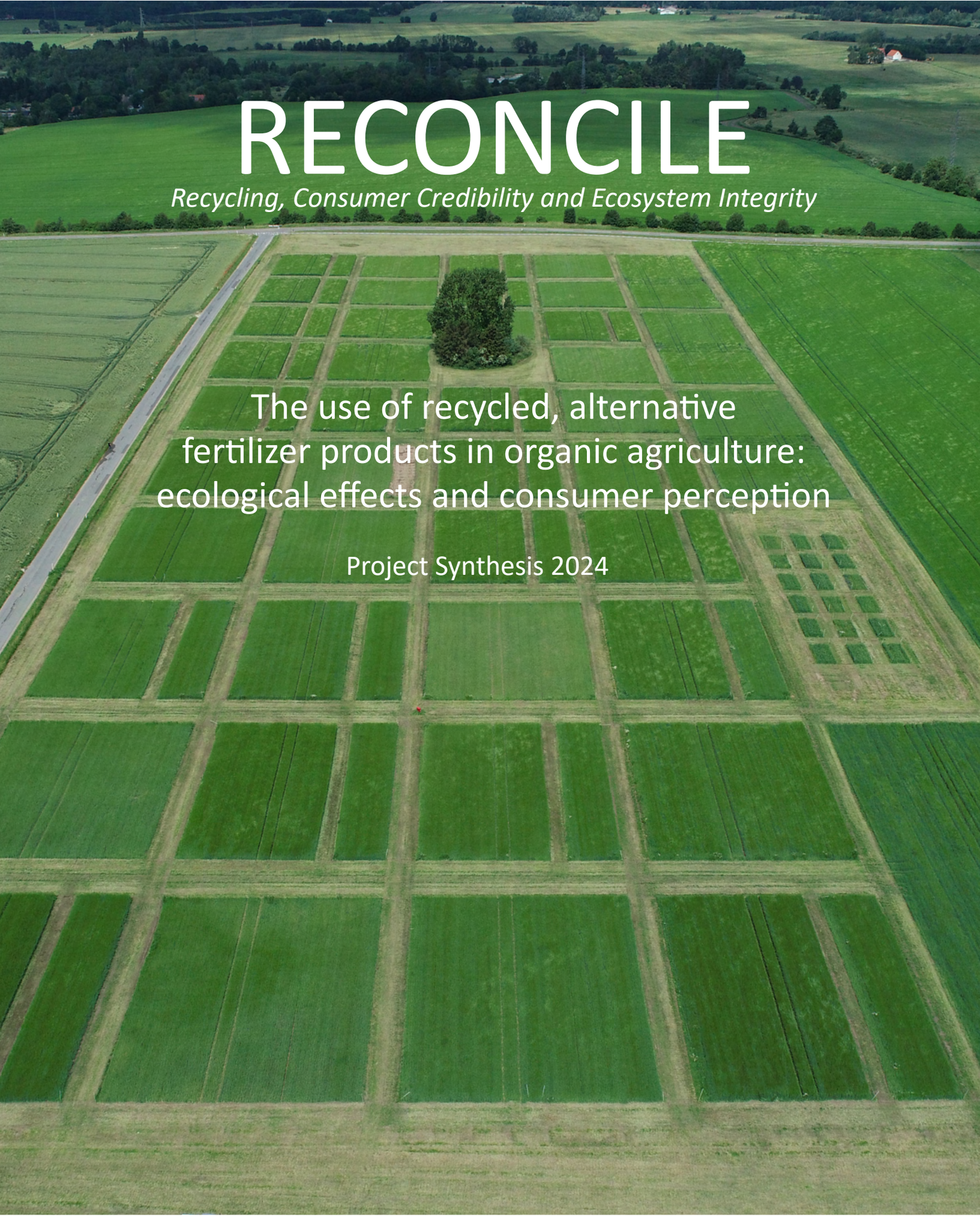

RECONCILE

Recycling, Consumer Credibility and Ecosystem Integrity

The use of recycled, alternative fertilizer products in organic agriculture: ecological effects and consumer perception

Project Synthesis 2024

Contents

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1 Introduction

The growth of organic agriculture in Western Europe, driven by consumer demand and policy goals, has occurred with a deficit of nutrients – particularly through reliance on external inputs sourced from conventional farming systems (Oelofse et al. 2013; Reimer et al. 2020; Reimer et al. 2023). The European Union recently set bold policy goals for the expansion of organic agriculture, which will expectedly drive demand for organic products, which in turn will increase the demand for nutrients on organic farms.

The European Commission's "Farm to Fork Strategy", part of the European Green Deal, sets out ambitious future targets for the European food system. The strategy seeks, amongst other climate and environmental goals, to increase the EU's agricultural land under organic farming to at least 25% by 2030 (Figure 1) - from 13.8 million ha in 2018 to 40.2 million ha by 2030 (Moschitz et. al 2021). The strategy furthermore includes a target to reduce nutrient losses in agriculture by at least 50%, while ensuring that there is no deterioration in soil fertility, and aims to reduce the use of fertilizers by at least 20% by 2030 (European Commission, 2020).

The ambitious policy targets will require efforts to rethink how nutrients are managed in organic farming systems. Organic production standards demand, as a minimum, that nutrients removed from farms through harvest shall be replaced by biological nitrogen, recycling, regeneration and/or addition of organic materials and nutrients. However, given that considerable nutrient exports are unavoidable, organic farms will inevitably require a degree of import of nutrients for replacement. It is documented that arable organic farms in the EU, on average, currently operate with minor nutrient deficits (Reimer et al. 2023).

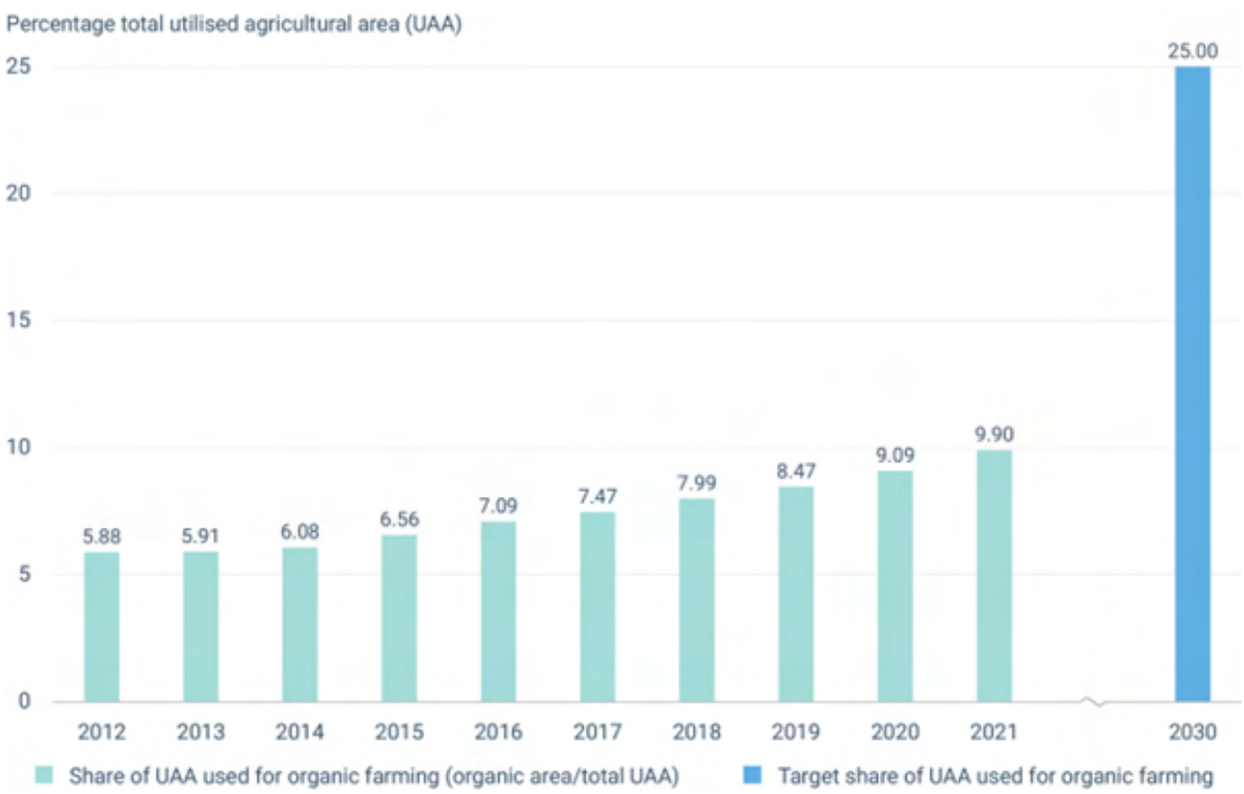

Figure 1 Organic agriculture share of Utilised Agricultural Area in the EU (European Environmental Agency, 2023)

An increase in organic agricultural production at the scale presented will therefore substantially increase the need for nutrient inputs permitted for use in organic farming. Coupled with this, the goal of reducing fertilizer inputs (for all farm types on the EU) and increasing efficiency to optimize nutrient use, will have an impact on the availability of currently permitted nutrient inputs in organic systems due to increased competition for nutrient resources.

Bold policy plans for organic agriculture provide a strong basis to support continued growth of the sector across the EU. To realize this target, the Commission acknowledges that a broad set of actions must be implemented, covering the full value chain, and the EU has developed 23 actions organized around three axes: i. stimulate demand and ensure consumer trust, ii. stimulate conversion and reinforce the entire value chain, and iii. improve the contribution of organic farming to environmental sustainability (European Commission, 2021).

1.1 Opportunity and challenges for increased use of societal wastes

Existing research demonstrates that, until now, the importance of securing a sustainable nutrient supply in organic agriculture, has been underestimated (Carmel, 2022). Research shows that, across Europe, many organic farming systems are in nutrient deficit, whilst in some areas there are surpluses which are too high – both of these constitute risk – one threatening the basis for organic production, the other an environmental risk (Reimer et al. 2020).

Finding a sustainable way forward will entail a tapestry of solutions as formulated in the Actions formulated by the European Union. There is therefore a need to, firstly, ensure a sustainable nutrient supply by exploring new alternatives, and, secondly, to ensure that this supply aligns with the requirements and principles of organic agriculture. Societal waste streams (e.g. sewage sludge, urban household wastes or food processing waste) represent one component of this tapestry, yet further research, and regulatory work, is needed to realize the potential for recycling of recycled waste products in organic agriculture.

The following areas have previously been identified as areas which require further illumination towards increased utilization of societal waste streams (Calmels, 2022):

Safety: environmental and human

We require more knowledge of risks, and guarantees of the safety of recycled products, especially regarding potential contaminants and the presence of microplastics. This would include documentation of levels of potential contaminants in recycled products, as well as their potential impact on the environment, the soil, food safety and human health.

Regulations and organic principles

Organic production, labelling and controls have been regulated at EU level since 1991. A new organic regulation (EU) 2018/848 was published in June 2018 and came into force in 2022. Specific principles guide the use and approval of external inputs, such as fertilizers, so that only substances and compounds listed as approved in specific legislation can be used in organic production. Broadly, the application of natural or naturally derived substances as external inputs is acceptable if their active components are listed in a positive list annex in the Regulation "Authorised fertilisers, soil conditioners and nutrients".

- Beyond treated household waste, organic agriculture regulations do not currently permit the use of treated products with societal waste origin (e.g. treated sludge, or organic industrial waste).
- While regulations of organic agriculture currently permit only a limited selection of external inputs compared to conventional agriculture, some of these inputs are still regarded as contentious as they may conflict with the sustainability goals oforganic farming.

The organic sector will require clear criteria for determining whether a recycled fertilizer is compatible with the principles of organic farming, and recycled products will need to be included in regulations governing permitted fertilizer use in organic agriculture.

Logistical and financial feasibility – will need to be clarified. The availability of materials for recycling varies according to regional contexts. Moreover, the development of the circular economy is likely to increase competition for access to bio-based materials, competition for which may limit availability and drive price up. Furthermore, organic wastes need to be collected and recycled in a manner which ensures alignment with existing and new waste systems to ensure affordability for farmers.

Social acceptability – farmers' willingness to utilize new products derived from societal waste will be a product of the first three – that they are safe, permitted and socially acceptable (including by consumers). Consumers' perception of risk is also related to the uncertainties around the presence of contaminants and their potential risk. Consumers will need to be reassured with a protective regulatory framework based on sound scientific studies, as well as communication about acceptability, even if the product is regarded as safe.

2 About the RECONCILE research project

Realization of the objectives set out by the EU for growth in organic agriculture will require a host of initiatives. It is evident that more nutrients, which are safe, will be required, and the inputs utilized will need to be broadly socially accepted.

The recycling of societal waste in organic agriculture is an opportunity to supply large amounts of carbon and nutrients to support the growth of the sector. However, this opportunity intersects with a dilemma of whether the use of recycled waste products in organic agriculture ultimately might weaken the credibility of organic farming from a consumer perspective. Furthermore, due to the nature of organic waste products, concerns are raised about human and environmental health impacts. Whilst the recycling of wastes adheres to the organic principle[1] of ecology, being based on ecological systems and cycles, the notion of utilizing currently unused organic societal waste is challenged by the principle of care and health.

The RECONCILE (Recycling, Consumer Credibility and Ecosystem integrity) research project focused on two key topics, namely environmental safety, and social acceptability from a consumer perspective. The project focused on exploring questions which can facilitate the pathway towards increased utilization of potential sources of nutrients from societal waste in organic agriculture, and which are currently not utilized or utilized under strict guidelines.

The scientific problem, which RECONCILE addressed was:

Can recycling from society to organic agriculture be developed in line with organic principles of ecology, health and care, while balancing consumer acceptability?

RECONCILE is a Danish project supported by a grant from the GUDP programme under the Ministry of Food, Agriculture and Fisheries of Denmark, as part of the Organic Research, Development and Demonstration (RDD)-5 programme (RECONCILE; grant no. 34009-19-1557) and financially supported by Organic Denmark and SEGES Innovation through a collaboration with the Danish center for developing sustainable, organic agriculture.

The research in RECONCILE has been undertaken in partnership between the University of Copenhagen, Aarhus University, Roskilde University and the Danish Agriculture and Food Council.

2.1 Project hypotheses

The project addressed two main hypotheses, focusing on safety, and consumers acceptance:

1. Contemporary waste and residue streams have improved considerably in quality over the past 40 years, and it is safe to use them, even if they contain some unwanted contaminants – for example regarding content of micro-plastics and low levels of heavy metals.

2. Consumers will be in favor of recycling to organic agriculture if it is safe and responsible to do so.

2.2 Research approach

To investigate this, the project focused on two intersecting themes, with the aim of contributing to the future growth of organic agriculture:

[1] The four organic agriculture principles, for example expressed by IFOAM, are considered the foundation upon which organic agriculture grows and develops. The four principles are for care, health, ecology, and fairness.

1. Ecosystem Integrity: The ecological and environmental risks and potential impact of various types of organic wastes utilized as fertilizers.

2. Consumer credibility: To explore consumer attitudes regarding the use of fertilizer products derived from organic waste use in organic farming, and how knowledge may be incorporated into ensuring consumer acceptance.

Further to this, the project recognized the need to synthesize the established knowledge from the project for dissemination to relevant sectoral actors, nationally and in the EU. To achieve this, the project undertook a series of high-level dialogues on challenges and potentials for consumer acceptance of societal recycling and discussing the way to communicate this kind of knowledge.

The **Ecosystem Integrity** theme explored environmental risks and impacts of waste types.

Soil health impact

- Soil nematode abundance and diversity across long-term treatments with different waste types
- Biological Nitrogen Fixation – functioning and diversity of rhizobia populations across long-term treatments with different waste types

Microplastics in soils

- Assessing breakdown of microplastics in soil.
- Extent and effects of microplastic pollution in soil with focus on recycling of sewage sludge and composted household waste.

The **Consumer Credibility** theme explored consumer attitudes of societal wastes.

- Qualitative interviews of 'progressive' consumers with a priority of sustainability.
- Quantitative questionnaire survey of 'ordinary' consumers to identify attitudes to benefits and risks of different types of waste derived fertilizers and explore acceptability.

Sectoral actor dialogues focused on

- Discussing of project results and stakeholder views on RECONCILE's findings regarding ecosystem integrity and consumer credibility.

2.2.1 Scope

As outlined above, efforts to increase the extent of organic agriculture production will require a range of mechanisms and initiatives. The RECONCILE project obviously cannot address all these aspects, hence it is important to highlight the focal areas of the research derived from the project.

- Primary waste types investigated were sewage sludge, urine and household waste, whilst some studies also included animal wastes.
- As a Danish project, the project focused on areas which are pertinent to the socio-cultural context in Denmark, for example the attitudes of consumers and sectoral stakeholders.
- Studies of the environmental risks of use of fertilizers derived from various waste types were undertaken in Danish conditions.

2.3 Report purpose and structure

The aim of this report is to provide a synthesis of the key findings from the project, and to highlight future needs for the sector to progress. The report outlines key findings of research conducted in RECONCILE - synthesizing findings and contextualizing our current knowledge of environmental risks, potential impacts and uncertainties regarding the use of different types of waste derived fertilizers. This includes a section outlining our current knowledge of microplastics and their potential environmental impacts and an assessment of the current level of (un)-certainty regarding risk. Following this, key findings from the qualitative and quantitative studies of Danish consumer perception and attitudes about the use of fertilizers derived from the three waste types is presented.

The final section of the report presents a discussion, highlighting key challenges and needs going forward.

3 Ecosystem Integrity: soil health and microplastics

3.1 Introduction

RECONCILE investigated knowledge gaps regarding the potential impacts of the utilization of potential nutrient sources derived from societal waste streams, focusing on sewage sludge, composted household waste and human urine on ecosystems. Before presenting the results of the RECONCILE studies, we provide a brief introduction to the input types assessed – what they are, and the potential opportunities and risks associated with their use.

3.1.1 Sewage sludge/biosolids

Sewage sludge (also known as biosolids) is the residual material that remains after wastewater treatment processes. Sewage sludge can potentially impact soil health both positively and negatively, depending on how the sludge is processed and in which amounts it is applied.

It is well established that sewage sludge contains significant amounts of organic matter and essential nutrients such as nitrogen, and phosphorus. If utilized, waste streams of sewage sludge can potentially represent a large volume of fertilizer input in a Danish context.

However, sewage sludge can potentially contain a variety of contaminants, including heavy metals, pathogens, medicine, estrogen, microplastics and organic chemicals. If not properly treated and controlled for, these contaminants can pose risks to soil health and the environment. This is the key concern regarding future use of sewage sludge.

3.1.2 Composted organic household waste

As with sewage sludge, the utilization of composted organic household waste in agriculture has both benefits and risks. Composted organic household waste, when properly collected and processed, can be a valuable source of organic matter and nutrients for soil, and can represent an important nutrient source in future. However, compost made from organic household waste may contain contaminants like heavy metals, pathogens, pesticides, microplastics and pharmaceutical residues. Importantly, the quality of composted household waste can vary depending on the source materials and the composting process.

3.1.3 Human urine

Human urine contains essential nutrients for plant growth, including nitrogen, phosphorus, and potassium, as well as micronutrients. However, urine contains sodium, and excessive application of urine can lead to increased soil salinity, which can harm plant growth and reduce soil quality. Urine can furthermore contain pathogens, and if not properly managed or treated, application can potentially introduce pathogens into the soil, posing health risks to crops and people. However, compared to the pathogen load in animal manures that contain animal feces, the pathogen load in human urine is small.

The use of human urine as a fertilizer may be more socially acceptable to some, while for others, it may be strongly discouraged or considered taboo. The social acceptability of using human urine as a fertilizer is influenced by a combination of factors, including cultural norms, perceptions of hygiene and safety, environmental awareness, and regulatory considerations.

3.1.4 Microplastics in waste derived fertilizers

There has been a growing awareness and concern regarding the contamination of agricultural fields and terrestrial environments by plastics, and micro-plastics, a source of which can be in alternative fertilizers, primarily composted household waste. While research suggests that microplastics do not negatively affect the health and reproduction of soil-dwelling macrofauna (earthworms), it remains unknown how microplastics might impact microfauna. RECONCILE aimed to address this knowledge gap by investigating the potential effects of microplastics on microfauna in soil ecosystems.

3.2 RECONCILE objectives

With a focus on sewage sludge, composted household waste and human urine, RECONCILE focused on furthering our understanding of the following:

- The effects of long-term alternative fertilizer application on the soil's micro food web
- The extent and soil effects of microplastic pollution from alternative fertilizers

To achieve this, the researchers hypothesized that:

- Contemporary waste and residue streams have improved considerably in quality over the past 40 years, and it is safe to use them, even if they contain some unwanted contaminants – for example regarding content of micro-plastics and low levels of heavy metals
- The work undertaken in RECONCILE sought to further our understanding of how the application of, primarily, **sewage sludge** and **composted household waste** as well as other waste types might affect soil ecosystems.

3.3 About the CRUCIAL research facility

The exploration of new insights into such long-term effects by the RECONCILE project were made possible by utilizing the unique long-term field experiment, CRUCIAL, located in eastern Denmark. Long-term field experiments are indispensable for studying the effects of novel fertilizer technologies, and the CRUCIAL field trial has formed the basis of a broad diversity of research.

CRUCIAL is a field-scale research facility designed to assess the feasibility of improved recycling of nutrients from urban areas to both conventional and organic farms, in the form of a long-term field trial. It serves as a field monitoring programme on soil quality changes brought about by using urban fertilizers in the long-term and as such attempts to take eventual unforeseen ill effects of increased re-circulation into account. CRUCIAL, initiated in 2003, comprises the following permanent treatments:

- Urban Fertiliser treatments: Human Urine (from urine separating toilets); composted organic household waste (normal or 3 x accelerated application rates); and degassed Sewage Sludge (normal or 3 x accelerated application rates)
- Reference treatments: Cattle Slurry; Deep Litter; Farm Yard Manure (FYM) at 3x accelerated rates; Mineral NPK fertilizer at recommended rates and no application of fertilizer (soil nutrient mining / extractive strategy).

3.4 The effects on soil nematodes and community structure

Effects of long-term fertilization with contemporary Danish human urine, composted household waste and sewage sludge on soil nematode abundance and community structure[2].

3.4.1 Background

Historically, sewage sludge fertilization is shown to have severe effects on several groups of soil organisms, for example Rhizobium bacteria, mycorrhizal fungi and nematodes. These effects have primarily been attributed to a high content of heavy metals in sewage sludge.

However, sewage sludge quality has improved significantly over the last decades, and the heavy metal content has decreased considerably. Liu et al. (2021) performed a critical statistical analysis of historical and contemporary sludge quality data in the United Kingdom. Importantly, they found that zink (Zn) and copper (Cu) would be the most limiting to agricultural recycling, yet would reach their maximum soil limit concentration values in approximately 120 and 200 years, respectively. Nickel (Ni), Cadmium (Cd), lead (Pb) and mercury (Hg) were unlikely to approach their maximum permissible soil limits, relative to Zn and Cu, leading the authors to state that:

"*the trace element quality of sludge in the United Kingdom has increased to the extent that the statutory soil limits for Ni, Cd, Pb and Hg have effectively become obsolete and could, therefore, be removed from the regulatory controls on the agricultural use of sewage sludge.*"

In the CRUCIAL long-term field experiment, the legally permissible upper limits of both sewage sludge and composted household wastes were intentionally breached in order to represent 'worst case' scenarios for waste recycling.

3.4.2 Objective

Nematodes are an essential, ubiquitous, and by number of individuals, the most abundant, group of animals in the soil food web. It is well-established that nematode community structure responds to soil heavy metal pollution. This study therefore utilized changes in soil nematode community composition as an indicator to understand biotic responses to soil management practices in the CRUCIAL trials.

This RECONCILE study investigated the effects of long-term fertilization with human urine, composted household waste and sewage sludge on nematode abundance and community structure. Essentially, the study investigates whether the composition of nematode communities indicated that soil health was compromised by these waste derived fertilizer products.

Assessing the consequences of alternative fertilization schemes on soil health is not straight-forward, given the complex nature of the soil environment. Given the complexity of the soil environment, the researchers measured the effects of long-term fertilization with human urine, composted household waste and sewage sludge on soil properties (pH, soil organic matter and nitrogen availability). Following this, the abundance of soil microorganisms (bacteria, fungi, small protozoa and ciliates) and nematode trophic groups was compared to control plots. Finally, the composition of nematode communities was assessed, to further understand the effects.

[2] Johansen, Jesper Liengaard, et al. "Effects of long-term fertilization with contemporary Danish human urine, composted household waste and sewage sludge on soil nematode abundance and community structure." Science of the Total Environment 860 (2023): 160485.

3.4.3 Key findings

- The research found that long-term fertilization with different types of contemporary Danish urban waste products affects both soil properties and abundance of soil organisms. Importantly, a key determinant of the impact on soil properties and abundance was reflected in the **organic matter input** of the fertilizer treatments.
- Fertilization with composted household waste and sewage sludge in accelerated dosages had **mainly beneficial effects** on soil health in terms of soil organic matter content and abundance of decomposer organisms.
- **No adverse effect on nematode communities** that could indicate pollution-induced stress on nematofauna or decreased soil fertility was found.
- The low abundance of omnivorous nematodes in composted household and sewage sludge treatments could indicate that components in soils treated with these waste products could compromise the growth of pollution- and disturbance-sensitive soil organisms. However, the abundance of predatory nematodes, which are generally sensitive to pollutants, was not negatively affected in compost and sewage sludge amended plots.

3.4.4 Outlook

- The results from this study are from a single location (CRUCIAL), so in essence applicable for similar soil types under similar climatic conditions.
- Research on effects on more sandy, more acidic soils recommendable.
- Effects of high doses of waste products, comparable to the accelerated CRUCIAL doses, on soil microbiota and microfauna can be assessed at small plot scale (e.g. 1 m^2) on more sandy soils. Assessments after >2 years of application would be relevant, preferably plots should be treated and monitored for at least 5 years.

3.5 Effects of long-term organic waste fertilization on earthworms

Effects of long-term organic waste fertilization of agricultural soils on the endogeic earthworm Aporrectodea caliginosa – with special emphasis on soil microplastic pollution[3]

3.5.1 Background

Earthworms perform a number of soil services and are therefore very important for soil fertility in many parts of the world. Additionally, earthworms may be susceptible to soil pollution, as they live most of most their lives buried in the soil, ingest soil and pass it through their gut.

Earthworms are therefore often used as model organisms in ecotoxicology studies. Several studies have demonstrated adverse effects of microplastics, heavy metals and persistent organic pollutants (POPs) on behavior, reproduction and survival of various earthworm species. However, the majority of these studies were made with artificial manipulation of soils using single contaminants, and only few were performed with soils where multiple contaminants were unintentionally increased through actual agricultural practices.

Until recently, there was limited knowledge about the prevalence and hazards of microplastics in terrestrial environments. Although there has been an increase in research on microplastics in soils in recent years, significant knowledge gaps still exist. Studies on the effects of microplastics on terrestrial organisms often yield contradictory results, ranging from clear impacts at the

[3] Jesper Liengaard Johansen, Monica Hamann Sandgaard, Jakob Magid, Mette Vestergård Madsen, Annemette Palmqvist (in preparation): Effects of long-term organic waste fertilization of agricultural soils on the endogeic earthworm Aporrectodea caliginosa – with special emphasis on soil microplastic pollution.

molecular and cellular level to no observable effects or even seemingly positive effects at higher levels of biological organization (e.g., survival, growth, reproduction). This complexity reflects the ongoing lack of clear conclusions regarding microplastic risks in terrestrial environments.

Many studies showing adverse effects on terrestrial organisms are conducted under conditions that are not environmentally realistic, such as using artificial media, unrealistic homogeneity of plastic particles, or unrealistically high concentrations. This limits the applicability of their findings to relevant agricultural conditions. Consequently, there is a need to investigate the potential effects of microplastics on terrestrial organisms under more environmentally realistic conditions.

3.5.2 Objectives

In this study, researchers designed an experiment to compare the effects of long-term fertilization with organic wastes in the CRUCIAL trial on earthworm growth, behaviour and reproduction. The study included composted household waste (at normal and accelerated level) and sewage sludge (at normal and accelerated level).

The researchers also included an experiment to assess how high amounts of microplastics impacted the earthworks. To do this, they spiked the treatments with high amounts of two different kinds of microplastics (polyethylene (PE) and polymethylmethacrylat (PMMA)).

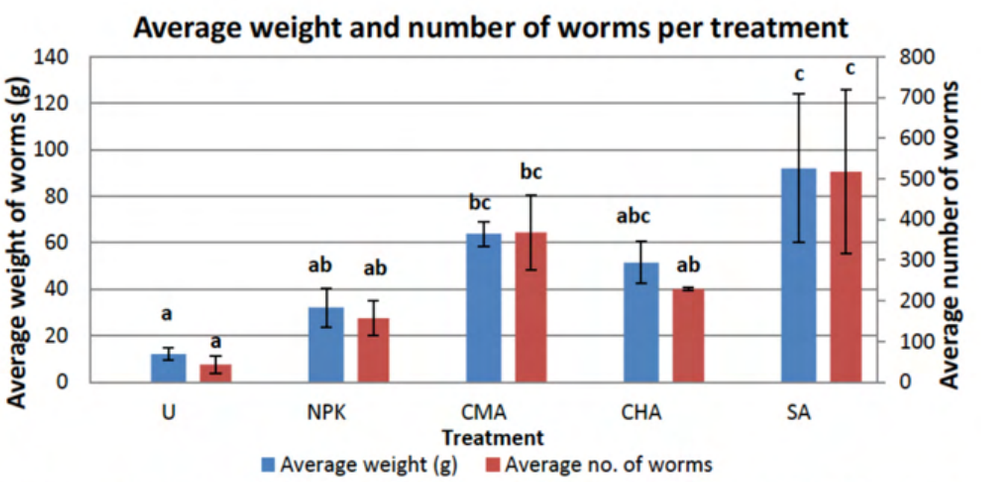

Figure 3 Average number (red bars) and average weight (blue bars) of earthworms in CRUCIAL fields treated with U-unfertilized, NPK fertilizer, CMA cattle manure, CHA composted household waste accelerated, and SA sludge accelerated (error bars are standard deviations). The values for the two parameters are compared with ANOVA and Tukey HSD test, where the letters indicate significant differences in the treatments (Karling, 2018).

3.5.3 Key findings

- The experiments found no significant effects of the plastic treatments on earthworm fitness, but saw indications that earthworms may be able to detect and avoid plastic particles at high concentrations in the soil.
- Significant differences in earthworm fitness in the soil screening experiment were found, but these effects were not related to pollution level in the soil.
- The earthworms in the soil treatments considered potentially problematic (i.e., recycled municipal waste products) performed better than comparable treatments.
- The researchers thus concluded that long-term fertilization with sewage sludge and municipal organic waste compost had no negative impacts on the fitness of the earthworm species investigated.

3.5.4 Outlook

- Future studies are required utilizing a long-term experimental site to refine and further our understanding of earthworm activity and reproduction, focusing on a broader suite of earthworm species in the long term experiment.

3.6 Recycled wastes and microplastics in agricultural soil

Extent and effects of microplastic pollution in soil with focus on recycling of sewage sludge and composted household waste and experiences from the long-term field experiment CRUCIAL[4]

Status report on microplastic content in CRUCIAL soils and organic fertilizers amended to the soils[5].

3.6.1 Background

Microplastics, which are slow to degrade in the environment, can come from various sources, including organic waste resources and plastic mulching in agriculture. Despite growing concern about microplastics in terrestrial environments, there are knowledge gaps regarding their prevalence, sources, and effects on ecosystems, soil organisms and plant growth.

Microplastics are present in composted household waste and sewage sludge. Sewage sludge contains many small particles (primarily fibers and fragments), whereas compost mainly contains larger fragments (flakes from packaging and bags). Recycling of waste products for agricultural use has many benefits, however, concerns regarding the effects of microplastics on soil health may set a limit to recycling of waste in future.

3.6.2 Objectives

The work undertaken was a review focusing on the extent and possible consequences of microplastic pollution in soils, with a focus on composted household waste and sewage sludge. The review assessed the benefits and challenges of using organic waste products in agriculture, primarily addressing concerns about contaminants, with a core focus on the emerging issue of microplastic pollution in agricultural soils. The work:

- Summarizes the results from studies that have measured microplastic concentration in soil and waste products.
- Review the possible hazards of microplastics on soil invertebrates, plant growth and microbial communities based on published studies.
- Presents results from the long-term field experiment CRUCIAL, which has received composted household waste and sewage sludge in dosages corresponding to more than 100 years of legal amendment.

3.6.3 Key findings

- Studies on the effects of microplastics on terrestrial organisms, such as invertebrates, plants, and microbial communities, often use concentrations higher than environmentally realistic levels, and that the potential risk of current microplastic concentrations in agricultural soil appears to be low.

[4] Johansen, Jesper Liengaard, Jakob Magid, Mette Vestergård, and Annemette Palmqvist. "Extent and effects of microplastic pollution in soil with focus on recycling of sewage sludge and composted household waste and experiences from the long-term field experiment CRUCIAL." TrAC Trends in Analytical Chemistry (2023): 117474.
[5] Palmqvist, Annemette (2024) Status report on microplastic content in CRUCIAL soils and organic fertilizers amended to the soils.

- Regarding microplastic quantities measured in agricultural fields, the review generally finds that microplastic contents in fields are below microplastic levels that cause negative effects in most current effect studies.
- Experiments with earthworms and quantification of various soil organisms do not indicate that household waste and sewage sludge, including the inherent contaminants, affect soil health negatively.
- In fact, growth of earthworms and abundances of organisms were often higher in these treatments compared to NPK-fertilized or unfertilized plots.
- Based on these assessments, it is concluded that the potential risk of current levels of microplastics in terrestrial environments is limited for agricultural soils, but more studies are needed to perform a robust risk assessment.
- However, the review emphasizes the need for further research to better understand the extent of microplastic pollution, its sources, and its effects on soil ecosystems.

3.6.4 Outlook

- There is a need for further research to better understand the extent of microplastic pollution, its sources, and its effects on soil ecosystems, which can serve as a basis to perform a robust risk assessment.
- To understand how microplastics affect microbial communities and functioning in the environment, there is need for experiments at environmentally realistic concentrations.
- In future studies, particular focus should be placed on including field and large-scale model ecosystem experiments. In order to be able to compare different studies, it is necessary to standardize methods for sampling and measuring the concentration of microplastics in manure and soil.
- Furthermore, it is important to investigate the effect of microplastics on soil-living organisms in the field or in terrestrial model ecosystems.

4 Consumer perceptions and acceptance

4.1 Introduction

Consumer choices regarding organic food are typically shaped by their perceptions, trust in certification schemes (logos), as well as individual characteristics. These attitudes can be influenced by broader societal trends, such as support for a circular economy or increased concerns about food safety, ethics or environmental aspects. Acceptance of crops grown with new fertilizer types is influenced by consumer perceptions of risks as well as benefits (Segre Cohen et al., 2020; Poortvliet et al., 2018). Gaining a deeper and more nuanced understanding of consumer attitudes of new fertilizer types is therefore regarded as an important precursor to working towards increased acceptance.

From previous studies, most consumers have been found to have low awareness and knowledge about current fertilizer practices and methods in agriculture, and generally have low knowledge of potential hazards (Robinson et al., 2012; Pahl-Wostl, 2005; Segre Cohen et al., 2020; Egolf et al., 2019). However, consumers still hold strong opinions on the matter, which demonstrates that consumer acceptance of recycling of nutrients may not necessarily be related to objective knowledge of the risks (and benefits) associated with the use of these (Segre Cohen et al., 2020; Finucane et al., 2000).

4.1.1 Key topics from existing research

Motivation for purchasing organic products: Consumer motivation for selecting organic products can be due to a variety of factors, including perceived health benefits, environmental improvement, reduced pesticide residues, natural qualities, better taste, eco-friendliness, and improved animal welfare.

Importance of organic certification and standards: Consumers typically rely on organic certification schemes and standards to ensure their preferences align with their purchases. Trust in these schemes, depicted by an organic logo, significantly impacts organic food consumption.

Heterogeneity in consumer trust: While systemic trust exists in organic certification schemes, trust at an individual level remains vital. Consumers have varying perceptions and levels of trust in organic products.

Knowledge types: consumer acceptance of recycling of nutrients is not necessarily related to objective knowledge of the risks (and benefits) associated with the use of these.

Correlation between knowledge, trust, and orientation: Positive correlations exist between consumer knowledge, trust in organic products, and a favorable orientation toward organic foods.

Confirmation bias: Consumers tend to confirm existing beliefs by seeking information that aligns with their views while avoiding contradictory information.

4.1.2 RECONCILE hypothesis

- Consumers will be in favor of recycling to organic agriculture if it is safe and responsible to do so.

Whilst there is fairly extensive research on consumer perceptions of organic attributes, it is more limited regarding the linkage between circular economy, recycling in organic production and consumer attitudes. The work undertaken in RECONCILE sought to explore this linkage, with a particular focus on the role of communication with consumers in driving increased consumer acceptance of recycling.

4.2 RECONCILE's approach

RECONCILE set out to investigate consumer perceptions of organic food in Denmark, and how they are impacted by different information and communication strategies. Two main research thrusts sought to explore beliefs and attitudes towards organic production, sustainability, circular economy, waste reduction, and the reuse of waste materials in food production, particularly in the context of organic farming.

The first, a qualitative approach, included a series of in-depth qualitative interviews with 20 individuals to explore their beliefs and attitudes related to organic production, sustainability, circular economy concepts, waste reduction, and the reuse of waste materials in food production.

Building on the insights gained from the qualitative work, a quantitative study survey of Danish consumers aimed to assess respondents' knowledge of the types of fertilizers used in organic farming and gather their perceptions regarding the risks and benefits associated with different fertilizer types. Additionally, through a choice experiment, consumer perceptions of attributes of recycled fertilizers were explored, with the aim of determining consumer acceptability of introducing new types of fertilizers in organic farming.

These two activities collectively aimed to provide a comprehensive understanding of consumer attitudes towards the use of different fertilizers in organic farming.

4.3 Qualitative study of organic consumers' opinions.

Organic Consumers' Opinions About New Types of Recirculation in Organic Production[6]

4.3.1 Introduction

The qualitative study sought to address the same overarching challenge facing organic agriculture in future - if organic production is to be expanded in future, then we need to utilize alternative sources of nutrients. Whilst the ecosystem integrity section explored what the potential environmental impacts are, the focus here was to gain a deeper understanding of organ consumers' opinions.

The objective of the qualitative study of Danish organic consumers was therefore to gain a deeper understanding of individuals' beliefs and attitudes regarding organic production, sustainability, circular economy principles, waste reduction, and the reuse of waste materials in food production.

4.3.2 Key questions addressed in the study

- How do organic consumers feel about sustainability and the role organic farming plays in this?

[6] Preuss, N., Mortensen, F.; Vesterbæk, P. (2021). Organic Consumers Opinions about New Types of Recirculation in Organic Production. Danish Agriculture and Food Council.

- How do organic consumers view the opportunities for recycling of nutrients in food production, relating to various waste types.
- What do organic consumers think about the idea of recycled material containing microplastics?
- Do organic consumers see a difference between organic and conventional production regarding what can be recycled?
- How do organic consumers view the use of recycled materials that contain materials of non-organic origin?

4.3.3 Methodology

The qualitative study explored beliefs and attitudes among a specific target group of 20 consumers who (by their own account) either 'often' or 'always' buy organic food and beverages- in this analysis referred to as 'organic consumers'. Personal, in-depth and face-to-face interviews were conducted with participants. The interviews explored the nuances of each individual's opinions and attitudes. A semi-structured interview guide was used to ensure consistency across interviews while allowing for flexibility to delve into the unique perspectives of each respondent.

Who were the participants?

An essential criterion for the selection was ensuring the 20 respondents were consumers of organic food. The selected respondents would have already formed an understanding of what 'organic' means prior to being interviewed, and their reactions and opinions on the subject will therefore naturally be influenced by this understanding. Specifically, respondents were identified by their responses during screening being that they 'often' or 'always' buy organic products-from now on referred to as 'organic consumers'. In the most recent representative poll carried out by Epinion on behalf of the Danish Agriculture & Food Council in February 2021, this particular group of consumers made up 35- 40% percent of Danes, a share that has remained relatively stable over recent years. An overview of the respondents is presented below, for more detail on the selection methodology, as well as reflections on the selection procedure and its influence on the findings, please refer to the full report.

Interview focus

The interviews focussed on firstly exploring consumers perception of organic products and sustainability, this was done to establish a reference framework for the exploring of opinions regarding the use of recycled products, which included:

- Urban fertilizers (composted household waste)
- Biosolids from wastewater
- Human urine
- Residual waste from the food industry (e.g. breweries, meat processing or dairies)

There was also a focus on gauging opinion on the content of microplastics in such wastes.

4.3.4 Findings

The most important findings from the study were:

- From the outset there was a general acceptance of the use of compost, sewage biosolids and potential industrial resources in organic food production as long as these are of natural origin and can be composted.
- This acceptance assumed that the material used is of organic origin and will be filtered/ purified to ensure that no unwanted/unsafe substances (such as artificial dyes, preservatives and additives in foods) are recycled into organic production.
- Materials containing microplastics were not acceptable to be used as fertilizer input.

As the interviews progressed, it became clear, however, that the initial enthusiasm over the different types of recirculation in organic production was underpinned by two important assumptions:

- That all raw materials that are recirculated back into organic production (e.g. as a fertilizer input on fields) are of organic origin. It must take place in a closed circuit where the purity of the organic way is not compromised.
- That before being used as fertilizer input, all organic material has undergone a form of purification process to get rid of all 'undesirables', for example, the preservatives and additives used in many food products. If the term 'natural fertilizer' is used, the organic consumer will presume that this is as clean and natural as the leaves and branches one would find in a forest.

Presented with the possibility that the fertilizer material cannot be of purely organic origin or purified before being used as fertilizer input, 'organic-consumers' fell into two groups of equal size:

- Group 1: for whom it is not acceptable to use non-organic materials: They perceive organic agricultural production as a guarantee for purity and a cleaner, more natural way of producing what needs to be protected. For this group, recycling non-organic material into organic production is, therefore, not acceptable, as it compromises the purity of the organic, ideal way of producing.
- Group 2: for whom it is acceptable to use non-organic materials: For them, organic agricultural production is perceived as a path to a more sustainable society among many other paths. The most responsible choice in favor of both a consideration of humans, animals, the environment and nature today and also the future ability of generations to survive for tomorrow. For this group, recycling non-organic material into organic production is, therefore, acceptable as it will raise the sustainability of food production in general -for the benefit of future generations.

Information material provided at the end of the interview about the current use of conventional manure in organic agricultural production, as well as the dilemmas associated with the use of alternative fertilizer inputs surprised participants and caused most of Group 1 to change their opinions:

- After reading the information material, most accept the use of non-organic, biological materials in organic agricultural production, since conventional manure is already used today: Either these materials can be used alongside conventional manure or they could replace conventional manure.
- Rules and regulations would need to be adjusted accordingly, but this is acceptable provided that scientists are able to guarantee the safety of implementing these materials.
- After reading the information material, a minority rejects the use non-organic, biological materials in organic agricultural production and find that it is better to implement this in conventional agricultural production or, alternatively, a new, third way of production. A few among these even find that the use of conventional manure should be prohibited. If it is not possible to replace conventional manure with other biological waste material of an entirely organic origin, organic agricultural production ought to be decreased to a level that can be sustained using organic manure only.

4.4 Quantitative Analysis of Consumers' Attitudes to recycling

Willingness to pay (WTP) for food produced with recirculated nutrients[7]

The organic consumers' willingness to Pay for food produced with re-circulated nutrients, barriers and facilitators[8]

4.4.1 Introduction

This component of the RECONCILE consumer studies used a quantitative approach to gain a further understanding of consumers attitudes to new fertilizer types. The researchers employed a large- scale questionnaire and assessed consumers' willingness to pay for products grown with recycled fertilizer products. Building on this, the researchers assessed consumers' perceived benefits and risks of products grown with re-cycled nutrients from household waste, waste from the food industry and bio-solids from wastewater.

Key questions addressed:

- How can we communicate with consumers in order to facilitate acceptance of recycling of nutrients to agriculture?
- What is consumers Willingness to Pay (WTP) for foods grown with recirculated nutrients as fertilizers?
- How does attitudes, as e.g. perceived risks and perceived benefits associated with recirculation affect this WTP
- To assess whether the above factors differ between heavy and light users of organic food.

[7] Smed, S., 2023. Willingness to pay (WTP) for food produced with recirculated nutrients. Poster at: EAAE Congress, Rennes, September 2023.
[8] Smed, S. (2024). The organic consumers' willingness to Pay for food produced with re-circulated nutrients, barriers and facilitators. EAAE Seminar, September 2024.

4.4.2 Who participated?

The study was based on an existing consumer panel managed by GfK Panel Services in Denmark. The panel consists of consumers that scan and record all their household purchases. Households participating in the panel record on a volume and value purchased for each product in an EAN code, how much was spent in total on the shopping trip, the shop, date and time of the day the purchase was made and whether the goods purchased were organic or conventional. In addition, each household fill in an annual background questionnaire on socio-demographics.

The survey was sent to 3712 panel members who participate in this panel. In all 1324 households responded to the survey. The average age of respondents was 58 years; 80% were female and the average household size was 1.9.

4.4.3 Approach used

The study focused on assessing two aspects of consumer perceptions. The first, a choice experiment, analyzed how both negatively and positively loaded information may affect respondents' willingness to pay (WTP) for an unprocessed food (carrots) and a processed food (brown bread) produced using various recycled fertilizers. Secondly, building on a questionnaire issued together with the choice experiment, the researchers analyzed the effect of general and specific perceived risk and benefit associated with re-circulation on the WTP. Perceived risk was analysed both as general risk, as well as specific risks associated with the use of recycled fertilizers from a specific fertilizer and as disgust. The questionnaire was conducted from December 2021 until the end of January 2022.

The survey included a set of questions seeking to:

1. Map respondents' knowledge about the types of fertilizers currently used in organic farming.
2. Gather insights into the respondents' perceptions regarding the risks and advantages associated with various types of fertilizers.
3. Utilize a choice experiment to identify which attributes of fertilizers are considered unsuitable for food production, and to understand the reasons behind these preferences.

It was hypothesized that the impact of how products are communicated about influence consumers attitudes. Therefore, the households were randomly split into 3 different groups, who received three different types of communication. The first group received information about the products regarded as neutral (a control group); the second group received negative information about current practices, whilst the third group received the same negative information as group 2, but with additional positive information about alternative nutrient sources.

4.4.4 Key findings

How did communication with neutral, negative and positive information influence responses?

- The researchers found a lack of clear effect of provided information on respondent's opinions.
- Results indicate that it is difficult to influence respondents' risk perception through the objective information provided, indicating that respondents typically rely on perceived risk rather than objective risk assessment - a finding consistent with the literature in the field.

Willingness to pay for the various products

- For bread and carrots, a positive willingness to pay (WTP) for organic products was found.
- For both bread and carrots, the study found a positive WTP for food produced with household waste. This WTP increases with the level of organic consumption
- For both bread and carrots, a negative WTP was found for food produced with food industry waste and bio-solids (sewage sludge). The WTP is most negative for bio-solids. The WTP decreased with the level of organic consumption.
- The dependence of WTP on organic consumption may be due to the fact that respondents with a high level of organic consumption were more likely to associate recycling of wastes with benefits and to find the use of household waste less risky when compared to respondents who did not purchase as many organic products. Furthermore organic consumers were shown to have less trust in the information received from the food industry, and less confidence with regards to that the food industry cares for food safety.

The effect of attitudes on WTP

- A higher WTP was found in capital or urban areas compared to rural areas, significant for bread.
- Attitudes towards sustainability or recycling had no systematic effects
- The Food Disgust scale found that the higher the score, the smaller the WTP – this was highly significant for food industry waste and bio-solids
- For all consumers a lower willingness to pay (WTP) was found for products perceived as risky, regardless of how risks are measured.
- Social norms were important for all consumers. The WTP findings for both bread and carrots produced with any recycled fertilizer implies that if the respondent thinks that its important others are willing to eat food produced with a specific fertilizer this increase WTP.

What was found regarding potential markets for products?

- A market exists for food produced from household waste, particularly with a potential for increased margins if household waste is separated into organic and conventional fractions as the latter are important for the organic consumers.
- A potential, but smaller, market exists for food produced with recycled nutrients from the food industry waste if waste can be separated into organic and conventional streams, with a positive WTP among those respondents favoring recycling.
- A very limited market exists for foods produced with recycled nutrients from wastewater bio-solids (sewage sludge) - unless farmers are paid to use them.

4.4.5 Outlook and research needs

- There is a need to understand how to improve the communication to organic consumers about the potentials of recycling of nutrients so choices will be driven more by objective facts than perceptions.

- Further exploration of the impact of social norms on the acceptance of food produced with recycled nutrients. How can it be possible to make nutrient recycling the norm?
- How can organic consumers trust in the food industry be increased?
- To analyze to what extent organic food waste can be separated into an organic and conventional fraction as the origin of the fertilizer is of importance for the organic consumer.

5 Sectoral dialogues

Over the course of the project, RECONCILE held three workshops to engage in dialogue with sectoral actors. The primary purpose of these sectoral dialogues was to discuss the project's scientific results and gather stakeholders' views on RECONCILE's findings regarding ecosystem integrity and consumer credibility. Additionally, the dialogues aimed to address broader sectoral needs. The dialogues were attended by a diverse group of actors from the Danish sector, including non-governmental organizations with specific interests, sectoral representatives, governmental departments, and the private sector, representing nine different entities. Key reasons given by actors for joining the sector dialogues included:

Access to knowledge: To be updated on the scientific aspects of the project, with insights into ecological risks and consumer behavior.

Collaboration and working towards common goals: participants were generally also interested in the dialogues to improve collaboration with other actors working towards common objectives, which include: ensuring the credibility of organic farming; ensuring nutrient access; promoting organic farming in Denmark; organic farming as an environmental policy tool; promoting recycling, circular economy, and bioeconomy; representing businesses interested in recycling and protecting nature and the environment.

Key knowledge needs: Two key knowledge needs identified by actors were, firstly, to further understand consumer views and acceptance of increased recycling in organic agriculture, and secondly, regarding obtaining a deeper understanding of environmental risks that are not well understood at this stage, for example microplastics.

Networking and dialogue: To strengthen professional networks through participation, and to engage in discussions on recycling challenges.

The workshops were an important avenue for sharing and discussing the research emerging from the project, obtaining feedback, and identifying sectoral needs related to opportunities and challenges in promoting recycling, as well as disseminating this knowledge. Moreover, the workshops focused on how the knowledge generated by the project could best be synthesized and disseminated, with the following key pointers for the synthesis:

- Ensure a concise summary of the project's main scientific results and a brief discussion of these in relation to the current state of organic farming in Denmark and the EU.
- Ensure the synthesis is written in a style which is accessible to a broader audience, and preferably in English.
- Ensure the scientific articles supporting the conclusions in the synthesis are easily accessible to readers (i.e., not behind paywalls) and available digitally.
- The synthesis should serve as a knowledge base for various stakeholders, supporting their work whether it be political or business-related, emphasizing that it is science-based.
- Maintain a high-level perspective in the synthesis, avoiding detailed discussions of specific products.
- The sectoral dialogues furthermore highlighted potential barriers to increased use of recycled products, which are not directly addressed by the project, for example the PFAS question.

6 Towards an increased utilization of recycled waste in organic agriculture?

The RECONCILE project investigated the use of recycled waste in organic agriculture, focusing on deepening our understanding, and challenging two key, commonly held constraints. The first being that waste streams are too contaminated to warrant their use in organic agriculture – the risk is simply too high from an ecosystem integrity perspective. The second being that consumer acceptance is regarded as an impediment to increased use of waste streams. The findings presented in this synthesis of RECONCILE's work demonstrates the complexity when dealing with wastes from various sources. The ecosystem integrity studies demonstrate that there can be a more nuanced presentation and understanding of risk for specific waste types what is feasible to use going, forward, whilst the consumer studies certainly demonstrate the importance of perceived knowledge, experiential knowledge and individuals own perception and world view may influence people's attitudes.

6.1 Are contemporary waste streams sufficiently safe?

Should consumer's perceived knowledge of risk be a basis for regulators decision-making? What does the science say? RECONCILE's first hypothesis was that:

- Contemporary waste and residue streams have improved considerably in quality over the past 40 years, and it is safe to use them, even if they contain some unwanted contaminants – for example regarding content of micro-plastics and low levels of heavy metals

The results presented in Chapter 3 provide findings **that support this hypothesis**. Given the potential differences in waste types and their treatment, we highlight the following key findings of RECONCILE.

1. The positive effect of nutrients from recycled wastes on soil fertility is well established

Fertilization with composted household waste and sewage sludge in accelerated dosages had **beneficial effects** on soil health in terms of soil organic matter content and abundance of decomposer organisms compared to unfertilized and mineral fertilized treatments. RECONCILE furthermore shows that unfertilized soil had the lowest micro- and organism biology content.

2. No demonstrable negative effect of recycled wastes on soil microfauna

Experiments with earthworms and quantification of various soil organisms indicate that household waste and sewage sludge, including the inherent contaminants, do not affect soil health negatively. It is well-established that nematode community structure responds to soil heavy metal pollution. No adverse effect of sewage sludge or composted household waste on nematode communities was found at the CRUCIAL site. No significant effects of the plastic treatments on earthworm fitness was found, but results indicated that earthworms may be able to detect and avoid plastic particles at high concentrations in the soil.

3. Heavy metal content in soils receiving recycled wastes does not raise soil health concerns

The studies found increases in the copper, zinc and silver content in the treatments that have received more than 100 years of legally permitted addition of sewage sludge and composted

household waste. No effect was found on cadmium and lead. However, the content of copper and zinc, as well as cadmium and silver metals was well below the soil quality criterion. The soil quality criterion is a value that must ensure that the use of the soil is sound in terms of health.

4. No detrimental effect on nitrogen fixation found

Preliminary results show that there has been no detrimental effect on the soil's ability to fix nitrogen from the air, despite the application of sewage sludge and composted organic household waste equivalent to more than 100 years of legal input.

5. The potential risk of current microplastic concentrations in soil appears to be low, and below levels that cause a negative effect, but more research is required

Regarding microplastic quantities measured in agricultural fields, the RECONCILE review finds that microplastic contents in fields are below microplastic levels that cause negative effects in most current effect studies. Growth of earthworms and abundances of organisms were higher in these treatments compared to NPK-fertilized or unfertilized plots

It was concluded that the potential risk of current levels of microplastics in terrestrial environments is limited for agricultural soils, but more studies are needed to perform a robust risk assessment. Furthermore, the researchers emphasize the need for further research to better understand the extent of microplastic pollution, its sources, and its effects on soil ecosystems.

6. The environmental risk of sewage sludge and composted household waste is generally low, but further work is required

RECONCILE researchers have previously concluded in a review that metals, pharmaceuticals and estrogens from sewage sludge pose a low risk to soil organisms, highlighting that the resilience of the soil and soil biotic communities generally is underappreciated. Overall this study found that the risk associated with agricultural use of Danish sewage sludge is comparable to that of conventional pig slurry, once the EU limits for Zn and Cu addition to pig feed have been fully implemented.

6.2 Organic consumers attitudes: a broad array of opinions

The qualitative and quantitative analyses explored a range of consumer types attitudes and perceptions of the use of societal wastes in organic farming. The results of these studies provide a diversity of contrasting views, indicating a plethora of opinions which are based on perceived knowledge and influenced by world view. Drawing generalizable findings, which resonate with all consumer types, is thus not straightforward.

The findings of the qualitative study indicate the following:

- The reactions and conflicting opinions among organic consumers concerning the dilemmas surrounding the recycling of materials into organic food production implies that not all consumers who often or always buy organic foods today will be able to support this way of developing organic agricultural production further. Thus, moving forward will potentially alienate some of those in the key target group.
- For the majority, learning about the use of conventional manure helps them to accept other forms of non-ecological, organic material as fertilizer inputs. For some, these materials can be used alongside the use of conventional manure, while for others, the materials should replace the use of conventional manure. A minority of respondents felt, on the other hand, that this route compromises organic production too much.

- The fact that conventional manure is used in organic production today is not general knowledge. This information has the potential to alienate some organic consumers, but on the other hand, with time, it can also pave the way for acceptance of alternative fertilizer inputs. Thus, consideration should be given as to whether any future communication about alternative fertilizer input should be accompanied by information concerning ways of organic agricultural production today.
- Moving forward, it is vital to consider which types of material to use as not all material carries an equal level of acceptance. Furthermore, the decision must be made as to whether these materials should be used alongside conventional manure or replace it.

How information is communicated is of vital importance and would require further exploration:

- Several participants' opinions matured as the interview progressed (and they received more information about fertilizer types). This may indicate that communication over time (possibly in several phases) could be beneficial.
- Findings suggest that the specific wording seems important for acceptance. Transparency is important, but too many details have the potential to alienate, especially when it comes to waste materials such as manure, biosolids from wastewater, and human urine, where some participants expressed ambivalence, even though the thought of using of these materials as fertilizer inputs made sense to them rationally.
- It can prove to be a balancing act between what information should be provided in a potential information campaign to the public, and what information should simply be made available on websites and in reference works:
    - Words like 'nutrients', 'biofertilizer', 'biodegradable', 'compostable', 'natural' and 'organic' appear to be more navigable than words such as 'household waste', 'industry', 'feces', and 'slurry', despite this study being too flimsy a foundation to be able to determine which specific words it would be best to use when communicating about this.
    - Framing the use of alternative fertilizer inputs in a larger context of responsible production, sustainability and circularity would aid acceptance among this key target group as it is a context in which they find organic agricultural production to have crucial relevance.
- The only thing that most organic consumers in this study reject is the thought of the waste material being at risk of containing microplastic. The use of materials containing microplastic should be carefully considered.

The quantitative study shed the following insights, some of which were in contrast to the qualitative study.

- The researchers found a lack of effect of provided information on respondent's opinions, results indicating that it was difficult to influence respondents risk perception through the objective information provided.

One may conjecture that the information provision in the two study types (i.e. how the various new fertilizer types were presented to consumers) had different levels of effect on consumer attitudes. It is apparent from the two studies that consumer attitudes matter and that there is some skepticism about the use of certain products. In this regard, communication and framing does matter, and should actors want to communicate explicitly about various waste types utilized as fertilizers, then significant effort to change attitudes is required.

6.3 The EU and regulatory acceptance

Whilst RECONCILE sought to understand environmental risks and consumer barriers to increased use of recycled waste as fertilizers, it is also important to consider what the regulatory requirements are. Potential authorization of any new input for organic production must follow two regulatory steps: first, the input has to comply with corresponding EU horizontal legislation, after which it has to be added to the annexes of the Regulation (EU) 2021/1165 (positive list). The EGTOP[9] assists the Commission by assessing compliance of the following criteria with the objectives and principles of organic production:

- Necessity for intended use and known alternatives
- Origin of raw material and manufacturing process
- Environmental issues, use of resources, recycling
- Animal welfare issues
- Human health issues
- Food quality and authenticity
- Social, economic, and ethical concern

The Organic Regulation (EU) 2018/848 defines the principles and practices of EU organic agriculture and establishes that external inputs in organic agriculture are limited to (i) inputs from organic production; (ii) natural or naturally-derived substances and/or (iii) low solubility mineral fertilizers. Furthermore, they must be compatible with the objectives and principles of organic production to be authorized, and finally, only products and substances that have been previously authorized in other relevant and applicable EU horizontal legislation can be used in organic production.

There are currently no clear provisions in the EU Organic Regulation regarding the conditions under which recycling of societal waste can be considered as compliant with the principles of organic farming. Important aspects need to be clarified, such as the sources of waste that are acceptable, the production process (in terms of energy consumption, additives), the quality of the end-product, or even the possibilities to certify compliance of the product with the organic rules. The quality of the waste source can vary greatly from country to country, making it difficult to establish harmonised rules for the quality of the final product. Without a clear regulatory framework, it is difficult to include new external inputs in Annex II of the Organic Regulation.

[9] The Expert Group for Technical Advice on Organic Production (EGTOP) is mandated to evaluate products, substances and techniques which can be used in organic production, in the light of the most recent technical and scientific information available. It can conclude whether substances and production methods are in line with the objectives, criteria and principles as well as the general rules laid down in Regulation (EU) 2018/848 and, hence, can be authorised for use in organic production under the EU organic legislation.

7 Future outlook: what is missing in the puzzle?

The need for increasing use of societal wastes is driven by projected growth in organic agriculture, resulting in increased competition for, and lowered supply of nutrients. Furthermore, increased utilization of waste is driven by a societal desire for circularity/a circular economy.

The RECONCILE project explored two broad areas relating to increased utilization of societal wastes in organic agriculture, namely furthering our understanding of environmental risks, and exploring consumer perceptions and attitudes about new fertilizer products.

Regarding environmental risk assessments, RECONCILE shows that, whilst we have scientific certainty related to certain risks for sewage sludge and composted household waste, there are risk areas which require further exploration. We know that contaminant levels have declined, and for various fertilizer types, the contaminant levels can be documented to be below regulatory requirements. In such instances, sound risk assessments can form a basis for increased utilization. However, RECONCILE's research on microplastics demonstrates that further work is required to provide a scientific basis for sound risk assessment. Furthermore, the RECONCILE project did not have a focus on PFAS, which remains a topic of contention more broadly.

The results from RECONCILE about organic consumer perceptions and acceptance of fertilizers derived from societal waste give rise to a number of considerations. The results indicate that merely providing more information about the use of fertilizer types in organic agriculture, even those currently permitted, has an effect on perception and attitudes. Further to this, presenting consumers with communication about societal needs, from a sustainability perspective, does have an effect. It is also evident that wording matters in communication, as it was shown that how information is communicated is of vital importance. A key sectoral consideration is thus to assess if, and what, information should be provided in a potential information campaign to the public, and what information should simply be made available on websites and in reference works.

A key question is how complete our understanding should be before recommending utilization of societal waste streams in organic agriculture. A balance between societal need and scientific certainty is required, particularly since the quality of societal waste derived fertilizers has improved substantially as shown in RECONCILE and other research. We therefore suggest that, the use of organic waste products in organic farming can be initiated, provided that the following conditions are met:

1. The waste's content of pollutants must remain below established threshold values.

2. The threshold values must be based on careful and reasonable risk assessments.

3. Knowledge of risks, and concerns regarding emerging contaminants can be assessed based on source types, with risk mitigated through effective source control, whilst research concomitantly furthers our understanding of certain risks. The role of long-term experimental sites is important in this regard.

These conditions ensure that the use of organic waste products does not compromise soil quality or food safety. It is important that the risk assessments consider both short-term and long-term effects on the environment and human health, so that organic standards are maintained.

7.1 Needs going forward

RECONCILE has identified the following needs going forward:

Microplastics

- There is a need for further research to better understand the extent of microplastic pollution, its sources, and its effects on soil ecosystems, which can serve as a basis to perform a robust risk assessment.
- To understand how microplastics affect microbial communities and functioning in the environment, there is need for experiments at environmentally realistic concentration.
- To explore feasible ways towards reducing 'unwanted' components in urban/industrial waste products.

Plants and soils

- Assessments of waste fertilizer biotic effects and/or the bio-availability of relevant compounds in more sandy and acidic soils would be relevant to evaluate potential adverse effects in other soils types.
- Future studies are required utilizing a long-term experimental site to refine and further our understanding of earthworm activity and reproduction, focusing on a broader suite of earthworm species in the long term experiment.
- Further studies of plant uptake of heavy metals by a suite of crops.
- Plant uptake of xenobiotic organic chemicals e.g. medicinal residues, and whether this is comparable or higher than plants fertilized with animal manure.
- A comparative assessment of the

Consumer perceptions and acceptance

- RECONCILE provides a nuanced view of perceptions and attitudes, and there is a need to assess how this knowledge shall be utilized from a sectoral perspective.
- There is a need to further understand how to improve communication to organic consumers about the potentials of recycling of nutrients.
- Further exploration of the impact of social norms on the acceptance of food produced with recycled nutrients. How can it be possible to make nutrient recycling the norm?

PFAS

- Risk assessment of PFAS content in various waste derived fertilizer products is required

Bringing certain knowledge forward into societal processes for change

- It is evident that there is varying scientific certainty of risks and opportunities of fertilizer types. Where scientific certainty is higher, for example, regarding the impacts of sewage sludge, then this knowledge needs to be brought forward into processes to enable a broader utilization in organic agriculture.

Continue to build our understanding of ecosystem effects through long-term experiments

- Long-term experimental sites, such as CRUCIAL, have enabled researchers to further our understanding of ecosystem effects of societal waste recycling. Such sites remain invaluable going forward to underpin knowledge needs to support ongoing risk assessments.

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Front page photo: *Experimental field at Højbakkegård near Taastrup, Department of Plant and Environmental Sciences, University of Copenhagen. The field is used for the long-term experiment CRUCIAL (Closing the Rural-Urban Nutrient Cycle - Investigations through Agronomic Long-term experiments). Photographer: Morten Resen.*

Back cover photo: *Dorette Müller-Stöver, Associate Professor, Department of Plant and Environmental Sciences, University of Copenhagen (left), and Marianne Tesdorpf, Product Manager, Solum (right), in front of a production of compost soil for the construction of roadsides and golf courses. Photographer: Jakob Magid.*