

CRUCIAL - Closing the Rural-Urban Nutrient Cycle - Investigations through Agronomic Long-term experiments

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

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LTE workshop June 7th 2022, Tjele Denmark



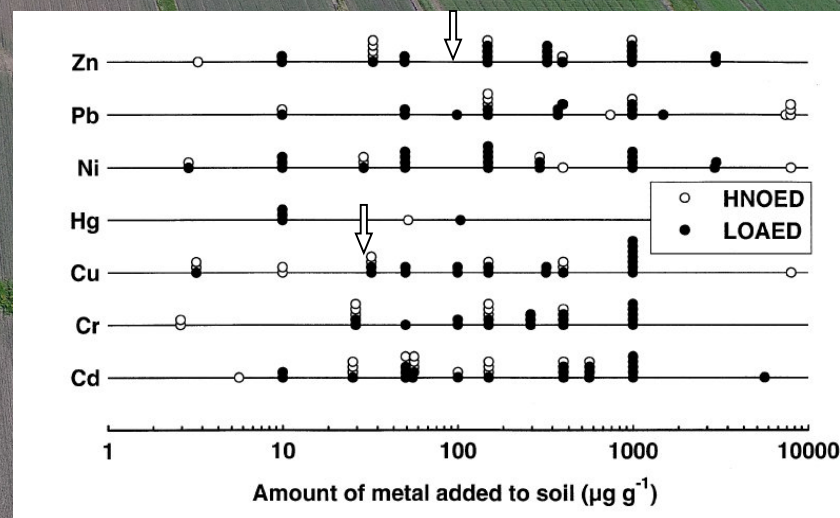
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Timeline

- 1997 Lecture: Is municipal waste compost good for soil? → Identified a need for long-term experiments to assess effects on soil quality...
- 2002 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

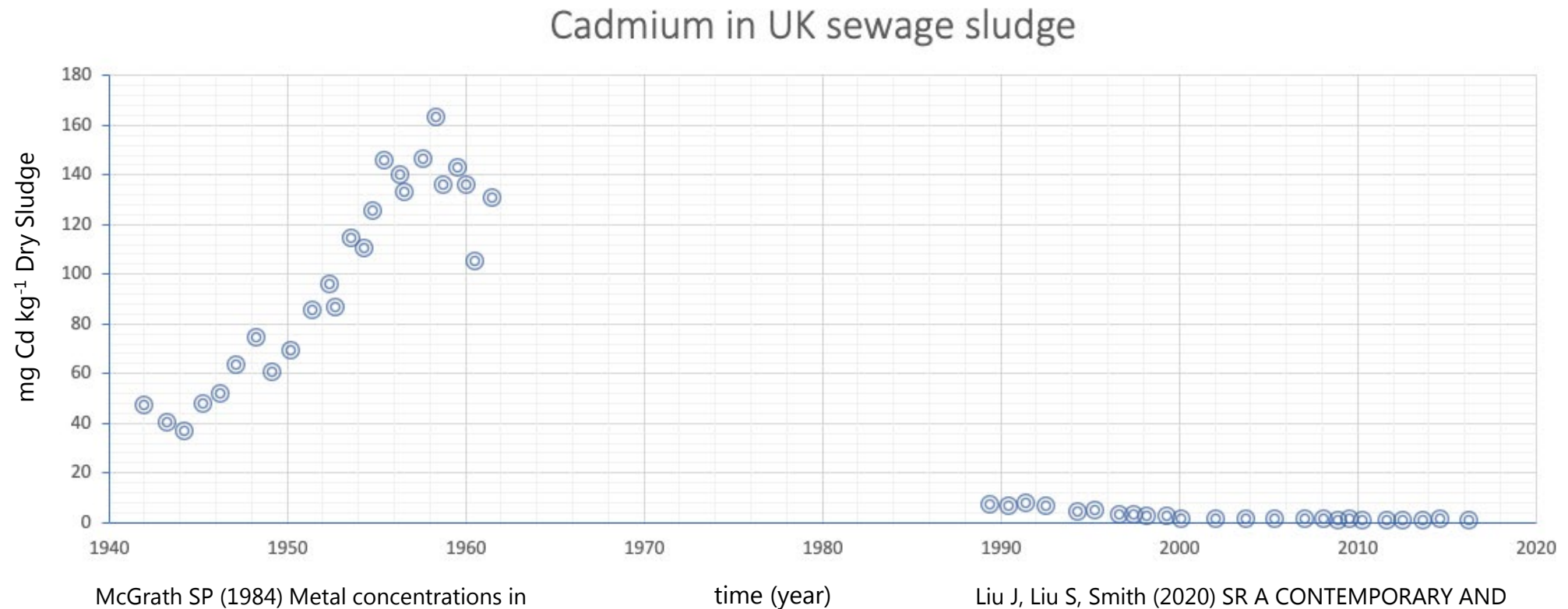
Giller, K.E., Witter, E. & McGrath, S.P. 1998. Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: A review. *Soil Biology & Biochemistry*, **30**, 1389–1414.



*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



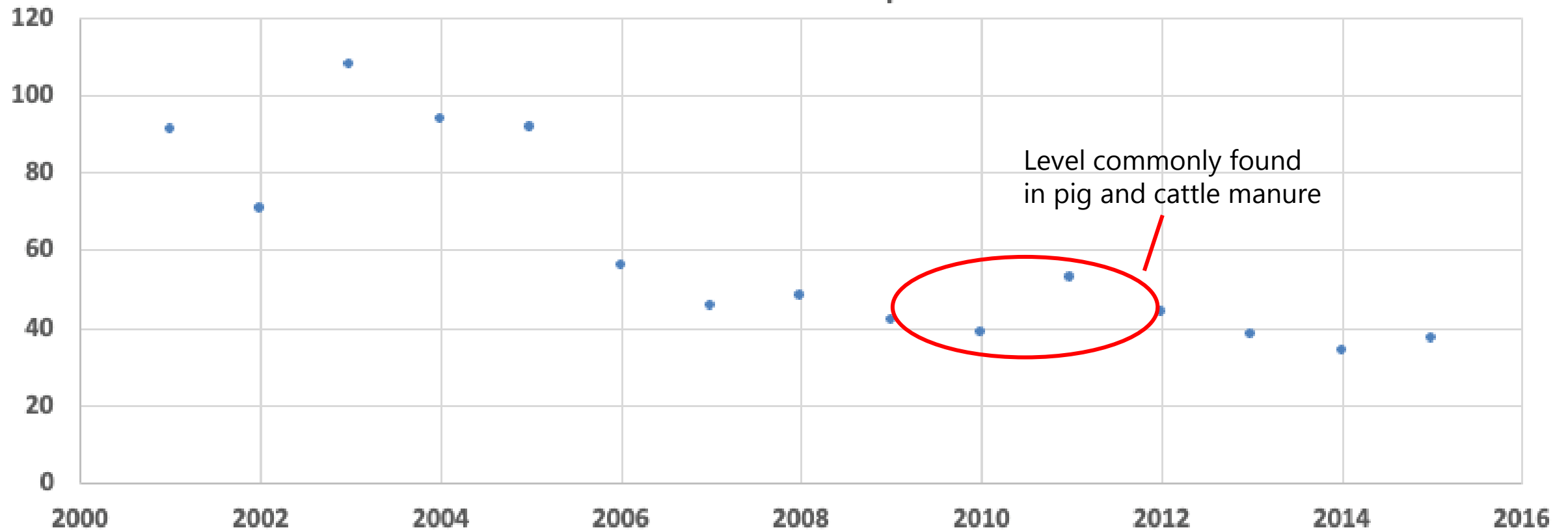
McGrath SP (1984) Metal concentrations in sludges and soil from a long-term field trial. *J Agric Sci* 103:25–35.
doi: [10.1017/S002185960004329X](https://doi.org/10.1017/S002185960004329X)

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>

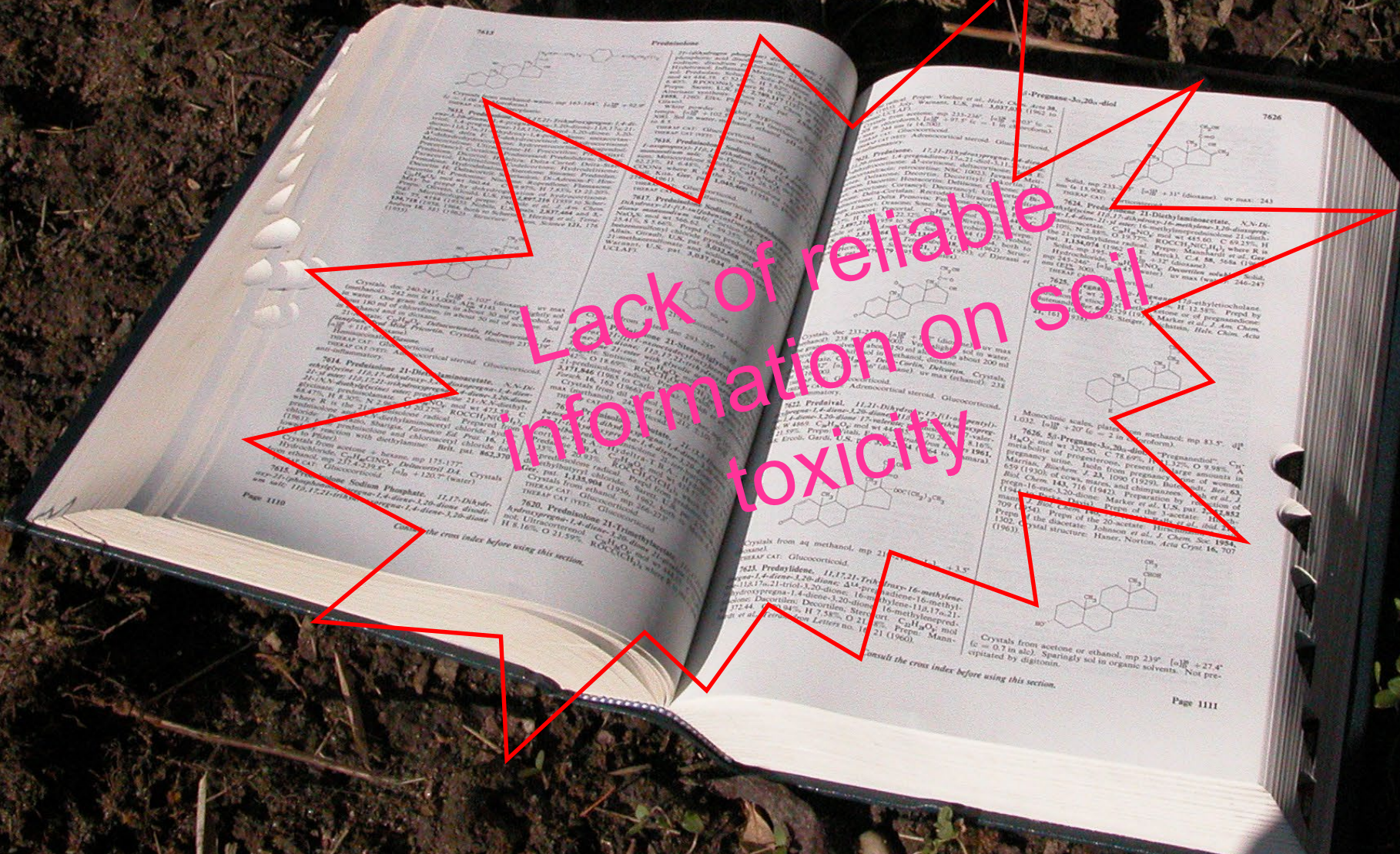
Cadmium in alternative Danish P sources

---limit for imported TSP is $100 \text{ mg Cd kg}^{-1} \text{ P}$ ---

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



The challenge with urban/industrial waste residues



Lack of reliable information on soil toxicity

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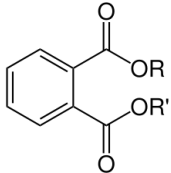
Page 1111

The unknown unknowns

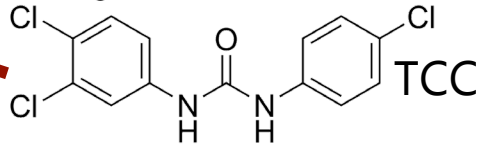
The known unknowns

The known

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



Phthalates



TCC



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 affect 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



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

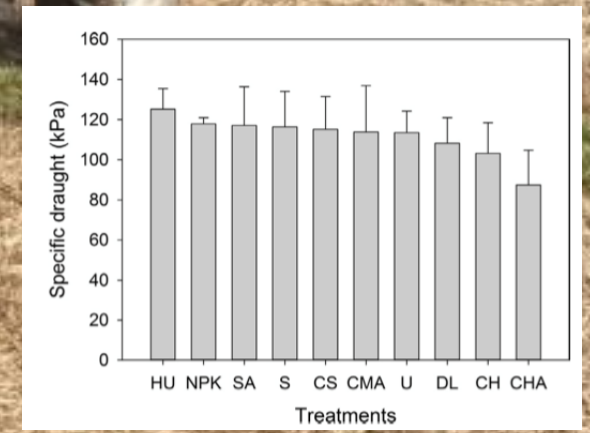
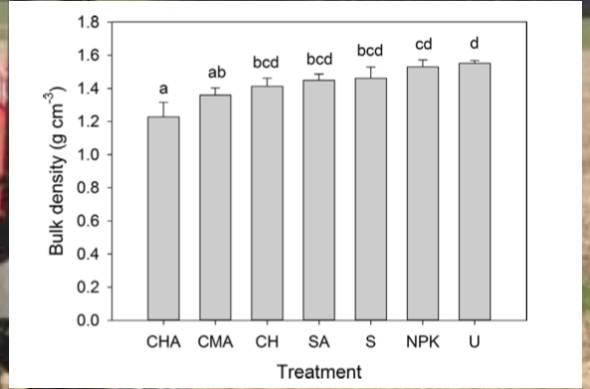
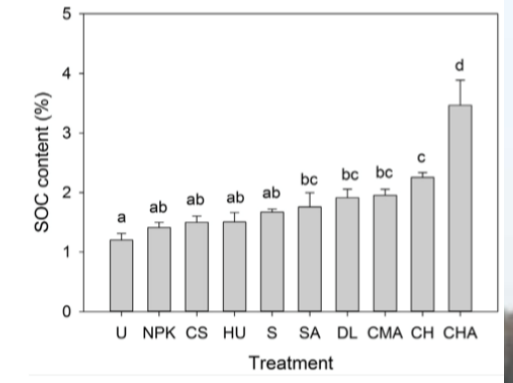
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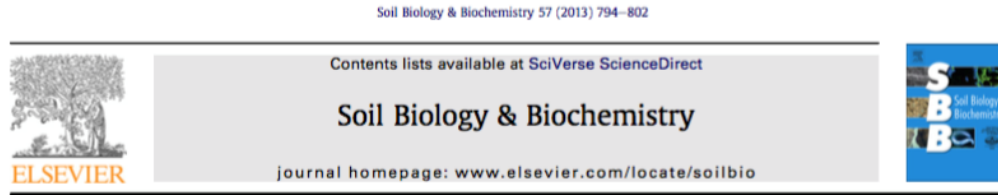
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The decrease in draught force could lead to a decrease in tractor fuel consumption for soil tillage of up to 25% for compost applied at an accelerated rate and up to 14% for compost applied at a normal rate



Summary of some results



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

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

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

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

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Agriculture, Ecosystems and Environment

journal homepage: 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

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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



Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio



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



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

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

An aerial photograph of a large agricultural field, divided into a grid of smaller plots. The field is lush green, indicating healthy crops. A road runs along the left side of the field. In the background, there are more fields, trees, and a few buildings. The overall scene is a typical rural agricultural landscape.

We can see that the soil and biology are positively affected by the application of the various organic fertilizers.

- The soil organic matter content is increased by the application of the organic fertilizers - in some cases so much that the content of plant-available water increases significantly
- There is a rather high long-term nitrogen and phosphorus effect on crops from sewage sludge, somewhat less from compost.
- The numbers of bacteria, fungi, and microfauna (amoebae, flagellates, ciliates, and nematodes) increases with the application of the organic fertilizers.
- The numbers of earthworms also increase - especially with the application of sewage sludge
- The biodiversity of nematods, bacteria and fungi appears to be unaffected
- **So despite the supply of large quantities of products containing small amounts of unwanted substances - including microplastics - equivalent to more than 100 years of legal supply, we do not see any harm to soil health!**

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

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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⁻¹ 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), PFSAAs (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

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

We are looking at microplastics – occurrence and possible breakdown..

INRA is addressing in depth studies of medicinal residues and antibiotic resistance in human urine treated plots, comparing with cattle slurry and sewage sludge

We basic questions on C, N, P and S cycling in the experiment now and in the coming years.

Perspectives ..

We have by and large resolved the question of whether it is safe to recycle contemporary resources from Denmark in the longer term, as we have so far been unable to find deleterious effects on the soil and plant system even when in some cases adding an equivalent of appr. 200 years of legal applications

While the task we set out to achieve is largely completed, we find a continued interest in the CRUCIAL site from society and the scientific community

Therefore we will keep up the trial in the coming years – with less frequent application of most waste materials (every 3rd year)

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

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

Thank you for listening



Questions and comments?