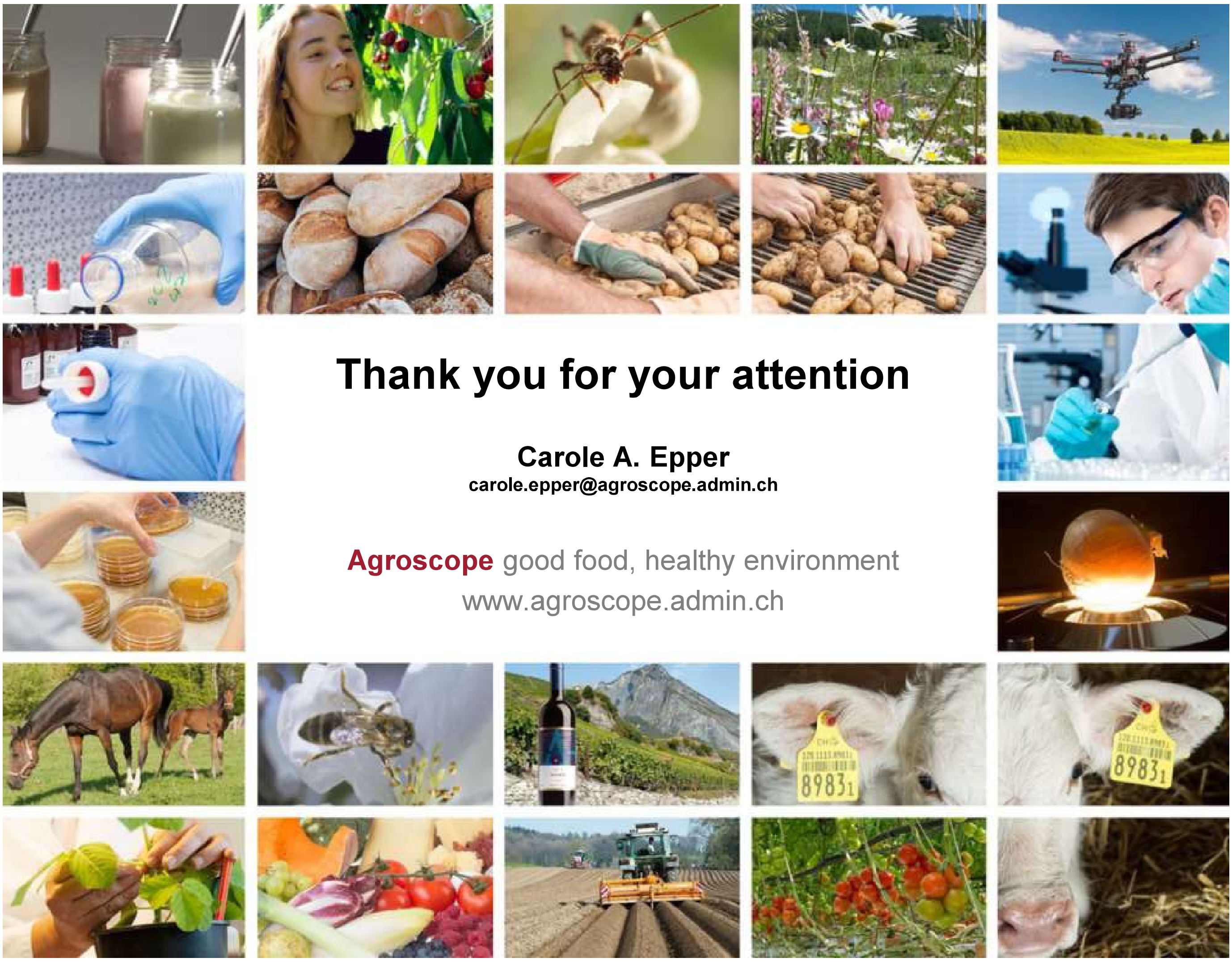

Thank you for your attention

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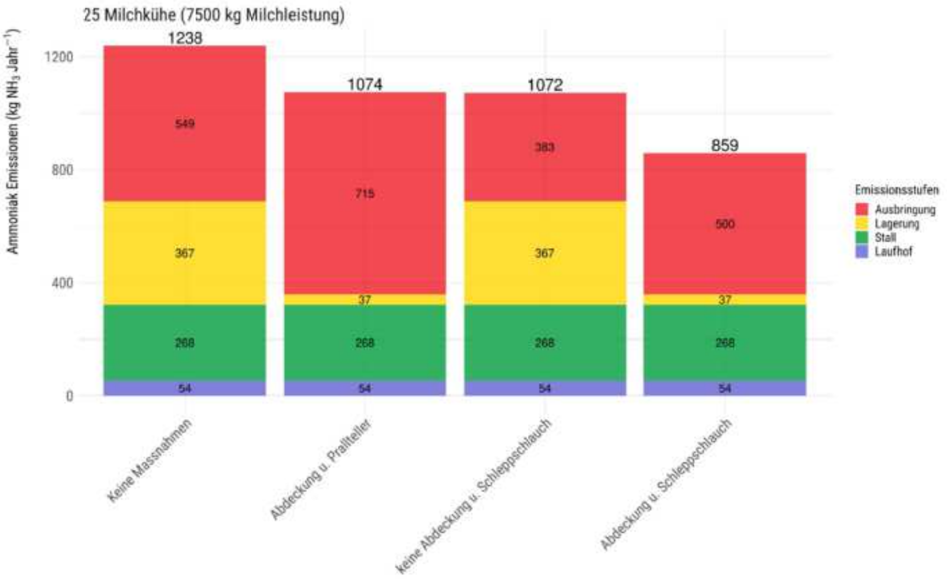
Veränderung der NH_3 Emissionen in Abhängigkeit des Hofdüngermanagements - Beispiel

N Ausscheidungsmengen nach GRUD2017:
Milchkuh (7500 kg Milchleistung) : 112 kg N (55% NH_4^+)



Veränderung des Ammonium N Gehalt im ausgebrachten Hofdünger in Abhängigkeit des Hofdüngermanagements

Beispiel 25 Milchkühe (Standard Milchleistung 7'500 kg)

Stickstoff (alles als kg N)	**Keine Massnahmen**	**Güllelager Abdeckung und Prallteller**	**Keine Güllelager Abdeckung und Schleppschlauch**	**Güllelager Abdeckung und Schleppschlauch**
N_{tot} ausgeschieden (kg N)	2'800	2'800	2'800	2'800
NH_4^+ N Anteil (kg N)	1'540	1'540	1'540	1'540
NH_3 Verluste (kg N)	1'238	1'074	1'072	859
NH_4^+ N ausgebracht * (kg N)	549	714	716	929
N_{tot} Ausgebracht (kg N)	1'562	1'726	1'728	1'941
Anteil NH_4^+ N ausgebracht (%)	35	41	41	48

* Hierzu wurde auch die Mineralisierung des Norg während der Güllelagerung mitberücksichtigt

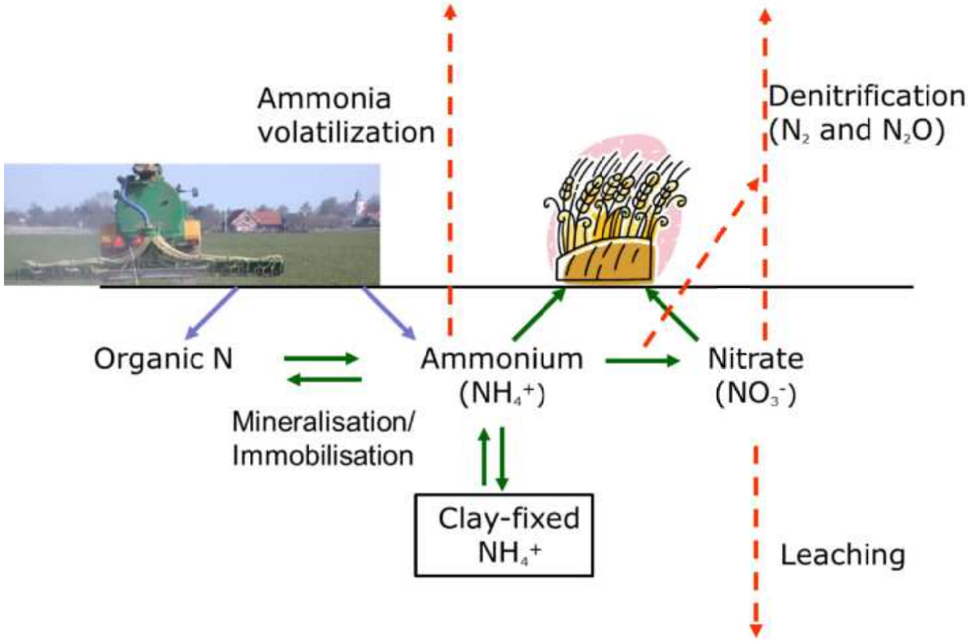
Long-term manure N dynamics in soil: long-term field trials as information base

Peter Sørensen

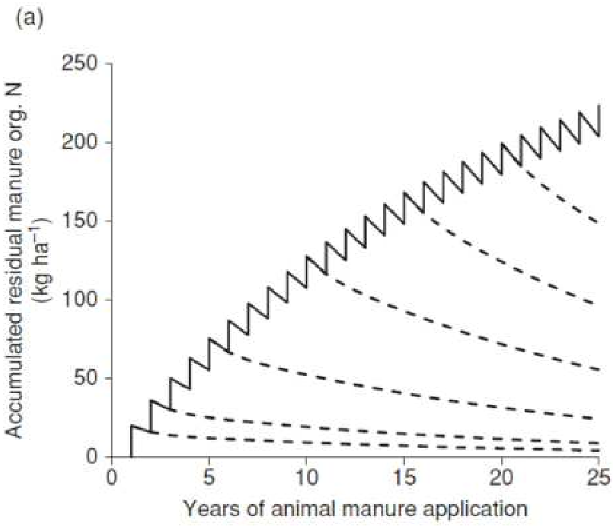
Outline – long-term manure N dynamics

- Introduction
- Askov Long-term experiment- 125 years with manure application
- Experiments with ^{15}N-labelled manures
- Manure N mineralisation estimated from crop N uptake
- Nitrate leaching from mineralised manure N

Manure N dynamics in soil



Residual organic N accumulated in soil by repeated manure application

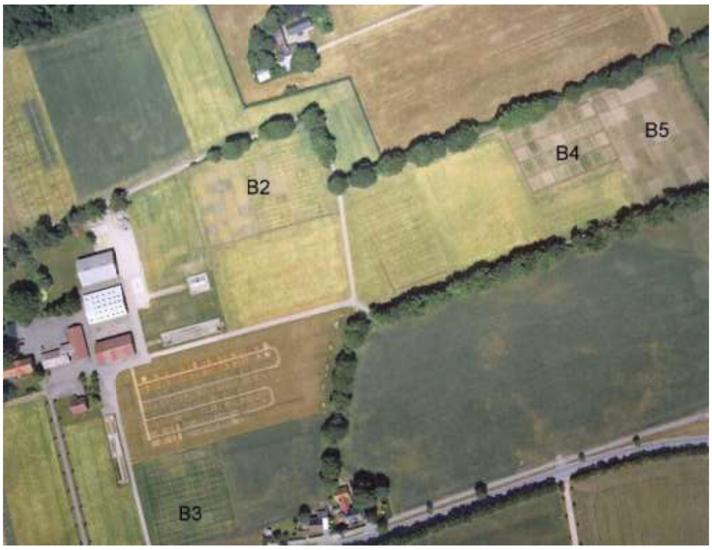


By continous application of
100 kg total-N/ha/yr with pig slurry.

Conceptual model calculation

(Jensen, 2013)

Askov long-term experiment in DK started 1896. Manure vs mineral fertilizers



Four fields B2-B5

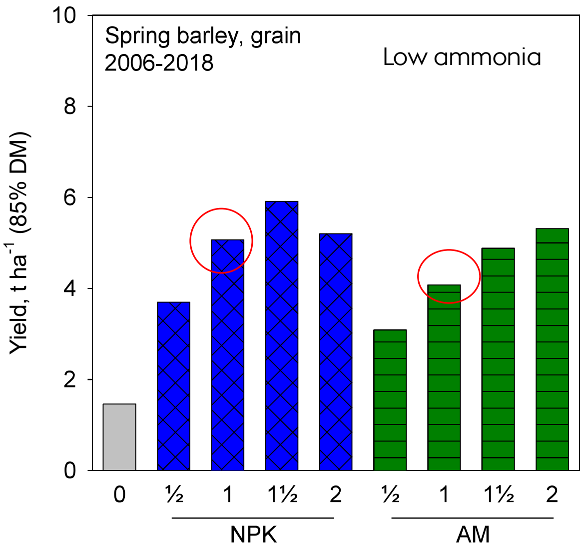
Askov long-term experiment - started 1896 mineral fertilizer (NPK) vs animal manure (AM)

Period	Crop	Kg ha^{-1} in 1 AM and 1 NPK		
		Total-N	P	K
1973-2005	Winter wheat	100	19	88
	Root crops	225	44	196
	Spring barley	75	14	65
	Grass-clover	0	0	0
Annual mean		100	19	87
2006-	Winter wheat	150	30	120
	Maize	150	30	120
	Spring barley	100	20	80
	Grass-clover	0	0	0
Annual mean		100	20	80

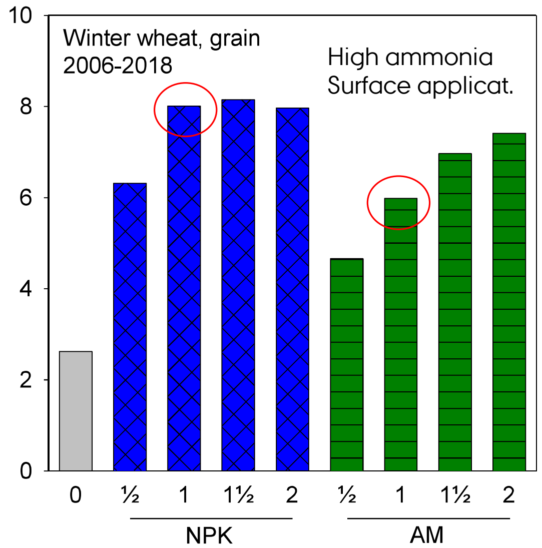
Same amount of N, P and K with either mineral fertilizer or manure **(AM, cattle slurry)**

Christensen et al. 2022 J Plant Nutr Soil Sci 2022, 1

Long-term cereal yields



1NPK/AM = 100 kg N/ha

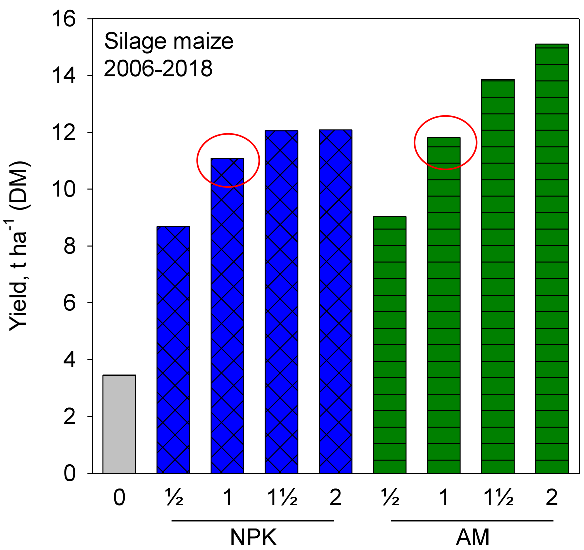


1NPK/AM = 150 kg N/ha

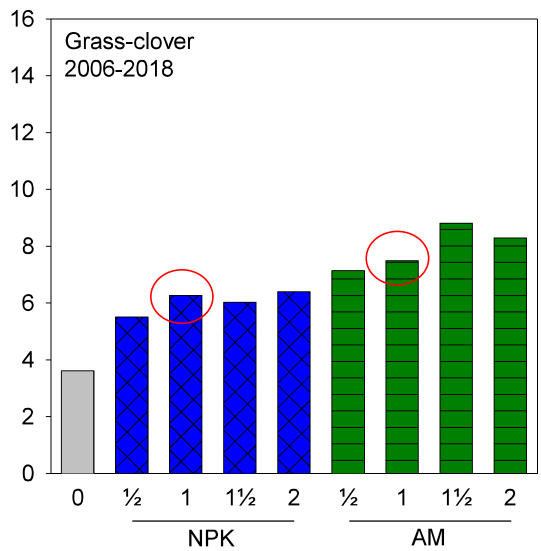
AM = cattle slurry

Christensen et al. 2022 J Plant Nutr Soil Sci 2022, 1

Long-term yields in maize and grass-clover



1NPK/AM = 150 kg N/ha

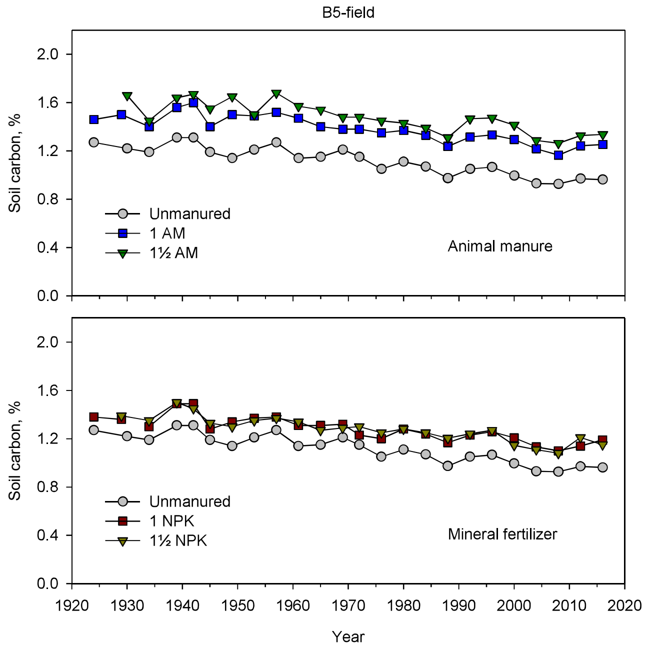


No nutrients applied in harvest year (N-fixing crop)

Maize likes manure!

Christensen et al. 2022 J Plant Nutr Soil Sci 2022, 1

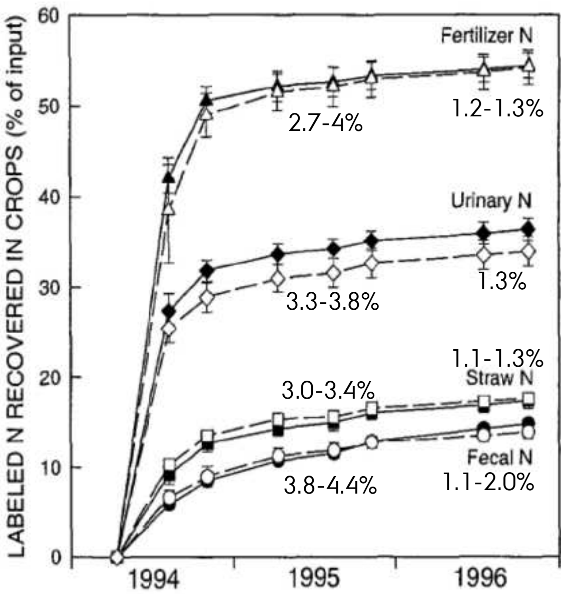
Soil C development in Askov soils (top soil)



Treatments started in 1896. After the first 25 years, the difference in soil C related to the un-fertilized plots is nearly constant

Christensen et al. 2022 J Plant Nutr Soil Sci 2022, 1

Cumulated crop uptake of ^{15}N-labelled manure components and mineral fertilizer over 3 yrs



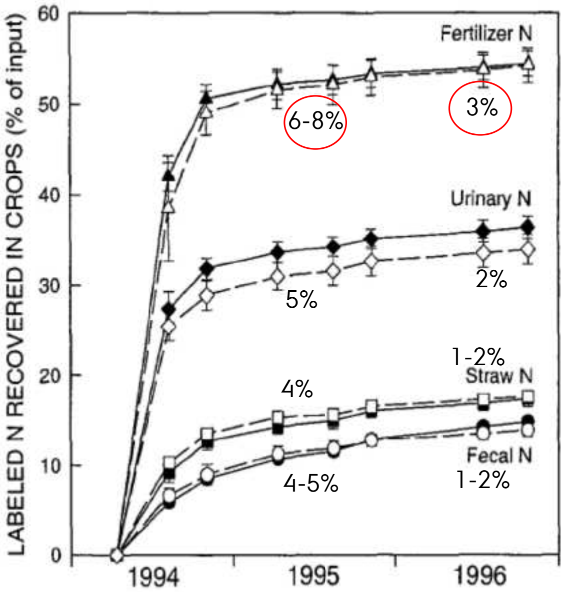
^{15}N uptake (% of ^{15}N input) shown in 2nd and 3rd year

Similar % uptake from all sources in 2nd and 3rd year

- ^{15}N-labelled solid sheep manure applied to spring barley in 1994. Cut ryegrass in 1995-96, low mineral N application.
- Loamy sand and sandy loam soils

Jensen et al 1999 SSSAJ 63,416

Cumulated crop uptake of ^{15}N-labelled manure components and fertilizer over 3 yrs



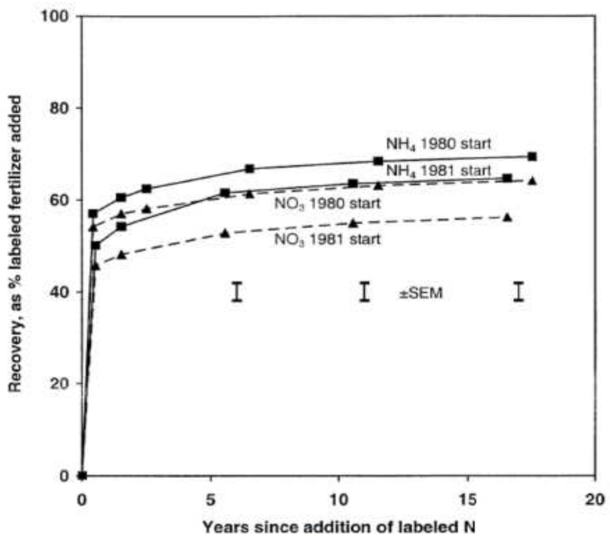
^{15}N uptake (% of residual ^{15}N in soil)
shown in 2nd and 3rd year

Larger uptake of residual N from mineral fertilizer

- ^{15}N-labelled solid sheep manure applied to spring barley in 1994. Cut ryegrass in 1995-96.
- Loamy sand and sandy loam soils

Jensen et al 1999 SSSAJ 63,416

Recovery of ^{15}N labelled fertilizer in grass over 17 years after one application



Gradual decrease in availability

Jenkinson et al 2004 SSSAJ 68, 865

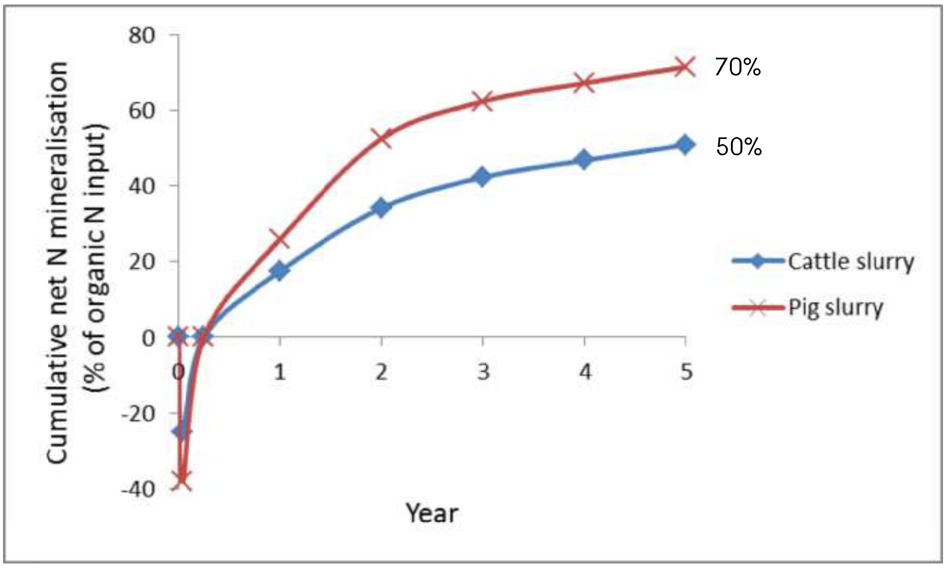
Extra N mineralisation based on crop N uptake measured during 3 years after pig and cattle slurry application

100 kg mineral N/ha was applied to spring barley in either mineral N or in cattle or pig slurry in the first year.
Only mineral N applied in the two following years.

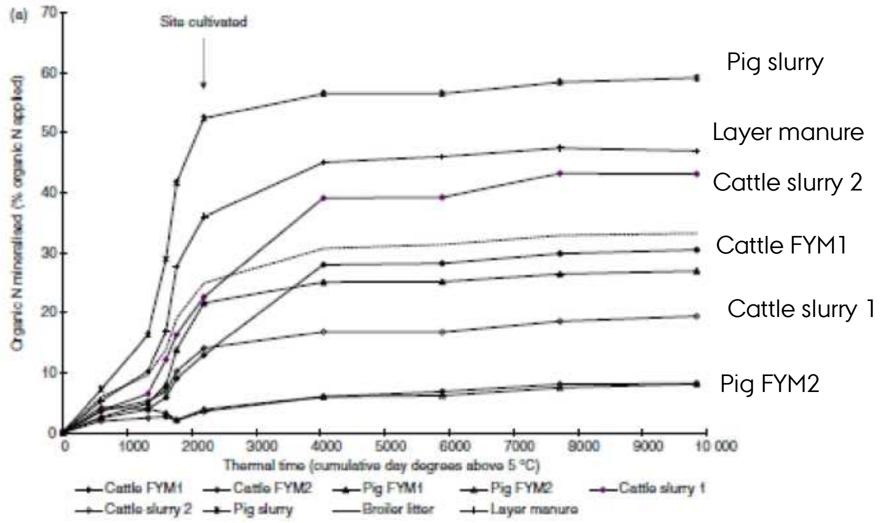
	1st year	2nd year		3rd year	
	Ryegrass CC	Spring barley	Ryegrass CC	Spring barley	Ryegrass CC
Estimated Apparent N recovery(ANR) of mineralised N (%)	49	60	49	60	49
Cattle slurry net mineralisation (% of organic N input)	17	7.2	10	3.1	5.0
Pig slurry net mineralisation (% of organic N input)	26	16	11	4.4	5.4

CC = cover crop

Simple model of manure N mineralisation based on 3 yrs measured N uptake in crops



Organic N mineralisation from different manure types over 5 yrs (%)

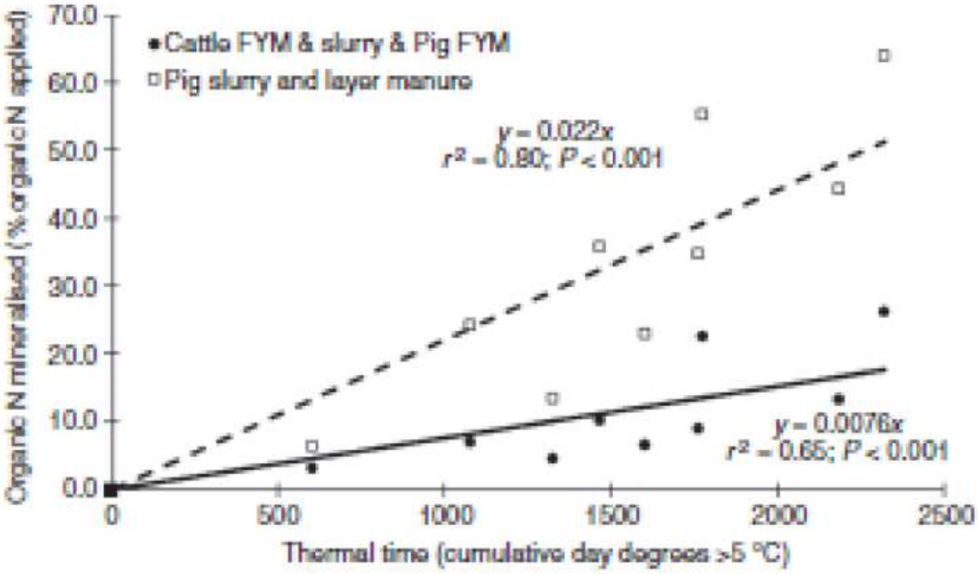


mineralisation estimated from extra N uptake in grass + extra N leaching compared to a control (at Gleadthorpe).

Ammonium-N stripped before application!

Bhogal et al 2016 SUM 32 (Sup1), 32

Organic N mineralisation (%) vs thermal time - first year



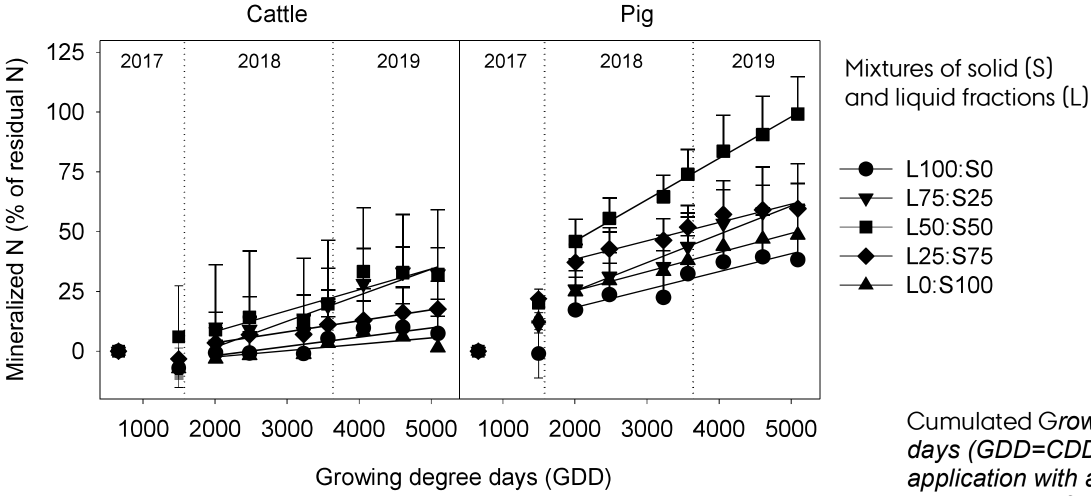
mineralisation estimated from extra N uptake in grass + extra leaching (Gleadthorpe).

Type	mineralisation 0-2300 CDD %/GDD
Pig slurry Layer manure	0.022
Cattle slurry FYMs	0.0076

Bhogal et al 2016 Soil Use Man 32 (Sup1), 32

mineralisation from solid and liquid slurry fractions based on N uptake in grass - 3yrs

Cumulated net mineralisation of residual organic manure N left in soil after harvest of the first barley crop (estimated from extra N uptake and ANR of mineral N)



Type	mineralisation 2000-5000 GDD %/GDD
Pig	0.0116
Cattle	0.0058

Cumulated G*rowing degree days (GDD=CDD) since application with a base temperature of 5* °C.

Pedersen et al. 2021 J Agr Sci 158, 707

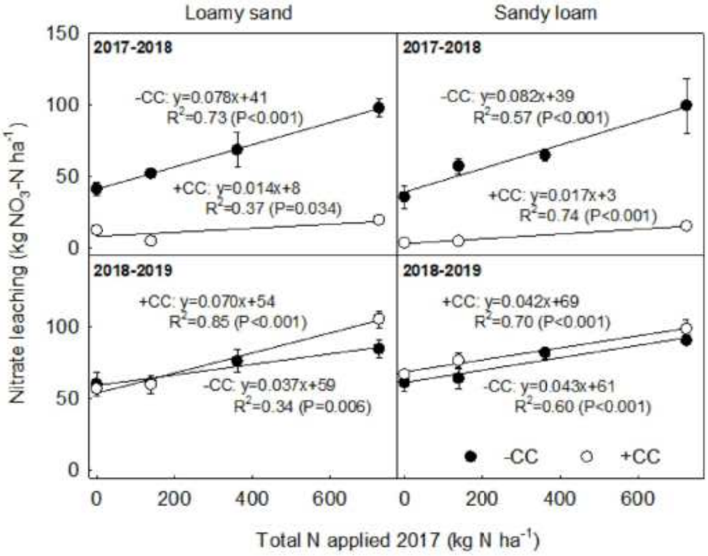
mineralisation of manure organic N in UK and DK studies

Type	mineralisation 0-2300* CDD (%/CDD)	mineralisation 2300*-5000 CDD (%/CDD)
Pig slurry, layer manure (UK)	0.022	<0.001
Pig slurry (DK)	0.020	0.012
Cattle slurry, FYMs (UK)	0.008	<0.001
Cattle slurry (DK)	0	0.006

Cumulated G*rowing degree days (GDD=CDD) since application with a base temperature of 5* °C.

* 2000 CDD in DK study

Nitrate Leaching after application of solid manure or mineral N to lysimeters with spring barley (2 yrs)



Year 1	Leaching rate (% of total N input)
- cover crop	**8 %**
+ cover crop	**1-2 %**
Year 2	
Only mineal N No cover crop	**4-7 %**

Applications to spring barley 2017	Kg total-N/ha
0 N	0
Mineral N	139
0.5 deep litter	362
1 deep litter	725

Pedersen et al. 2021 Soil Tillage Res 209, 104954

Ratio between N leaching and crop N uptake

-Vegetation in autumn/ winter is critical for reducing leaching from mineralized soil N and organic manure N

Application to spring barley 2017	Kg total-N/ha	N leaching/ Crop N uptake	
		- Cover crop	**+ Cover crop**
0 N	0	**1.0**	**0.3**
Mineral N	139	**0.4**	**0.04**
Cattle deep litter	725	**0.9**	**0.2**

Leaching measured 2017-18 in 1.5 m deep lysimeters (first year after application)
Cover crop: fodder radish sown after barley harvest

Data from Pedersen et al. 2021 Soil Tillage Res 209, 104954

Interactions between added N and historical N inputs?

- In a field study we observed higher residual N uptake from previous manure application on unfertilized grass compared to N-fertilized grass (unpublished).
- 'Added nitrogen interactions' (Jenkinson et al. 1985).
- Mores studies are needed.

Conclusions

- Net mineralisation of organic manure N is close to zero during the first 3 months after application of most manure types.
- In the following year mineralisation varies from c.10 to 50%.
  - Highest from pig slurry and layer manure
  - Lower from cattle slurry and farmyard manures containing straw
- After the 3rd year, N mineralisation is low for all manure types.
- Vegetation in autumn/winter is a key to reducing nitrate leaching from mineralized soil N and manure N.

Thank you

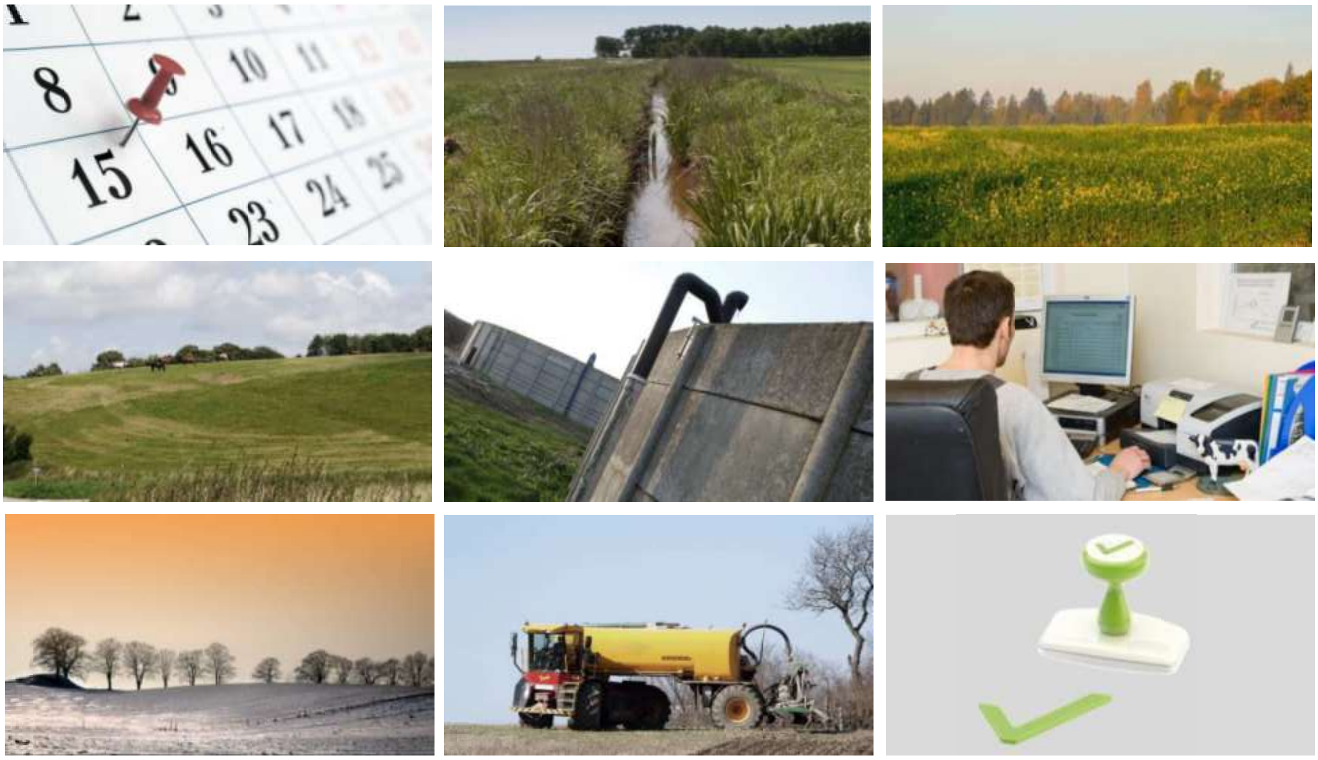
Ministry of Food, Agriculture and Fisheries of Denmark
Department

Regulatory framework in Denmark

- Successes & challenges of the Danish fertilization reports -

Expert workshop: potential nitrogen recovery of manure
06/05-2022
AGROSCOPE - Switzerland

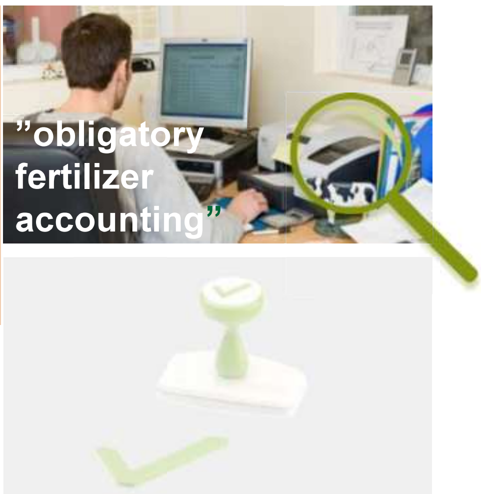
Obligatory key elements of Danish Agricultural Regulation (ND)



Obligatory key elements of Danish Agricultural Regulation (ND)

ZOOM IN: The obligatory fertilizer accounting system

- **Obligatory fertilizing planning** in the national (IT-based) **Fertilizer Accounting system for all farms**
  - larger than **10 ha**
  - Producing or using **organic fertiliser**, incl. livestock manure, containing at least **1000 kg N** (annually) **or**
  - Applying **organic fertilizer**, incl. livestock manure, equivalent to at least **100 kg N/ha**
  - voluntarily for some other farms to avoid tax on N-fertilizer
- **→ approx. 90% registered with fertilizer accounts**



ZOOM IN: The obligatory fertilizer Accounting System

Registration of information on:

- type of crops & the N standard norm for the respective crops (based on nationally centralized calculation of the economic optimum)
- type of livestock & the N resulting from livestock production
- use of fertilizers – both manure & commercial fertilizer
- delivery of fertilizer & exchange of fertilizer or manure
- establishment of catch crops
- number of livestock units (coupled to the national central animal husbandry register)
- general facts on the holding, i.e. address, stable construction, etc

A maximum N-quota for each registered farm is automatically calculated on the basis of:

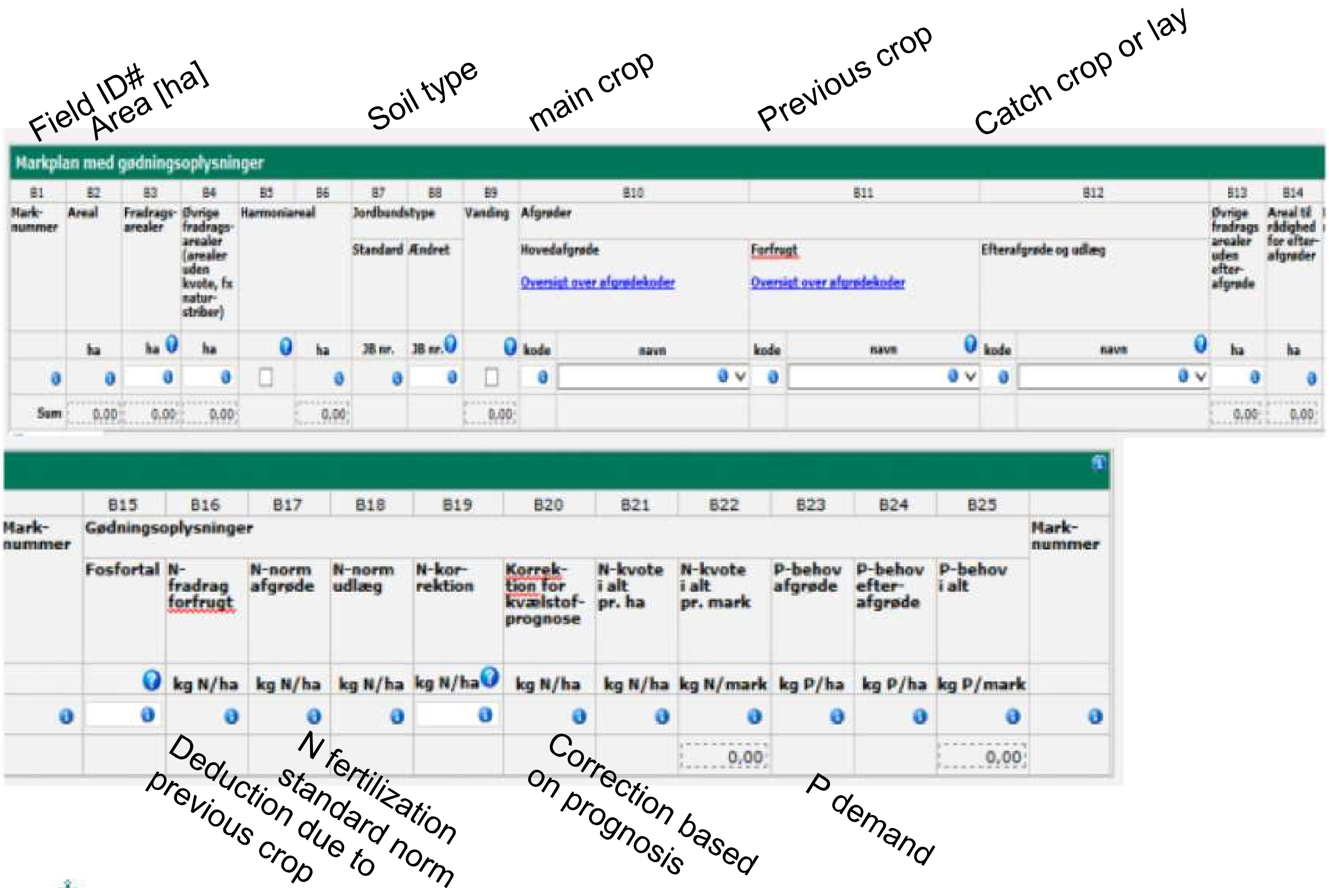
- choice of crops in the planning period
- size of cultivated area with the crops
- pre-crops composition
- soil type (sandy vs. loamy soils)
- expected yields
- irrigation of the fields
- N forecast

Setting of share of manure-N, to be accounted for:

type of animal manure	Efficiency (N ex storage)
pig slurry	80 %
cattle slurry	75 %
Poultry slurry/solid manure	80/70 %
deep litter (pig & cattle)	50 %
liquid fraction after manure processing	85 %

Source: https://www.retsinformation.dk/eli/lta/2021/1601

ZOOM IN: The fertilizer plan at field scale



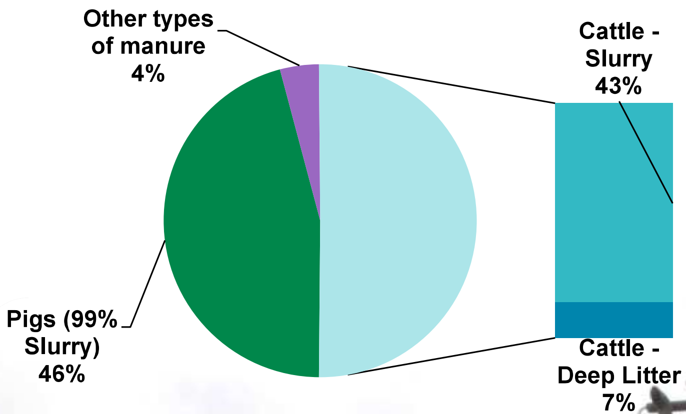
ZOOM IN: The fertilizer plan – N norms etc.

Excerpt of 14 main crops our of ca. 300 different crop codes – updated annually

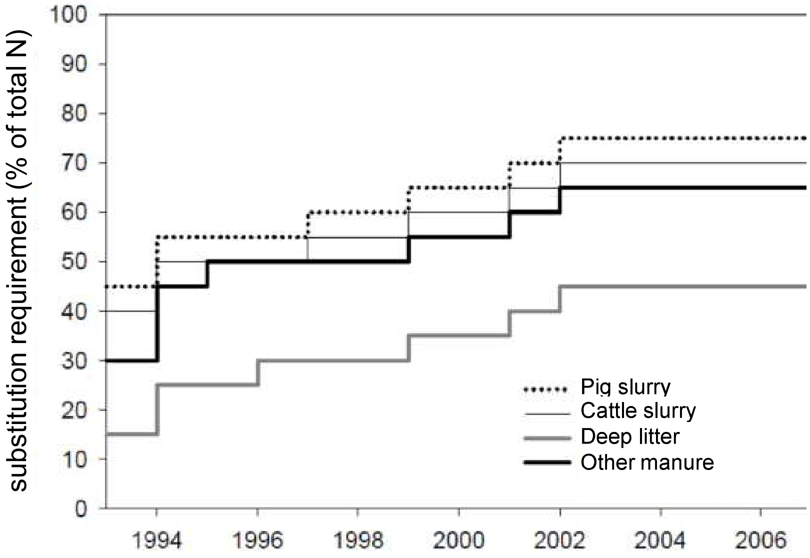
Crop & code · Previous crop value · Yield norm · N norm · Different soil types · P demand

Afgrødekode	Afgrøde	Forfrugts-værdi	Indregning af forfrugtsværdi i afgrødens kvælstofnorm	Uvandet grovsand JB 1 + 3		Uvandet finsand JB 2 + 4 og 10-12		Vandet sandjord JB 1-4		Sandblandet lerjord JB 5-6		Lerjord JB 7-9		Korrektion for udbytte (salg)	Korrektion for udbytte (opfodring)	Retnings-givende normer for fosfor og kalium	
		kg N/ha	Ja/Nej	Udbytte-norm hkg/ha	Kvæl-stof-norm kg N/ha	Udbytte-norm hkg/ha	Kvæl-stof-norm kg N/ha	Udbytte-norm hkg/ha	Kvæl-stof-norm kg N/ha	Udbytte-norm hkg/ha	Kvæl-stof-norm kg N/ha	Udbytte-norm hkg/ha	Kvælstof-norm kg N/ha	kg N/hkg		kg P/ha	kg K/ha
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
13	Vinterhvede, brødhvede[2]	0	Ja	55 (61)	212	69 (76)	221	73 (80)	243	88 (97)	252	93 (102)	266	1,7	0,0	21	67
57	Vinterhavre	0	Ja	51 (56)	143	65 (72)	144	64 (70)	158	77 (85)	159	81 (89)	168	1,2	1,2	18	53
14	Vinterrug[2]	0	Ja	51 (56)	143	65 (72)	144	64 (70)	158	77 (85)	159	81 (89)	168	1,2	1,2	18	53
Vintersæd til modenhed (fortsat)				hkg/ha		hkg/ha		hkg/ha		hkg/ha		hkg/ha					
15	Vinterhybridrug[2]	0	Ja	62 (68)	155	77 (85)	159	77 (85)	174	88 (97)	172	93 (102)	183	1,2	1,2	22	63
16	Vintertriticale[2]	0	Ja	48 (53)	178	60 (66)	177	60 (66)	192	68 (75)	187	72 (79)	197	1,2	1,2	20	39
9	Vinterspelt	0	Ja	51 (56)	143	65 (72)	144	64 (70)	158	77 (85)	159	81 (89)	168	1,2	1,2	18	53
17	Blanding af efterårssæde arter[2,12]	0	Ja	51 (56)	143	65 (72)	144	64 (70)	158	77 (85)	159	81 (89)	168	1,2	1,2	18	53
Oliefrø og Bælgsæd				hkg/ha		hkg/ha		hkg/ha		hkg/ha		hkg/ha					
21	Vårraps	23	Ja	19	137	22	127	24	145	25	121	26	123	1,5	0	22	51
22	Vinterraps	23	Ja	31	196	39	208	39	208	44	216	46	219	1,5	0	26	84
23	Rybs	23	Ja	19	137	22	127	24	145	25	121	26	123	1,5	0	22	51
24	Solsikke	23	Ja	19	185	21	170	24	185	25	160	26	160	0	0	16	74
25	Sojabønner	23	Nej	47	0	47	0	47	0	47	0	47	0	0	0	30	103
180	Gul sennep	23	Ja	20	139	22	128	25	146	25	121	26	122	1,5	0	20	49
182	Blanding af oliearter	23	Ja		137		127		145		121		123	1,5	0	22	51

Composition of livestock manure in Denmark



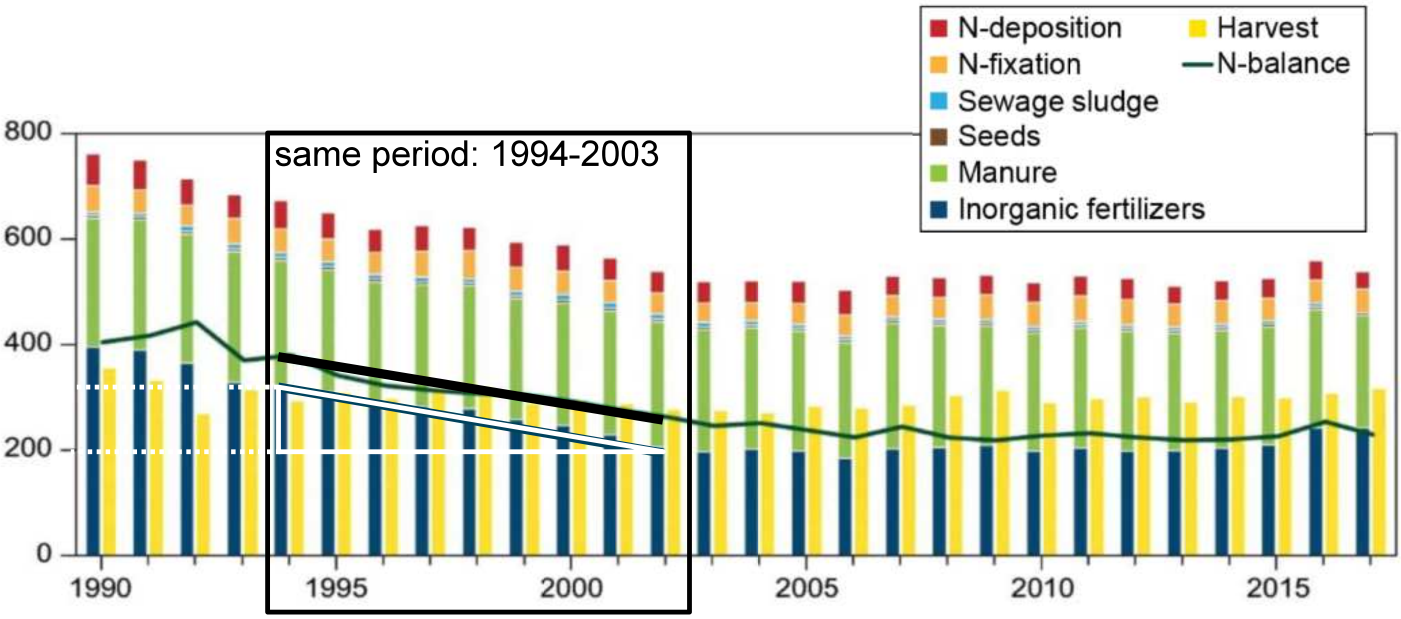
Development of utilization/substitution requirements for livestock manures in the past



Stepwise increase of the ”fertilizing value” of nitrogen in the different livestock manures types

Average utilization efficiency requirement (weighed according to amounts) since 2002 = **71%**

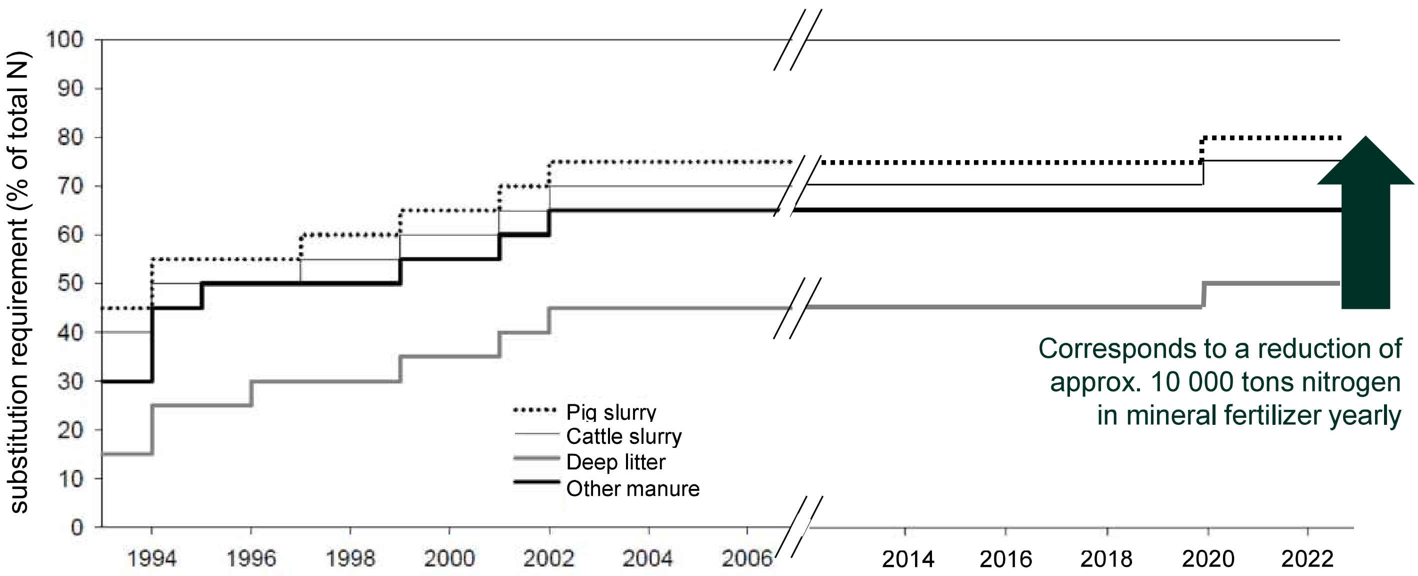
Agricultural Nitrogen balance [1.000 tons]



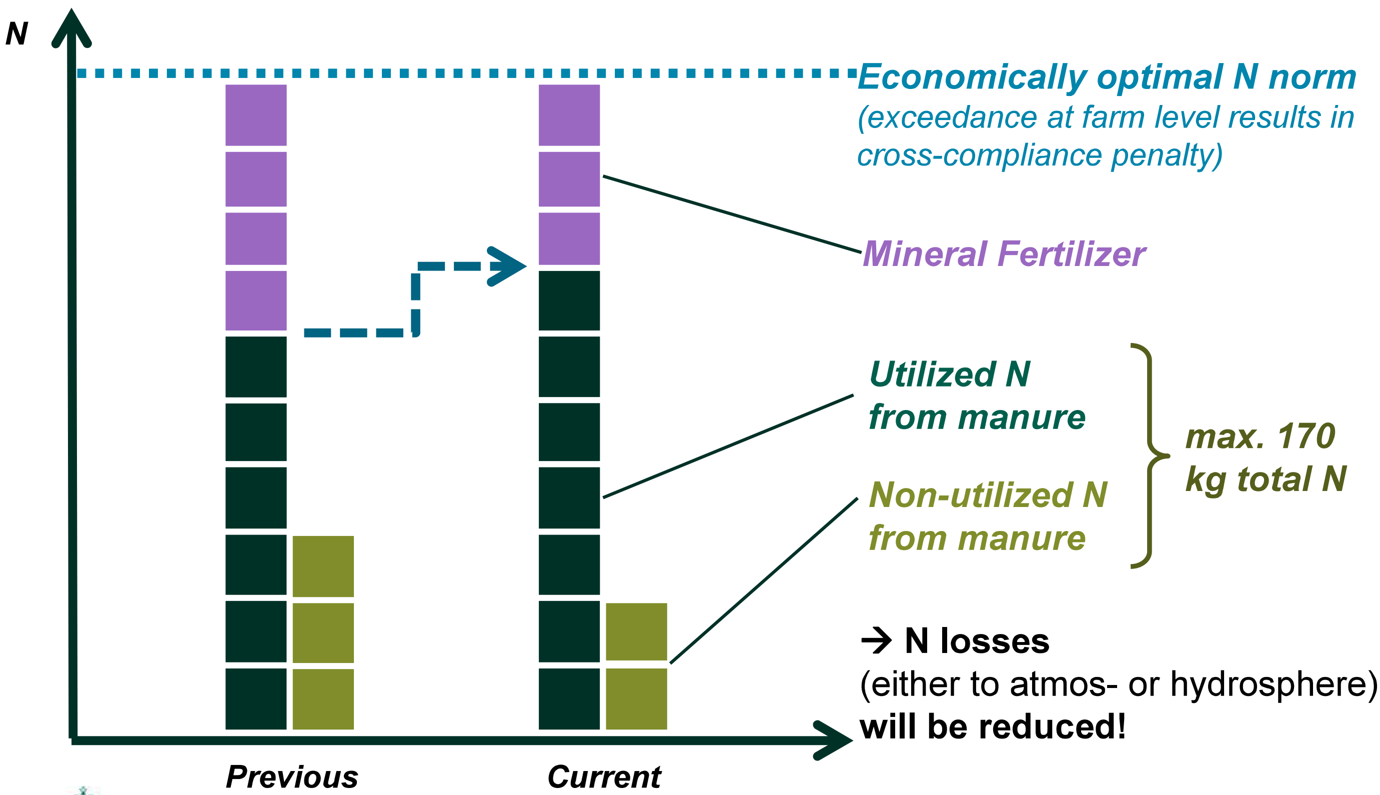
Increase in livestock manure utilization/substitution requirement → contribution to clear **reduction in use of inorganic fertilizer** - and consequently - **improvement of the N-balance**

Source: Vandmiljø og Natur 2017

Most recent adjustment in August 2020



Beneficial side effects due to limitation of ”total utilized” N



Beneficial side effects due to limitation of ”total utilized” N

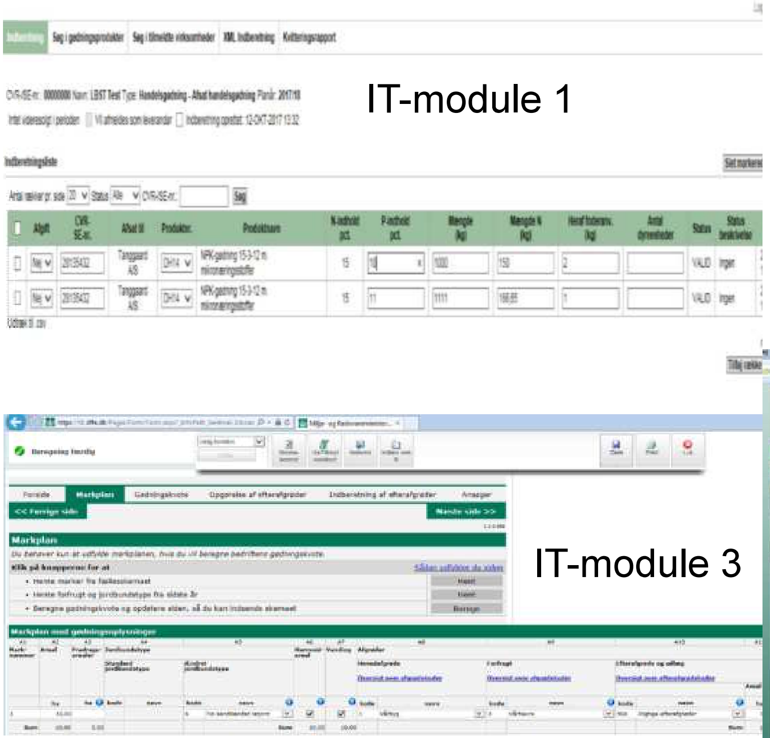
Incentives for farmers to…

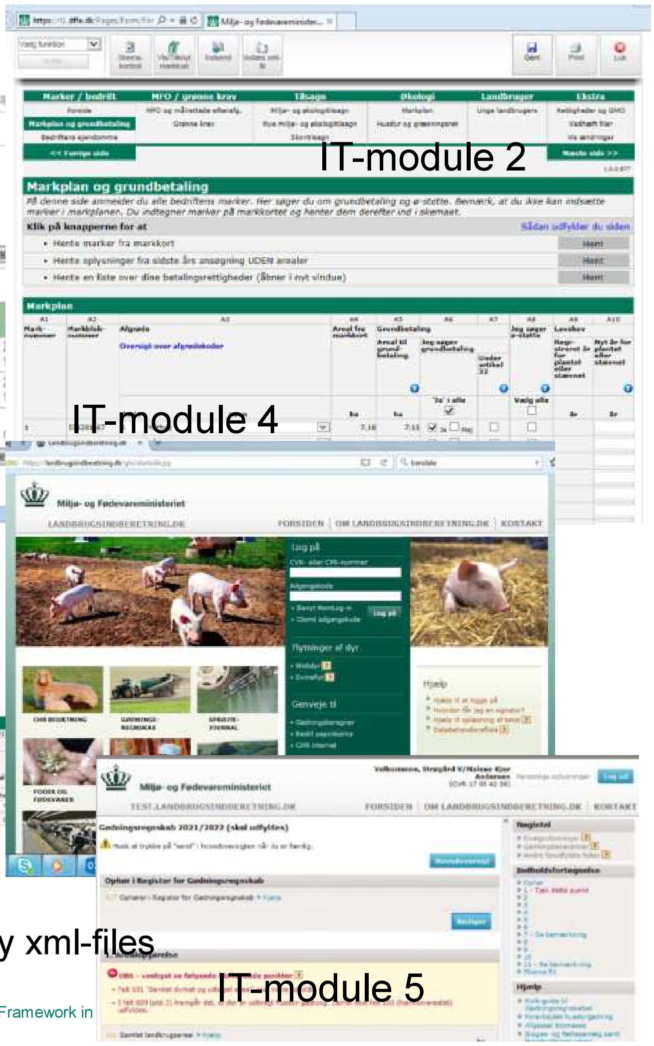
- **Invest in** manure **treatment**
- Deliver manure to **biogas plants** for anaerobic digestion
- Use **advanced techniques** for manure field application more
- **Avoid** manure application in **less suitable time periods**
- **Improve storage facilities/capacity** for manure

Results:

- **Better agricultural management**
- A number of (indirect) environmental benefits - but more flexible & efficient than ”direct” regulation:
  - larger storage capacity requirement
  - prolonged close periods, etc.
- **Lower N leaching risk and/or lower N_2O emissions** (for farmers who choose not to invest in new technologies)
- **Lower ammonia emissions** (from farms with investments in manure treatment, acidification etc.)
- **Synergy** with obligations under the EU NEC-directive
- **Benefits** for other environmental and nature-EU-regulation

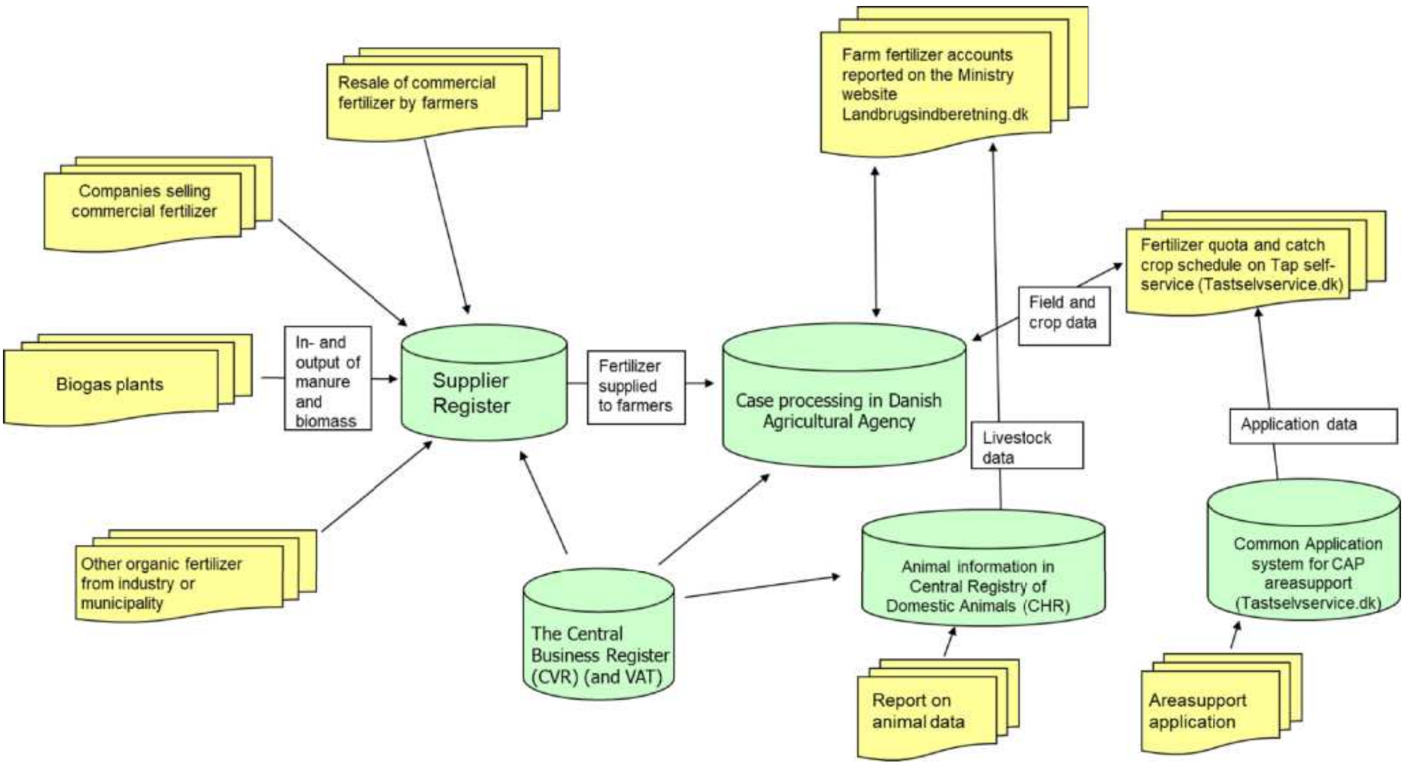
Back to the fertilizer reports…





- 80% of farmers use advisory service
- Reporting to authorities - use of upload by xml-files

Data collection & reuse of data for fertilizer reports



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- Important tool for awareness-building for farmers & consultants
- Constant maintenance & further development of registry & accounting system

Thanks for your interest & attention!

Questions are welcome…

Expert workshop: potential nitrogen recovery of manure
06/05-2022
AGROSCOPE - Switzerland

Für Mensch & Umwelt

Umwelt Bundesamt

Expert workshop: potential nitrogen recovery of manure

Dealing with nitrate vulnerable zones in Germany

Dr. Maximilian Hofmeier
Section II 2.8/ Agriculture
German Environment Agency

Agenda

BACKGROUND

- Environmental indicators (N surplus, nitrate in groundwater,...)
- A brief history of fertilizer legislation in Germany

NITRATE VULNERABLE ZONES

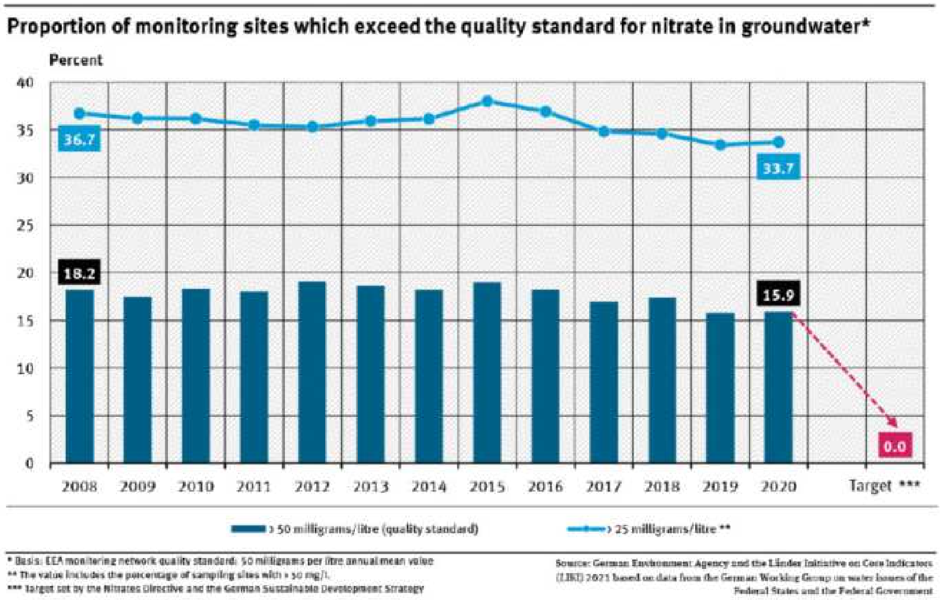
- Legal background
- Approaches to the designation of NVZ
- Obligatory measures in NVZ

OUTLOOK

- How to proceed with the NVZ?
- Further activities on fertilizer legislation

Background

Nitrate in groundwater



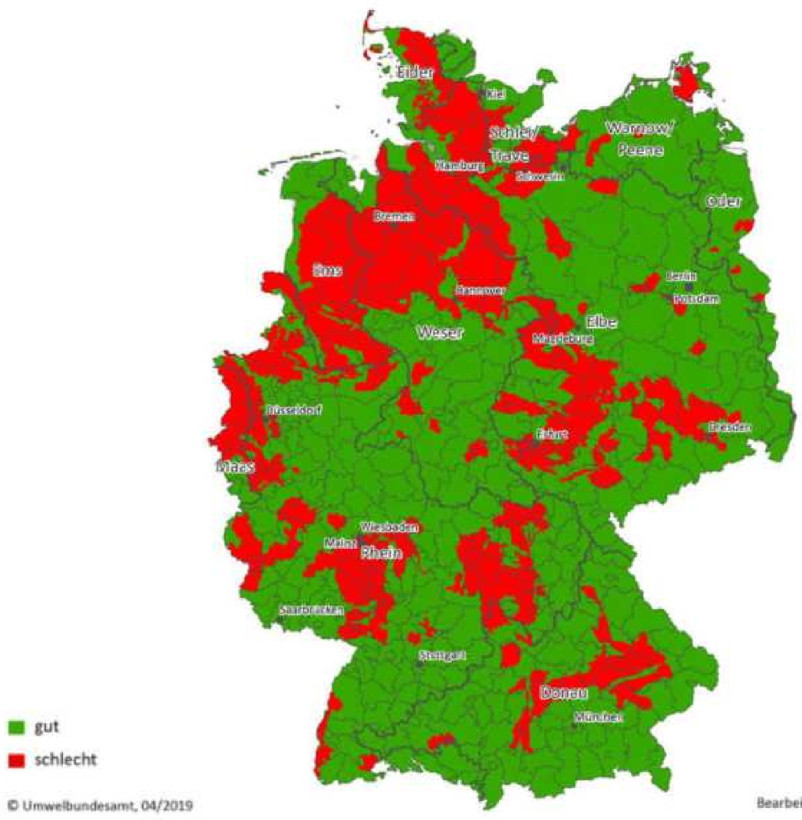
Since 2016, compliance with the nitrate quality standard has also been a target of the German Sustainable Development Strategy

Since 2008 the proportion of monitoring sites which exceed the quality standard lies between 16 and 19 %.

The proportion of monitoring sites with a nitrate concentration above 25 mg/l has also stagnated since 2008 at 33–38 %.

Background

Groundwater bodies in poor chemical status



Groundwater bodies that have poor chemical status due to nitrate pollution.

WFD reporting

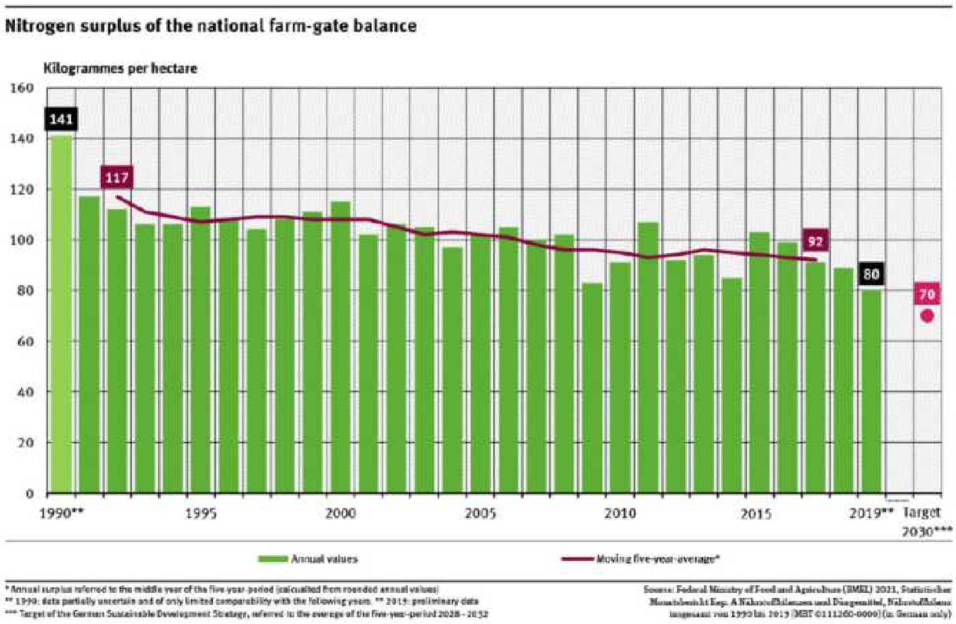
Criterion: at least 20% of a groundwater body with nitrate › 50 mg/L or ›37.5 mg/L with increasing trend

In the last management cycle 27.1% of groundwater bodies in Germany were in poor chemical status

Geobasisdaten: GeoBasis-DE / BKG 2015
Fachdaten: Berichtsportal WasserBLIcK/BfG, Stand 23.03.2016
Bearbeitung: Umweltbundesamt, Bund/Länderarbeitsgemeinschaft Wasser (LAWA)

Background

Agricultural nitrogen surplus



Balance is calculated according to a farm-gate balance on sectoral level

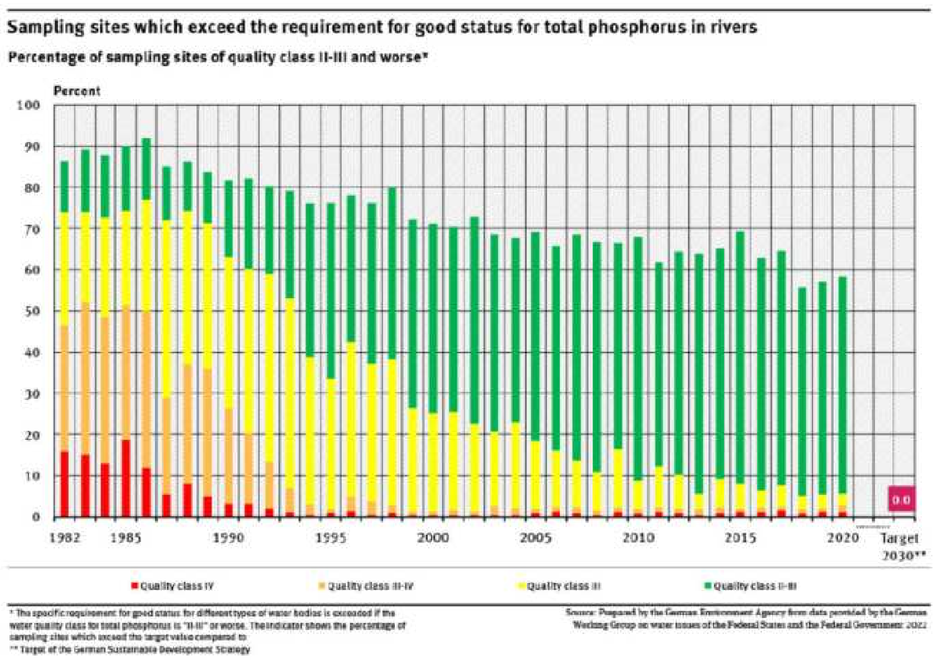
Balance surplus shows the total nitrogen loss potential of German agriculture

Goals:
- German sustainability strategy: Reduction of N surpluses by 2030 to 70 kg/N*ha

Causes for decrease:
- Reduced fertilizer use
- higher yields
- decrease in livestock density in eastern Germany
- Fertilizer legislation
- Weather conditions

Background

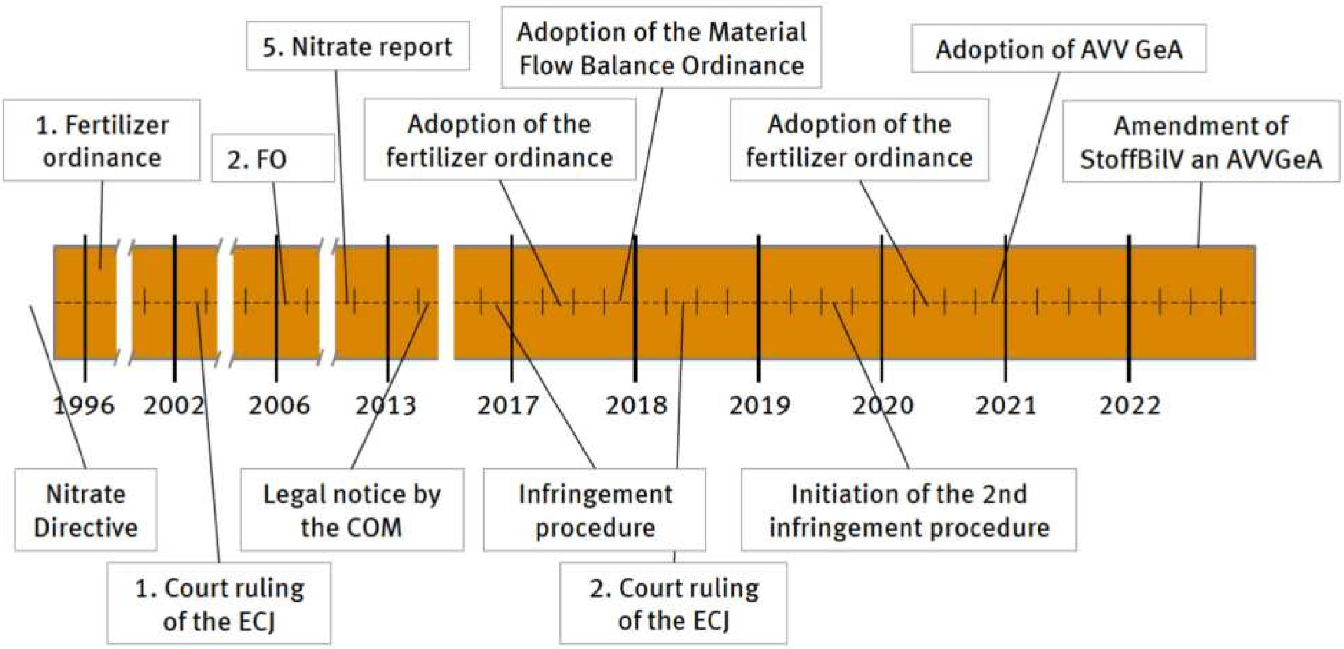
River eutrophication by phosphorus



Goals:
- WFD: All water bodies to be in good status by 2027
- DNS 2016: Water body-typical orientation values are to be complied with at all monitoring sites by 2030

Assessment:
- Agriculture is responsible for approx. 50% of P inputs
- Main reasons for improvement since 1990: phosphate-free detergents and phosphate precipitation in wastewater treatment plants

A brief history of fertilizer legislation in Germany



Designation of NVZ 1996-2020

1996-2017

- the entire agricultural area was designated as NVZ
- the action programme applied to all farms nationwide

2017-2020

- with the adoption of the fertilizer ordinance in 2017, the federal states were obliged to designate "red areas" and eutrophicated areas in which further measures were mandatory
  - Each state had to implement at least three measures from a catalog of measures for NVZ
- basis for the area designation were the red groundwater bodies according to WFD
- optionally, the federal states could also carry out a so-called internal differentiation
  - Identification of sub-areas where the quality standard is exceeded
  - the methodology of the differentiation was not specified

Designation of NVZ

Nitratkulisse nach § 13 Düngeverordnung

Designation of NVZ 2021-???

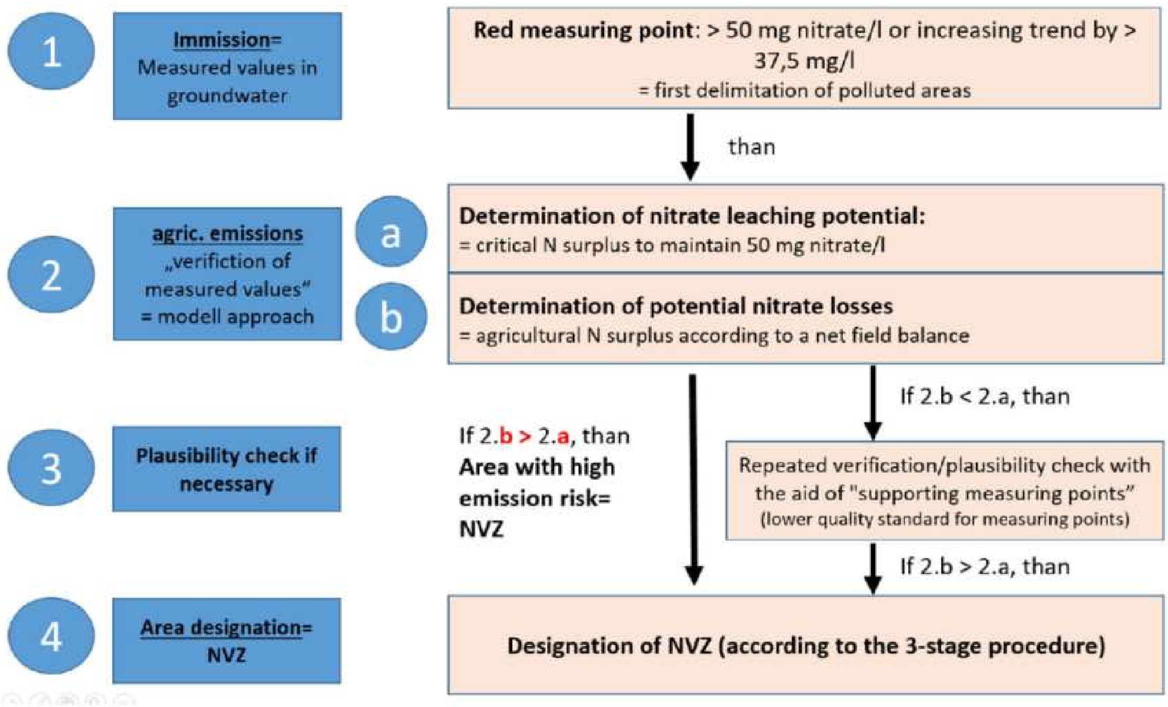
DEMANDS OF THE COM

- Changes to the fertilizer ordinance
- Uniform designation of NVZ by the federal states (issuance of administrative regulations)
- Establishment of an impact monitoring

2021-PRESENT

- to implement the ECJ ruling, the fertilizer ordinance was amended once again and adopted in May 2020
- Additionally, a general administrative regulation was generated to standardize the procedure for designating NVZ and for eutrophicated areas (AVV GeA)
  - Areas (plots) with high nitrogen pollution and endangerment of groundwater
  - eutrophic areas were designated for P in surface waters
- With the adoption of the fertilizer ordinance in 2020, the internal differentiation of the “red areas” was mandatory for the federal states

Uniform designation of NVZ



Nitratkulisse nach § 13 Düngeverordnung

Nitrat belastete Gebiete nach §13a Düngeverordnung

Bundesweite Gebietsausweisung 2021 auf Grundlage der allgemeinen Verwaltungsvorschrift zur Ausweisung von mit Nitrat belasteten und eutrophierten Gebieten

Additional measures in NVZ

In 2021, seven additional measures were mandatory implemented in NVZ:

1. Nitrogen fertilization 20 % below calculated fertilizer requirement
   – Applies to the average of the areas in NVZ
2. Compliance with the 170 kg N/ha limit for the use of organic fertilizers at the field level
3. Autumn fertilization only in exceptional cases
   – Catch crops with forage use are excluded
   – Exception for winter rape if Nmin < 45 kg N/ha
   – Exception for catch crops without forage use: if there is a building application for the expansion of storage capacities
4. Limitation of N fertilization in autumn on grassland
   – From September to begin of the banning period to 60 kg N_{tot}/ha
5. Obligatory cultivation of cover crops
   – Nitrogen fertilization for crops sown after 01/02 is only permitted if a cover crop was grown and that was not turned over before 15/01
6. Extended blocking period for solid manure to 3 month (01/11 to 31/01)
7. Extended blocking period for grassland by four weeks from 01/10 to 31/01

Additionally: Each state has to identify at least two further measures for NVZ

How to proceed with the NVZ?

ACTUAL DISCUSSION

- COM has raised objections to the current designation of NVZ
  – Modeling of N-emissions must be deleted without replacement
  – designation of NVZ should be based exclusively on the monitoring sites
  – Red measuring points were partly outside red areas
- Numerous methods were discussed to designate the red areas
- The draft of the new area designation is with the COM

DECISION ON THE FURTHER PROCEDURE OF THE COM IS PENDING

SECOND PROCEDURE SUSPENDED ON CONDITION THAT THE PACKAGE OF MEASURES IS FULLY IMPLEMENTED

Further activities on fertilizer legislation

IMPACT MONITORING

- Introduction was committed by the two former ministers to the COM at its "Manure Report" 2019 in Brussels.
- Objective is to document the development of agricultural management and its impact on the status of water bodies
- show positive development trends, avoid negative developments
- nation-wide, annual, digital
- Involvement of all necessary levels (agriculture, water management, federal government, federal states)
- Supplement to the nitrate report to be compiled every four years
- Financing not yet secured
- So far, no legal basis exists for the extensive collection of the required operational data

MATERIAL FLOW BALANCE ORDINANCE

- Amendment has to be completed 2023
- The key point of the adjustment is the valuation of the balance surplus

Conclusion

NEED FOR ACTION REMAINS HIGH

INFRINGEMENT PROCEEDINGS AS A KEY DRIVER FOR ADJUSTMENTS

HUGH UNCERTAINTIES IN THE DESIGNATION OF NVZ

NVZ ONLY BASED ON MEASURING SITES

HIGH LEVEL OF DISSATISFACTION WITH CURRENT REGULATIONS

DO WE NEED A CHANGE IN THE WHOLE SYSTEM?

Thank you for your attention

Maximilian Hofmeier
Maximilian.hofmeier@uba.de

Umwelt Bundesamt

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Depatment of Economic Affairs,
Education and Research EAER
Agroscope

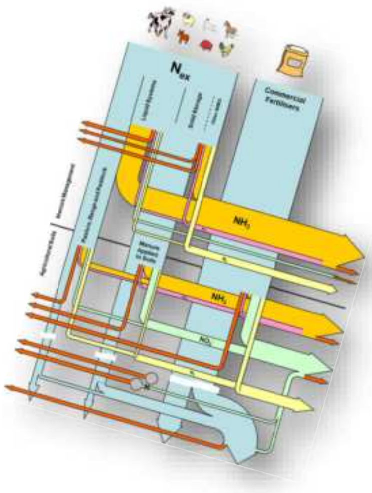
Quantity and drivers of nitrous oxide emissions during storage (or application)

Expert Workshop on Nitrogen Recovery in Manure

Daniel Bretscher

Agroscope
Climate and Agriculture Group

4.-6. May 2022

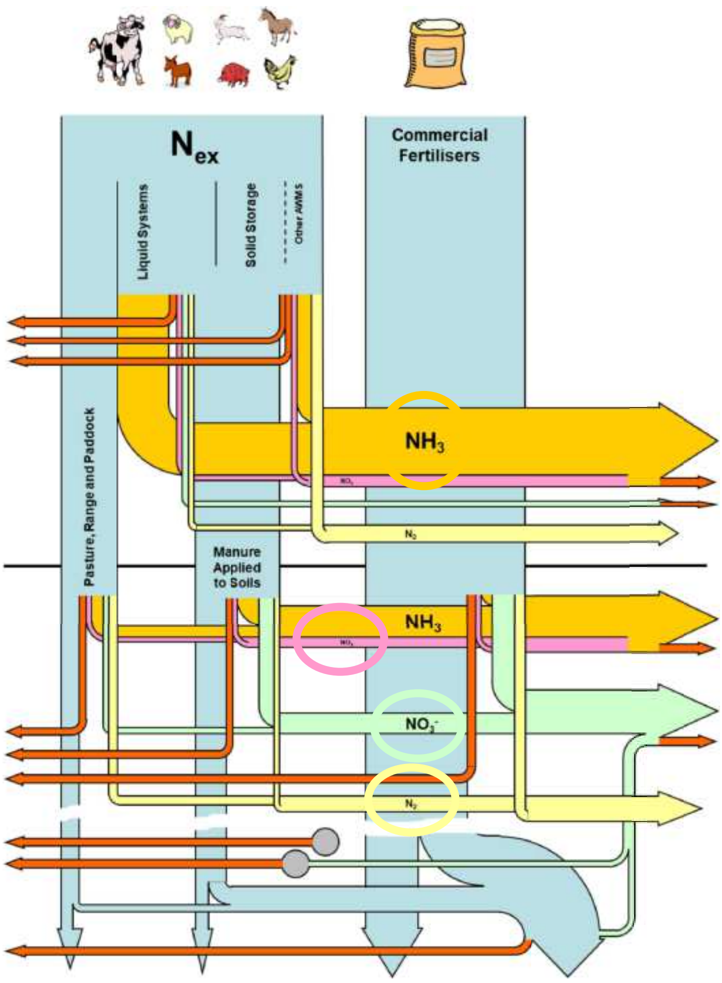


Agroscope

N_2O

Manure Management

Direct Emissions

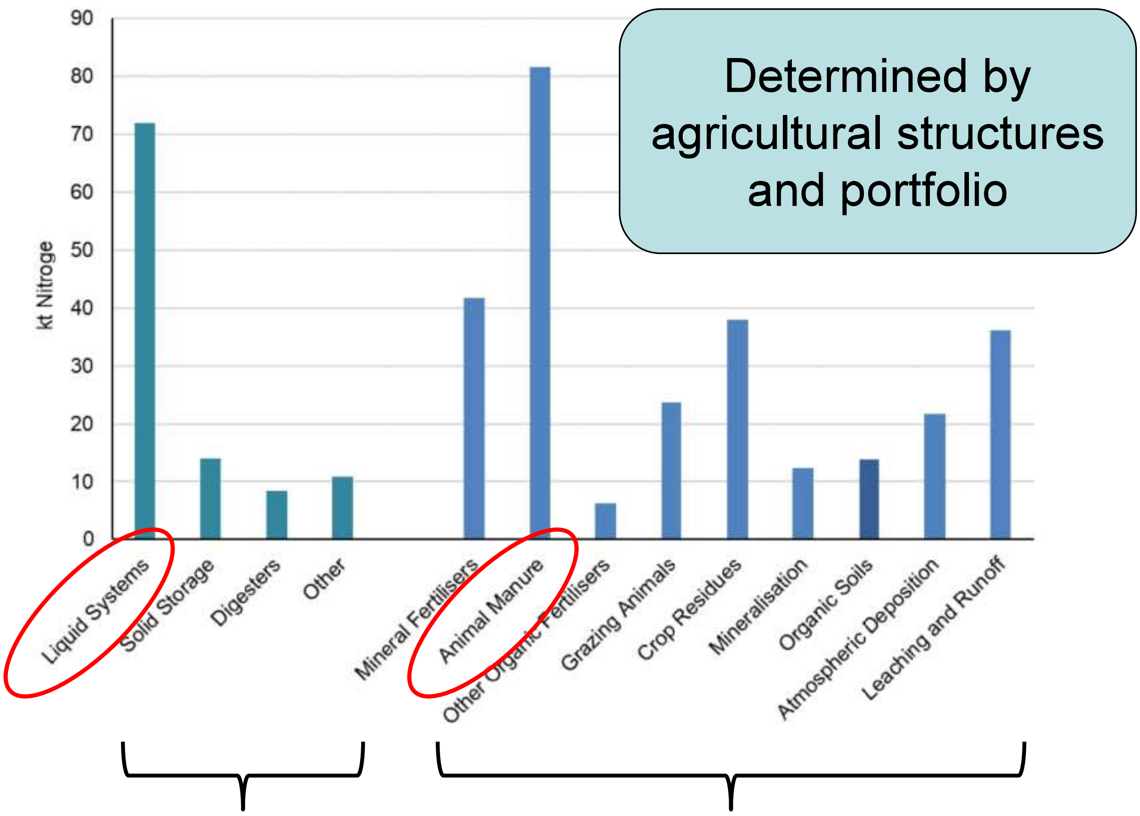


Indirect Emissions

Agricultural Soils

Agroscope

Sources of Nitrogen (Swiss National GHG Inventory, year 2020)



Manure Management **Agricultural Soils**

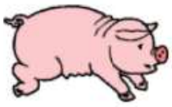
Source: Based on FOEN 2022

Agricultural structures / portfolio

- Number and type of animals
- Crop species
- Leguminous crops
- Locally adapted portfolio and management

Allocation Livestock Categories

N_2O



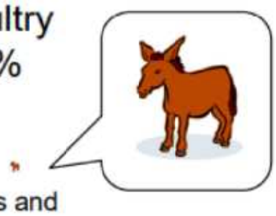
Swine
10.6%

Sheep
3.0%

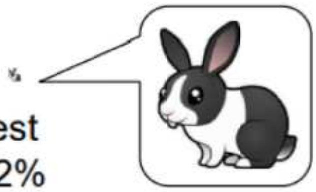
Horses
2.4%

Poultry
5.0%

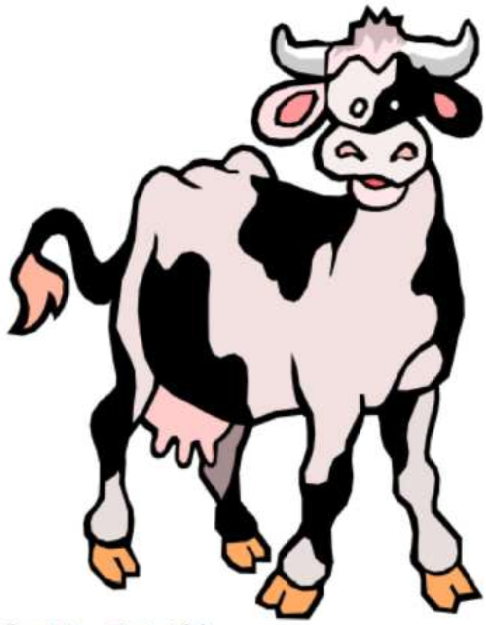
Goats
0.9%



Mules and Asses
0.4%



Rest
0.2%



Cattle 77.4%

Dairy Cattle 48.0%

Source: FOEN 2020

Crop Species

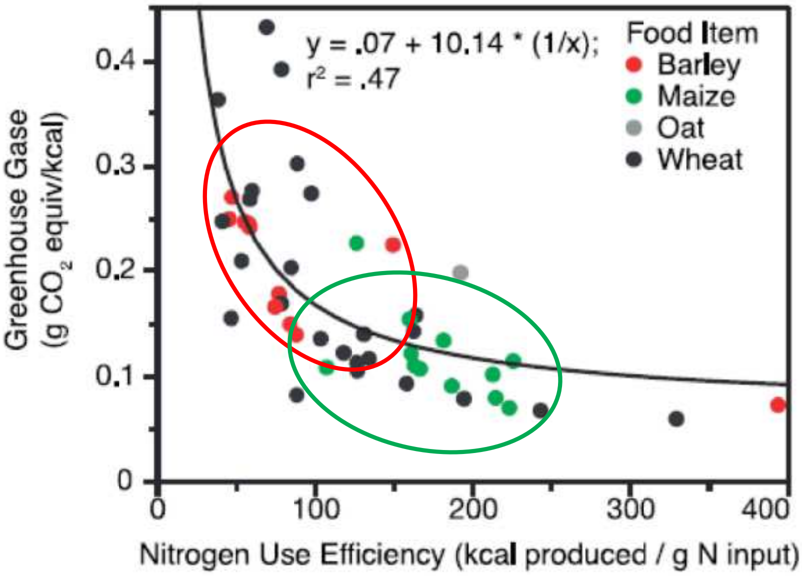


Figure 6. Correlations between nitrogen use efficiency, or calories produced per g of nitrogen input, and the environmental impacts of non-rice cereal crops. Regression lines are reciprocal fits between nitrogen use efficiency and a food's environmental impact. All relationships are significant at $p < .05$ except for acidification potential.

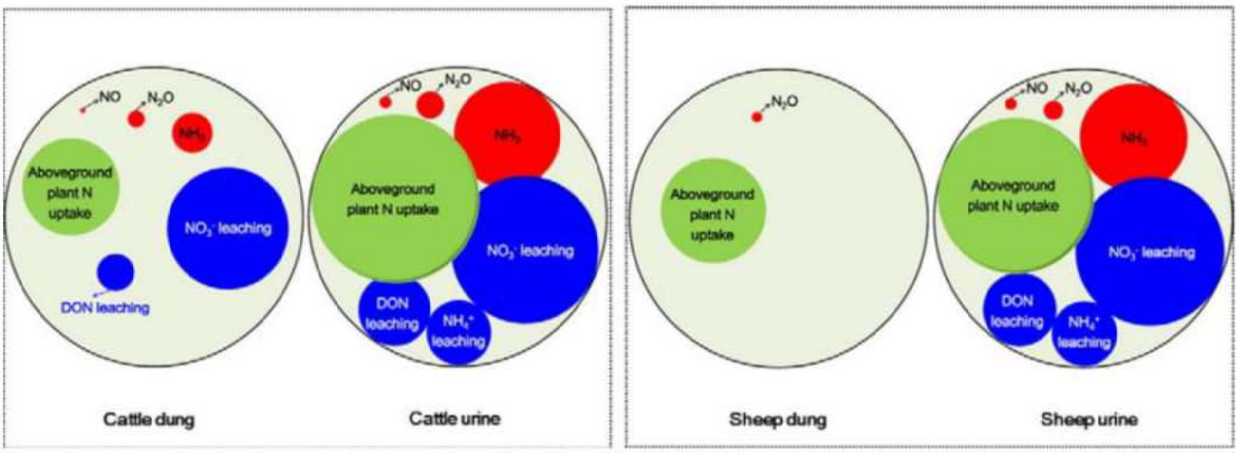
Source: Clark and Tilman 2017

Agricultural structures / portfolio

- Number and type of animals
- Crop species
- Leguminous crops
- Locally adapted portfolio and management

General management options

Pasture or Liquid or Solid Manure?



HIGHLIGHTS

- N_2O emission factors for excreta (0.08–0.35%) were lower than IPCC default value.
- NO and NH_3 losses were 0.01–0.12% and 1.69–12.7% of excreta N.
- NH_4^+, NO_3^-, and DON leaching were 0–4.58%, 16.4–24.6%, and 1.43–5.91%.
- Urine patches always caused more N losses or plant N uptake than dung patches.
- NO_3^- leaching was significantly negatively correlated with plant N uptake.

Source: Cai and Akiyama, 2016

Agricultural structures / portfolio

- Number and type of animals
- Crop species
- Leguminous crops
- Locally adapted portfolio and management

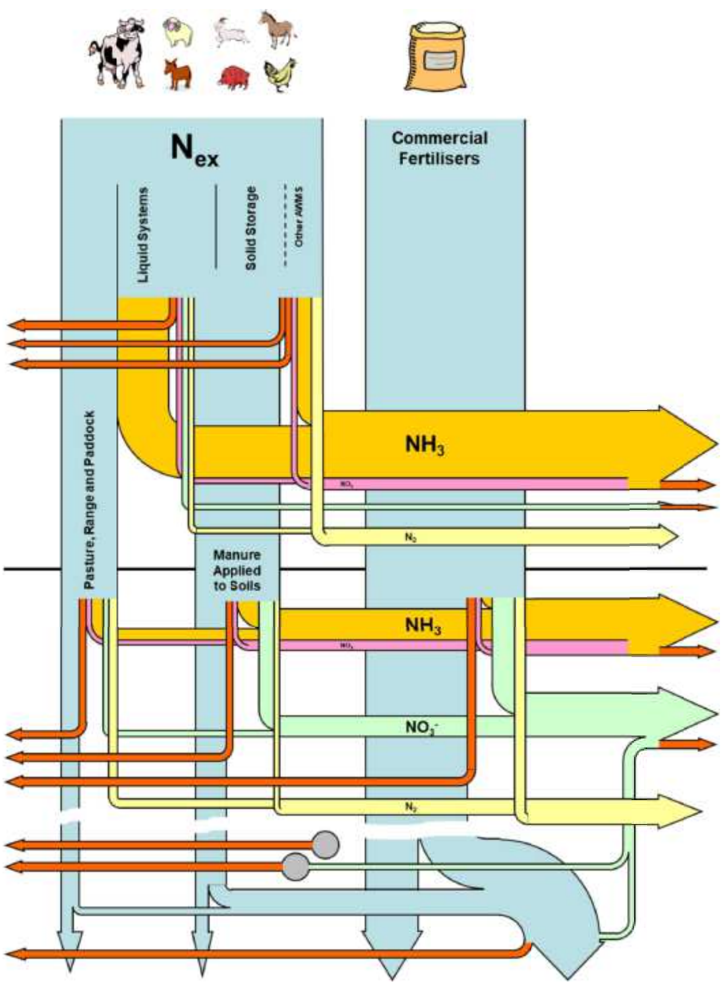
General management options

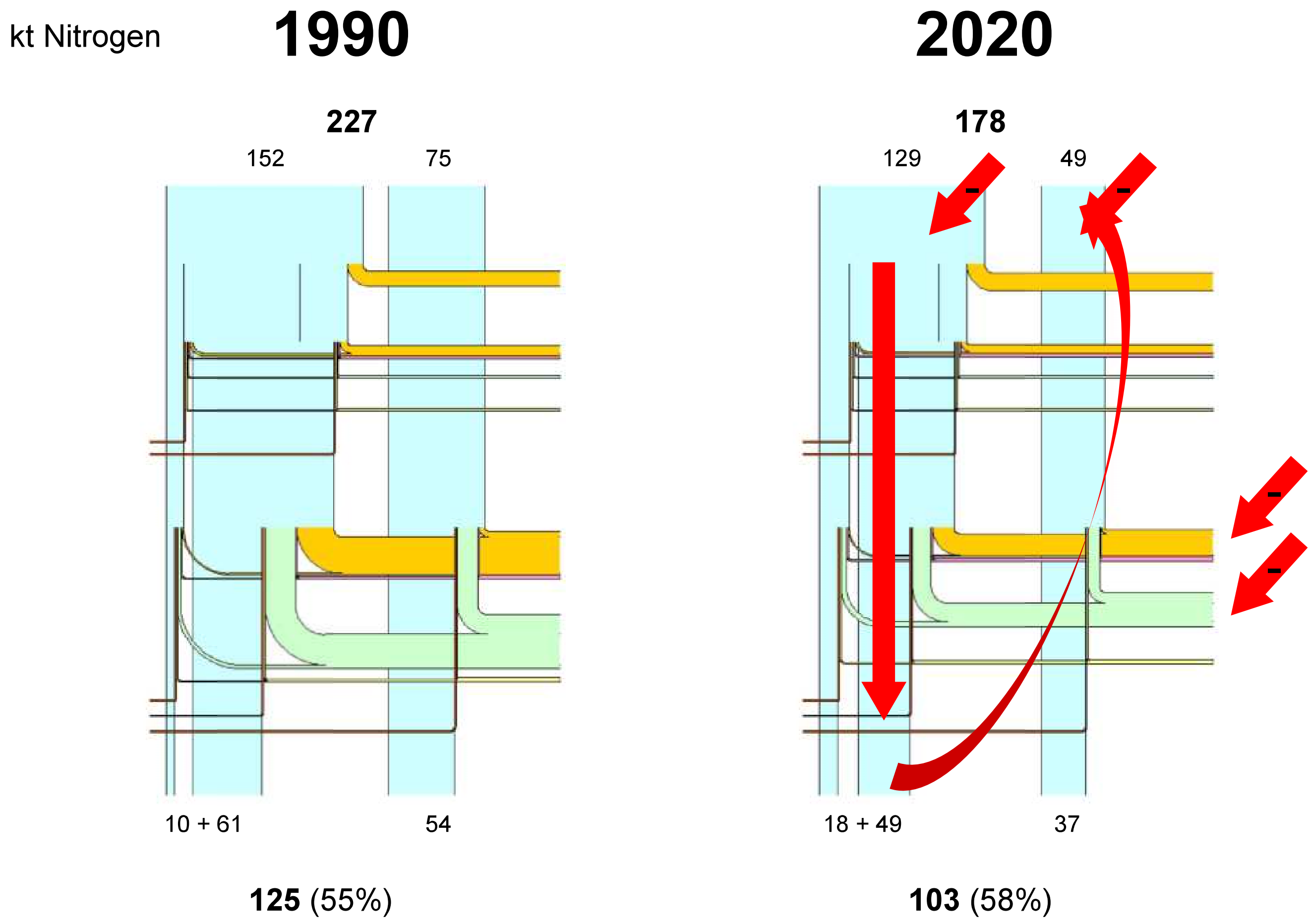
- Feeding strategy
- Housing systems
- Storage Systems

Nitrogen use efficiency

- Nitrogen loss pathways (NH_3, NO_3^-)
- Precision farming (feeding, fertiliser management)
- 4R – Principle

N_2O





Mitigation

Agricultural structures / portfolio
- Number and type of animals
- Crop species
- Leguminous crops
- Locally adapted portfolio and management

General management options
- Feeding strategy
- Housing systems
- Storage Systems

Nitrogen use efficiency
- Nitrogen loss pathways (NH_3, NO_3^-)
- Precision farming (feeding, fertiliser management)
- 4R – Principle

Emission factors (end of pipe solutions)
- Environmental conditions (T, moisture, pH, O_2, C)
- Crop species
- Application method
- Nitrification inhibitors / Urease inhibitors

N_2O Emission Factors

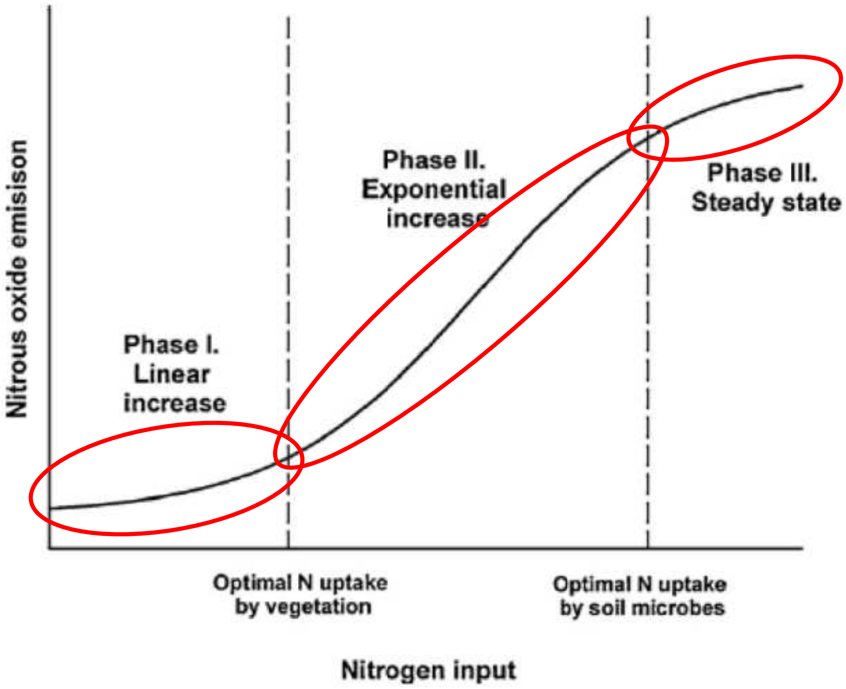
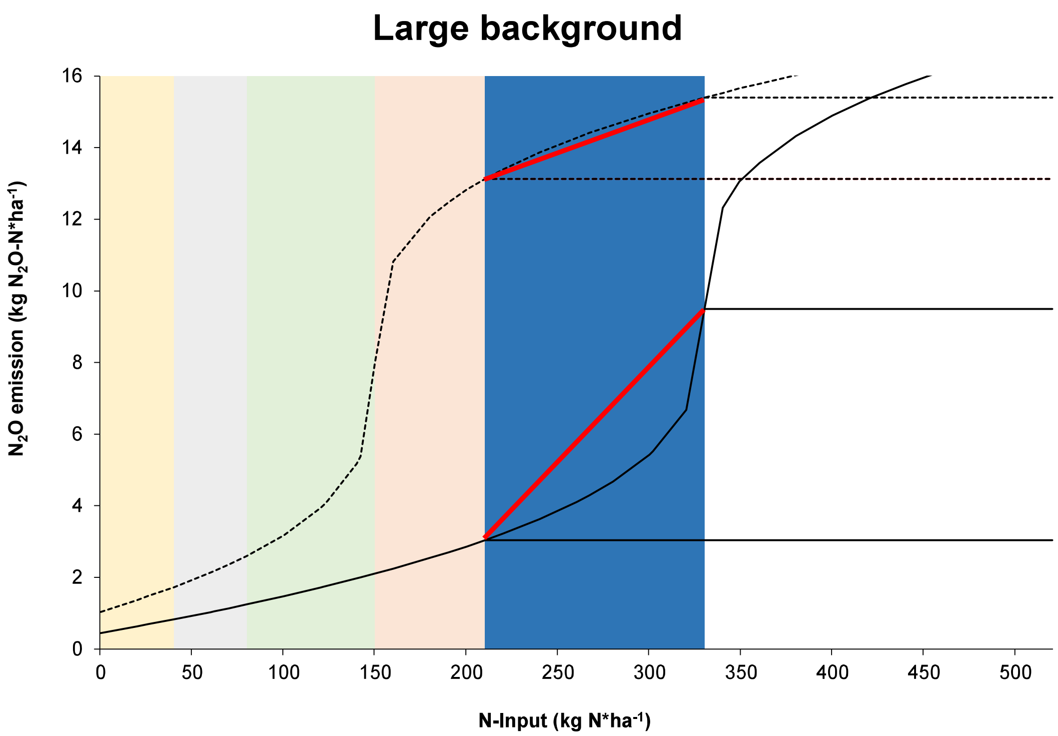


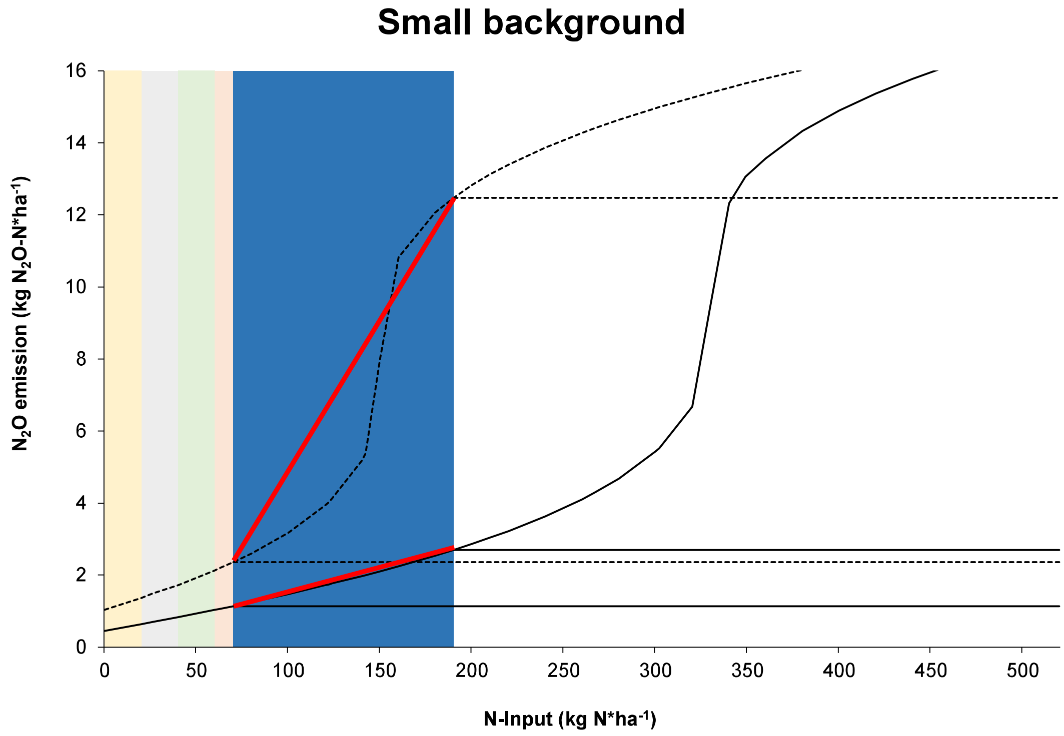
Fig. 4. Hypothetical diagram representing variation of direct nitrous oxide (N_2O) emission by increase of nitrogen (N) input.

Source: Kim et al. 2013

N_2O Emission Factors



N_2O Emission Factors



Quantity and drivers of nitrous oxide emissions during storage and application

Mitigation

Agricultural structures / portfolio
- Number and type of animals
- Crop species
- Leguminous crops
- Locally adapted portfolio and management

General management options
- Feeding strategy
- Housing systems
- Storage Systems

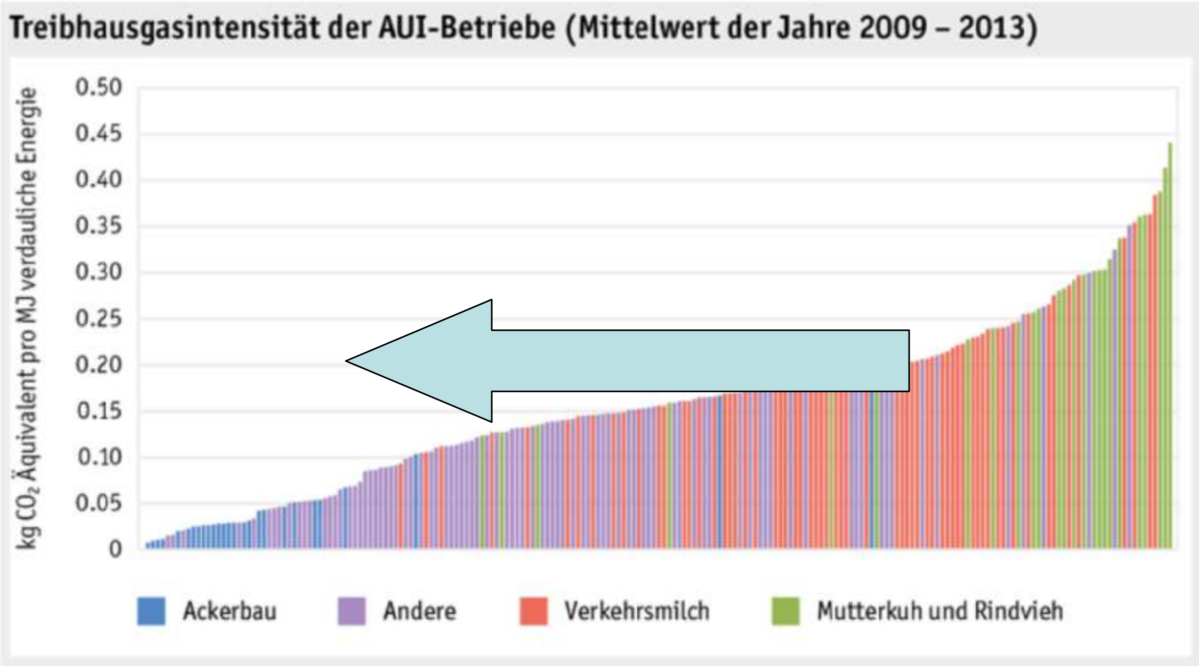
Nitrogen use efficiency
- Nitrogen loss pathways (NH_3, NO_3^-)
- Precision farming (feeding, fertiliser management)
- 4R – Principle

Emission factors (end of pipe solutions)
- Environmental conditions (T, moisture, pH, O_2, C)
- Crop species
- Application method
- Nitrification inhibitors / Urease inhibitors

Instruments
- Incentives vs. provisions
- Requirement for a balanced nutrient management
- Subsidy programs
- Fiscal instruments (e.g. taxes)

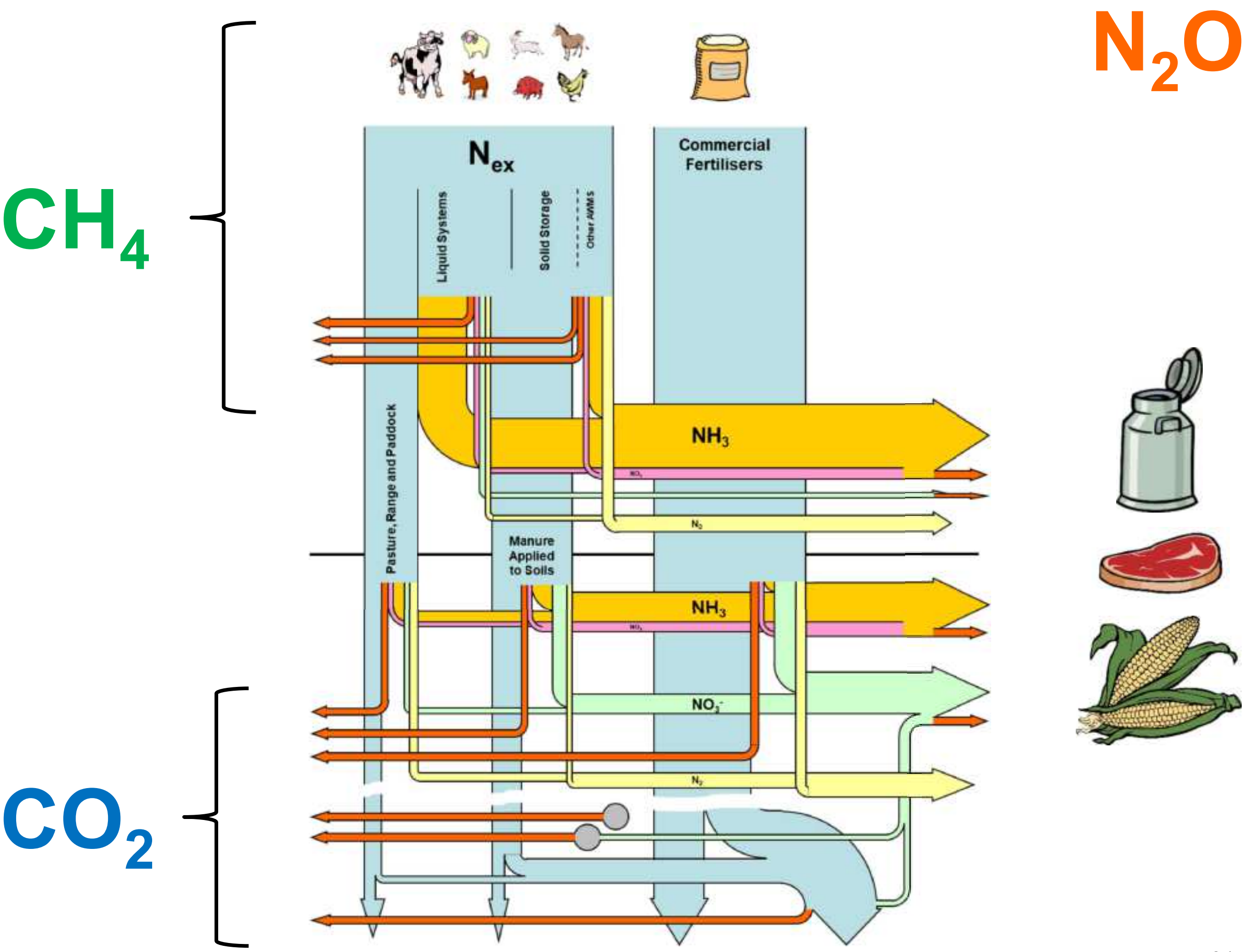
Implementation

Swiss Agri-Environmental Data Network (SAEDN)



Quelle: Agroscope

Source: BLW 2015 (Agrarbericht)



Thank you for your attention

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Agroscope good food, healthy environment
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Berner Fachhochschule

Expert Workshop on Nitrogen recovery in manure
4 - 6 May 2022

Strategies and technologies to reduce volatilisation during manure storage

Thomas Kupper

- Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften HAFL

Principal mechanisms driving ammonia emissions

- Amount of N in the agricultural system
- Physical-chemical conditions for ammonia generation (urease activity, temperature, pH)
- Size of the emitting surface
- Turbulence at the emitting surface
- Elimination of the TAN flow (air scrubbers, incineration of manure)

Techniques to reduce emissions from slurry storage: covering

- Covering
  ➔Reduces turbulence and gas exchange at the emitting surface
- The lower the turbulence → the tighter the cover
  the higher the emission reduction

~80% reduction
(measured at pilot scale*)

~48% reduction
(measured at farm scale**)

*De Bode, M.J.C., 1991. Odour and ammonia emissions from manure storage, in: Nielsen, V. C., Voorburg, J. H., L'Hermite, P. (Eds.), Odour and ammonia emissions from livestock farming. Elsevier Applied Science, London, England, pp. 69-76.
**Kupper, T., Eugster, R., Sintermann, J., Neftel, A., Häni, C. 2021. A novel approach to estimate the abatement of ammonia emissions from mitigation techniques at farm-scale slurry stores exemplified by a semifloating cover. J. Environ. Qual. 50(5): 1074-1083.

Techniques to reduce emissions from slurry storage: covering

		#	NH_3			N_2O			CH_4		
			n	Avg	Std	n	Avg	Std	n	Avg	Std
Impermeable structural covers	Lid (wood, concrete)	C	6	73%*	29%	2	-4%	23%	2	15%	2%
		P	7	64%*	35%	4	31%	56%	4	45%*	17%
	Tent covering	C	2	77%	9%	-	-	-	-	-	-
		P	2	89%	7%	-	-	-	-	-	-
Impermeable synthetic floating covers	Plastic film	C	4	66%*	22%	-	-	-	-	-	-
		P	6	88%*	18%	2	100%	0%	2	62%	54%
Permeable synthetic floating covers	Plastic fabrics	C	1	89%	-	1	68%	-	1	-2%	-
		P	5	39%*	15%	-	-	-	3	-17%	18%
	Expanded clay	C	4	59%	39%	-	-	-	2	11%	7%
		P	12	74%*	20%	1	-8%	-	6	8%	17%
	Expanded polystyrene	C	2	79%	2%	-	-	-	-	-	-
		P	4	64%*	32%	-	-	-	2	-26%	41%
	Plastic tiles	C	-	-	-	-	-	-	-	-	-
		P	2	88%	11%	1	-7%	-	1	25%	-

#C cattle, P pig.
*statistically significant difference ($p<0.05$) between storage with a cover and uncovered storage

Kupper, T., Häni, C., Neftel, A., Kincaid, C., Bühler, M., Amon, B., VanderZaag, A.C. 2020. Ammonia and greenhouse gas emissions from slurry storage - a review. Agr. Ecosyst. Environ. 300(106963): 1-18.

Techniques to reduce emissions from slurry storage: covering

- Covering: efficient technique***
  - to reduce NH_3 emissions from slurry storage
  - which tends to concomittantly reduce GHG emissions (mainly CH_4 which dominates GHG emissions)

  This statement can be considered as valid although robust experimental data are somewhat sparse.

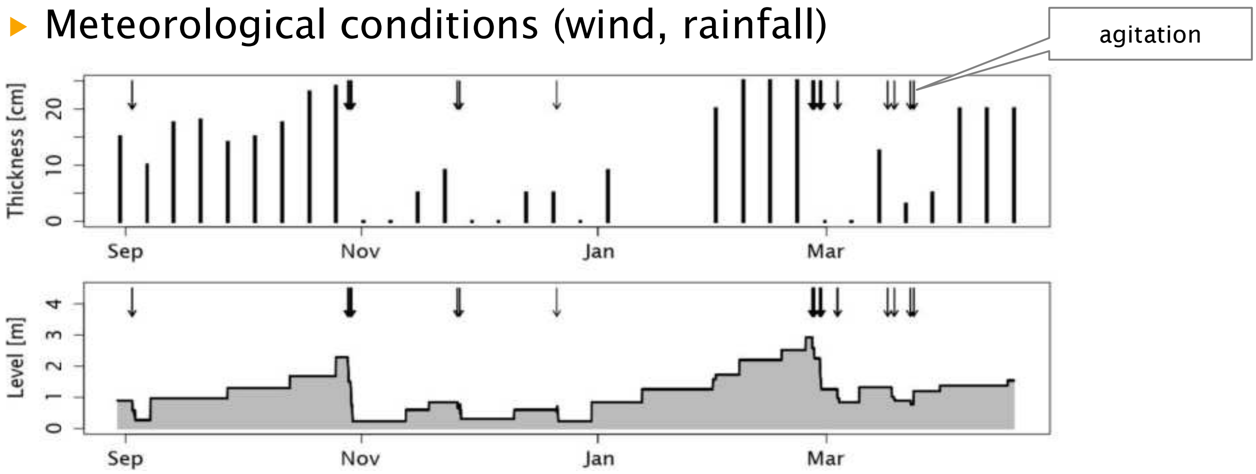
~80% reduction
(measured at pilot-scale*)

~48% reduction
(measured at farm-scale**)

***Kupper, T., Häni, C., Neftel, A., Kincaid, C., Bühler, M., Amon, B., VanderZaag, A.C. 2020. Ammonia and greenhouse gas emissions from slurry storage - a review. Agr. Ecosyst. Environ. 300(106963): 1-18.

Techniques to reduce emissions from slurry storage: natural crust

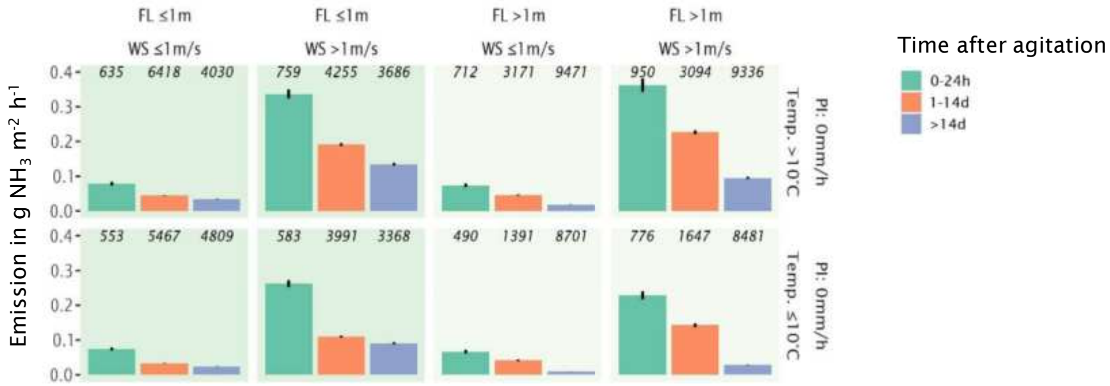
- Natural crust:
  - Formed from particles in the slurry
  - Ability to crusting depends from
    - Type of slurry 8e.g. cattle, pig)→type of particles (fibres, other)
    - Amount of particles→thickness of slurry layer
    - Meteorological conditions (wind, rainfall)



Kupper, T., Eugster, R., Sintermann, J., Häni, C. 2021. Ammonia emissions from an uncovered dairy slurry storage tank over two years: Interactions with tank operations and meteorological conditions. Biosyst. Eng. 204: 36-49.

Techniques to reduce emissions from slurry storage: natural crust

- Natural crust (although not equivalent to covering):
  ➔barrier to the gas molecules between the liquid and the air and microbial degradation of NH_3, CH_4
- Avoid disturbance of the stores surface



- Monitoring over > 2 years at a slurry storage tank
  - With crust: 0.044 g NH_3 m^{-2} h^{-1}
  - Without crust: 0.103 g NH_3 m^{-2} h^{-1}

Kupper, T., Eugster, R., Sintermann, J., Häni, C. 2021. Ammonia emissions from an uncovered dairy slurry storage tank over two years: Interactions with tank operations and meteorological conditions. Biosyst. Eng. 204: 36-49.

Techniques to reduce emissions from slurry storage: slurry treatment

		NH_3			N_2O			CH_4		
		n	Avg	Std	n	Avg	Std	n	Avg	Std
Acidification	Cattle	5	71%*	17%	1	−4%	–	5	61%*	36%
	Pig	3	77%*	22%	1	−39%	–	3	96%*	3%
Anaerobic digestion	Cattle	3	−59%	64%	3	−16%	29%	5	−2%	129%
	Pig	1	45%	–	1	−363%	–	1	99%	–
Solid-liquid separation	Cattle	12	−23%*	21%	6	43%*	36%	10	32%*	27%
	Pig	7	−1%	18%	1	−258%	–	7	39%*	39%
Dilution	Cattle	5	48%*	29%	5	57%*	38%	5	39%	33%
	Pig	–	–	–	–	–	–	2	47%	15%

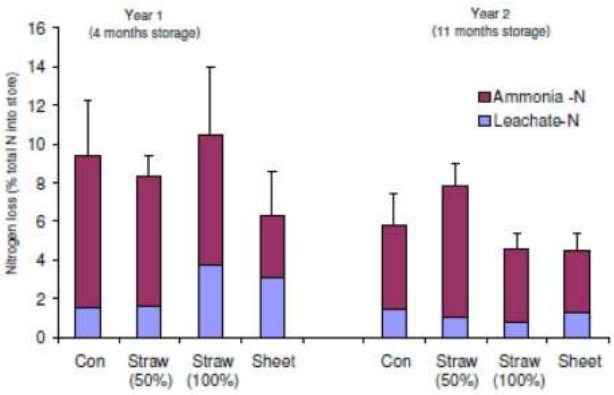
Cells denoted with "-": value is not available.
* Numbers with an asterisk indicate a statistically significant difference ($p < 0.05$) between the treated and the untreated slurry.

- Emission reduction/increase (for total GHG em.: CH_4=dominating gas)
  - Acidification: ↓ NH_3, ↓ CH_4, ↑ N_2O?
  - Anaerobic digestion: ↑ NH_3 (probably different for cattle and pig), ↓ CH_4, ↑ N_2O?
  - Solid-liquid separation: ↑ NH_3, ↓ CH_4, ↓ N_2O
  - Solid-liquid separation: ↑ NH_3, ↓ CH_4, ↓ N_2O
  - Dilution: ↑ NH_3, ↓ CH_4, ↓ N_2O:
    data obtained from pilot-scale studies: volume identical for diluted and untreated slurry; at farm-scale: increase of slurry volume and increase of emitting surface → overcompensation of emission reduction

Kupper, T., Häni, C., Neftel, A., Kincaid, C., Bühler, M., Amon, B., VanderZaag, A.C. 2020. Ammonia and greenhouse gas emissions from slurry storage - a review. Agr. Ecosyst. Environ. 300(106963): 1-18.

Techniques to reduce emissions from solid manure storage: covering

- Covering (sheeting)
  ➔ Reduces turbulence and gas exchange at the emitting surface
  ➔ Keeps manure moist and avoids/reduces self-heating



...sses from cattle FYM heaps at IGER North Wyke, May - September 2000 a...
...h 2003

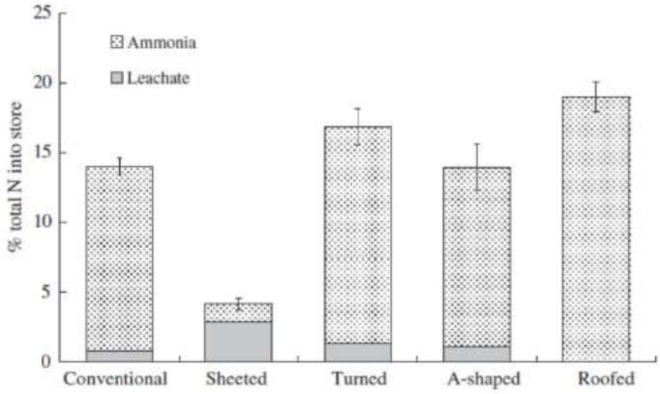


Fig. 1 – Nitrogen lost from broiler litter heaps during storage.

Sagoo, E., Williams, J.R., Chambers, B.J., Chadwick, D.R. 2006. Defra Project WA0716, Management Techniques to Minimise Ammonia Emissions from Solid Manures. Final Report to Defra, London. Mansfield, Notts. NG20 9PF ADAS Gleadthorpe Research Centre.

Sagoo, E., Williams, J.R., Chambers, B.J., Boyles, L.O., Matthews, R., Chadwick, D.R. 2007. Integrated management practices to minimise losses and maximise the crop nitrogen value of broiler litter. Biosyst. Eng. 97(4): 512-519.

Techniques to reduce emissions from solid manure storage: covering

- Covering (sheeting)
  ➔ reduces turbulence and gas exchange at the emitting surface
  ➔ keeps manure moist and avoids/reduces self-heating
- Compaction reduces self-heating (microbial decomposition of OM) and thus, gas transfer and increase of pH*
- Emission reduction achieved for NH_3 due to covering and/or compacting: >50%, but increase of CH_4 emission
- Other measures (storage under a roof, addition of straw, narrow A-shaped heaps that shed water more readily, turning**, composting are ineffective or increase emissions***
- Additives may reduce emissions from manure composting#

*Chadwick, D.R. 2005. Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. Atmos. Environ. 39(4): 787-799.

**Sagoo, E., Williams, J.R., Chambers, B.J., Chadwick, D.R. 2006. Defra Project WA0716, Management Techniques to Minimise Ammonia Emissions from Solid Manures. Final Report to Defra, London. Mansfield, Notts. NG20 9PF ADAS Gleadthorpe Research Centre.

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#Cao, Y.B., Wang, X., Bai, Z.H., Chadwick, D., Misselbrook, T., Sommer, S.G., Qin, W., Ma, L. 2019. Mitigation of ammonia, nitrous oxide and methane emissions during solid waste composting with different additives: A meta-analysis. J. Clean Prod. 235: 626-635.

How do we maximise the nutrient value of manures?

John Williams ADAS Soil Scientist

Expert workshop; Agroscope, Zurich 4 -6 May 2022

www.adas.uk

Organic manure nutrient content is variable

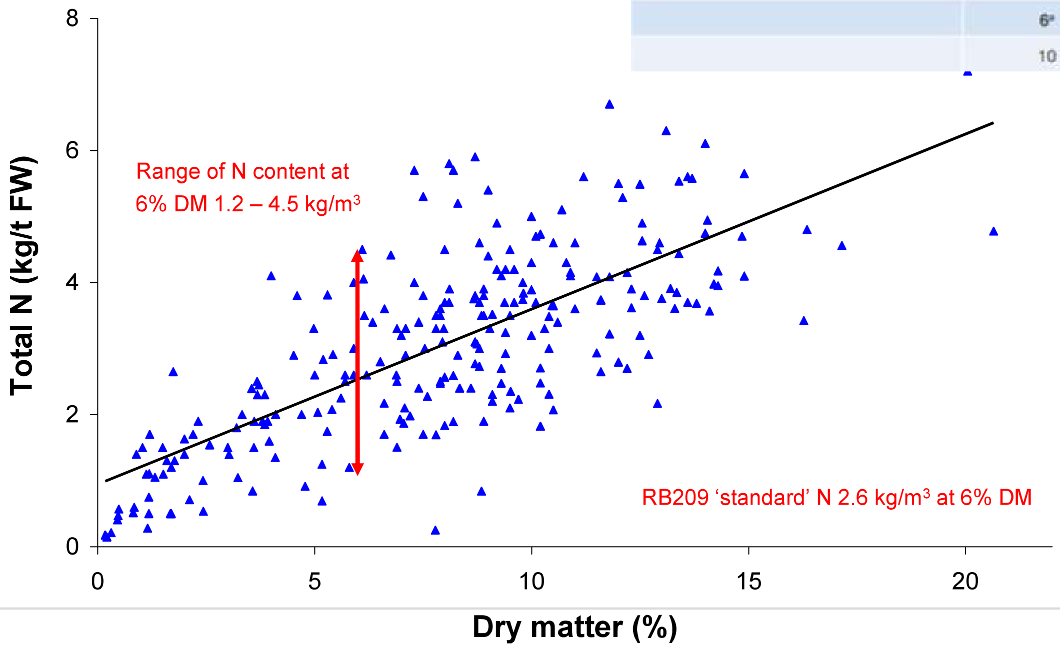
Manure type	Dry matter	Total N	Total P_2O_5	Total K_2O	Total SO_3	Total MgO
	%	Kg/t				
Cattle FYM	25	6.0	3.2	9.4	2.4	1.8
Pig slurry	4	3.6	1.5	2.2	0.7	0.7
Poultry manure	60	28	8.0	8.5	8.2	5.9
Food based digestate	4	4.8	1.1	2.4	0.7	0.2
Biosolids	25	11	11	0.6	8.2	1.6

Know the nutrient content

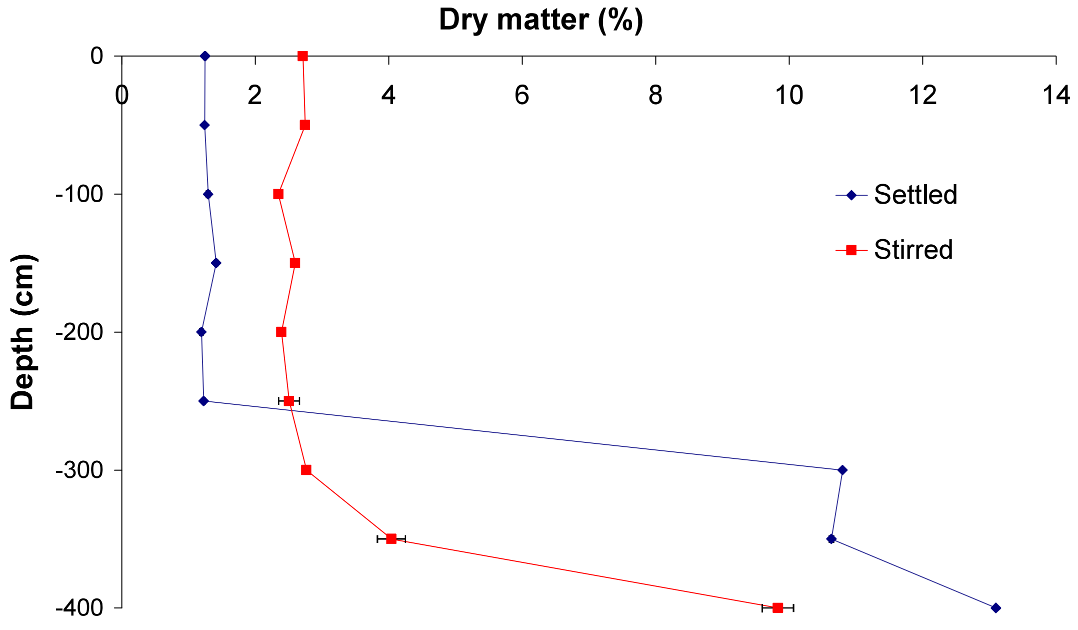
- Factors affecting manure nutrient content -
  - Livestock type
  - Diet
  - Bedding type and quantity
  - Water use
  - Manure/slurry storage

Cattle slurry, total N

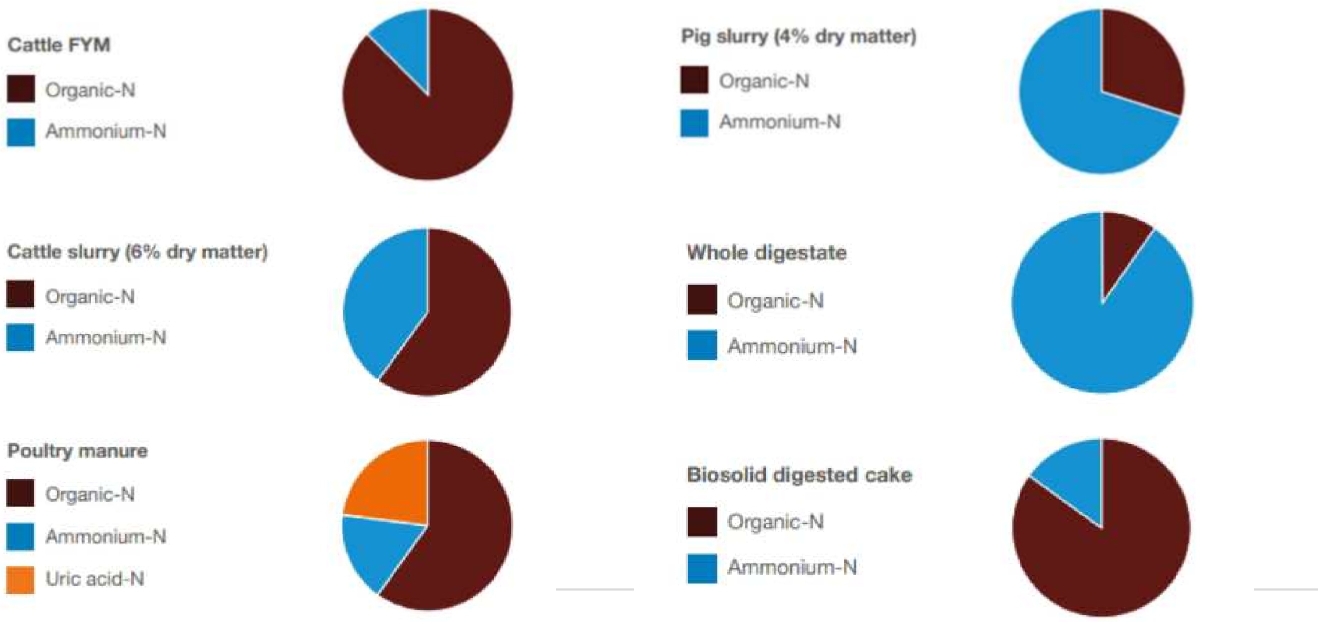
	Dry matter %	Total nitrogen[b] kg N/m³ or /t
Slurries/liquids		
Cattle	2	1.6
	6[a]	2.6[a]
	10	3.6



Impact of sampling depth and mixing on slurry analysis - pig slurry



Manure nutrient supply - nitrogen



Slurry separation for improved nutrient utilisation

- Can reduce slurry storage requirement by between 10-20%
- Liquid fraction has low dry matter and high readily available N content
- Organic matter and phosphorus is concentrated in the solid fraction
- Apply solid fraction to low P index soils

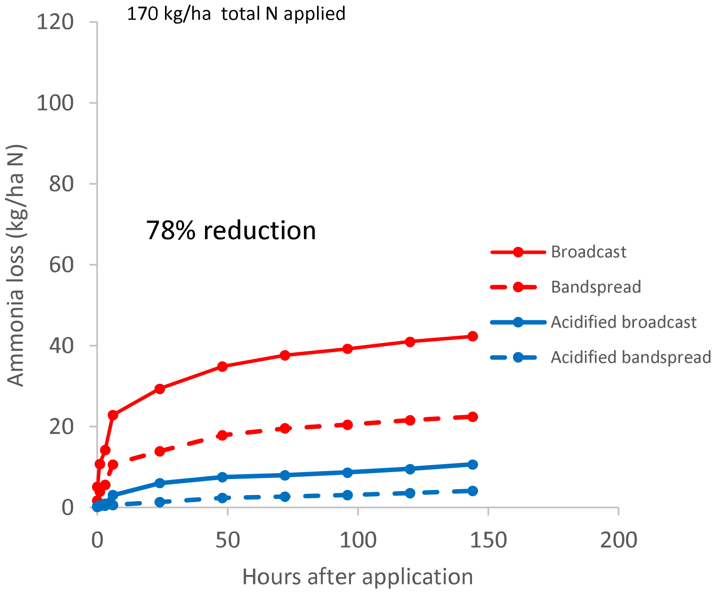
What about acidification ?

- Acidification affects the NH_4^+ / NH_3 equilibrium:

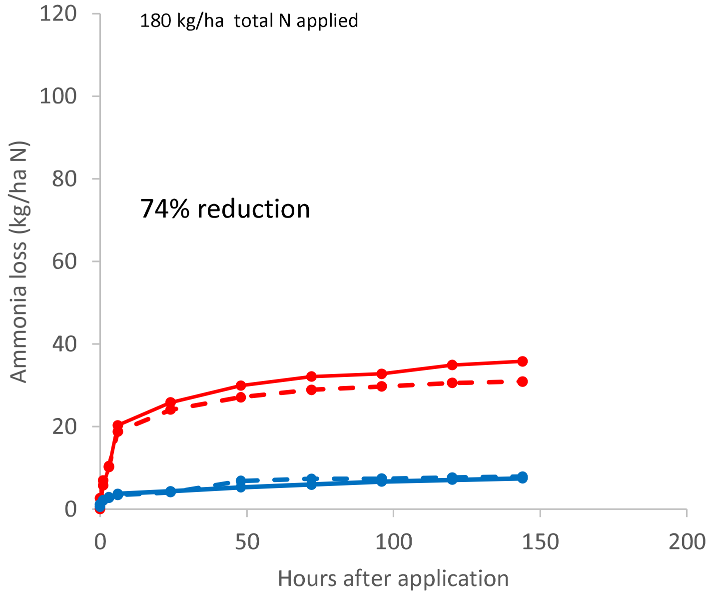
$$NH_3(g) + H^+(aq) \longleftrightarrow NH_4^+(aq)$$

- Literature suggests reducing pH to *c.*5.5 can reduce ammonia emissions by more than 80%
- Has potential to increase crop available N supply.

Impact of acidification on ammonia emissions(Defra project SCF0215)

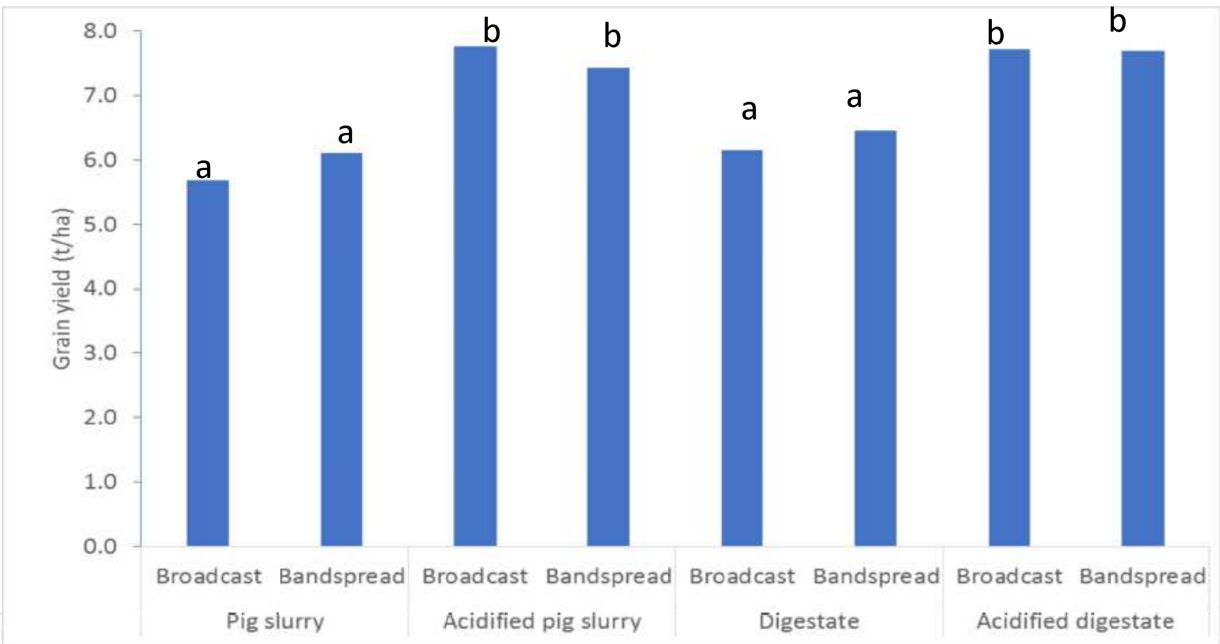


Pig Slurry; pH 7.7 ➡ 5.3



Digestate; pH 7.8 ➡ 5.8

Impact of acidification on N use efficiency



P<0.05; letters indicate statistically significant differences between treatments

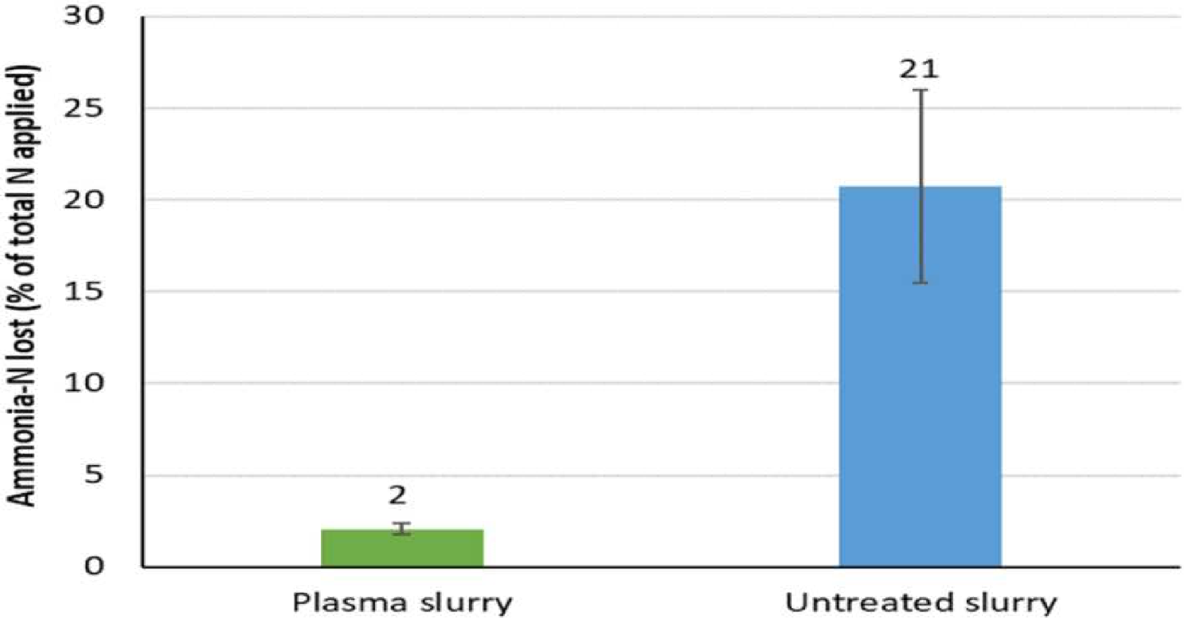
What about plasma technology (e.g. N_2Applied)?

- The process absorbs nitrogen oxides into the slurry which lowers the slurry pH without the need for the addition of large quantities of industrial acids.

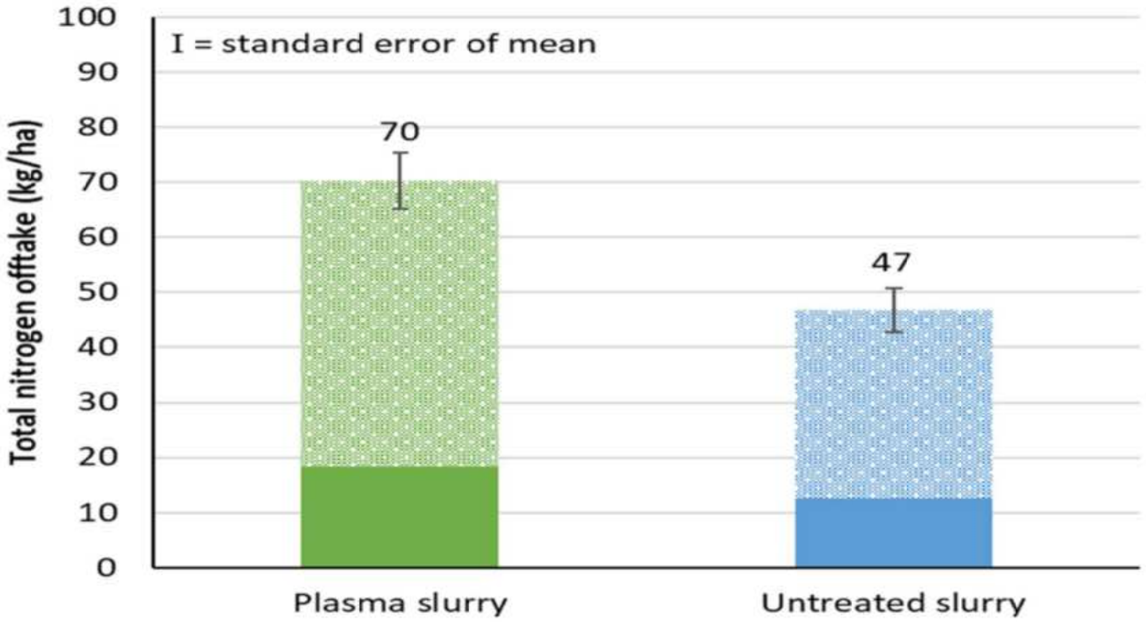
Impact of Plasma treatment on slurry N content and pH

	Untreated slurry	Plasma treated slurry
Total nitrogen (kg/m³)	2.50	4.55
Ammonium-N (kg/m³)	1.36	1.44
Nitrate-N (kg/m³)	<0.1	0.60
Nitrite-N (kg/m³)	<0.1	0.55
Organic N (kg/m³)	1.14	1.96
Available N (kg/m³)	1.36	2.59
Dry matter %	3.36	3.24
pH	7.87	5.41

Impact of plasma treatment on ammonia emissions



Impact of plasma treatment on N use efficiency



Conclusions & key questions for workshop

- Accounting for variability is challenging
  - Manure analysis to minimize uncertainties
- Simple separation techniques can be very useful in providing materials with more consistent and balanced nutrient contents
- Acidification and plasma treatment stabilize available N – costs and practicalities?

Key questions:

How do we validate crop available nutrient supply from organic fertilisers (N &P)?

Do we fully understand the benefits and trade offs of manure treatment processes?

Strategies and technologies to reduce ammonia volatilisation during manure application

Dominika J. Krol, Gary J. Lanigan, Karl G. Richards
Teagasc, Environment, Soils and Land Use Department
Johnstown Castle, Co. Wexford, Ireland

Factors influencing ammonia emissions from land spreading of animal manures

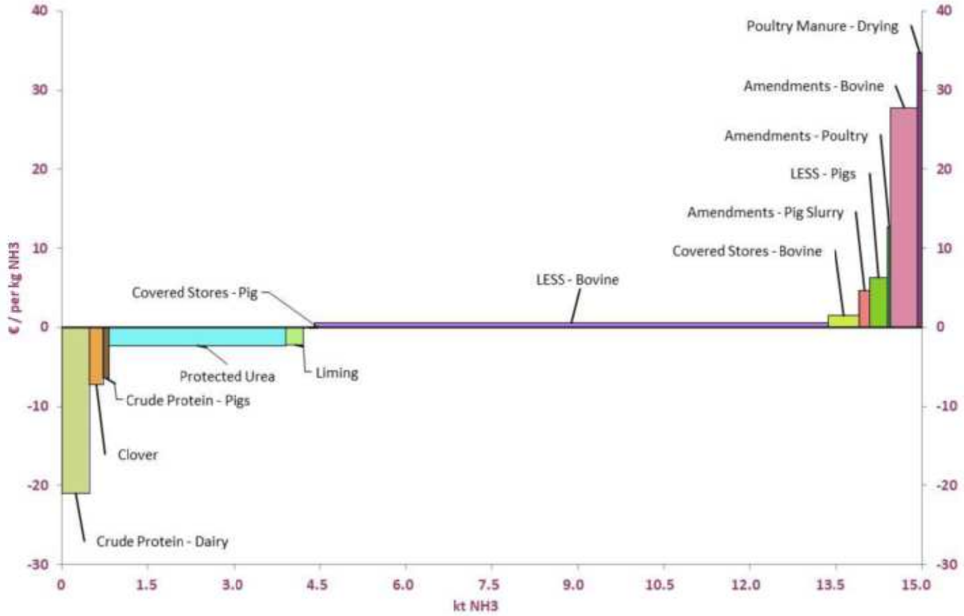
- Manure properties: viscosity / dry matter, TAN content, C content and pH
- Soil properties: pH, CEC, Ca content, moisture, buffering capacity and porosity
- Meteorological conditions: precipitation, solar radiation, temperature, humidity and wind speed
- Method and rate of application
- Height and density of crop present

Manure management systems in the EU

- Examples of AWMS for dairy cows in 2019 / 2020

	Liquid / slurry	Solid storage	Pasture, range & paddock	Digesters	Notes
Austria	54.0	29.0	3.7	2.4	1.9 composting, 9.0 other
Belgium - Flanders	60	9	14	-	17 dry lot
Belgium - Wallonia and Brussels	20.7	35.3	44	-	
Germany	57.9	11.5	7.3	22.5	
Ireland	31.1	2.1	66.8	-	
Switzerland	68.2	9.0	16.7	6.0	

Irish Ammonia Marginal Abatement Cost Curve

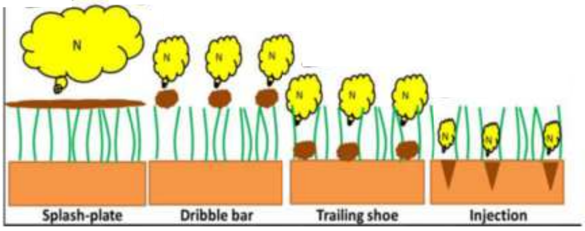


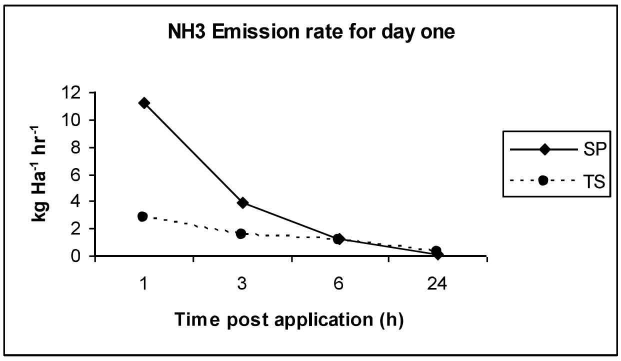
Effect of application technology

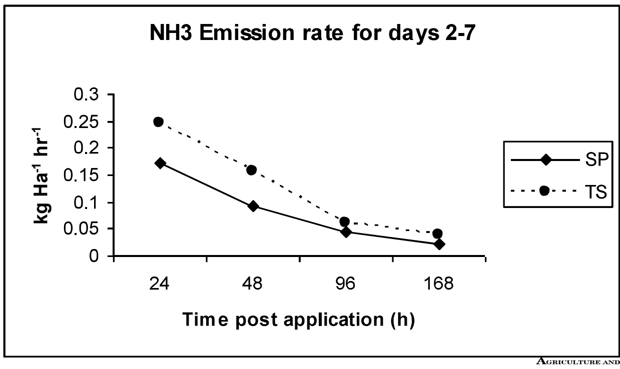
Grassland application:
- Dribble bar
- Trailing hose
- Trailing shoe
- Shallow injection
- Deep injection

Arable application:
- Broadcast + incorporation:

-by plough in one process
-by plough immediately
-by disc immediately
-by plough within 3, 6, 12hrs
- Trailing hose +/- incorporation

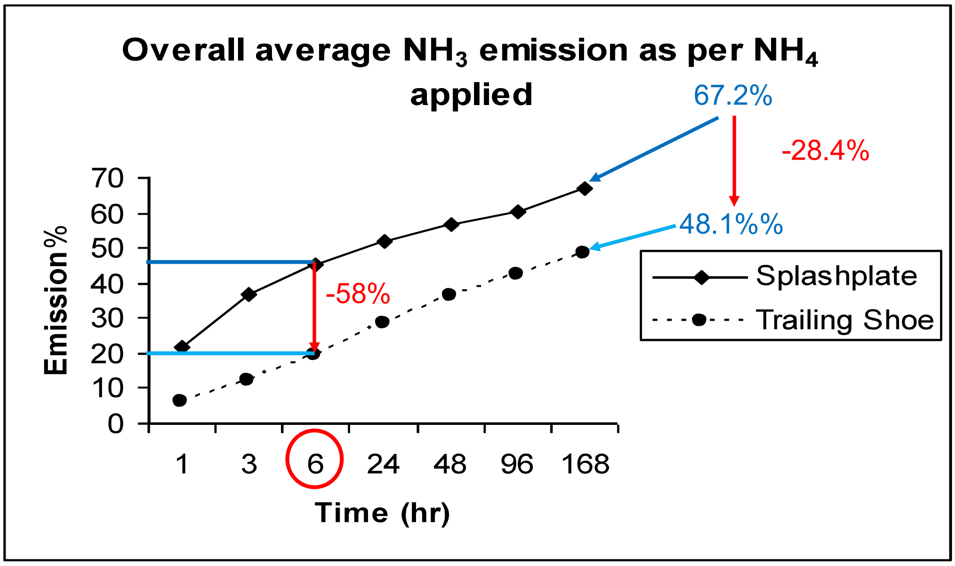






Dowling et al. (2010)

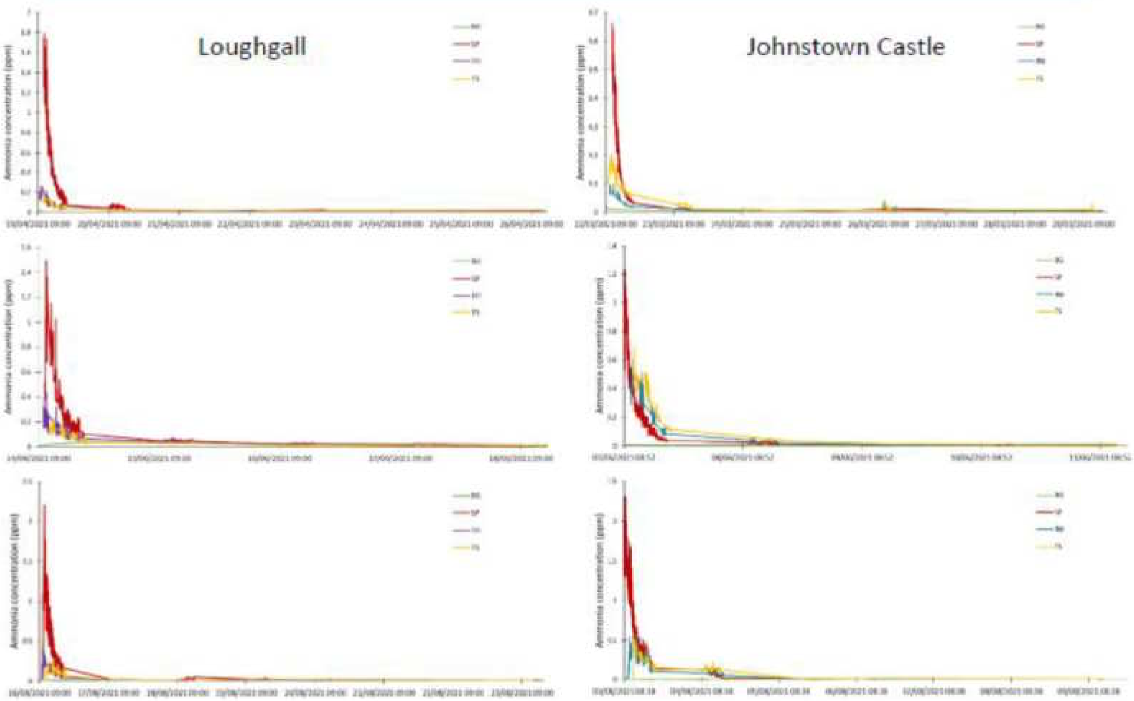
Effect of application technology



Dowling et al. (2010)

Effect of application technology

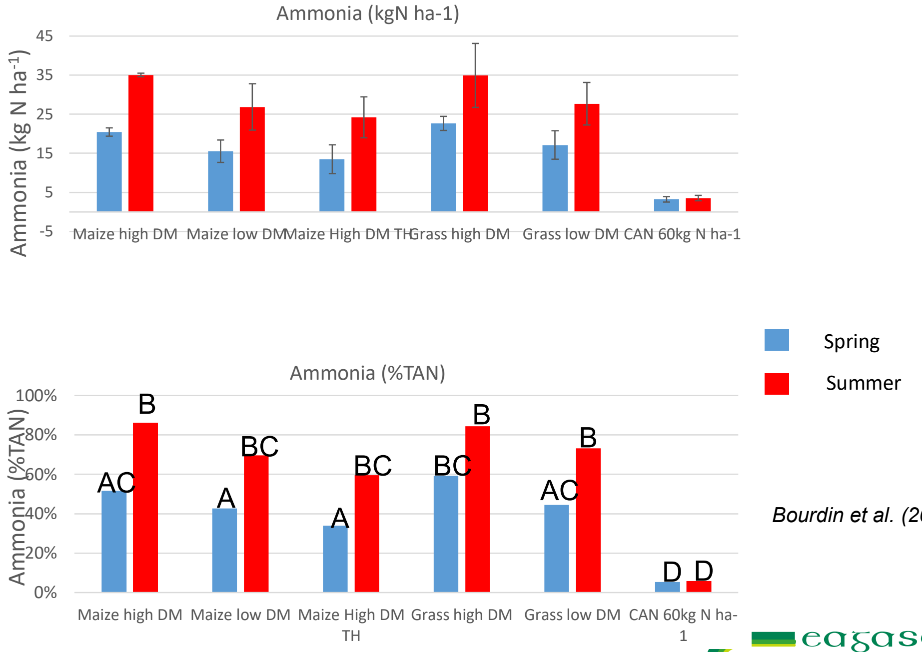
Effect of application technology



Effect of timing / slurry type and DM

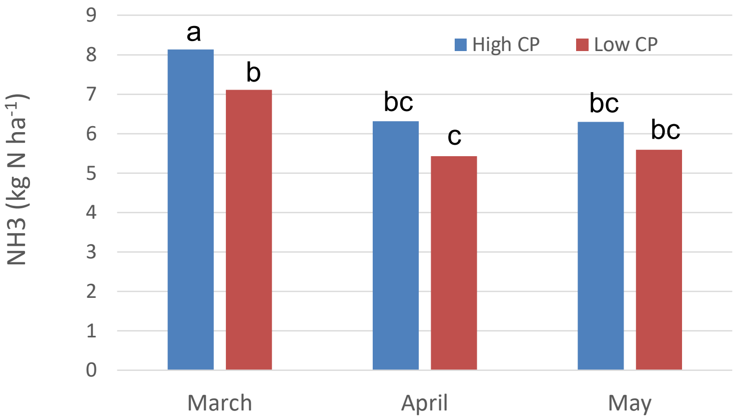
Slurry derived from maize silage or grass silage-fed cows

April	DM	TAN (%)	N applied kg/ha
Maize	7.70%	1.13	39.55
Grass	7.58%	1.09	38.15
Maize	3.90%	1.04	36.4
Grass	3.45%	1.1	38.5
July			
Maize	7.70%	1.16	40.6
Grass	7.70%	1.21	42.35
Maize	3.90%	1.1	38.5
Grass	3.90%	1.07	37.45



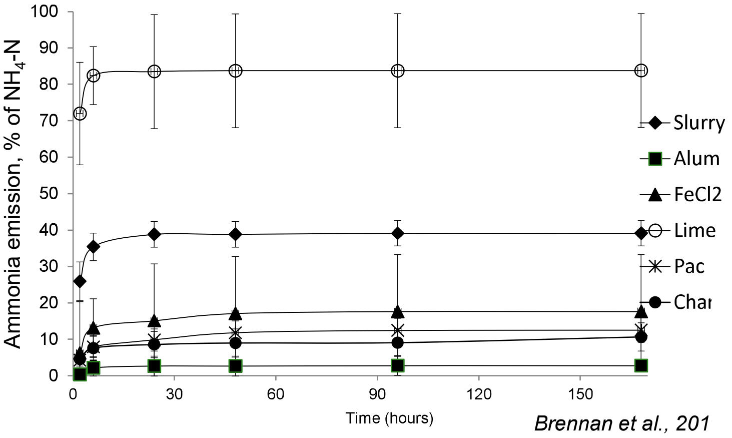
Bourdin et al. (2014)

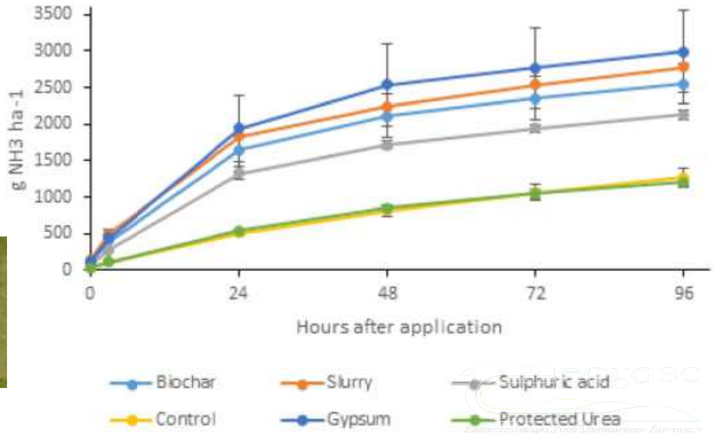
Effect of slurry crude protein



Meade et al., unpublished

Effect of slurry acidification / amendments





Effect of slurry pre-treatment

Considerations

- Type of manure management system
- Land use of application
- Pre-treatment of manure
- Abatement efficiency
- Ease of adoption
- Monitoring and verification

Teagasc Agriculture and Food Development Authority

THANK YOU FOR YOUR ATTENTION

Teagasc Agriculture and Food Development Authority

Estimation of manure N recovery based on measurable & affordable characteristics for model parameterization: field data and/or laboratory data

France & tropical countries

Laurent THURIÈS[1], Florent LEVAVASSEUR[2] & coll.

[1] CIRAD, Research Unit « Recycling & risk », Montpellier, France
[2] INRAe, Research Unit « ECOSYS », Thiverval-Grignon, France

Manure values (fertilizer equivalent, amendment potential)?

« value » / « quality » = *f* (time, location, animal species, husbandry, physical state…)

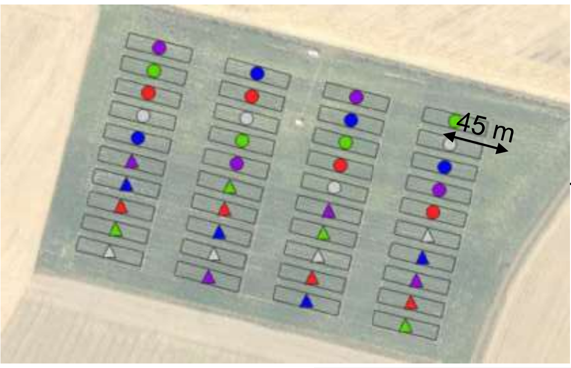
Estimated fertilizer value
- Field trials
- Laboratory tests
- …

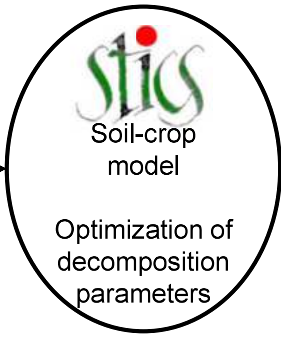
→ Models / Indicators →

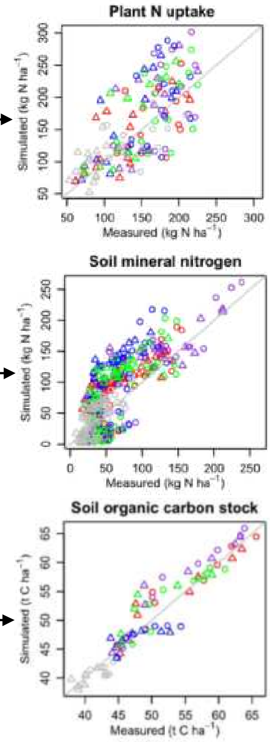
- Typology / grids
- Decision support systems

Use of long term field trials to calibrate soil-crop model

- QualiAgro Long term field experiment, France (1998-…)
- Maize – wheat rotation
- Application of organic wastes every two years (4 t C/ha), with a minimal (Δ) or optimal (o) mineral N fertilization :
  - Green waste and sludge compost
  - Biowaste compost
  - Municipal solid waste compost
  - Farmyard manure
  - Control



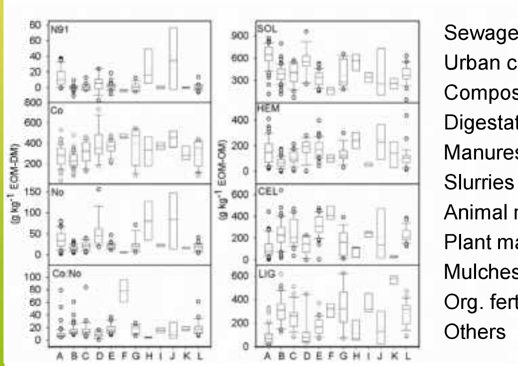




Limited number of treatments
Climatic events - dependent
Hum ressources & money

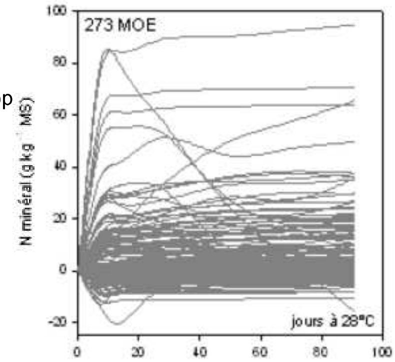
Levavasseur et al. (2021)

Lab data: chemical, incubations…for typology, indicators, models



Sewage sludges
Urban composts
Composted manures, slur, drop
Digestates
Manures
Slurries + droppings
Animal materials
Plant materials
Mulches
Org. fertilizers
Others

Ref analyses by NIRS



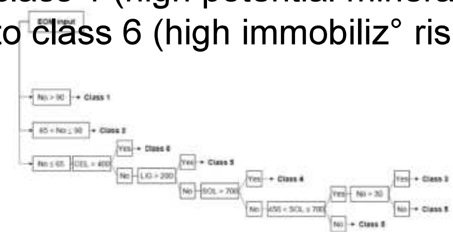
Incubation data

High variability (inter & intra groups)

Indicator by NIRS of remaining organic carbon (« humus potential »)

I_{ROC} = 44.5 + 0.5 **SOL** – 0.2 **CEL** + 0.7 **LIC** - 2.3 **$MinC_{3d}$**

N typology: class 1 (high potential mineraliz°) to class 6 (high immobiliz° risk)

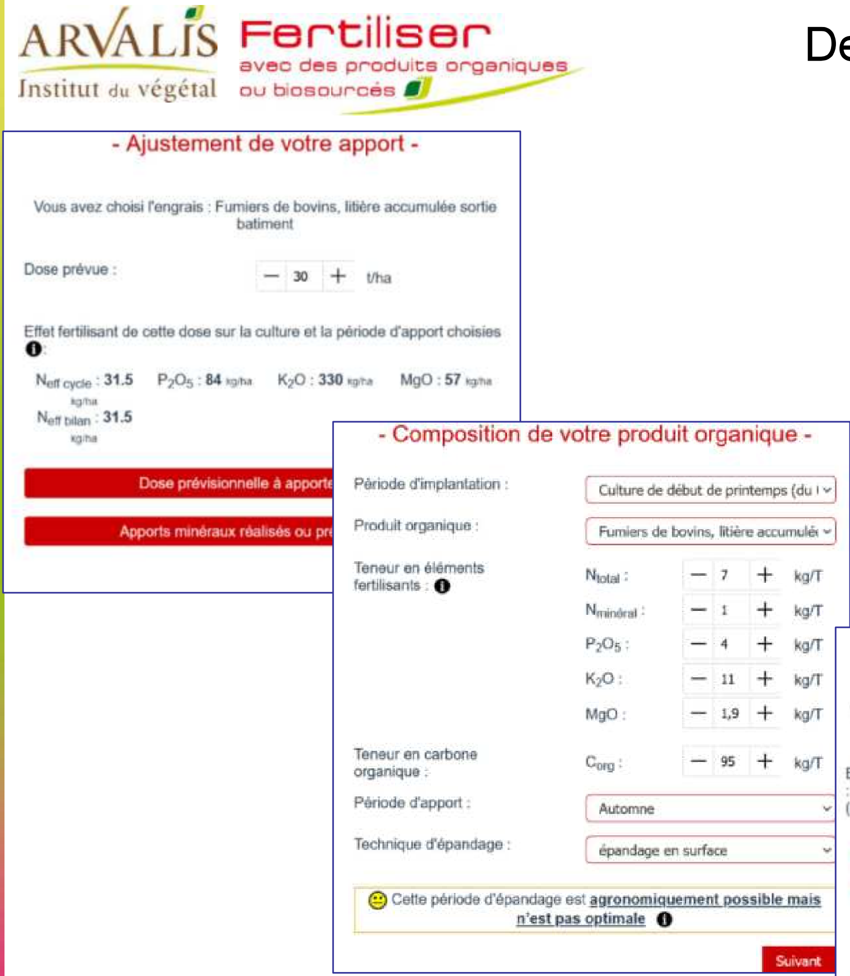


Models: by NIRS compartments, Decomp° consts

Soil module (STICS)
DPM (RothC)
PS (TAO)
NCSoil…

Peltre et al. (2009); id. (2011) *SBB*; Kaboré et al. (2012) *JNIRS*; Noirot-Cosson et al. (2017); Levavasseur et al. (2020; 2021)
AFNOR standards + Lashermes et al., (2009) *EJSS*; id. (2010) *BioresTech*

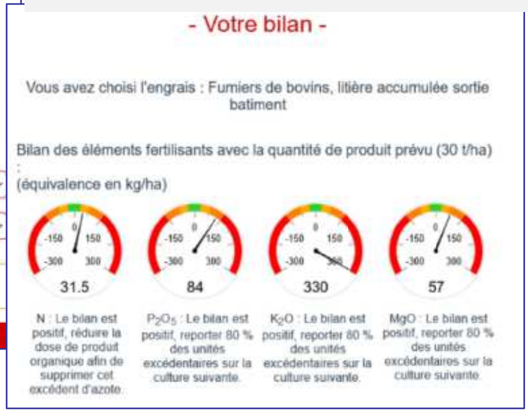
Decision Support Systems



Calibration on:
++ field trials
≠ regions (1 country)
mean characteristics of EOM

Outputs:
fertilizer equivalents
amendment potential
nutrient balance
advices

Agronomic (no envir, no regul)
Static



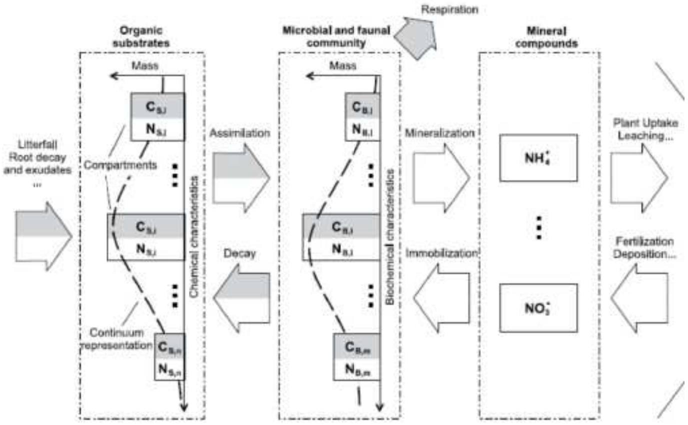
Do we still need models?

- New organic materials
e.g. manures: new husbandry methods, bedding materials…

- Future climatic conditions
easier to be « tested » by modeling than Ecotrons…

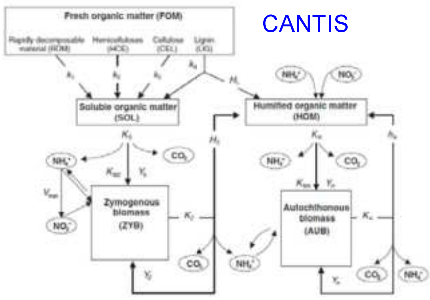
- …

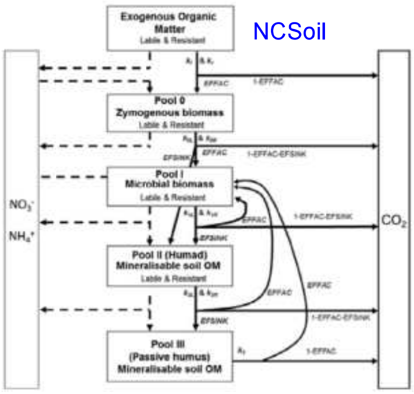
Models?

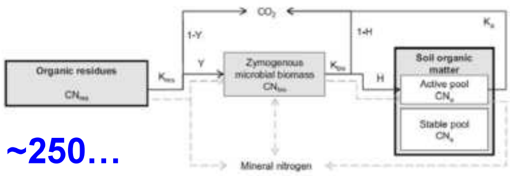


~ common structure:

- ✓ 1(+) OM compartment(s)
- ✓ 1(+) Biological compartment(s)/population(s)
- ✓ Coupled C & N mineralizations
- ✓ +/- Abiotic control of K (e.g. pH, WHC, θ…)



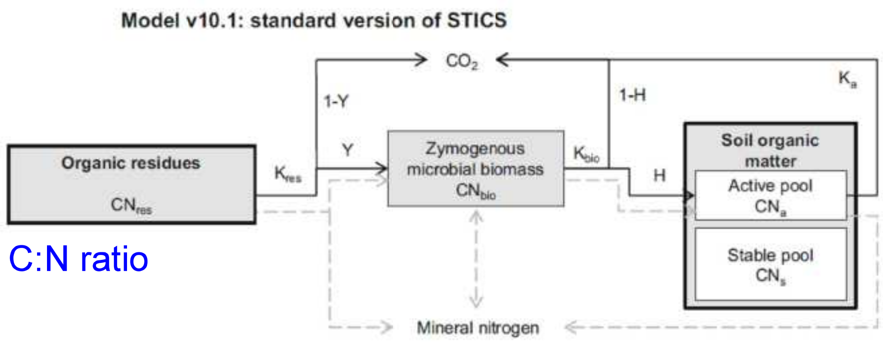




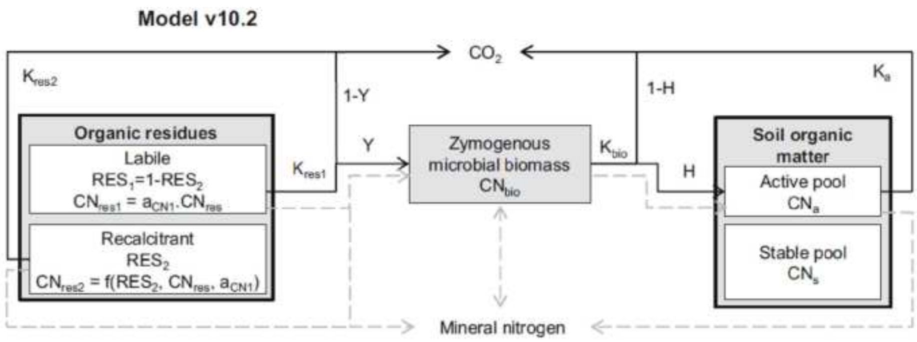
~250…

From Manzoni & Porporato (2009) *SBB*; Noirot-Cosson et al. (2017) *SBB*; Garnier et al. (2003) *EJSS*

Example of the submodel (soil module) of the STICS soil-plant model



1 C:N ratio



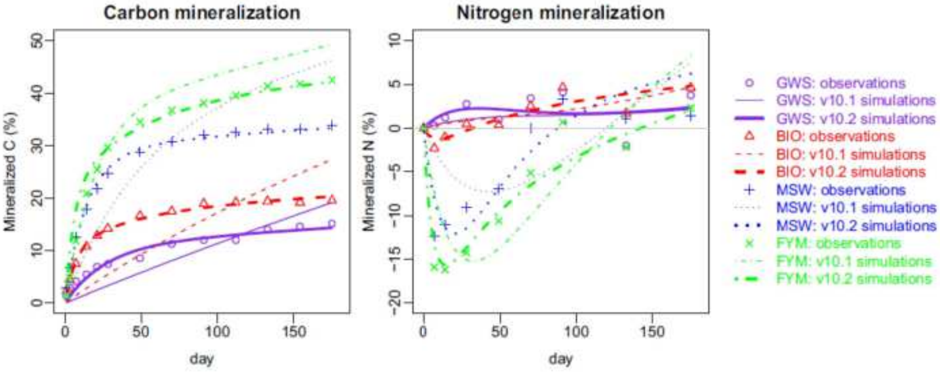
Decomposition model of EOM in the standard (v10.1) and modified version of the STICS model.
C fluxes = solid black lines,
N fluxes = dashed gray lines.

2 C:N ratios (CN_{res1} and CN_{res2})
a_{CN1} = allocation of N between labile and recalcitrant pools
Labile pool: mineralized or assimilated by zymogenous biomass
Immobilization of N: if $CN_{res1} >> CN_{bio}$

From Levavasseur et al. (*2021) Nut Cycl Agro*

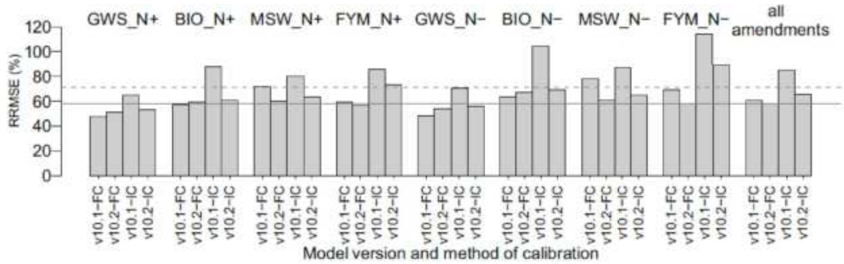
Calibration on laboratory or field data; with which version?

Cmin and Nmin predictions based on lab incubation data (same EOM / Qualiagro)



C&Nmin:
≠ Performances
f° (model version; EOM)

SON stocks predictions based on lab incubation *vs* field data (Qualiagro)



SON stocks: Performances
≈ 2 versions; lab/field data

So, let's use lab data?

! Caution: for long-term scale

From Levavasseur et al. (2021) *Nut Cycl Agro*

Calibration on laboratory data: extension of the approach?

Example of a national database of EOM with chemical analyses and incubations:

(manures, composts, sludges, digestates, food by-products, animal residues, plant residues, organic fertilizers, algae, others)

Main characteristics of the 663 organic materials

Group	C_{org} *	N_{org} *	$C_{org}:N_{org}$	N_{min} *	I_{ROC} (%OM)
Manures	**353 - 428**	**12 - 45**	**9 - 25**	**0.5 - 31**	**27 - 59**
Composted manures	**322**	**22**	**15**	**1.4**	**67**
All others (sludges, digestates, food byproducts, animal or plant residues, composts non-animal)	**155 - 483**	**8 - 39**	**7 - 38**	**0.1 - 36**	**21 - 80**

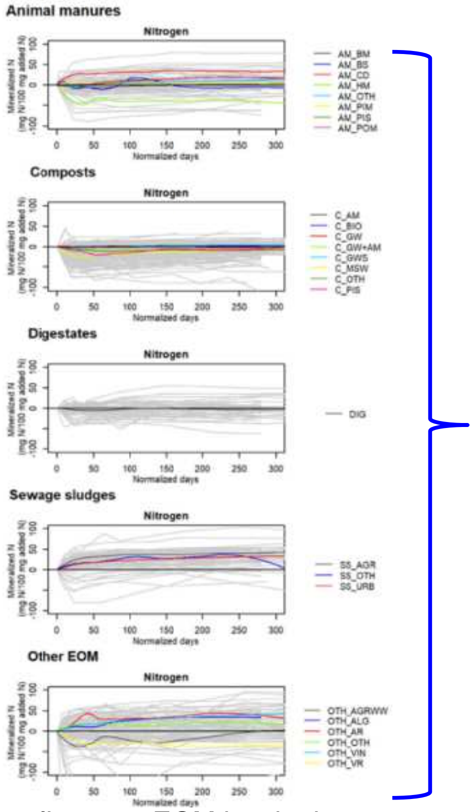
* in g kg^{-1} DM

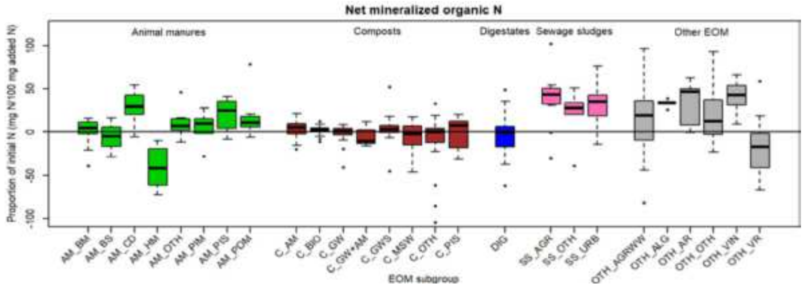
Large diversity of C & N [ ], ratio, indic levels

Manures within « others » C & N [ ], ratio, indic ranges

Modified from Levavasseur et al. (2021) *Soil Use Man*

Calibration on laboratory data: extension of the approach?



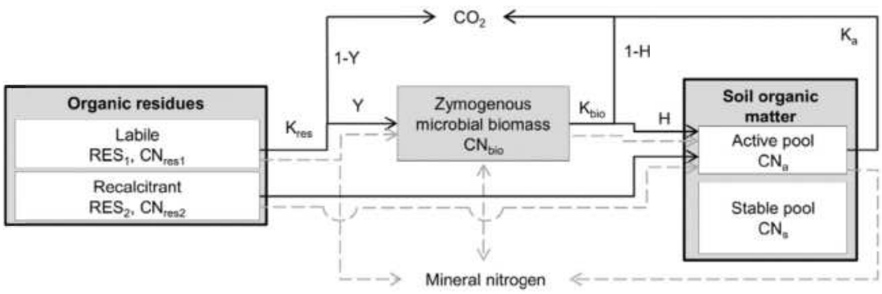


Large diversity of mineralized N measured in lab conditions (equiv 1yr field) **between** and **within** subgroups

gray line = an EOM incubation;
colored lines = fitted local polynomial regressions per EOM subgroup

From Levavasseur et al. (2021) *Soil Use Man*

Simplified version of v10.2 STICS soil module

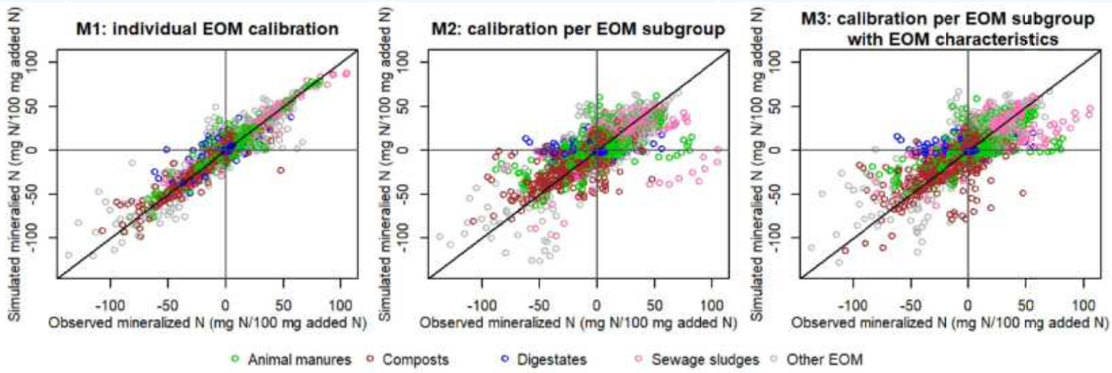


2 C:N ratios (CN_{res1} and CN_{res2})
a_{CN1} = allocation of N between labile and recalcitrant pools
Labile pool: mineralized or assimilated by zymogenous biomass
Immobilization of N: if CN_{res1} >> Cn_{bio}
~~$Kres_2$~~
Recalcitrant pool directly incorporated into the SOM Active Pool

From Levavasseur et al. (2021) *Soil Use Man*

Example of model calibration: 3 strategies

	M1	M2	M3
Calib°	/ individual EOM	/ EOM subgroup	Id M2 + with I_{ROC} & C_{3d}
=	param optimized for each EOM	same optim param for 1 subgroup	1st step: relationship bw M1 optim param and I_{ROC} & C_{3d} $RES_1 = \alpha_{res1} + \beta_{res1} \times I_{ROC}$ $K_{RES} = \exp(\alpha_{kres} + \beta_{kres} \times C_{3d})$
			2nd step: use these relationships to calib param by subgroup



Perfs: 1>3≥2

From Levavasseur et al. (2021) *Soil Use Man*

And for mixtures? Interactions? e.g. manure + crop residues

Digested dried sewage sludge

Sugarcane straw

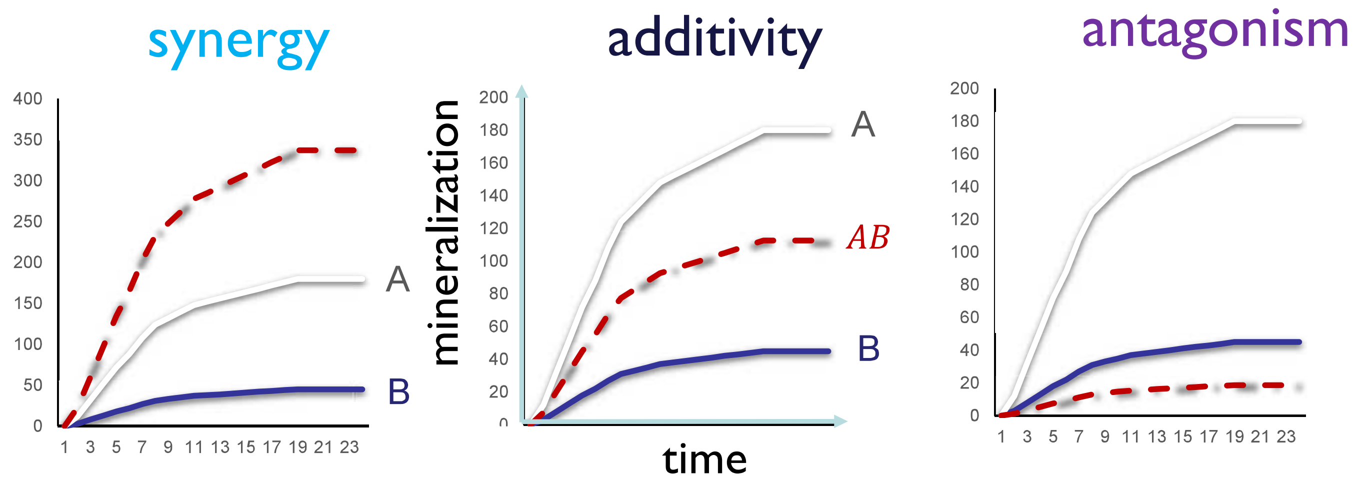
Pig manure (slurry)

DS + straw

PS + straw

From Kyulavski (2019) *phD*

And for mixtures? Interactions? e.g. manure + crop residues



$A+B > \overline{AB}$ | $A+B = \overline{AB}$ | $A+B < \overline{AB}$

Chantigny et al. 2001

Aita et al. 2012
Giacomini et al. 2015

From Kyulavski (2019) *phD*

Field trials: organic fertilizers on sugarcane cropping

Long-term experiment (2013) on a Nitisol (clay + fine silt > 70%; pH_{KCL} 4.9)

Sugarcane monocropping

6 treatments
5 replicates

Urea (control)
Pig liquid manure
Digested-limed-dried-pelleted sew. sludge
(Poultry manure or Greenwaste + sludge compost)
(Bare soil)
(Rotat. control)

Tropical climate (Réunion Island)

$\overline{T°}$ = 25 °C
P_{an} = 1650 mm

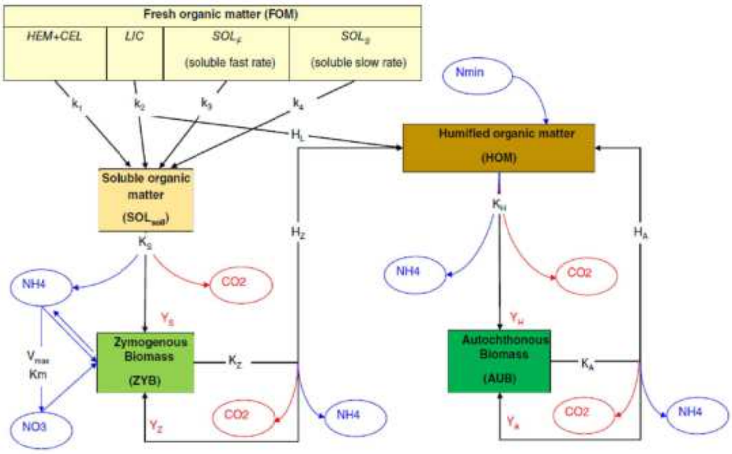
Limited number of treatments
Climatic events - dependent
Hum ressources & money

- ❑ Environmental risks (e.g. trace elements, GHG emissions, nitrate leaching) vs improvement of « soil health » (e.g. SOC & functions, biodiversity…)
  - ➢ SOC stocks?
  - ➢ Drivers of the SOC stocks and GHG emissions?

And for mixtures? Interactions? e.g. manure + crop residues

Lab incubations

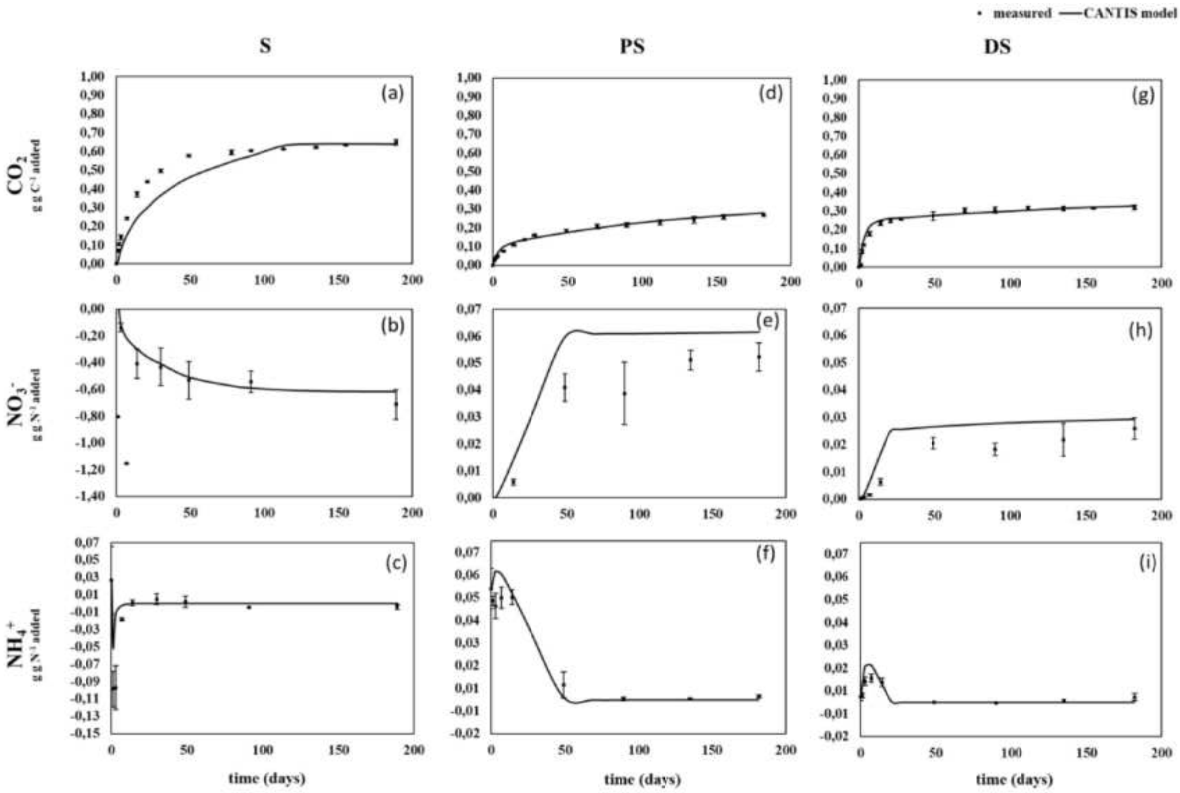
CANTIS model



Dried sludge (DS)
Pig slurry (PS)
Sugarcane straw (S)
DS+S
PS+S

From Garnier et al. (2001) *EJSS*; Kyulavski et al. (2019) *EJSS*

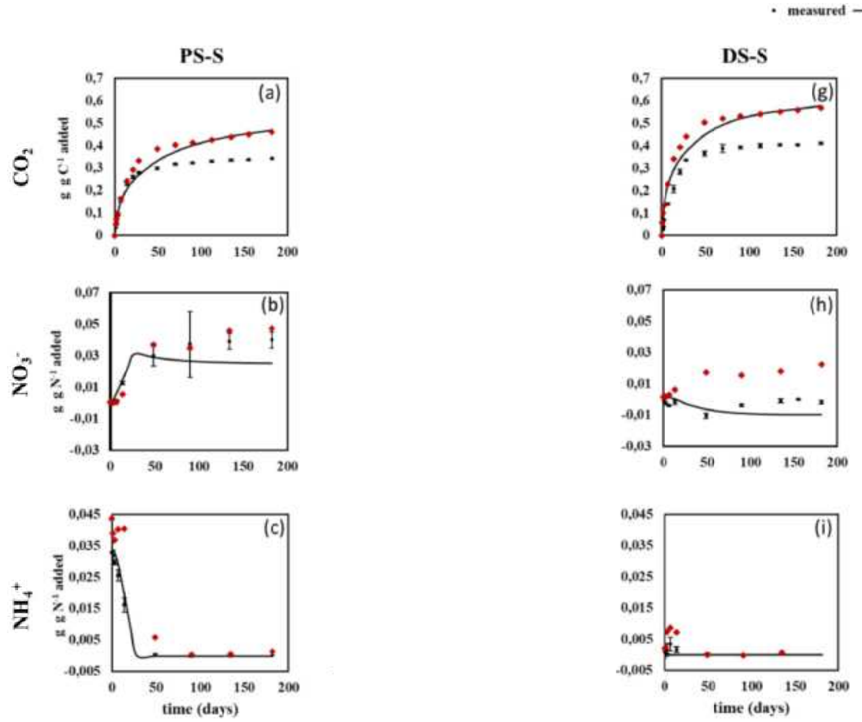
And for mixtures? Interactions? e.g. manure + crop residues



OK for each EOM (alone)

From Kyulavski et al. (2019) *EJSS*

And for mixtures? Interactions? e.g. manure + crop residues



additive
CANTIS

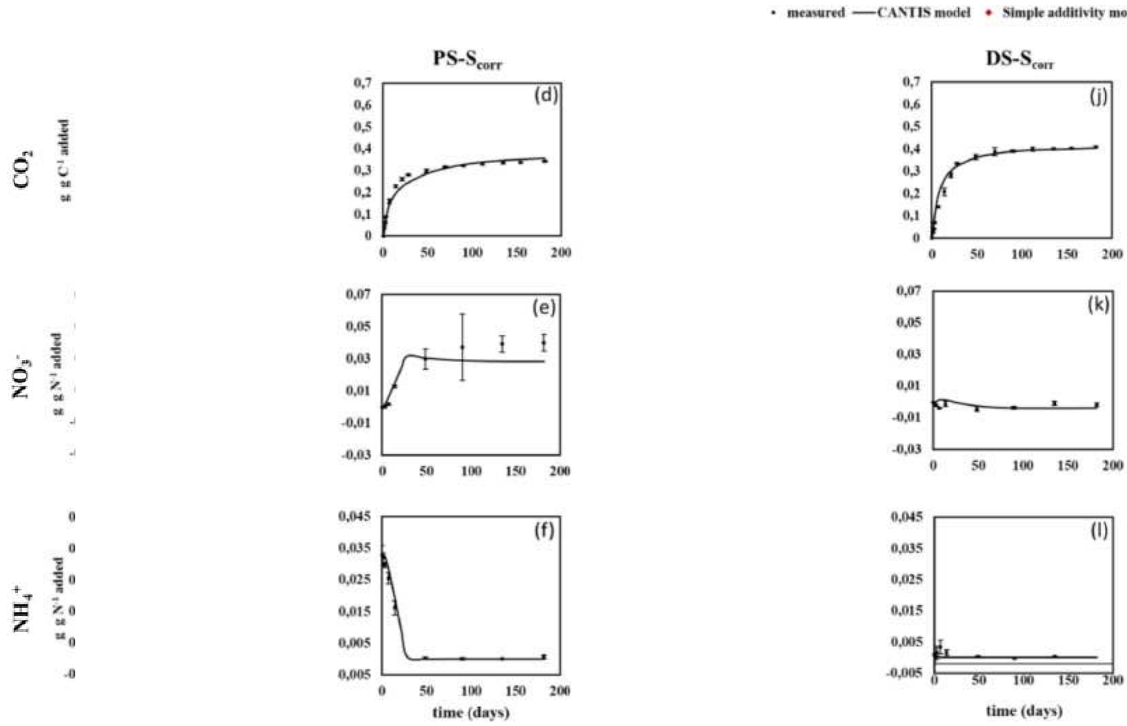
additive
CANTIS

additive ~
CANTIS

C and N net min° kinetics (PS-S; DS-S).
measurements = black circles.
predictions (additive model) = red diamonds.
predictions CANTIS =black lines.

From Kyulavski et al. (2019) *EJSS*

And for mixtures? Interactions? e.g. manure + crop residues



CANTIS KMZ

CANTIS KMZ

CANTIS KMZ

(PSScorr) and (DS-Scorr) = CANTIS simulation with modified contact factor KMZ

K_{MZ} = 0 : optimal accessibility for C & N by microbial biomass

K_{MZ} >> 0 : contact limitation bw microbial biomass and C, N, or both

From Kyulavski et al. (2019) *EJSS*

Gaps, limitations, perspectives

Analyses:
- type (spectrosc. e.g. NIR substitutes to ref analyses)
- nature (e.g. C:N, other easily accessible & affordable)

Field vs lab data (± standardized, e.g. AFNOR dried, 1mm, +KNO_3)
Moisture
Particle size
Loss of NH4/NH3 when EOM preparation for lab (drying)

Accessibility to decomposers
Physical state (liquid, paste, solid)
Specific surface

Sensitivity to gazeous losses
Physical state (liquid, paste, solid)
Specific surface

Microbial and other biological (fauna, nematodes…) drivers
…

Let's talk about (all of?) this!






Using manure?

Action/Choice = *f (fertilizer value X availability X cost X regulations …)*

- I use it at the same dose because it is available… and I've always done it this way
- I would like to use it but they say that manure is poor in nutrients
- I would like to use it but they say that lots of N is lost (I will loose money & time)
- I don't use it because I don't know its fertilizer value
- I don't use it because it is difficult to have it & spread, + regulations… and it stinks!

∑ = a wide range of potential ways for the improvement of manure utilization

Objectives (at ≠ levels):

- improve N recovery (& reduce losses)
- document the fertilizer value
- provide decision support systems or easy tools
- …
- improved comprehension of processes (drive adequate levers)

Decision tree

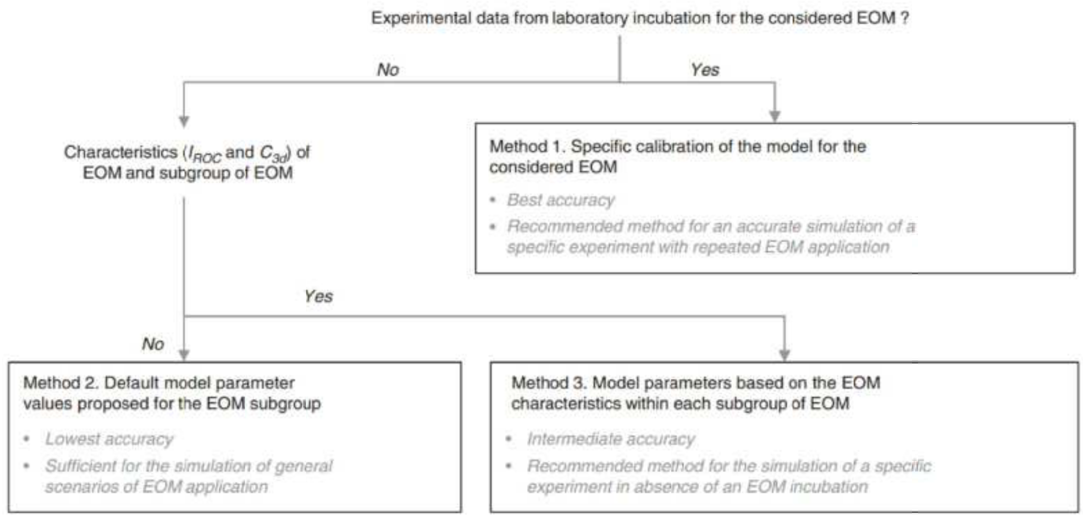


FIGURE 5 Conceptual diagram for the calibration of an EOM in the decomposition model

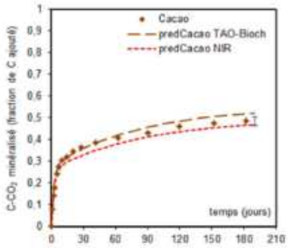
From Levavasseur et al. (2021) *Soil Use Man*

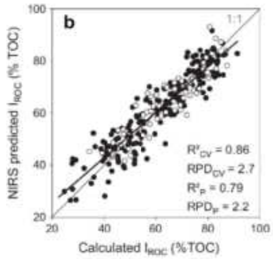
Supp material: Indicators & characterization techniques (e.g. NIRS)

Humification (K1) via field trials: several yrs several 10k€
- Alternative = lab incubations in controled conditions (ICC) several months 5-15k€

Alternatives to ICC: several days <1000€
- C & Nmin° predict° by C:N, Van Soest.. & model (e.g. TAO-Bioch; STICS…)
- Humus potential by I_{ROC}

Alternative to models and calculated indicators: couple of hours (minutes) <100€ (Investment excluded)
- C & Nmin° prediction by NIRS
- I_{ROC} prediction by NIRS
- Compartment size, constants by NIRS



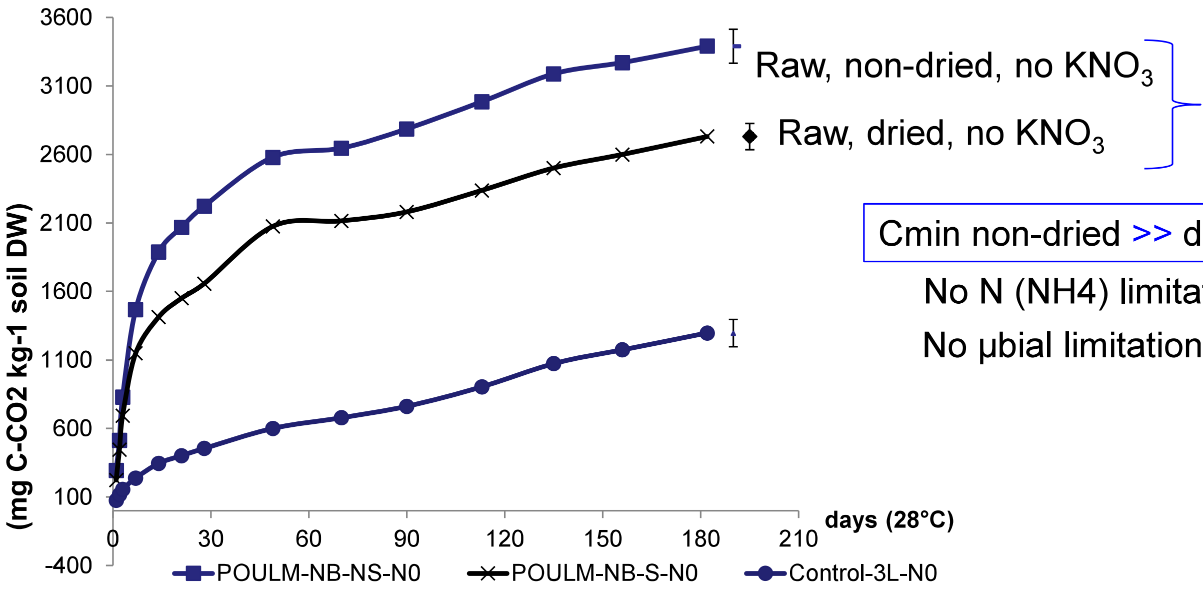


Thuriès et al. (2001) SBB; Thuriès et al. (2005) JNIRS; AFNOR (2009-2016); Lashermes et al (2009) SBB; Peltre et al. (2009) SBB

Supp material: PROLAB, lab vs field & lab standard vs lab ~field

AFNOR standard for lab incubations:
40°C dried EOM, 1mm particle size, +KNO_3 solution (non-limiting conditions)

3L cumul Cmin Poultry manure



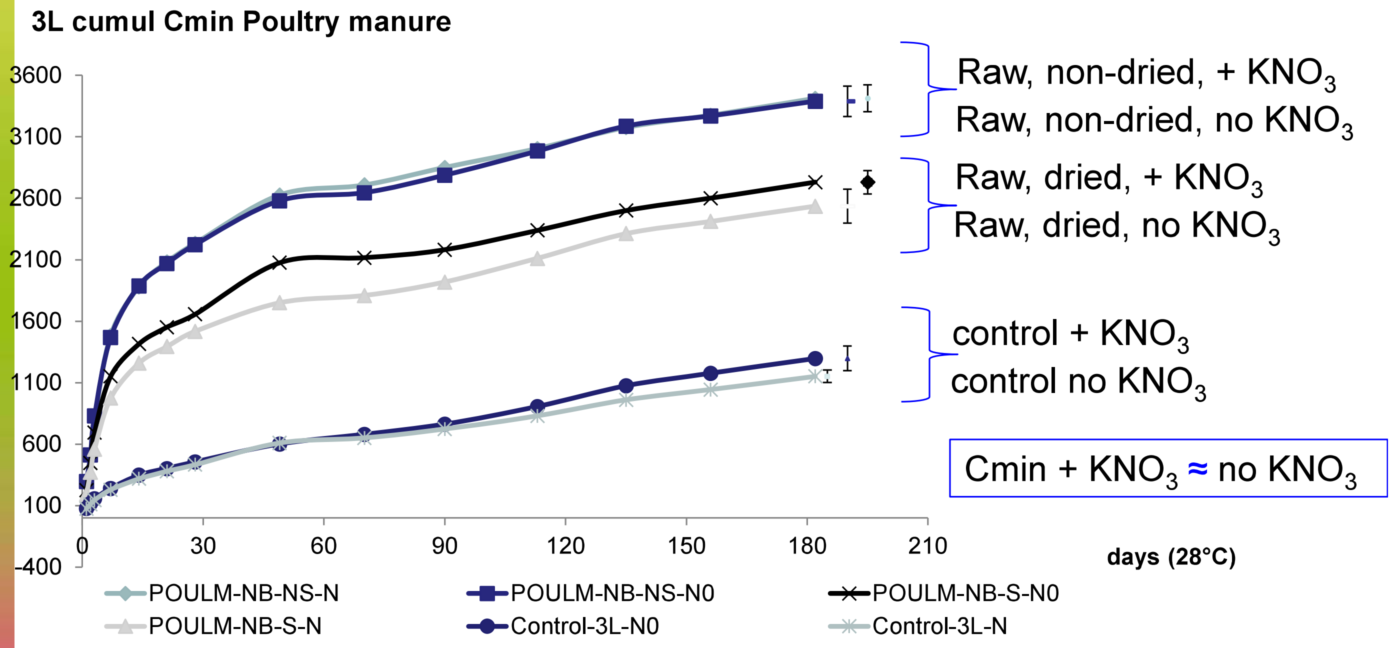
Cmin non-dried >> dried

No N (NH4) limitation?

No µbial limitation?

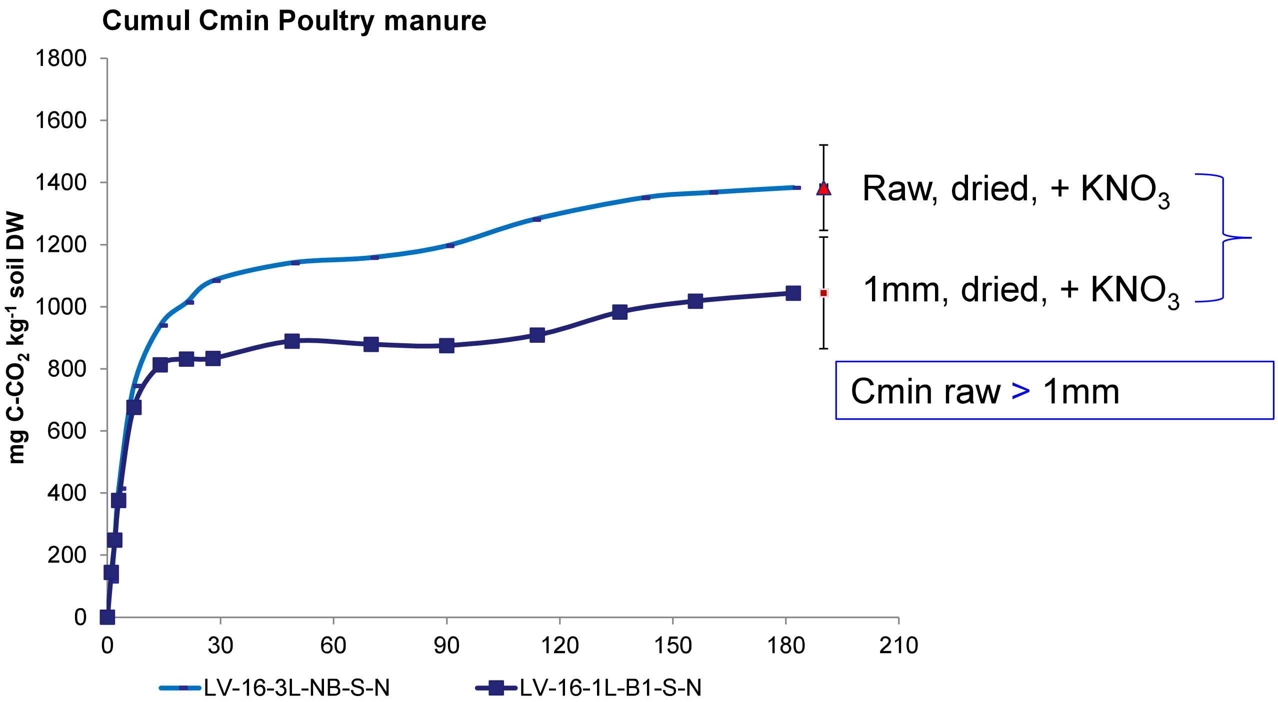
AFNOR FD U44-162 (2016); project ADEME PROLAB (unpublished results)

Supp material: PROLAB, lab vs field & lab standard vs lab ~field



AFNOR FD U44-162 (2016); project ADEME PROLAB (unpublished results)

Supp material: PROLAB, lab vs field & lab standard vs lab ~field



AFNOR FD U44-162 (2016); project ADEME PROLAB (unpublished results)

Workshop 3.B
N recovery vs. site conditions: opportunities and challenges of combining studies from different locations

Influence of external factors on manure N recovery

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Commitment

Factors that influence N recovery from manures

External factors (3.B)

- Soil → texture, pH, SOM; water content…
- Climate → T, rainfall, ET…

Internal factors (3.A)

- C/N, type of C compounds…

Management factors (1,2)

- Crop, season, incorporation depth, frequency of distributions, amount…

N recovery

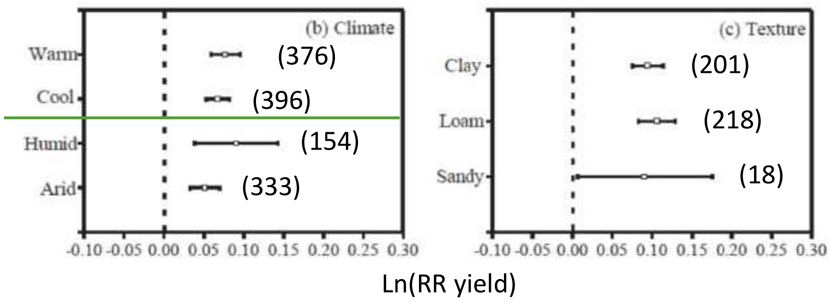
Which indicator?

Recent meta-analyses or reviews

- Du, Y., Cui, B., Zhang, Q., Wang, Z., Sun, J., Niu, W., 2020. Effects of manure fertilizer on crop yield and soil properties in China: A meta-analysis. CATENA 193, 104617. doi:10.1016/j.catena.2020.104617
- Li, B., Song, H., Cao, W., Wang, Y., Chen, J., Guo, J., 2021. Responses of soil organic carbon stock to animal manure application: A new global synthesis integrating the impacts of agricultural managements and environmental conditions. Global Change Biology 27, 5356–5367. doi:10.1111/gcb.15731
- Maillard, É., Angers, D.A., 2014. Animal manure application and soil organic carbon stocks: a meta-analysis. Global Change Biology 20, 666–679. doi:10.1111/gcb.12438
- O'Brien, P.L., Hatfield, J.L., 2019. Dairy Manure and Synthetic Fertilizer: A Meta-Analysis of Crop Production and Environmental Quality. Agrosystems, Geosciences & Environment 2. doi:10.2134/age2019.04.0027
- Wei, L., Chen, S., Cui, J., Ping, H., Yuan, C., Chen, Q., 2022. A meta-analysis of arable soil phosphorus pools response to manure application as influenced by manure types, soil properties, and climate. Journal of Environmental Management 313, 115006. doi:10.1016/j.jenvman.2022.115006
- Zavattaro L., Bechini L*. Grignani C., van Evert F.K., Mallast J., Spiegel H., Sandén T., Pecio A., Giráldez Cervera J.V., Guzmán G., Vanderlinden K., D'Hose T., Ruysschaert G., ten Berge H.F.M., 2017. Agronomic effects of bovine manure: A review of long-term European field experiments. European Journal of Agronomy 90: 127-138. doi:10.1016/j.eja.2017.07.010

Climate and texture → yield

Du et al., 2020



(n comparisons)

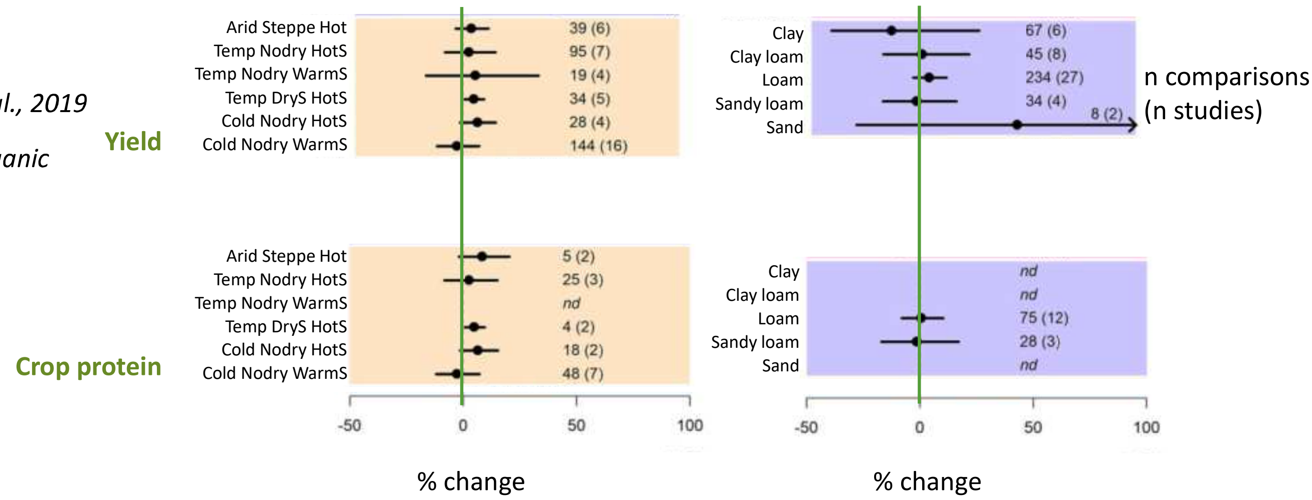
		n	Change (%)	95% CI
Climate types	Warm	376	**7.0**	1.6
	Cool	396	**8.0**	2.0
Arid index	Humid	154	**9.5**	5.9
	Arid	333	**5.3**	2.0

		n	Change (%)	95% CI
Soil texture	Clay	201	**9.9**	2.1
	Loam	218	**11.2**	2.6
	Sandy	18	**9.5**	9.7

Climate and texture → yield and N in yield

O'Brien et al., 2019

"equal inorganic N rate"



Climate and texture → SOC, TN

Du et al., 2020

SOC

		n	Change (%)	95% CI
Climate types	Warm	186	**14.2**	2.2
	Cool	206	**20.8**	2.6
Arid index	Humid	97	**19.3**	3.8
	Arid	173	**15.1**	1.8

		n	Change (%)	95% CI
Soil texture	Clay	105	**14.1**	2.9
	Loam	97	**22.5**	4.2
	Sandy	10	**15.5**	17.9

TN

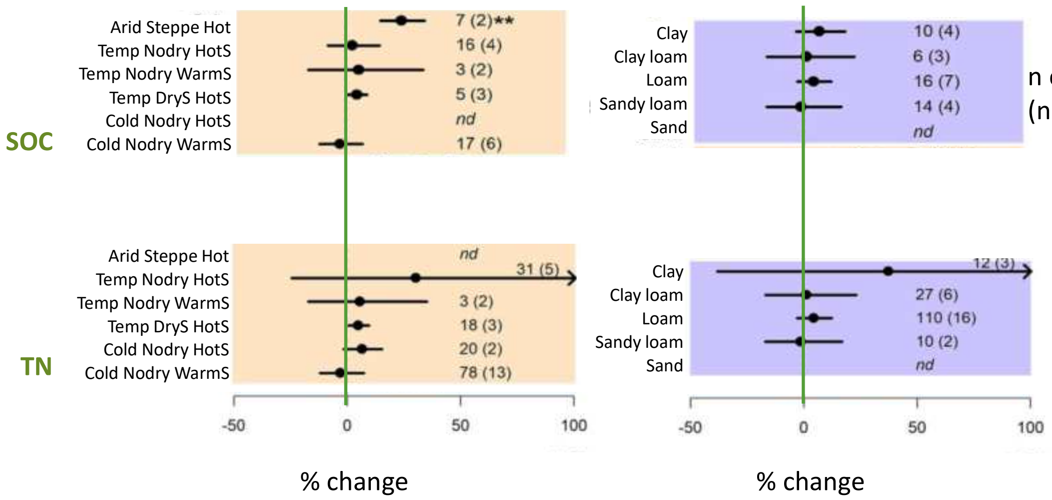
		n	Change (%)	95% CI
Climate types	Warm	165	**11.6**	2.4
	Cool	152	**19.7**	4.4
Arid index	Humid	78	**22.1**	6.1
	Arid	141	**13.5**	2.7

		n	Change (%)	95% CI
Soil texture	Clay	98	**10.8**	3.5
	Loam	60	**16.3**	5.4
	Sandy	10	**17.9**	13.6

Climate and texture → SOC, TN

O'Brien et al., 2019

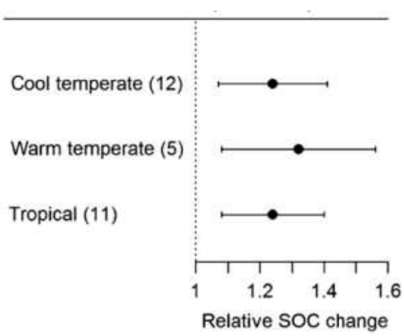
"equal inorganic N rate"



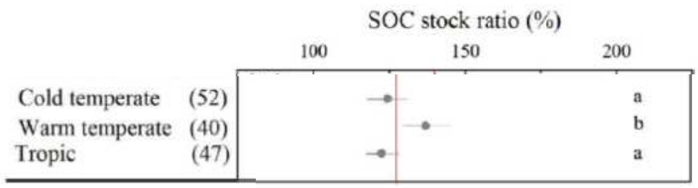
n comparisons
(n studies)

Climate → SOC

Maillard & Angers, 2013



Li et al., 2021



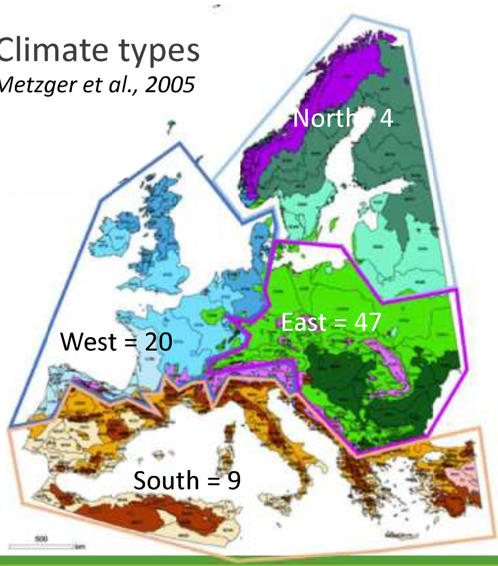
A review on EU data

Zavattaro et al., 2017

80 Long-Term Experiments in EU
Comparing manure and mineral at a similar N rate

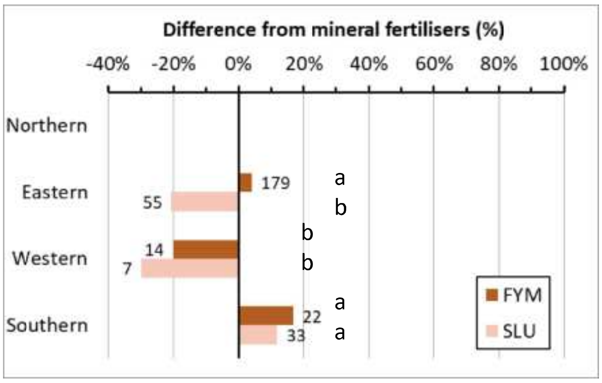
Soil texture

Climate types
Metzger et al., 2005



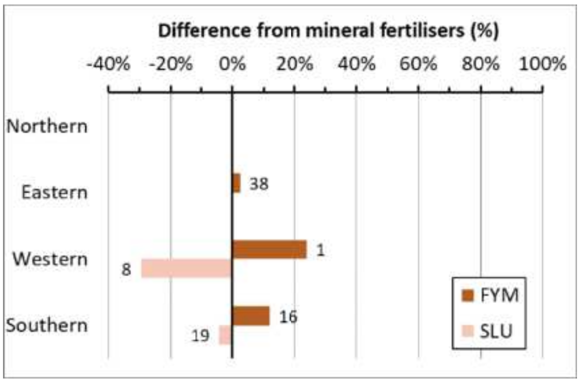
Climate → yield and N in yield

Yield



p=0.001 FYM
p=0.000 SLU

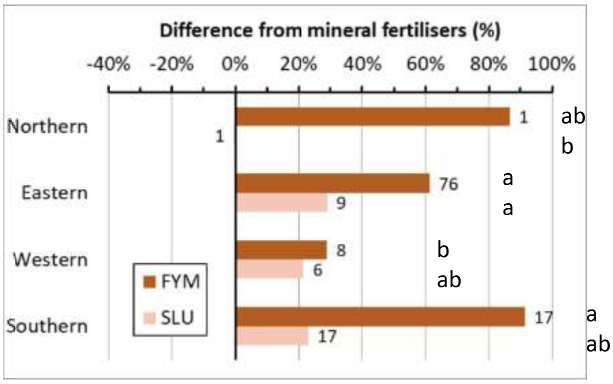
N in yield



p=0.373 FYM

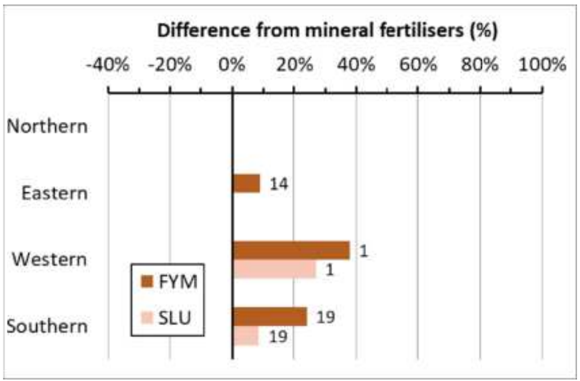
Climate → SOC, TN

SOC



p=0.006 FYM
p=0.012 SLU

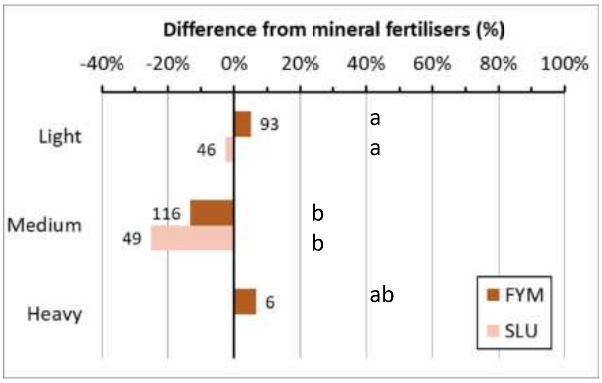
TN



p=0.380 FYM

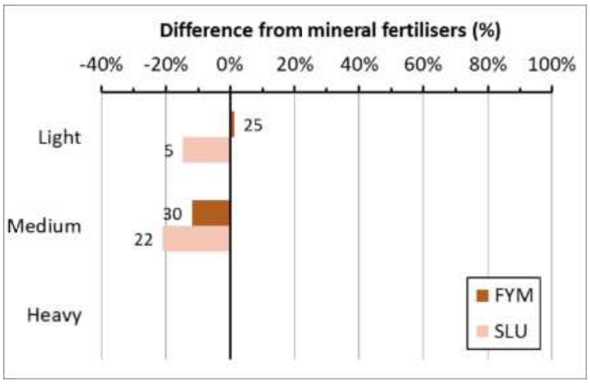
Soil texture → yield and N in yield

Yield



p=0.000 FYM
p=0.000 SLU

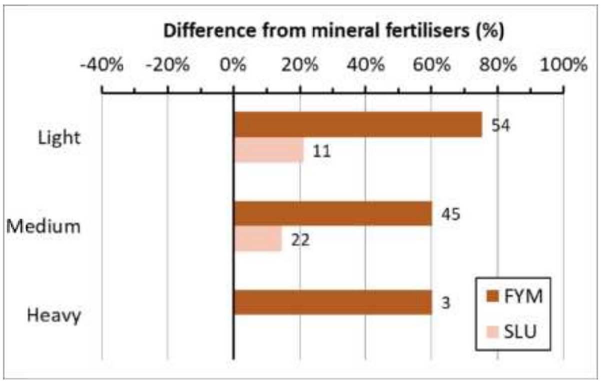
N in yield



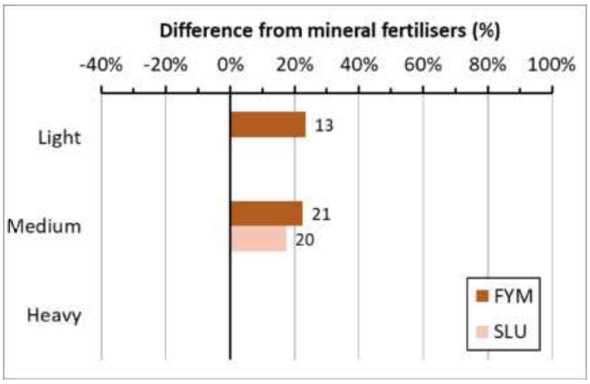
p=0.168 FYM

Soil texture → SOC, TN

SOC



TN



p=0.032 FYM
p=0.599 SLU

Climate, texture → efficiency indicators

FYM

Factor	Level	Yield/Nfert			Nyield/Nfert			N appar recov		
		mean		n	mean		n	mean		n
Climate	*p*	*0.149*	*ns*	*212*	*0.001*	*++*	*55*	*.*	*+*	*33*
	North			-			-			-
	East	-3%		175	-22%	b	38	-76%	b	18
	West	-10%		14	+17%	ab	1			-
	South	+10%		23	+15%	a	16	+174%	a	15
Soil texture	*p*	*0.987*	*ns*	*212*	*0.000*	*++*	*55*	*.*	*+*	*33*
	Light	-2%		92	+33%	a	25	+62%	a	17
	Medium	-2%		114	-23%	b	30	-60%	b	16
	Heavy	0%		6			-			-

SLU

Factor	Level	Yield/Nfert			Nyield/Nfert			N appar recov		
		mean		n	mean		n	mean		n
Climate	*p*	*0.001*	*++*	*88*	*.*	*ns*	*27*	*.*		*20*
	North			-			-			-
	East	-34%	b	47			-			-
	West	-31%	b	7	-9%		8	1.154		3
	South	+14%	a	34	-26%		19	0.672		17
Soil texture	*p*	*0.000*	*++*	*88*	*.*	*ns*	*27*	*.*		*20*
	Light	+7%	a	45	-14%		5	-12%		3
	Medium	-39%	b	43	-22%		22	-12%		17
	Heavy			-			-			-

Open questions

Factors: Classes or continuous variables?

Texture: sand / clay?

Climate: mean annual T, mean annual R?

Factors: Are we testing the right factors?

Soil pH, initial SOM, C/N

Measurable ≠ relevant (e.g. soil particles vs pores)

N recovery indicators: Which system boundaries?

recovery = plant + soil

modern NMPs should include SOC

Thanks for your attention!

Predicting manure N availability

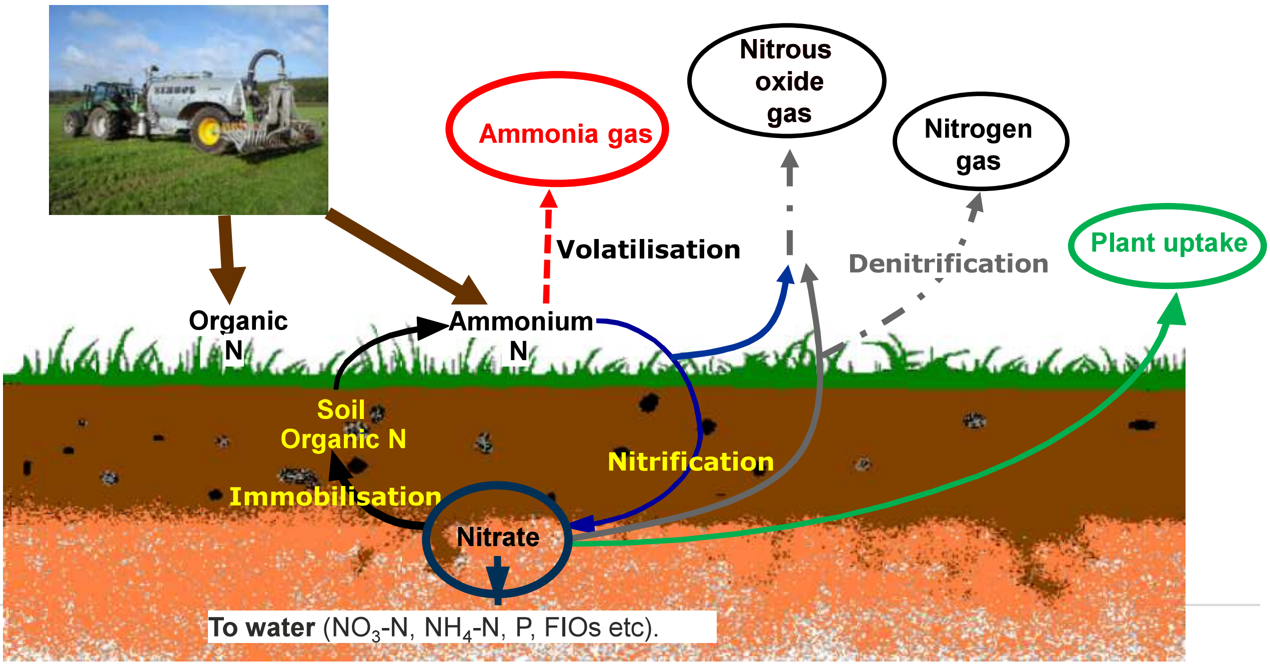
Anne Bhogal

Expert workshop; Agroscope, Zurich

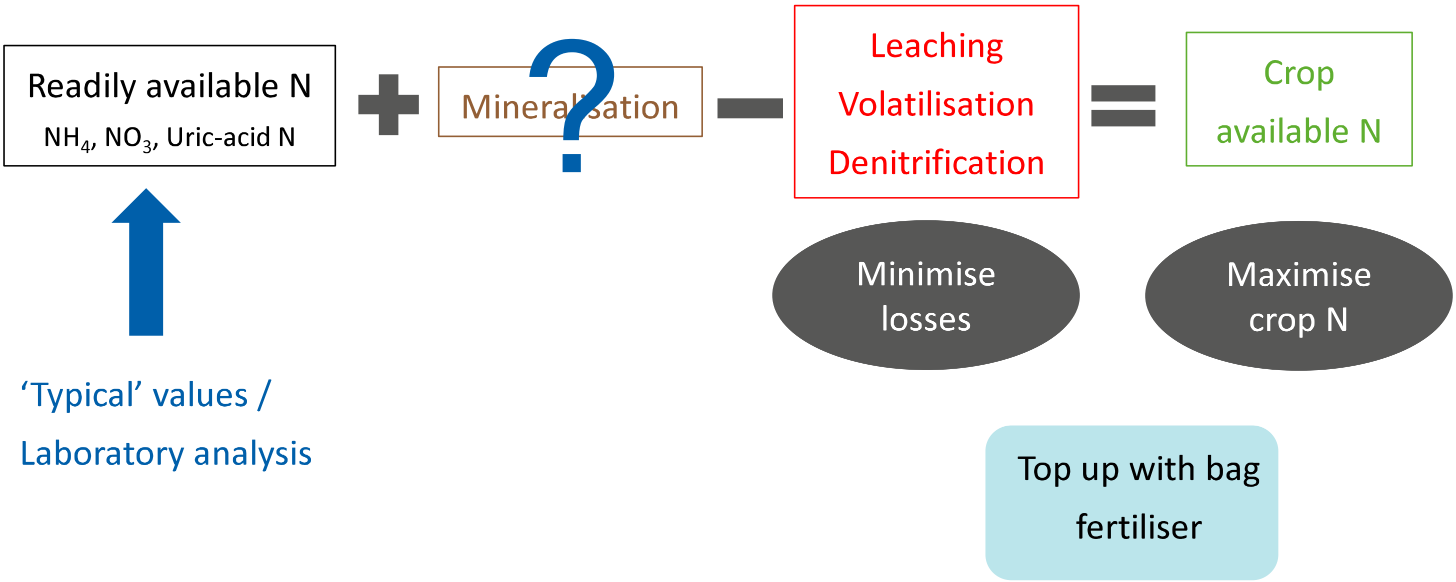
May 2022

www.adas.uk

Quantifying crop available nutrient supply from manures is 'challenging' !



Estimating crop available nitrogen



What is the contribution from mineralization of manure organic N?

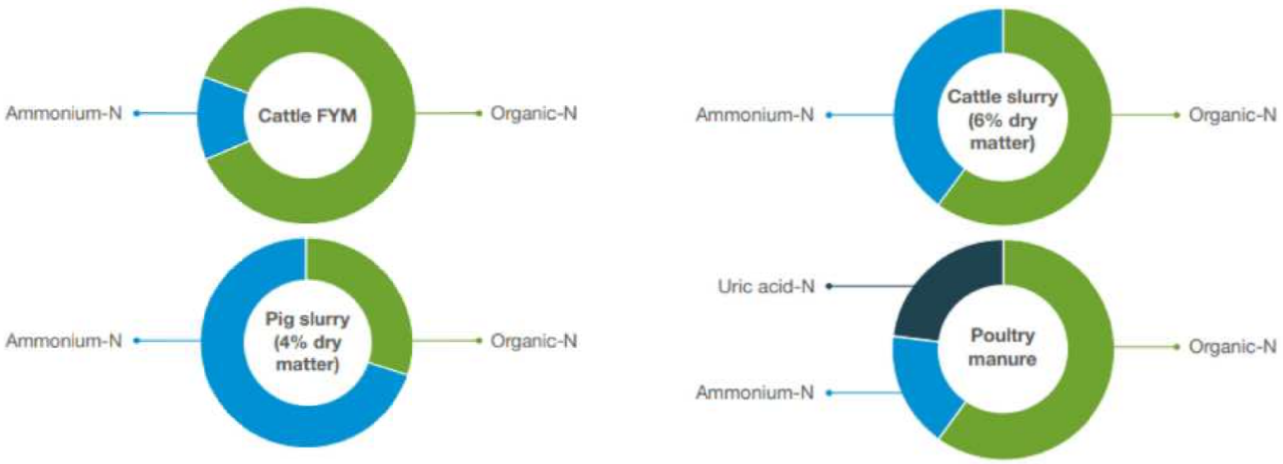
Key questions:

- How much and when?
- Timescale?
- What about repeat additions/cumulative effects?

Key factors:

- Manure type
- Soil type
- Climate (temperature/moisture)

Manure N forms



Contribution of mineralized organic N will vary with manure type:

- Dry matter and total organic N content
- 'quality' of the organic N e.g. C:N ratio

Soil Use and Management

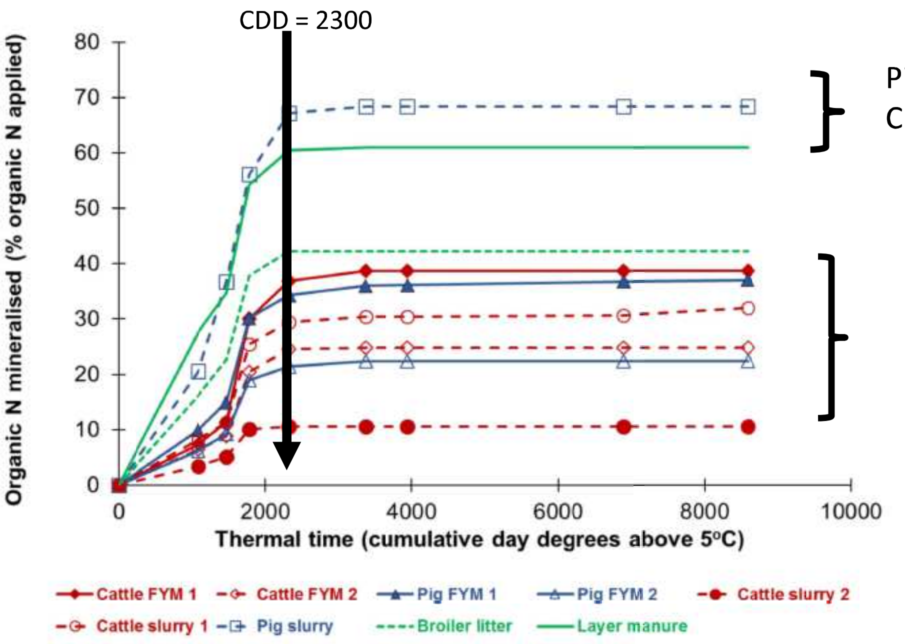
Soil Use and Management, June 2016, **32** (Suppl. 1), 32–43 doi: 10.1111/sum.12263

Mineralization of organic nitrogen from farm manure applications

A. Bhogal[1], J. R. Williams[2], F. A. Nicholson[1], D. R. Chadwick[3], K. H. Chambers[4] & B. J. Chambers[†]
[1]*ADAS Gleadthorpe Meden Vale, Mansfield, Nottinghamshire, NG20 9PD, UK,* [2]*ADAS Boxworth, Cambridge, CB23 4NN, UK,*
[3]*School of Environment, Natural Resources and Geography, Bangor University, Dieniol Road, Bangor, LL57 2UW, UK, and*
[4]*School of Agriculture, Food and Rural Development, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK*

- Fate of organic N (uptake/leached) in 9 'ammonium-N stripped' manures tracked for 5 years at 2 sites (sandy loam soils), high/low rainfall regions in England

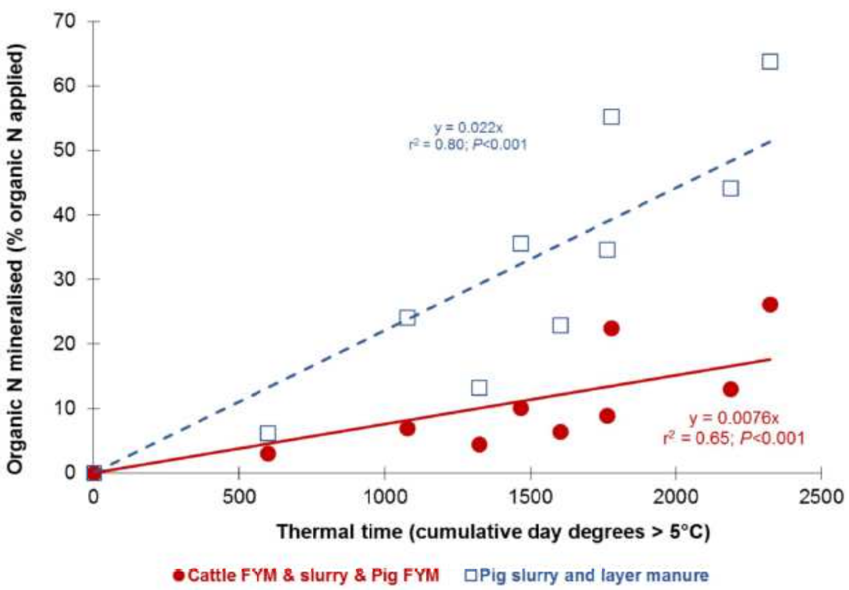
Manure organic N mineralisation vs. thermal time (North Wyke)



Pig slurry & Layer manure
C:organic N ~10

FYMs & cattle slurry
C:organic N ~14

Relationship between manure organic N mineralisation and thermal time



Pig Slurry, Layer manure:

% Organic N mineralised =

(**0.022***2300)+ [(CDD -2300) ***0.001**]

➢ *Up to 70% of the organic N mineralised*

Cattle & pig FYM, Cattle Slurry:

% Organic N mineralised =

(**0.0076***2300)+ [(CDD -2300) ***0.004**]

➢ *10-30% of the organic N mineralised*

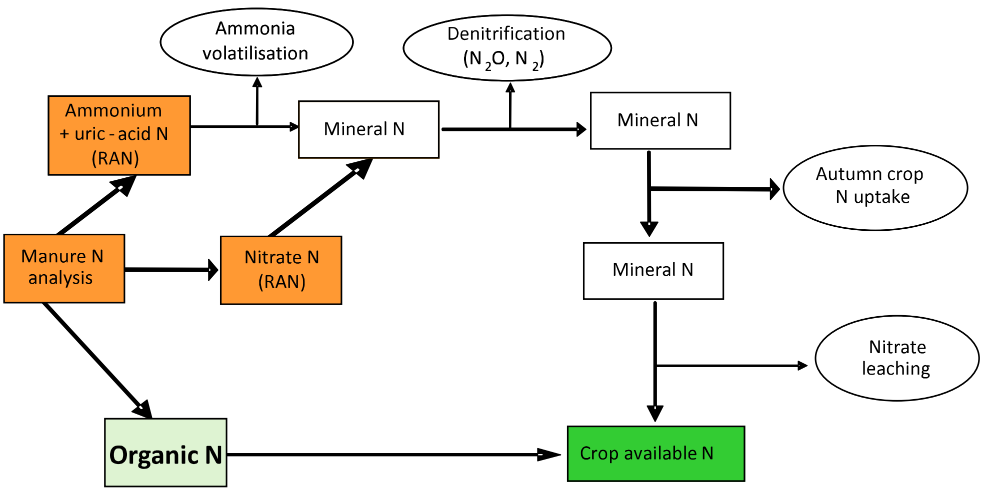
Estimates crop available nutrient supply based on:

- nutrient & dry matter content
- Application method & timing
- Incorporation method & timing
- Rainfall (UK postcodes)

Soil type (volumetric moisture content)

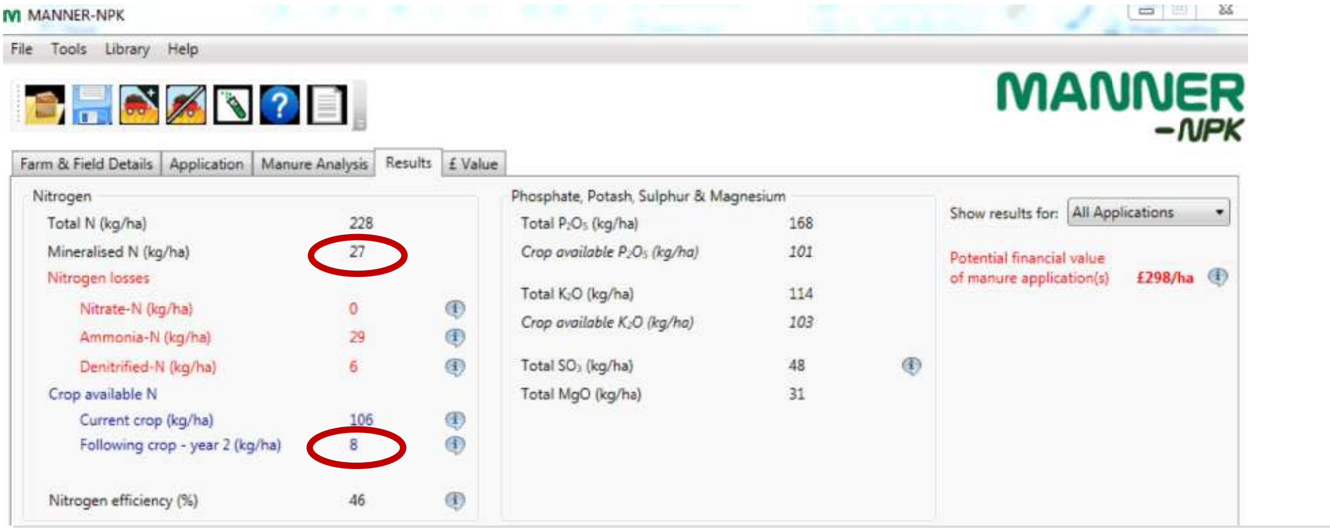
Nicholson et al. (2013) Soil Use and Management 29, 473-484

MANNER-*NPK*



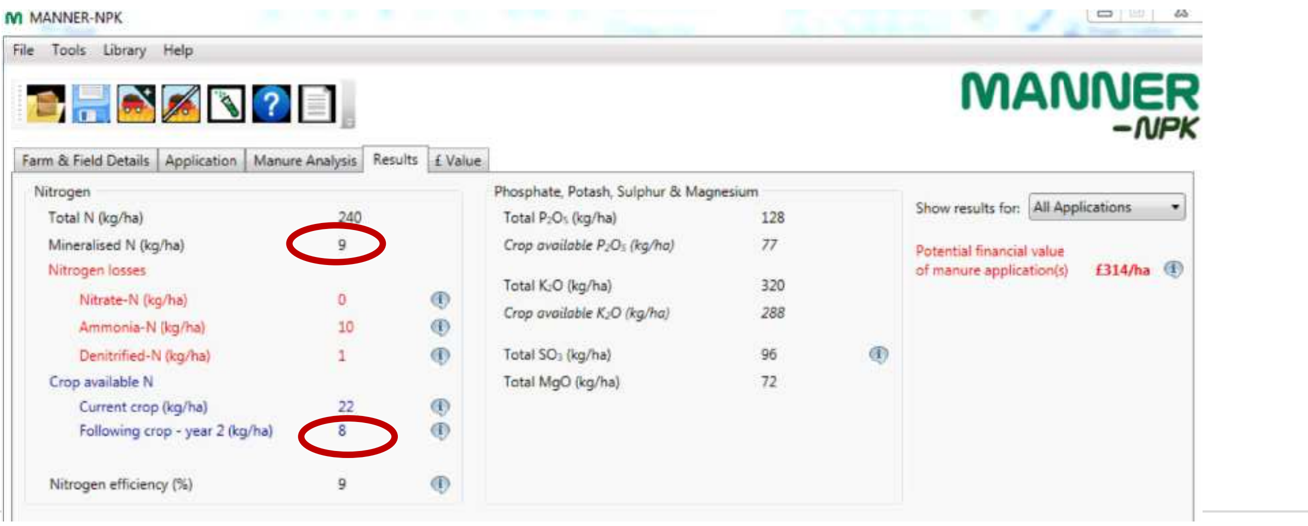
Typical output – layer manure

12 t/ha Layer manure; Applied in March prior to a spring cereal



Typical output – Cattle FYM

40 t/ha Cattle manure, applied in March prior to a spring cereal



Conclusions & key questions for workshop

- Mineralisation of organic N from manures can contribute significant amounts of N, both in the year of application and subsequent seasons
- This varies with manure type and is related to thermal time

Key questions:

- How does this vary with soil type?
- How long should you account for manure N mineralisation
- What about repeat applications/cumulative effects?
- Are there any other / better models that we should be looking at?

Implementation of manure N use efficiency for farmers

Daniele Cavalli

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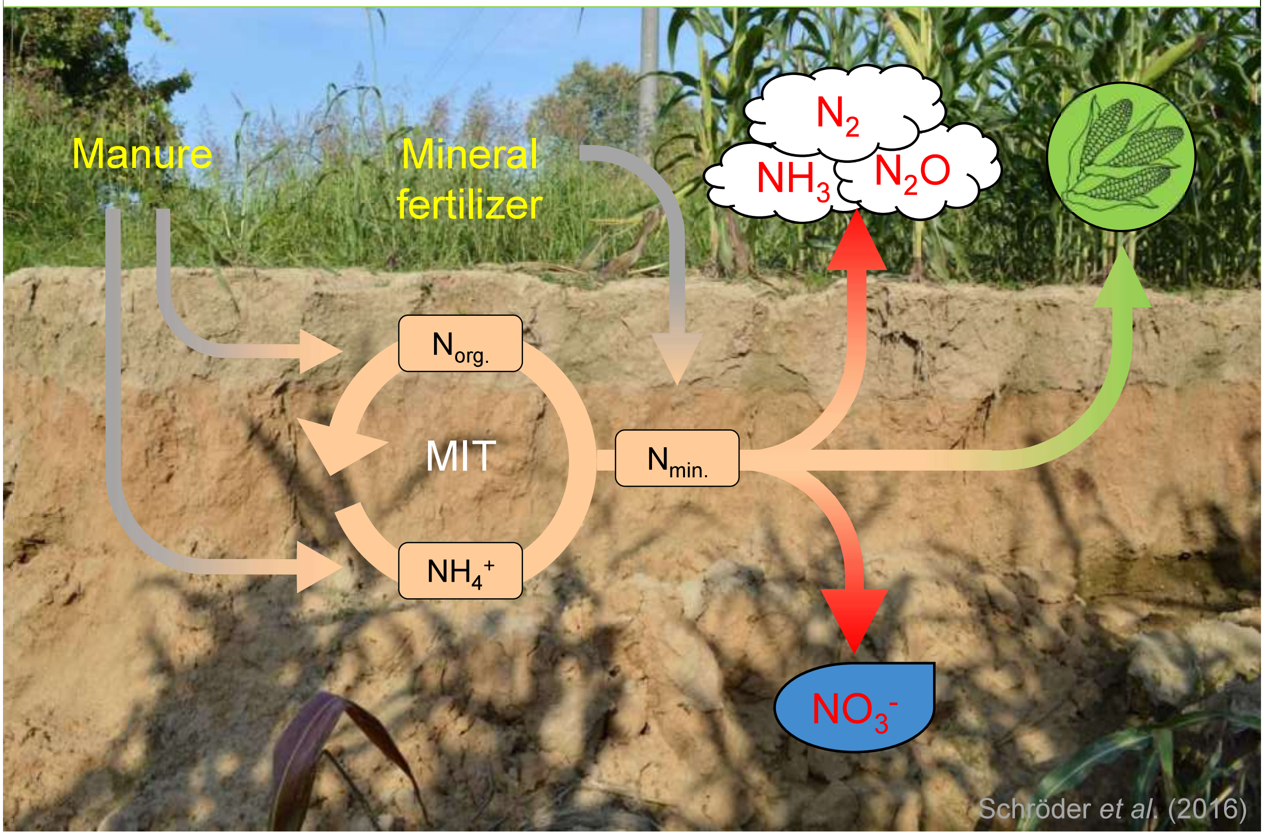
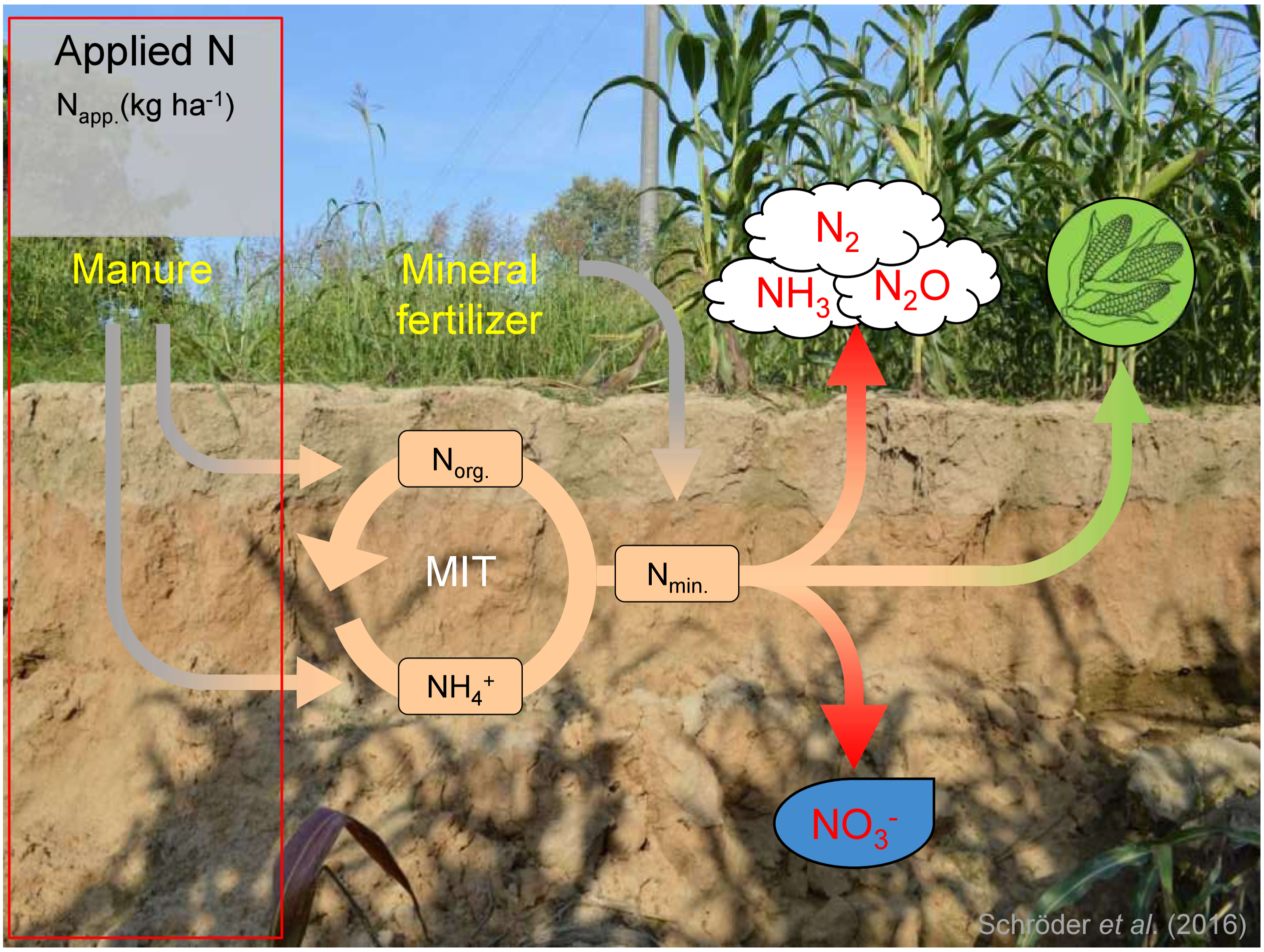
Council for Agricultural Research and Economics – Animal Production and Aquaculture (CREA-ZA)

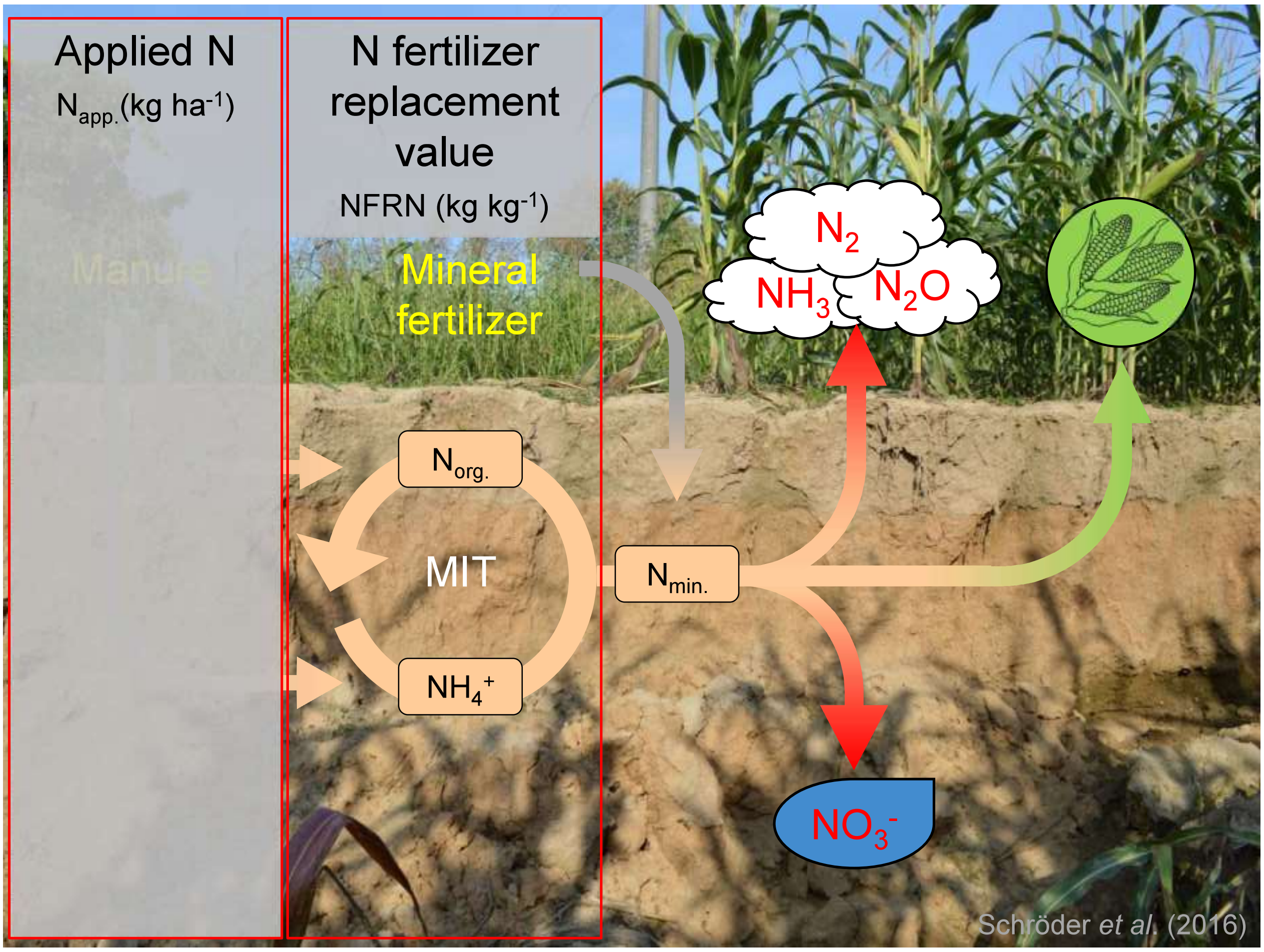
Agroscope, Zurich, Switzerland

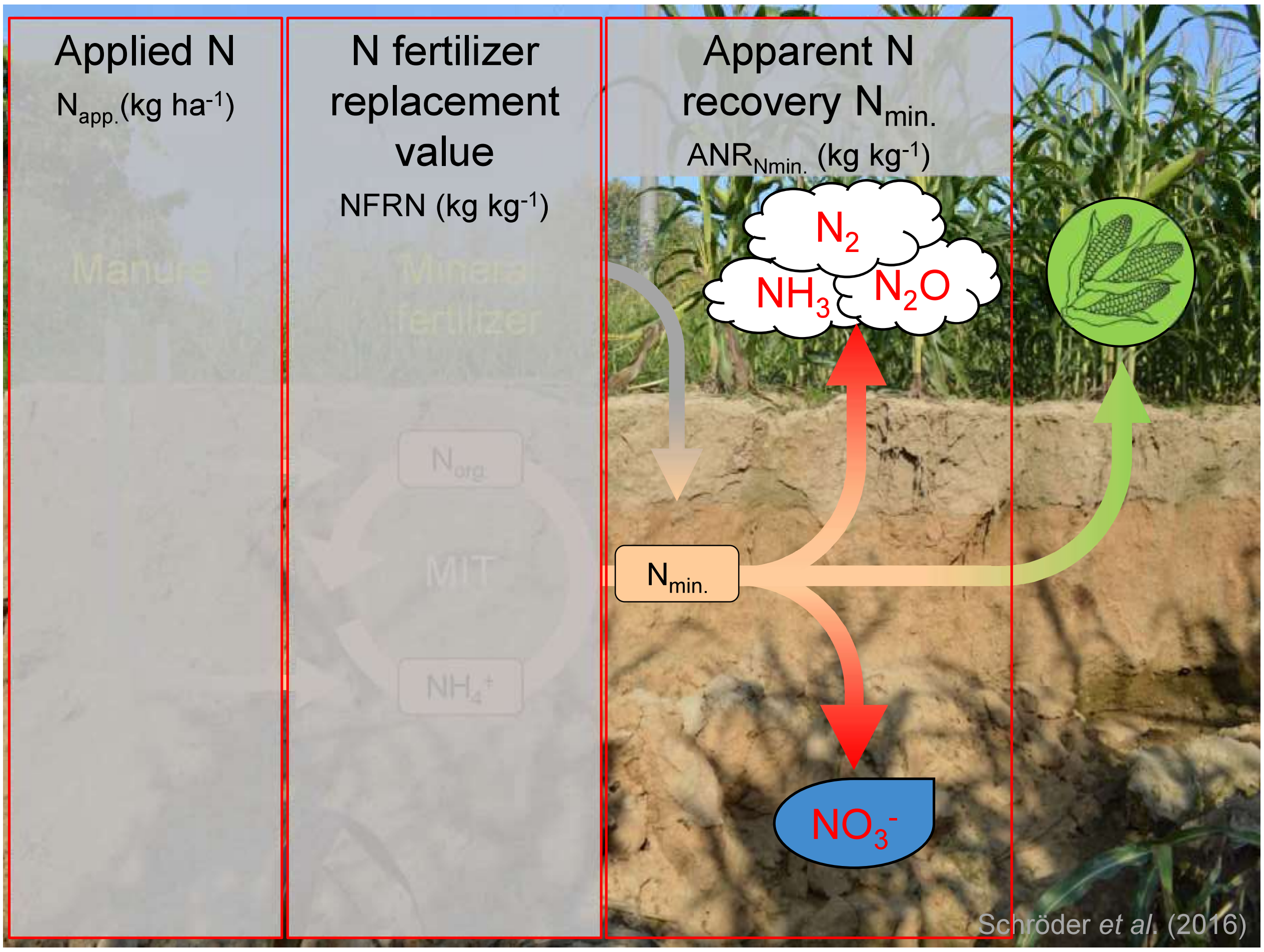
04-06 March 2022

Manure N use efficiency



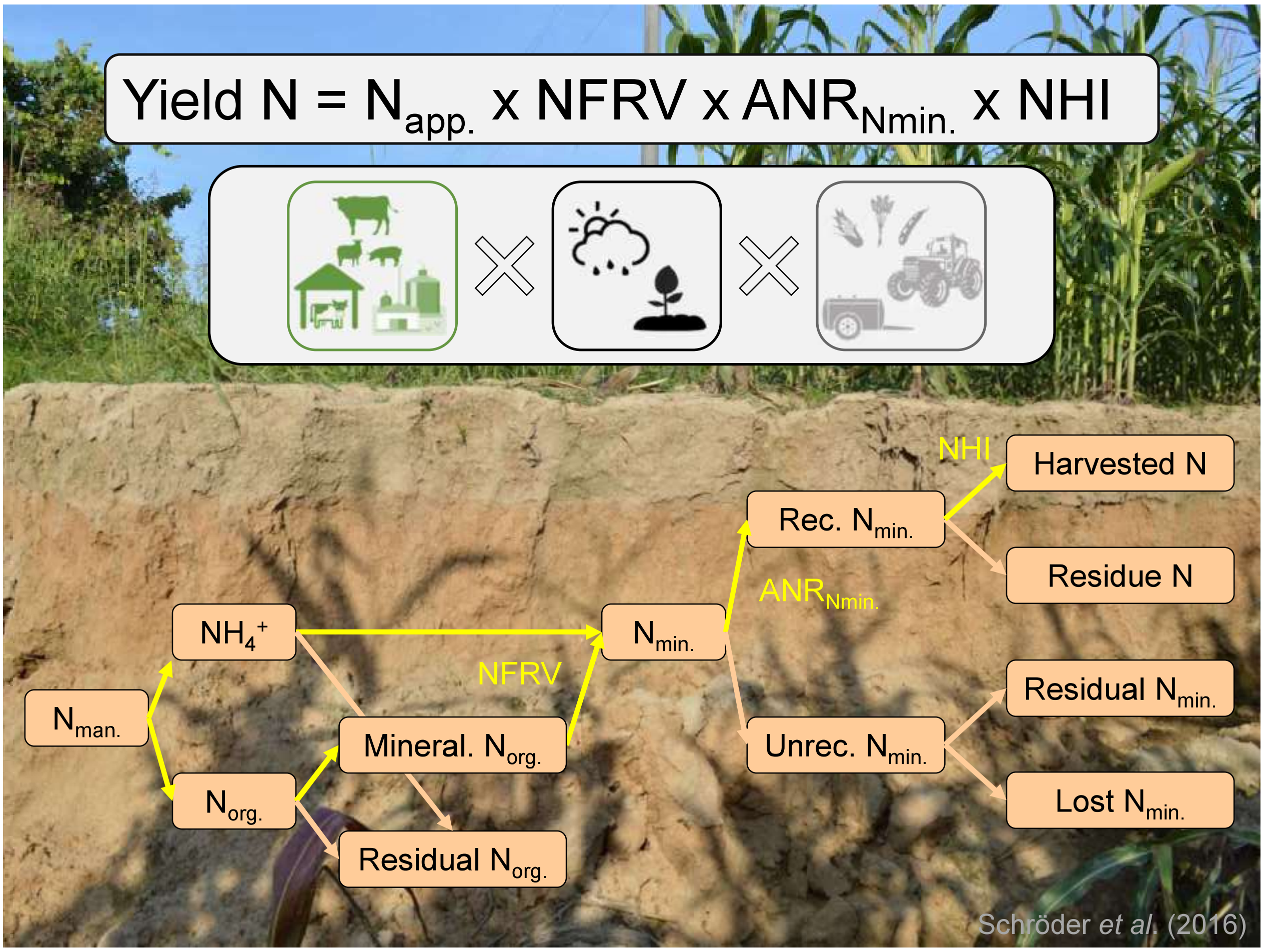

Applied N
N app. (kg ha-1)
Manure
Mineral fertilizer
N org.
MIT
NH4+
N min.
N2
NH3
N2O
NO3-
Schröder et al. (2016)


Applied N
N app. (kg ha-1)
N fertilizer replacement value
NFRN (kg kg-1)
Manure
Mineral fertilizer
N org.
MIT
NH4+
N min.
N2
NH3
N2O
NO3-
Schröder et al. (2016)



Applied N
N app. (kg ha-1)
N fertilizer replacement value
NFRN (kg kg-1)
Apparent N recovery N min.
ANR Nmin. (kg kg-1)
N2
NH3
N2O
N min.
NO3-
Schröder et al. (2016)

Applied N
N app. (kg ha-1)
N fertilizer replacement value
NFRN (kg kg-1)
Apparent N recovery N min.
ANR Nmin. (kg kg-1)
N harvest index
NHI (kg kg-1)
hröder et al. (2016)



Factors affecting NUE

- Animal: species/age/diet
- Husbandry system: litter/storage
- Treatments: storage/digestion/separation/etc...
- Soil: chemical, physical and biological properties
- Climate/yearly weather
- Application: method/time/amount
- Crop: species (variety/hybrid)/crop cycle/plant density
- Cultivation: tillage/irrigation/weed and pest control/harvest

Experimental determination of NUE

Nitrogen use efficiency:

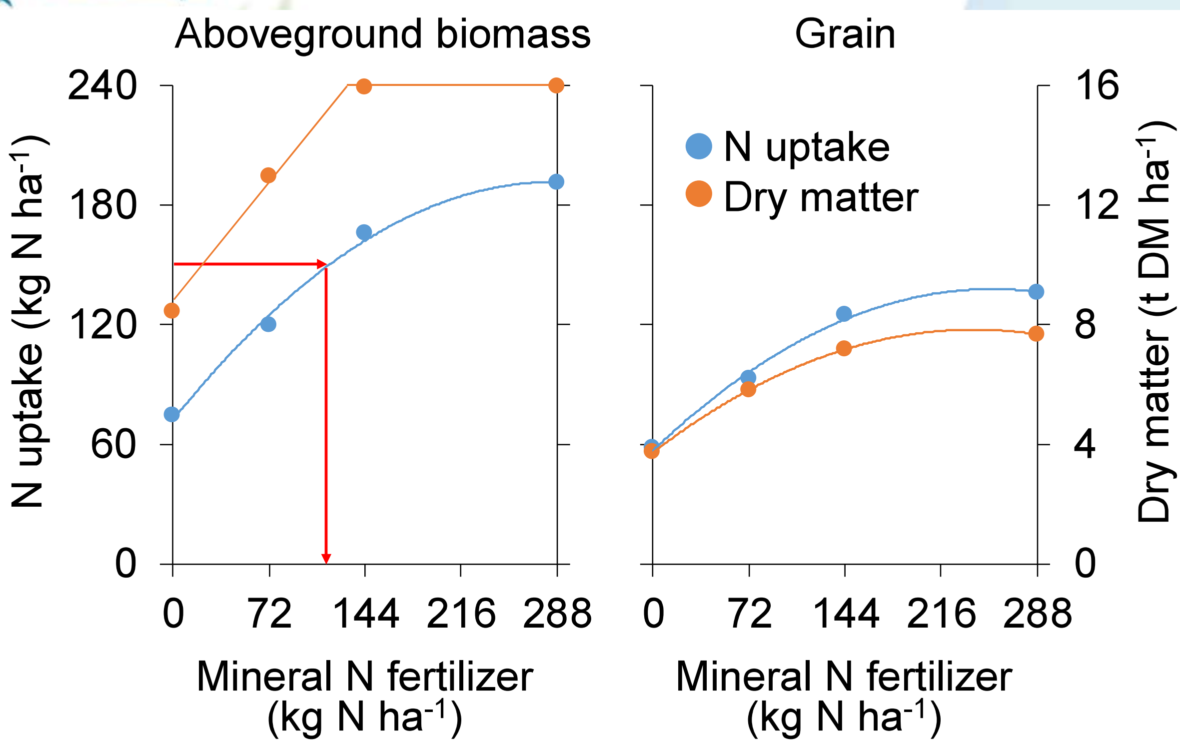
- $ANR\,(\%) = 100 \times \dfrac{N_{uptake\_treatment} - N_{uptake\_control}}{N_{applied}}$
- $\text{Recovery}^{15}N(\%) = 100 \times \dfrac{N_{uptake\_treat}}{N_{applied}} \times \dfrac{AT\%exc.^{15}N_{uptake\_treat}}{AT\%exc.^{15}N_{applied}}$

Nitrogen fertilizer replacement value:

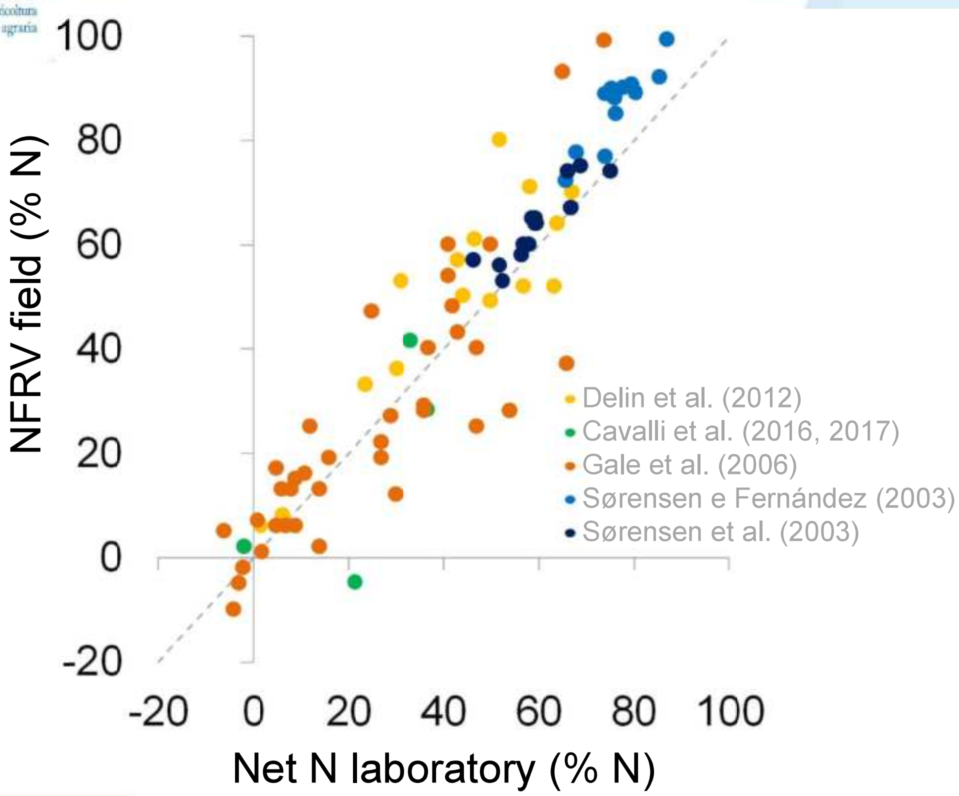
- $NFRV\;(\%) = 100 \times ANR_{manure} \,/\, ANR_{chemical\_fertilizer}$
- $NFRV\;(\%) = Chem\_fertlizer\_N\_replaced \,/\, N_{manure}$
- $NFRV\;(\%) = f\,(netN_{\min\_from\_incubation})$

Muñoz *et al.* (2004); Cusick *et al.* (2006)

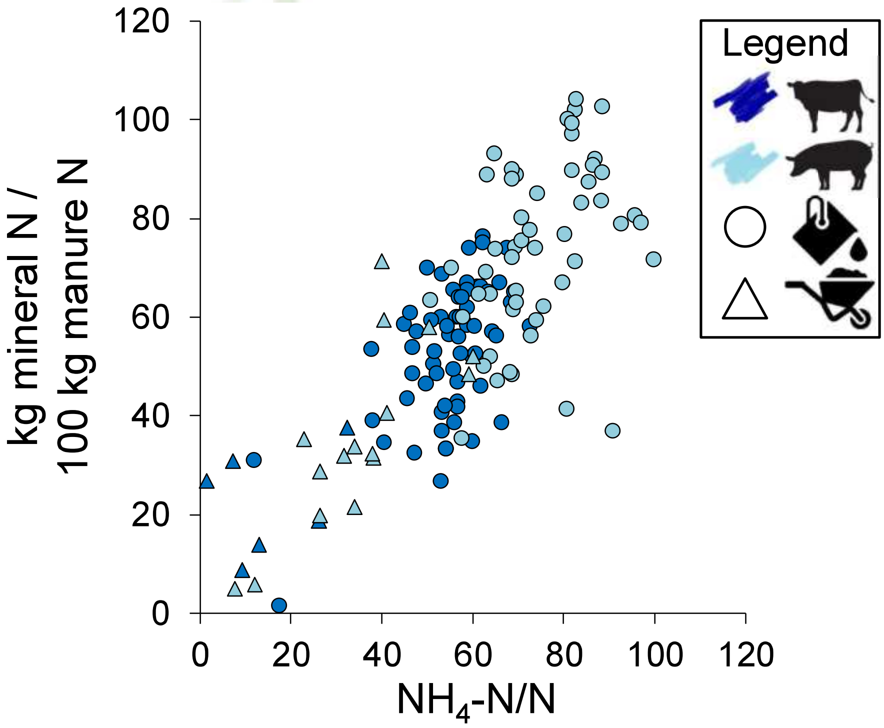
NFRV from a response curve



NFRV from incubation experiments

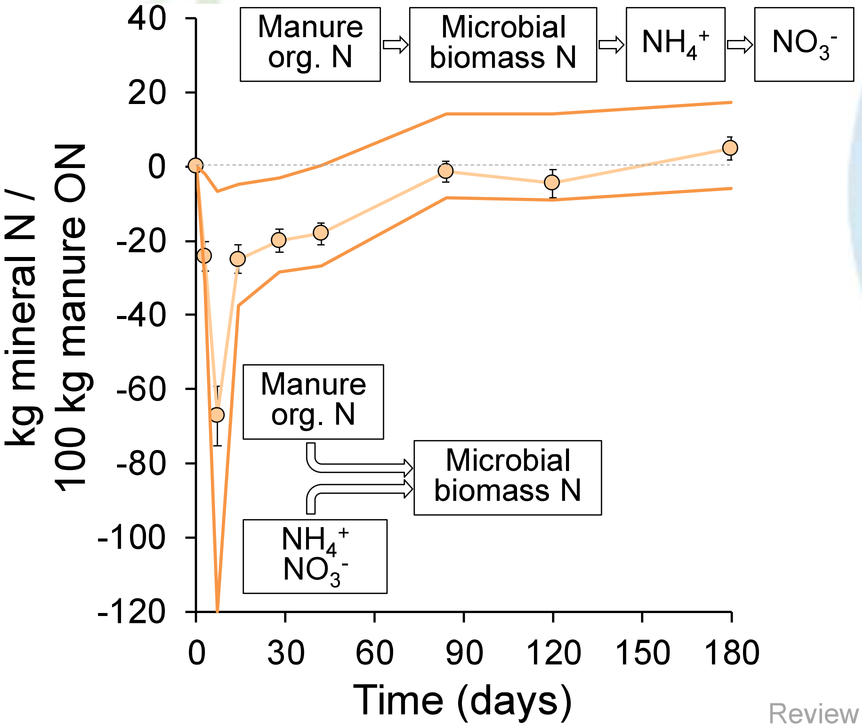


NFRV in the year of application



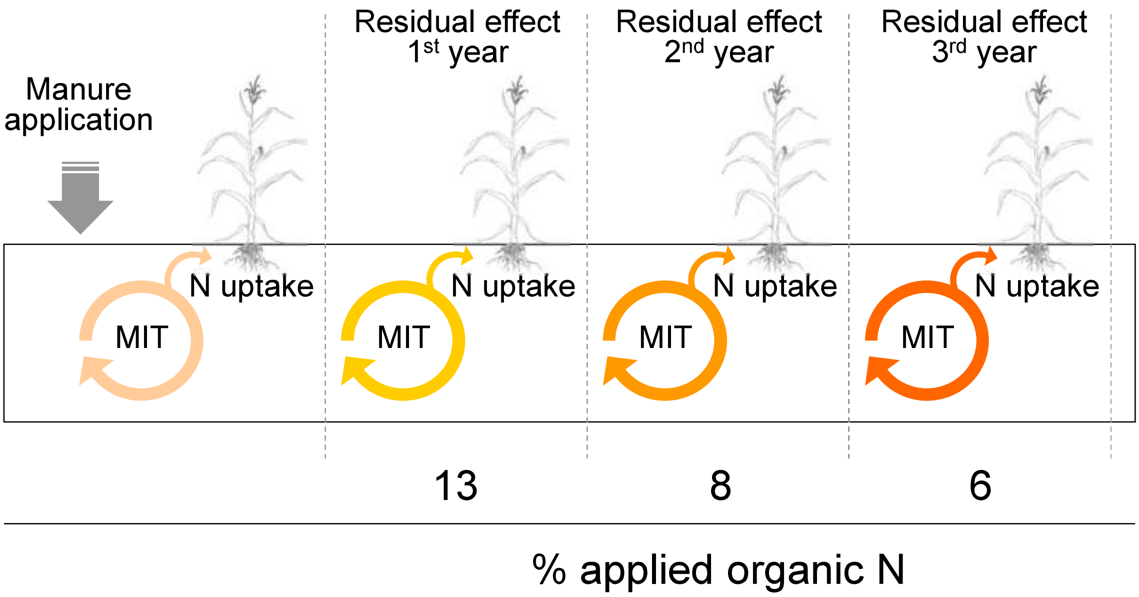
Cavalli *et al.* (in preparation)

Net N mineralization of manure ON



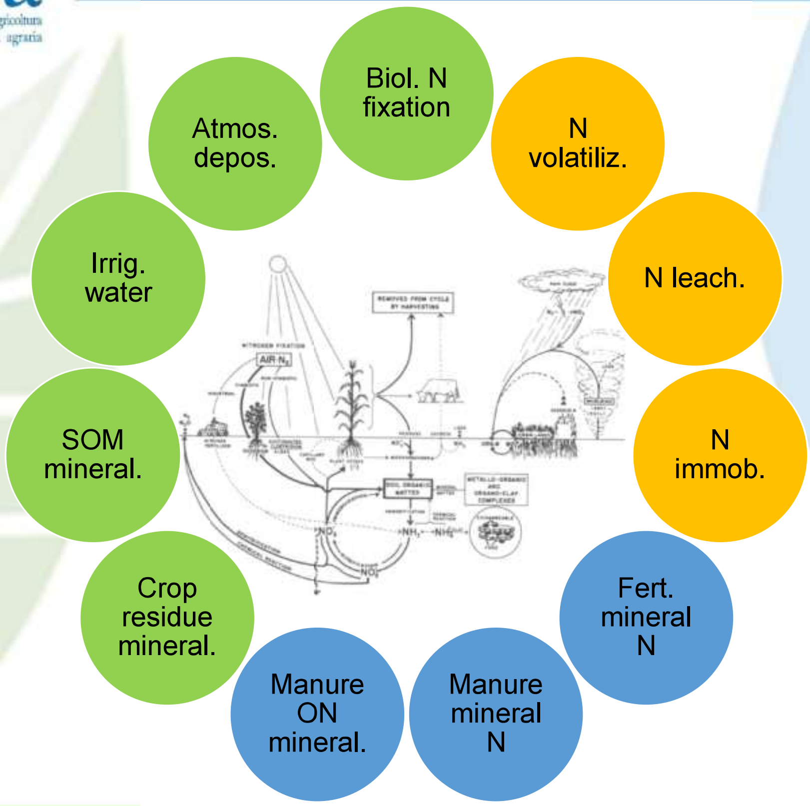
Review in Cavalli *et al.* (2019)

NFRV in the years after application



Schröder *et al.* (2013)

Manures in a crop fertilization plan



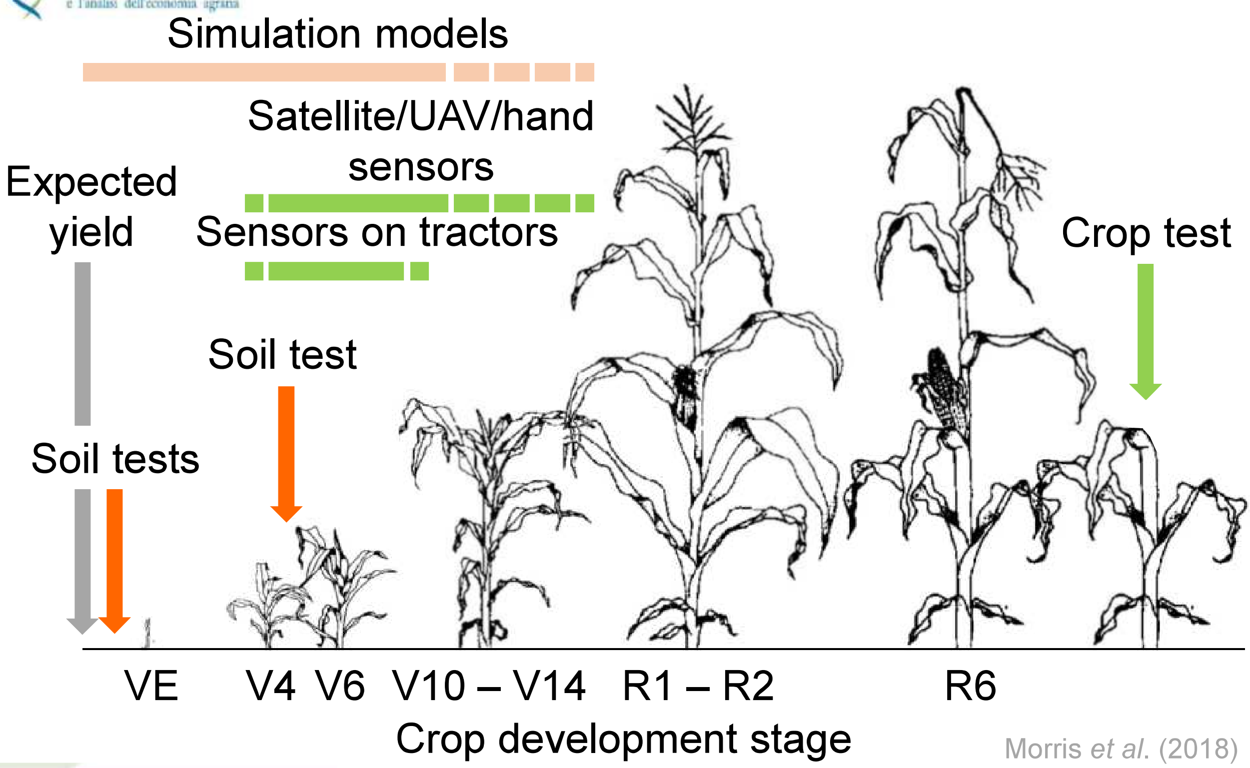
Coefficients of NUE for farmers

Tabulated values
- Type of animal
- Application (time, method, dose)
- Crop (type/growing season)

Models
- Statistical (C/N, NH_4-N/N) (Joseph *et al.*, 2017)
- Empirical (Schröder *et al.*, 2013; Sørensen *et al.*, 2016)
- Mechanistic (Schröder *et al.*, 2005, Nicholson *et al.*, 2013)

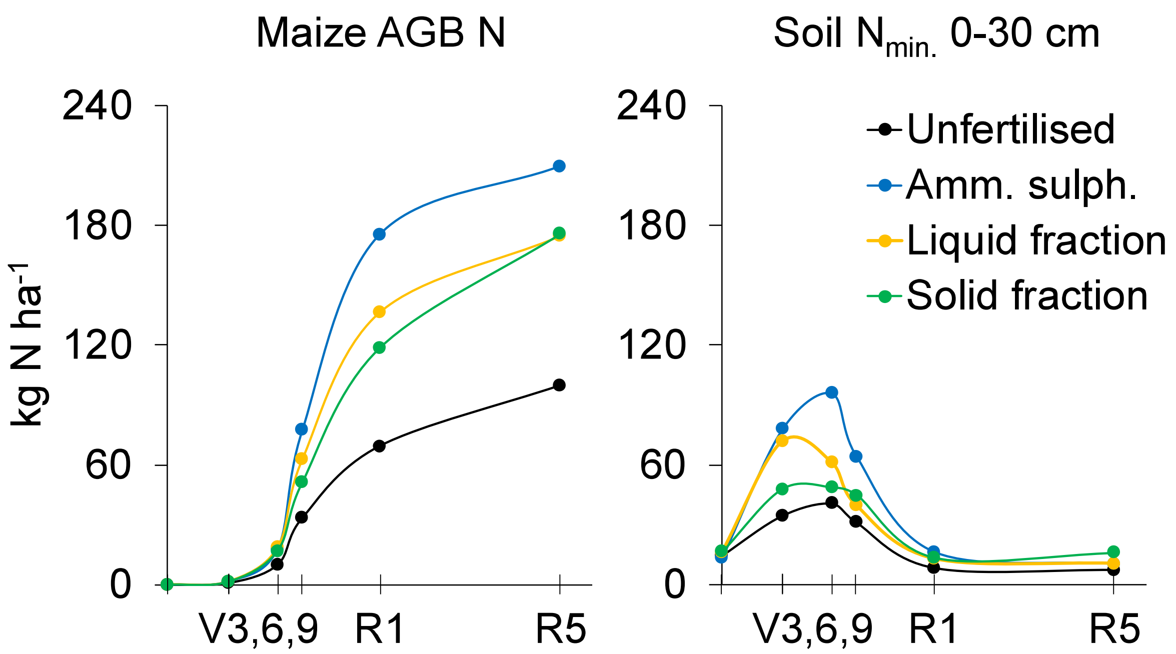
Provided values
- First year NFRV and ANR_{manure}
- Residual effects
- N losses

Timing to assess N rates



Morris *et al.* (2018)

From pre-season to in-season



Cavalli *et al.* (2016)

Modeling soil N dynamics

- Different models (Manzoni and Porporato, 2009)
  - n° pools
  - n° fluxes
  - decomposition kinetics

- Sensitivity analysis for the simulated dynamics (Saltelli *et al.*, 2004)
  - understanding how the model behaves
  - identify parameters to be calibrated
  - model simplification

- Parameter calibration
  - tradeoff between C & N simulations (Cavalli and Bechini, 2012)
  - different calibration strategies (e.g. manure-specific parameter set, manure-category parameter set, manure-specific set based on measured properties) (Levavasseur *et al.*, 2021)

From uniform to site-specific

Variable rate according to crop yield (Moshia *et al.*, 2014)

- Strategy 1: Higher rates in low-yielding zones
- Strategy 2: Higher rates in high-yielding zones

Variable rate to increase stable soil organic matter (Corti *et al.*, submitted)

- Higher rates in fine-textured zones and with lower C content

crea
Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria

References

- Cavalli and Bechini (2012). Multi-objective optimisation of a model of the decomposition of animal slurry in soil: Tradeoffs between simulated C and N dynamics. Soil Biology & Biochemistry 48, 113–124
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