

# Recycling, Consumer Credibility and Ecosystem integrity

Discussions and developments in the last 20  
years on recycling nutrients from society in  
organic farming in Denmark

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UNIVERSITY OF COPENHAGEN



# Conclusions

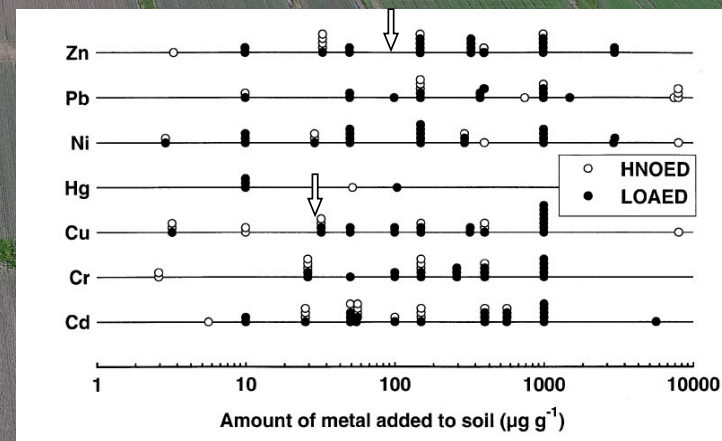


- Heavy metal concentrations in sewage sludge have declined substantially over the past decades
- So far we have been unable to identify unwanted effects on soil and crops caused by recycling of societal wastes in accelerated amounts (>200 years of legal doses)
- We have rather been surprised by the resilience of the soil ecosystem, and conclude that the resilience of the soil ecosystem and soil biotic communities is generally underappreciated
- The risk associated with agricultural use of Danish sewage sludge is comparable to that of pig slurry, once the EU limits for Zn and Cu addition to pig feed have been fully implemented
- Danish organic farmer organizations agree that recycling from society is preferable to using conventional straw and manure, and are working towards this, even in the case of sewage sludge in the longer term

## Timeline

- 1997 Lecture: Is municipal waste compost good for soil? → Identified a need for long-term experiments to assess effects on soil quality...
- 2003 Establishment of the CRUCIAL long-term experiment on organic waste
- 2008 Danish Organic farmer organizations decided phase out the use of manure and straw from conventional farms by 2021
- 2013 Publication of a study of possibilities for phasing out, assessing that it will be impossible to cover the need for P fertilization in Danish non-dairy farms without resorting to reuse of sewage sludge
- 2015 Decision to moderate the phasing out due to the lack of acceptable alternatives, in favor of a more gradual approach to replenishing fertility from alternative sources.
- 2018 The Danish Organic Business Development Team recommended that organic farmers should have an opportunity for utilizing nutrients from treated domestic wastewater for nutrient recycling provided that it was deemed safe and acceptable for consumers

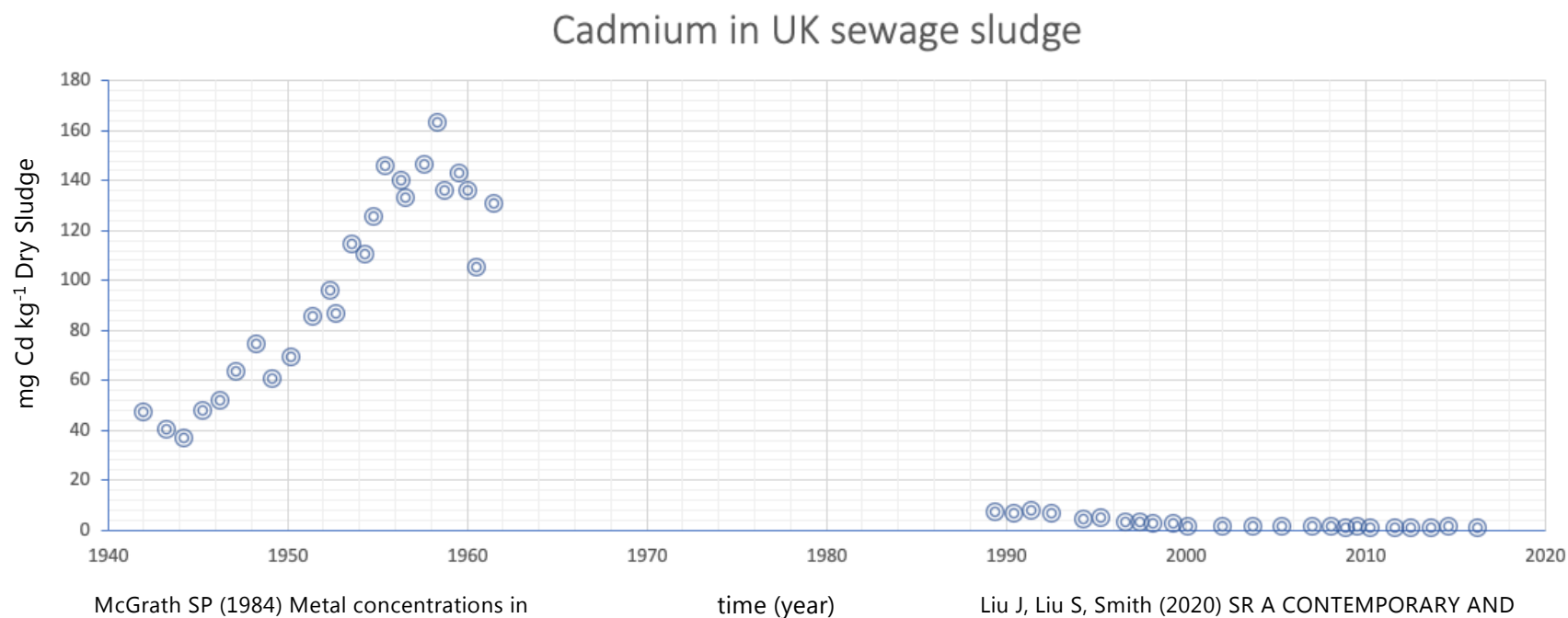
Giller, K.E., Witter, E. & McGrath, S.P. 1998. Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: A review. *Soil Biology & Biochemistry*, **30**, 1389–1414.



*Short-term laboratory studies have little relevance and are no use for legislative purposes!*

Ken Giller, University of London

# Heavy metal concentrations in sewage sludge have declined



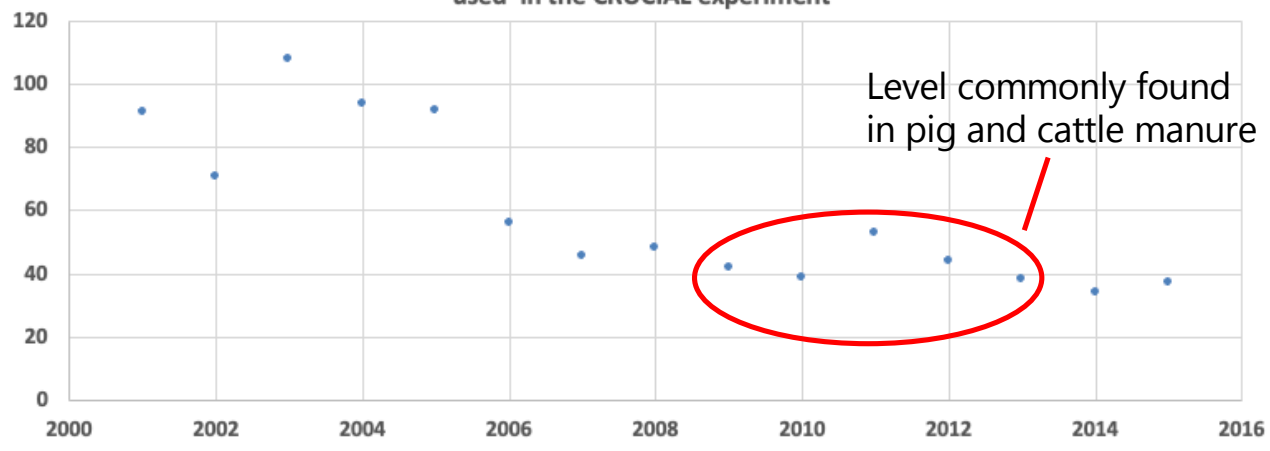
McGrath SP (1984) Metal concentrations in sludges and soil from a long-term field trial. *J Agric Sci* 103:25–35.  
doi: 10.1017/S002185960004329X

Liu J, Liu S, Smith (2020) SR A CONTEMPORARY AND HISTORICAL ANALYSIS OF THE TRACE ELEMENT COMPOSITION OF SEWAGE SLUDGE IN THE UK. *Water and Environment Journal*  
<https://doi.org/10.1111/wej.12677>

# Cadmium in alternative Danish P sources

---limit for imported TSP is 100 mg Cd kg<sup>-1</sup> P ---

Cd - to - P (mg Cd per kg P) ratio in sewage sludge from Avedøre used in the CRUCIAL experiment

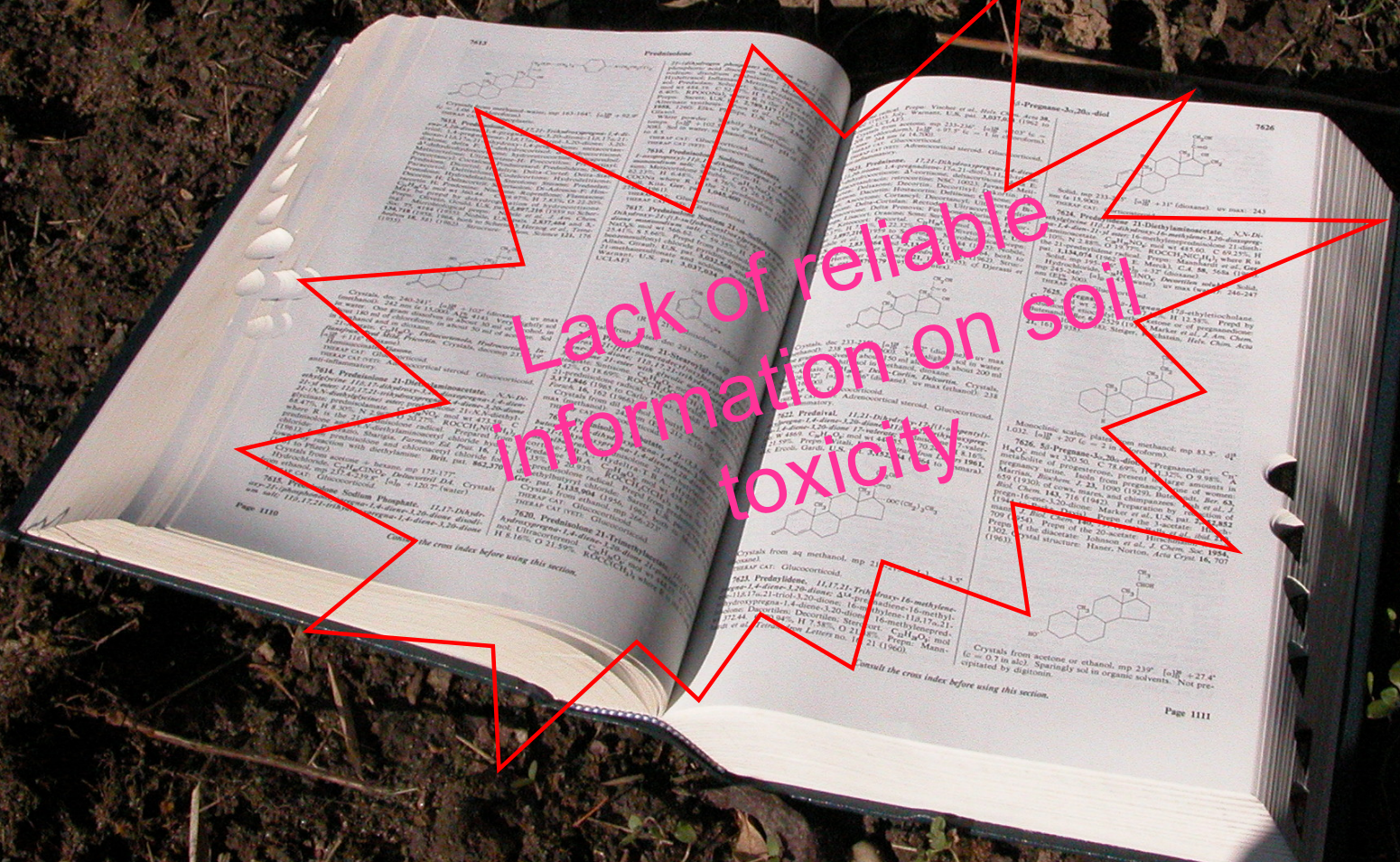


Ash from combined heat and power plants in Denmark 2021		Cd-to-P ratio mg Cd /kg P
<b>Fynsværket</b>	Straw ash	518
<b>Avedøreværket</b>	Straw ash	753
<b>Herning</b>	Wood ash	721
<b>Skærbæk</b>	Wood ash	1615
<b>Amager 4</b>	Wood ash	1233
<b>Amager 1</b>	Wood ash	746
<b>Asnæsværket</b>	Wood ash	828

Straw ash is rich in K

Wood ash has well balanced Ca:Mg:K:P ratios

# The challenge with urban/industrial waste residues



Lack of reliable information on soil toxicity

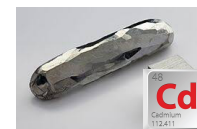
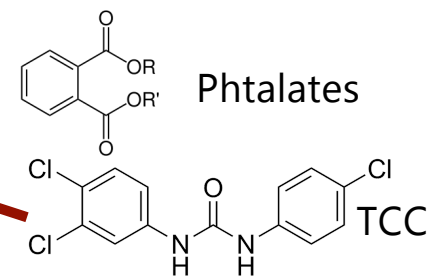


The  
unknown  
unknowns

The known  
unknowns

The known



We postulate that it is possible and necessary to address the known unknowns and unknown unknowns through integrated and realistic 'accelerated' experiments



## CRUCIAL - long-term field trial

Treatments are:

- Composted household waste (normal and accelerated level)
- Sewage sludge (normal and accelerated level)
- Human urine
  
- Cattle manure (accelerated level)
- Deep litter
- Cattle slurry
- NPK fertilizer
- Green manure
- Unfertilized

-  One/two spare treatment available
-  One extra block on side of exp. available



## More about the organic (waste) fertilizers

- CH: compost made from municipal solid waste mixed with garden and park waste using a combined biogas-composting process (AIKAN)
- S: sewage sludge from Avedøre wastewater treatment plant. Bio-P+Fe- dosing, anaerobic digestion + dewatering
- HU: Human urine collected from an eco-village with urine-diverting toilets. Store in airtight tanks for at least six months before application
- DL: Deep litter, consisting mainly of straw
- CMA: Cattle manure with less straw

*Peltre et al 2015, Lopez-Rayó et al. 2016*

## Creating a historical site for agroecosystem resilience studies

How does cycling of matter plant and soil quality, the environment and the integrity of agricultural production systems?

Cycling of matter is broadly defined and includes e.g. nutrients, heavy metals, and xenobiotics, medicinal residues, pathogens and genes

## The Frankenstein effect



How bad can it get?



Accelerated treatments  
Presently > 200 yr dose

# Summary of some results



Effects of fertilization with urban and agricultural organic wastes in a field trial – Waste imprint on soil microbial activity

Pernille Hasse Busk Poulsen<sup>\*</sup>, Jakob Magid, Jesper Luxhøi, Andreas de Neergaard

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**Microbial activity is closely related to input levels, microbial function unaffected**



Effects of fertilization with urban and agricultural organic wastes in a field trial – Prokaryotic diversity investigated by pyrosequencing

Pernille H.B. Poulsen<sup>a,b,\*</sup>, Waleed Abu Al-Soud<sup>b</sup>, Lasse Bergmark<sup>b</sup>, Jakob Magid<sup>a</sup>, Lars H. Hansen<sup>b</sup>, Søren J. Sørensen<sup>b</sup>

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**Highly robust system – when measuring prokaryotic diversity**



RESEARCH ARTICLE

**Exploring the immediate and long-term impact on bacterial communities in soil amended with animal and urban organic waste fertilizers using pyrosequencing and screening for horizontal transfer of antibiotic resistance**

Leise Riber<sup>1</sup>, Pernille H.B. Poulsen<sup>1,2</sup>, Waleed A. Al-Soud<sup>1</sup>, Lea B. Skov Hansen<sup>1</sup>, Lasse Bergmark<sup>1,3</sup>, Asker Brejnrod<sup>1</sup>, Anders Norman<sup>1,4</sup>, Lars H. Hansen<sup>1,5</sup>, Jakob Magid<sup>6</sup> & Søren J. Sørensen<sup>1</sup>

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Agriculture, Ecosystems and Environment

journal homepage: [www.elsevier.com/locate/agee](http://www.elsevier.com/locate/agee)



**Long-term amendment of urban and animal wastes equivalent to more than 100 years of application had minimal effect on plant uptake of potentially toxic elements**

Sandra López-Rayó, Kristian H. Laursen, Jonas D.S. Lekfeldt, Fabio Delle Grazie, Jakob Magid\*

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Antibiotic resistance of pseudomonads was only affected in the very short term (3 weeks) by waste application treatments

Horizontal gene transfer to *P. Putida* was only observed on day 1 after application

Increases of Zn content in oat grain in 'urban' treatments were beneficial to human/animal needs (biofortification)

The treatment with sewage sludge (appr. 75 yr loading) resulted in the same Cd concentration in oat, as cattle manure and deep litter



A REDUCTION IN TILLAGE FUEL CONSUMPTION OF 14% AT THE 'NORMAL' COMPOST AMMENDMENT RATE

### Repeated soil application of organic waste amendments reduces draught force and fuel consumption for soil tillage



Clément Peltre<sup>a,\*</sup>, Tavs Nyord<sup>b</sup>, Sander Bruun<sup>a</sup>, Lars S. Jensen<sup>a</sup>, Jakob Magid<sup>a</sup>

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different C compounds accumulated for the different types of applied organic waste

### Repeated application of organic waste affects soil organic matter composition: Evidence from thermal analysis, FTIR-PAS, amino sugars and lignin biomarkers



Clément Peltre<sup>a</sup>, Edward G. Gregorich<sup>b</sup>, Sander Bruun<sup>a</sup>, Lars S. Jensen<sup>a</sup>, Jakob Magid<sup>a,\*</sup>

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related to the degree to which microbial activity was stimulated and the type of microbial communities decomposing



## The double challenge

The organically farmed area must be doubled, while at the same time as the use of conventional straw and livestock manure is being phased out... ..



## Debates within the organic farming community and dialogue with researchers

### The implications of phasing out conventional nutrient supply in organic agriculture: Denmark as a case

Myles Oelofse · Lars Stoumann Jensen · Jakob Magid

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**Abstract** Soil fertility management in organic systems, regulated by the organic standards, should seek to build healthy, fertile soils and reduce reliance on external inputs. The use of nutrients from conventional sources, such as animal manures from conventional farms, is currently permitted, with restrictions, in the organic regulations. However, the reliance of organic agriculture on the conventional system is considered problematic. In light of this, the organic sector in Denmark has recently decided to gradually phase out, and ultimately ban, the use of conventional manures and straws in organic agriculture in Denmark. Core focal areas for phasing out conventional nutrients are as follows: (1) amendments to crop selection and rotations, (2) alternative nutrient sources (organic wastes) and (3) increased cooperation between organic livestock and arable farmers. Using Denmark as a case, this article discusses the background and implications of the strategy to phase out conventional manure and straw, and explores possible solutions to the challenge of ensuring a sustainable nutrient supply to organic systems. Alternative strategies to ensure nutrient supply will require a tapestry of small solutions. One element of this tapestry is to review the volume and type of nutrient sources available in alternative, non-farm organic waste streams and consider their suitability for use in organic systems.

**Keywords** Organic agriculture · Soil fertility management · Organic fertilisers · Nutrient management · Organic waste

#### Introduction

Soil fertility management in organic farming systems, seeking to build healthy soils, can occur through crop rotation design, crop residue management and the application of animal manures, composts and a variety of permitted fertilisers and soil conditioners (European Communities 2007; IFOAM 2005). Organic farms should, where possible, be self-sufficient in nutrients by producing and reusing materials on-farm (Davis and Abbott 2006) and farmers' nutrient management strategies should focus upon efficient use of organic materials and land management practices (von Fragstein und Niemsdorff and Kristiansen 2006). Organic regulations permit the use of approved fertilisers and soil conditioners (European Communities 2007). However, import of nutrients should not form the core fertility management strategy on organic farms and should only supplement nutrient supply under circumstances where the farmer has no other option (IFOAM 2005).

Although organic agriculture seeks to decrease reliance on external nutrients sources, organic farmers in different contexts still rely upon the import of nutrients from conventional agriculture to varying degrees, see for example Kirchmann et al. (2007). Current organic regulations for countries of the European Union (Council Regulation (EC) No 834/2007) permit the use of 170 kg N ha<sup>-1</sup> from animal manure. Although farmers

Alternative strategies to ensure nutrient supply will require a tapestry of small solutions.

For some waste types, there is a need for discussion, and perhaps a rethinking, about the acceptability of use of such resources

Does recycling of non-farm organic wastes actually represent a real reliance on conventional nutrients or a sensible reuse of a product?

This is a discussion of principles and is perhaps an issue which requires discussion within organic agriculture about whether this can be a considered breach of principles, a compromise or a fulfilment of the organic ideology of working with closed cycles.

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## Debates within the organic farming community and dialogue with researchers



In 2015 it was decided to moderate the phasing out due to the lack of acceptable alternatives, in favor of a more gradual approach to replenishing fertility from alternative sources.

There was a principle agreement to the fact that it was preferable to recycle 'safe' societal resources rather than use conventional manures and straw.

It was decided to take a serious look at sewage sludge

# A risk assessment comparing contemporary conventional animal manure and sewage sludge

## A quantitative environmental risk assessment

Table 1 Summary of compound and compound groups included.

Compound group	Included compounds
Metals	Sb, Al, As, Ba, Pb, B, Cd, Cu, Co, Hg, Mo, Ni, Se, Ag, Tl, Sn, U, V, Zn
Organic contaminants	Aromatic hydrocarbons (7), chlorophenyls (3), dioxins (7), furans (10), halogenated aliphatic and aromatic hydrocarbons (7), LAS, PAH (21), PBDEs (12), PCBs (2), PFSA (6), phenols (6), phosphate-triesters (4), phthalates (7), PCN (35), PCA short and medium chained, triclosan, triclocarban
Medicines	Sulfonamides (6), trimethoprim, tylosin, tetracycline, amlodipine, cimetidine, erythromycin, furosemide, paracetamol, salicylic acid, ibuprofen, naproxen, ketoprofen, diclofenac,
Estrogens	Estrone (E1), estradiol (E2), estriol (E3), ethinylestradiol (EE2)

## A qualitative risk assessment addressing

Human health impacts of

Medicinal residues and Potentially Toxic Elements transmitted through edible plants

Antibiotic resistance in agricultural soils

## Main conclusion

The risk associated with agricultural use of Danish sewage sludge is comparable to that of pig slurry, once the EU limits for Zn and Cu addition to pig feed have been fully implemented

Magid J, Pedersen KE, Hansen M, Cedergreen N, Brandt KK (2020) Comparative assessment of the risks associated with use of manure and sewage sludge in Danish agriculture, Adv Agron - ADVAN AGRON 162: 289-334,

<https://doi.org/10.1016/bs.agron.2020.06.006>

## Underlying report freely available for download:

[https://plen.ku.dk/raadgivning/rapporter/Assessment\\_of\\_risks\\_related\\_to\\_agricultural\\_use\\_of\\_sewage\\_sludge\\_pig\\_and\\_cattle\\_slurry.pdf](https://plen.ku.dk/raadgivning/rapporter/Assessment_of_risks_related_to_agricultural_use_of_sewage_sludge_pig_and_cattle_slurry.pdf)

## Debates within the organic farming community and dialogue with researchers



The organic farmer organizations have asked the Food and Agriculture ministry to work towards the legalization of using sewage sludge subject to quality criteria

(based on the risk assessment comparing contemporary conventional animal manure and sewage sludge)

## Emerging studies

Long-term fertilization with organic wastes: Nematode faunal response reveals positive effects on soil quality despite detection of pharmaceuticals and personal care products  
Vuaille J, Gravert TKO, Magid J, Hansen M, Cedergreen N (submitted)

A total of 12 pharmaceuticals and personal care products were identified as up concentrated in the different treatments compared to the controls (mineral fertilizers), among which 8 were found in sludge and 2 in urine treated soils.

Our results, however, showed a significantly greater abundance of nematodes in soils amended with sludge and manure, while *C. elegans* had the lowest reproduction capacity in the controls.

The reproduction capacity tests did not reveal any chronic toxicity.

Toxicity ranking screens in *C. elegans* have repeatedly been shown to be as predictive of rat LD50 ranking as mouse LD50 ranking. Additionally, many instances of conservation of mode of toxic action have been noted between *C. elegans* and mammals.

## Emerging studies

Follow up studies on plant uptake of of pharmaceuticals and personal care products

INRA is adresssing in depth studies of medicinal residues and antibiotic resistance in human urine treated plots

We are very open to collaboration – the CRUCIAL site is now a well developed 'historical site' for contemporary waste recycling

# RECONCILE

2020 -2023

REcycling,  
CONsumer  
CredibLity and  
Ecosystem integrity



## Consumer credibility

### Qualitative interviews

- Focus on 'progressive' consumers that have sustainability high on their agenda
- Preliminary conclusions are imminent

### Quantitative questionnaire survey

- Focus on 'ordinary' consumers
- identify attitudes to benefits / risks of different types of fertilizer
- what is acceptable / unacceptable ?
- Couple quantitative data with detailed information on consumer preferences

## Ecosystem integrity

### Soil health

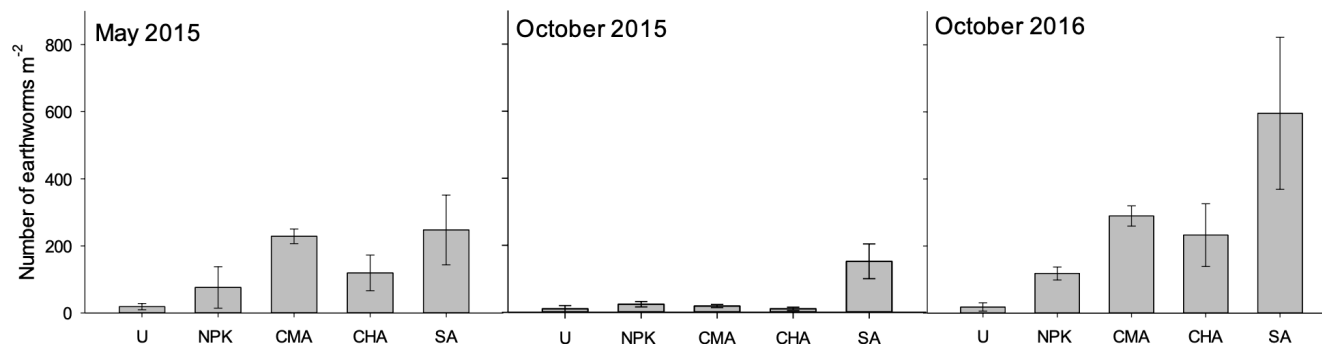
- Soil nematode abundance and diversity over a growing season across long-term treatments in CRUCIAL
- BNF – functioning and diversity of rhizobia populations across long-term treatments in CRUCIAL

### Microplastics

- Assessing breakdown in soil
- Assessing toxicity to a specific nematode



# Earthworm number and biomass from different treatments



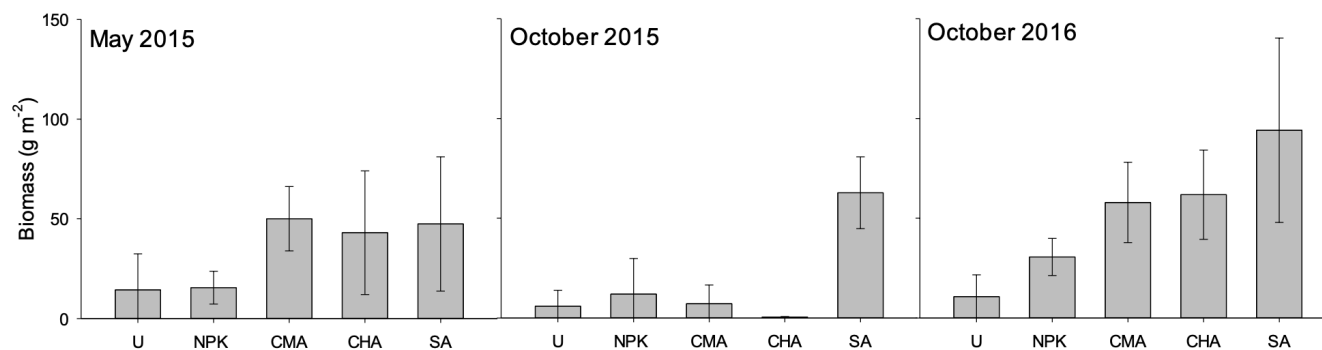
U: unfertilized

NPK

CMA: CattleManure accelerated

CHA: Composted Municipal Household Waste accelerated

SA: Sewage sludge accelerated



# FertiHood

2021-2024

Nutrient recycling  
for soil fertility and  
improved organic  
livelihood




- Quantify industrial waste streams potentially available for Danish organic farms
  - The industry has tentatively assessed that this contains similar amounts of P as sewage societal sewage sludge, and will be a substantial N source
- Assess the use of high-quantity potential waste streams for nutrient interactions, salinity effects and effects on soil fertility indicators
- Assess the effect of long-term fertilization practices (traditional / alternative) fertilizers on biological and physical soil fertility indicators
- Work with organic farmers on perception of fertility, and their use of traditional / alternative soil fertility measures

# Conclusions



- Heavy metal concentrations in sewage sludge have declined substantially over the past decades
- So far we have been unable to identify unwanted effects on soil and crops caused by recycling of societal wastes in accelerated amounts (>200 years of legal doses)
- We have rather been surprised by the resilience of the soil ecosystem, and conclude that the resilience of the soil ecosystem and soil biotic communities is generally underappreciated
- The risk associated with agricultural use of Danish sewage sludge is comparable to that of pig slurry, once the EU limits for Zn and Cu addition to pig feed have been fully implemented
- Danish organic farmer organizations agree that recycling from society is preferable to using conventional straw and manure, and are working towards this, even in the case of sewage sludge in the longer term

A red tractor is shown from a rear-quarter perspective, pulling a red agricultural implement, likely a moldboard plow, through a field of harvested crops. The tractor has a large glass cab, a rearview mirror, and a red triangular warning sign on the back. The implement has two large rear wheels with yellow hubs and several smaller front wheels. The field is filled with dry, golden-brown stalks, and the background shows a line of trees under a clear sky.

The CRUCIAL facility is available for collaborative partners – please remember this

There are numerous questions that can still be addressed on recycling and safety as well as basic soil fertility work

Thank you for listening

Questions and comments?