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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.

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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 must provide documentation for the need to use manure from a conventional source, its use is still permitted (European Communities 2007). For example, in Denmark, where the EU regulations are a minimum requirement, the rules state that a maximum of 70 kg N ha^{-1} can be sourced from conventional manure without justification, whilst the Soil Association in the UK allows the use of non-organic manure, yet require justification and documentation of sourcing (Soil Association 2010; Plantedirektoratet 2010).

The uptake and spread of organic agriculture is a transitional and dynamic process. This process encompasses working out how best to move towards the goal of a more ideal organic agriculture, embodied in the organic principles. The goal of an ideal organic agriculture entails seeking agricultural systems with minimal negative effects on the environment, animals and society in general, and can be seen as something as an ultimate goal, which organic agriculture seeks to move toward. An example of the dynamic nature of organic agriculture is the decision to disallow the use of conventional feed in organic systems. Similarly, the organic sector in Denmark is aware that reliance on nutrients produced in a manner not aligning with the organic principles is not acceptable in the long term. Organic agriculture in Denmark should ideally be sustainable and operate independently of the conventional food system (Kyed et al. 2006).

In recognition of this conflict between principle and practice, the two main organic agricultural organisations in Denmark have decided to gradually phase out, and ultimately ban, the use of conventional straw and manure in organic production. The decision was made in order to improve internal and regional nutrient recycling on organic farms and decrease organic agricultures' reliance upon conventional agriculture. The decision was also made to prevent the import of genetically modified organisms (GMOs) into organic systems via manure from animals fed with feeds from genetically modified crops. It raises a number of challenges for the organic sector in Denmark, particularly since many organic farmers' nutrient management strategies are based upon the current rules, which allow a broad range of inputs which in the future will be banned (Jørgensen and Kristensen 2010).

The decision to eliminate the use of conventional manures and straw in organic systems in Denmark means that organic farmers will need to rethink both farming system design (crop rotation, tillage systems, livestock integration) as well as sourcing of nutrients in future strategies. The aim of this paper is to discuss and explore the implications of banning the use of conventional animal manure in organic systems, using Denmark as a case. We will focus upon nutrient recycling in arable systems and review what types of technological options are currently applied and might be available in the future for organic farming systems. The paper will particularly focus upon the role that the recycling of different types of organic waste products can play as a nutrient source in organic systems.

Methodology

The analysis is based upon a review of peer-reviewed literature and literature specifically related to the Danish context. Using Denmark as a case, we start by giving a background to the decision to phase out manures and straw and the solutions already set forward within the Danish organic sector. The core focal areas for phasing out conventional nutrients are as follows (1) amendments to crop selection and rotations, particularly the role of catch crops in the rotation and improving nutrient use efficiency; (2) alternative nutrient sources (organic waste), including the role of biogas and (3) increased cooperation between organic livestock and arable farmers. The focus of our review is on the potential role of alternative nutrient sources. The review thus focuses upon plant production systems, and therefore on the effects of banning conventional animal manure, as the impact of banning conventional straw will primarily affect animal producers (and some specialist vegetable producers such as carrot). Following the presentation of the Danish case, we broaden the review to explore the general literature to discuss the advantages and disadvantages of alternative nutrient sources.

The case of Denmark

Background and proposed strategy

The strategy for phasing out conventional manure and straw is the result of a process started almost 10 years ago. Organic Denmark (OD) and the organic section at the Danish Agriculture and Food Council (DAFC) sought to make a decision in 2003 to be implemented by 2011. However, given the extensive consequences of such a decision, the decision was delayed until further research had been conducted to investigate the implications of a ban and possible solutions explored. An extensive analysis was thus prepared by Kyed et al. (2006) to, firstly, report the extent of use of conventional manures and straw in Danish organic agriculture and, secondly, conduct economic calculations based upon scenarios for different producer types in order to estimate the economic consequences. Following further investigation into the consequences of a ban, the proposal to phase out conventional animal manures and straws in organic agriculture was passed at Organic Denmark's annual general meeting in 2008. The decision thus emanates from the organic farmers themselves and still needs to be linked legislatively with the current rules in Denmark. The proposed strategy, passed in 2008, was originally intended to start in 2015. It was decided that for manure sources,[1] in line with current regulations, organic farmers are allowed to import 70 kg N ha^{-1} from conventional sources until 2015. In 2015, the amount will be reduced annually by 10 kg N ha^{-1}, and by 2021, the permitted amount of conventional manures will be zero. In early 2012, the boards of OD and DAFC agreed to an amendment of the 2008 proposal. The new plan has removed the requirement of annual reductions of 10 kg N ha^{-1} from 2015 until 2021 but retains the 2022 target of a complete ban on conventional manure use in organic agriculture.[2] The amendment was made in order to give more time to find new solutions, and in recognition of the fact that the 2015 deadline has caused significant uncertainty among organic farmers as well as farmers considering conversion. The two organisations, furthermore, recognise that there need to be concrete solutions available for farmers before starting such a ban. It is expected that as more alternative nutrient sources become available, or improved methods developed, the amount of N permitted from conventional sources will be reduced. As such, it is expected that the amount of permitted N will be reduced to 50 kg ha^{-1} in 2017.

Possible consequences

The main organic production system types in Denmark are dairy, arable and horticultural systems. Geographically, organic farming in Denmark is characterised by a marked regional distribution pattern of farm types (Frederiksen and Langer 2004). The geographical spread of organic farms emanates from specialisation trends in the general farming sector. Animal production is mostly concentrated in West Denmark (Jutland), whilst most plant production is located on the islands of Eastern Denmark. This geographical divide will, in particular, have connotations for (1) the supply and trade of organic manure and straw in the future, and (2) how the organic sector is expected to develop and expand with the new rules, given that land ownership requirements for conventional animal producers, which stipulate that animal producers must have an area corresponding to the number of animals, is expected to drive land prices up in livestock-rich areas.

Kyed et al. (2006) presented a number of scenarios with calculations of the potential economic consequences of the ban for organic crop and vegetable producers. The ban will invoke responses other than a simple input substitution (purchasing of organic manures), as explored below. The results of the economic scenarios are strongly influenced by organic farm location: the price of imported manure was calculated to increase from 2.8 to 5.2 Euro per ton manure for farms located in areas where organic animal production is concentrated, whilst the price was calculated to increase from 4.2 to 12.1 Euro per ton manure in areas with a low concentration of organic animal farms. Predictions of this nature have a high uncertainty, although they provide an idea of the extent of possible increased production costs for farmers.

Tvedegaard (2007) conducted ten case studies of different types of organic farms in order to elucidate the type of case-based consequences. Scenarios for the three arable farmers studied generally entailed a large reduction in the amount of manure applied and changes to their rotation involving an increase in nitrogen (N)-fixing plants and a reduction in grain production, resulting in considerable additional costs for farmers. Likewise, the case studies of specialist

[1] For straw, from 2015, organic farmers will be required to document that: (1) straw used has not been sprayed with pesticide up to 1 month before harvest and (2) that no crop growth regulator has been applied. From 2021, the use of non-organic straw can only occur if approved by the authorities.

[2] For straw, the legislative requirements of proving the origin of straw require further investigation by The Danish AgriFish Agency. However, the new strategy stresses the desire to work towards a reduction in use of non-organic straw in organic agriculture.

vegetable producers showed increased economic cost and the risk of either discontinuing production or having to move farms closer to an organic animal farm. Paradoxically, for one farmer, the ban would also entail an increased import of organic fertiliser (which he sources from Holland) and organic straw (from approximately 80 km away).

Kyed et al. (2006) present a range of possible responses by organic crop producers, the most noteworthy of which include strategies to increase the amount of fertility building crops in the rotation, the importing of organic livestock manure (up to 40 km away), reverting to conventional farming or including an animal production component on the farm (integrated production). A particularly startling potential scenario is that there is a risk that a large number of organic crop producers in areas with a low concentration of organic livestock will either stop farming or revert to conventional farming (Kyed et al. 2006).

Tvedegaard's (2007) conclusions from the farm case studies succinctly outline the potential challenges ahead. The ban will mean that a contentious issue (reliance on conventional agriculture) in organic agriculture will be resolved, but it will also cost organic farmers money, lead to fewer organic farmers, result in increased imports of organic products, increase transport and not improve animal welfare (due to challenges in supply of organic material for bedding). The decision puts Denmark at the forefront of the international organic sector and, taking an optimistic outlook, the decision will enhance the reputability and consumer credibility of organic agriculture and secure a future sustainable development of the sector. However, from a critical standpoint, the initiative might undermine the foundation of the Danish organic farming sector, putting an expansion of organic farming in Denmark at risk. The recognition of this risk is already evident in the recent amendment of the strategy. In particular, organic farmers in the rest of the EU might have a comparative advantage over Danish farmers in that they will not be restricted in their use of conventional manures and straw. Furthermore, concern has been raised whether the ban might lead to increased nutrient mining due to lower inputs as well as the fact that organic farmers in the future are likely to increasingly transport organic inputs from further away, causing higher energy use in organic production. However, in the long term, a decision of this nature will move the organic sector closer to realising the goal of being independent of the conventional system.

Looking forward: strategies to meet the challenge in Denmark

There are a number of important institutional initiatives which have been implemented in the past few years which are of great strategic importance for the organic sector. In 2009, the Danish government announced their vision for 2020, entitled Green Growth. The plan contains an ambitious goal of doubling the organic area in Denmark by 2020 which will mean organic land will make up 15 % of the total farmed area (Ministry of Economic and Business Affairs Denmark 2009; Dalgaard et al. 2009). In conjunction with this, the government plans to increase biogas production significantly, not only in order to decrease reliance on fossil energy sources but also to increase energy recovery and recycling of animal manure, the goal being set at 50 % of all manure to be processed in biogas plants by 2020. Institutional support for such initiatives is imperative to ensure the continued growth of the organic sector as well as to ensure the regional supply of organic inputs. This point will be elaborated upon in the biogas section below.

Central actors in the organic sector in Denmark recognise that there is no single solution to meet the future challenge of operating without conventional nutrients—meeting the challenge will require a mosaic of different strategies (Jørgensen and Kristensen 2010). For example, studies such as Thorup-Kristensen et al. (2012) can be central to finding applicable solutions. The Danish organic agriculture advisory services will play a pivotal role during the phasing out process and considerable attention has been given in the past few years and will be in the forthcoming years, to ensure farmers are fully prepared. The overall strategy outlined by a working group commissioned by OD and DAFC identifies an array of programme areas which should be considered in unison (Jørgensen and Kristensen 2010). Central elements of the strategy include:

- Crop rotation design: even more important than before the ban, particularly enhancing understanding of nutrient supply and release at different stages in the rotation
- Increased and improved nutrient recycling: in the field, from animal houses to field, and at a regional scale from urban to rural areas

- Green manures and catch crops: increased knowledge building and dissemination of their role, particularly optimization of timing of nutrient release
- Biogas: develop biogas plants that can run on plant-based feedstock. Particularly in East Denmark, where the lack of organic animal production means farmers will lack manure
- Yields: increased focus on factors other than fertilisers effect on yields, such as climatic factors, crop rotations and crop health
- Breeding and use of crop cultivars which are more appropriate for low-nutrient conditions
- Increased cooperation between organic livestock and arable farmers (Jørgensen and Kristensen 2010)

Nitrogen supply is not the largest challenge in arable organic systems in Denmark as its supply can be biologically controlled in the system (Thorup-Kristensen et al. 2003). The challenge with nitrogen is to reduce losses from the system whilst ensuring a sufficient supply. Supplying nutrients which cannot be reintroduced biologically such as potassium (K) and phosphorous (P) will be an increasing future challenge for organic farmers. Phosphorous is very insoluble and immobile in the soil; therefore, even if the soil contains considerable amounts, availability is typically low for many plant species. The challenge with phosphorous and other immobile nutrients is thus not just one of supply but also improving plant accessibility. Measures to improve the bioavailability of phosphorous centre upon improving the crops' ability to access immobile nutrients, for example crops with root systems developed for low-nutrient conditions, and ensuring that soils have high biological activity (Brady and Weil 1999). Potassium supply in soils is mainly influenced by soil mineralogy, an inherent property which is difficult to amend. Amendments to improve potassium-depleted soils will thus have to be based upon external inputs, either in permitted mineral forms or in organic inputs such as animal manure. Micronutrient supply in organic systems can primarily be improved by ensuring a continued supply of organic matter to soils coupled with increased biological activity (Stockdale et al. 2002).

Securing a sufficient supply of nutrients will play a pivotal role in securing cropping system sustainability. In the next section, we explore the various types of nutrient sources, which either currently are or might be available to organic farmers in the future, and discuss the feasibility as well as the pros and cons of their use.

Organic fertilisers and amendments

Fertilisers permitted in organic agriculture can be broadly categorised into two groups: organic materials and naturally occurring geological resources (Davis and Abbott 2006). Figure 1 presents an overview of sources of organic materials which currently are or might, in future, be used in organic systems. Before application to arable land, organic regulations demand that most sources presented in Fig. 1 be subject to pretreatment, typically through a composting process or a biogas digester. This may not always be ideal from a nutrient efficiency viewpoint, as losses are almost inevitable; however, it is often required for sanitary reasons. Some of the sources are currently permitted in organic regulations, for example animal manure, whilst other sources are currently not permitted (e.g. sewage sludge) or permitted with restrictions (e.g. household food waste). With justification and documentation of contents, a variety of naturally occurring minerals are currently also permitted in organic systems, for example rock phosphate, natural rock potash, lime and elemental sulphur (European Communities 2007; Davis and Abbott 2006). Restrictions in agronomic use of treated organic waste and naturally occurring mineral resources typically arise due to potential risk of contamination from heavy metals, pathogens, salts and weed seeds (Hargreaves et al. 2008; Quilty and Cattle 2011). Organic fertilisers permitted for use in organic farming, and the restrictions which might apply, are stipulated in the specific requirements of organic certifiers (e.g. European Union regulation).

Products labelled as organic fertilisers or organic amendments in various forms are increasingly being produced by manufacturers for commercial purposes. Following treatment, organic wastes can be processed to varying degrees for use in agriculture. End products can range from a bulky product such as slurry to products such as chicken manure pellets marketed as organic fertiliser. For example, Quilty and Cattle (2011) demonstrate in their categorisation of organic fertiliser products available on the Australian market that there is a very large supply of different product types developed from a broad variety of feedstocks (see Table 2, Quilty and Cattle (2011)) .

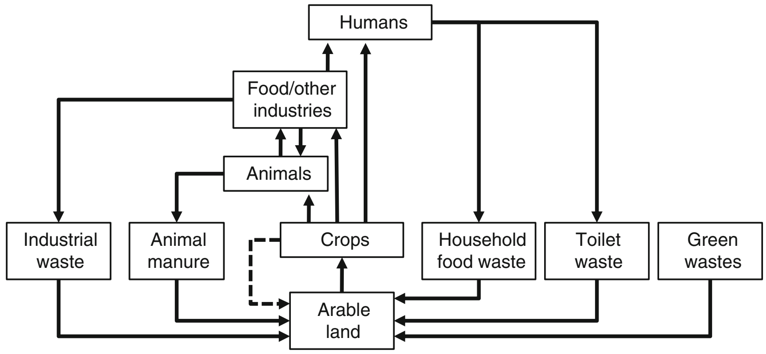

Fig. 1 Options for nutrient recycling from different organic waste sources. Wastes are treated before land application by processes such as composting or biogas. Figure adapted from Kirchmann et al. (2005)

Organic waste products can effectively be treated either by composting or anaerobic digestion (Odlare et al. 2011). Composting of organic matter is a biologically mediated and oxidative process which results in the formation of humified organic material (Hargreaves et al. 2008). The mineral composition of composted organic matter depends upon the type of feedstock used; however, composted organic matter is generally considered a sufficient source of plant nutrients and organic matter (Evanylo et al. 2008; Bulluck et al. 2002). Anaerobic digestion of organic wastes leads to the production of biogas (methane and carbon dioxide) and a residual product, which can be used as an organic amendment (Arthurson 2009).

In the following sections, we will present and discuss different potential uses of organic amendments, focussing upon: (1) the amount and technical feasibility of their use in organic agriculture from the Danish case perspective, (2) the efficacy of the product from a plant production perspective and (3) use of the amendment in organic agriculture regarding technological feasibility and legislation.

Animal manures and slurry

The merit of using animal manures, in different forms, as a fertiliser is a well-researched topic (Diacono and Montemurro 2010; Edmeades 2003). Animal manures[3] are the most readily available organic nutrient inputs for organic farmers in Denmark. However, the question is whether organic systems in Denmark can be self-sufficient in organically produced manures and slurries? The most recent analysis of Danish organic farmers' production and use of manure and slurry was conducted by Kyed et al. (2006) and presented in Table 1. Their analysis is based on Danish fertilisation/manure accounting statistics from 2002 and uses the organic area in Denmark as registered in the General Agriculture Registry in Denmark. Manure amounts are registered in kilogram of total nitrogen per hectare. We used weighted ratios of N to P and K standard values for nutrient contents from the Danish manure registry (Ministry of Food Agriculture and Fisheries 2008) in order to calculate applied amounts of phosphorous and potassium.[4]

The amount of imported non-organic manure was on average 24 kg N ha^{-1}. Organic arable farms supply of organic manure consists of organic manure either from the farms own livestock or through imports from other organic farms. Noteworthy is the difference in amount of manure applied by arable and dairy farmers. Organic dairy farmers, with their own supply of manure, applied on average 51 kg N ha^{-1} more than arable farmers. Dairy farmers were found to sell organic manure to other organic farmers, although they still imported non-organic manure. It is important to note that the per hectare reliance upon imported non-organic manure presented in Table 1 is most likely much higher when considering actual manure use on organic farms. The aggregated amount of non-organic manure presented in Table 1 is calculated based on all organic land, thus including areas receiving no or very little manure (such as all organic land planted to nitrogen fixing crops). As such, it is estimated that for

[3] Animal manure includes faeces and urine excreted by the animal as well as bedding material and spilt feed depending on the different production systems

[4] According to Kyed et al. (2006), conventional pig slurry is the primary type of imported manure to organic farms. The proportion (DK total) of applied manures in 2002 was as follows: deep bedding, 26 %; cattle slurry, 39 %; pig slurry, 17 %; other liquid, 14 %; and other, 4 %.

Table 1 Average amounts (in kilogram per hectare) animal manure applied in Denmark by organic farmers (for 2002), based on analysis by Kyed et al. (2006)

	Arable farms			Dairy farms			Total DK		
	N	P	K	N	P	K	N	P	K
Total applied	65	13	59	116	24	105	88	18	80
Amt of total from conventional sources	25	5	23	22	4	20	24	5	22
Sale of organic manure	0	0	0	14	3	13	0	0	0

land receiving manure, the amount of non-organic manure actually applied is most likely to be considerably higher (Personal communication, Mejnertsen (2011)).

Table 2 presents the latest figures (2008) for production of animal manure, from conventional and organic farms, in Denmark. Whilst the values presented in Table 2 are for volumes, they provide an indication of the amount of organically derived manure available. For example, a hypothetical application of all organically derived manure to all organic land, from Table 2, would supply 10.8 tons/ha. Using a nitrogen content of 0.5 % would give a supply of 54 kg/ha. Comparing this to the average of 88 kg N ha^{-1} from Table 1, even though these numbers are derived from different years, provides an indication that there might be a shortfall in supply. Livestock, and hence manure, production is concentrated in western Denmark. Although the theoretical shortfall of organic manure supply may not be very large, the problem for organic farmers will be one of distribution. Organic crop and vegetable farmers located in an economically feasible radius (for transportation) of organic livestock producers will, to a certain extent, be able to trade bedding material for organic manure, whilst transport and other costs will determine how much other farmers will import.

Table 2 Annual production of animal manure (in 1,000 tons) in Denmark by livestock and holding type (2008)

	Conventional	Organic	Organic %
Pig	20,600	133	0.6
Cattle	15,486	1,660	9.7
Poultry	703	22	3.1
Other[a]	1,295	51	3.9
Total	38,083	1,866	4.7

Source: Personal communication, Knowledge Centre for Agriculture 2011

[a] Other includes fur animals, horses, sheep, deer and goats

Residues from biogas production

Biogas and residue production through anaerobic digestion of organic wastes from agriculture and other sources has a potential for increased regional energy production and nutrient cycling (Arthurson 2009). Biogas production is identified as a priority area in the Danish governments' Green Growth Plan (Ministry of Economic and Business Affairs Denmark 2009). The strategy involves providing financial support for the establishment of localised biogas production plants. The Danish government is interested in the production of energy with the co-benefit of reducing the environmental threat posed by the large amount of manure produced in Denmark by utilising animal manure as a feedstock. The vision thus entails locating biogas plants strategically to ensure that local benefits are accrued. Organic organisations in Denmark are generally optimistic about the contribution organic biogas plants can make to more sustainable energy production as well as a source of organic fertilisers, and concerted efforts are underway to pursue the development of organic biogas plants across the country.

Organic standards permit the use of biogas residues as a soil amendment, although with restrictions. Of particular importance is that the feedstock must be organically produced, for example the land application of residue of digested conventionally produced clover would not be permitted in organic systems. However, source-segregated household waste is permitted as an input in organic farming, although the waste should either be composted or digested in a biogas plant. Other feedstocks which, following digestion, provide residues permitted in organic farming include organic manure, organic crops and residues, biomass from meadows, organic butchery waste products (Tersbøl 2009).

In Denmark, there are approximately 80 biogas plants: 20 of which are centralised plants and 60 are farm-scale plants (Birkmose 2009). Typical feedstock for the centralised plants is a mixture of pig and cattle slurry, deep litter and industrial organic waste products. Farm-scale plants are typically located on pig farms and utilise pig slurry and organic waste (Birkmose 2009). As such, the use of energy crops as a feedstock for biogas plants is minimal as it is not economically viable. A general challenge for the development of biogas production in organic agriculture in Denmark will be the sourcing of sufficient biomass to ensure an optimal mix of feedstock. Manure and slurry from conventional agriculture is produced in abundance; however, the use of this in organic biogas plants is not permitted. Since organically derived manure will be a contested resource in the future, feedstock for organic biogas plants will primarily be made up of biomass from green manures, such as clover grass, grown by organic farmers (Tersbøl 2008). Running biogas plants on feedstock with a high percentage of dry matter, as is the case for green manures, is not a standard procedure and will thus require technological advances to ensure an optimal functioning of the plant (Tersbøl 2008).

Amendments to organic farmers' rotations that increase the amount of green manures and reduce the amount of cash crops will invariably have economic implications for farmers, as will investment in new biogas plants. The economic outcome for farmers will depend upon a range of factors, particularly whether farmers have their own plant or a shared local plant.[5] Economic calculations based on scenarios are often farm specific; therefore, the implications for farmers will depend on a range of factors such as potential earning from sale of energy production, sale of organic fertilisers, sale of biomass, potential increase in subsidies due to an increased proportion of green manures in the rotation, either reduced earnings from crop production (lower percentage of cash crops in the rotation) or increased earnings (higher yields following the use of biogas slurry as a fertiliser), transport costs depending on location of plant and future crop prices (Tersbøl 2008, 2009; Fog 2010).

The quality of biogas residue as a soil conditioner is influenced by the composition of feedstock used for biogas production (Arthurson 2009). Arthurson (2009) found that biogas residues typically contain high concentrations of mineralized N and low concentrations of heavy metals and thus offer an alternative to mineral fertilisers. The experimental work reviewed consisted of biogas effluents from various sources, typically animal manures in different forms, domestic household waste and municipal solid waste. Birkmose (2007) compared analyses of digested slurry (based on a mixture of 50 % pig slurry, 25 % cattle slurry and 25 % organic industrial waste) with undigested cattle and pig slurry, showing that the digested slurry had a slightly lower dry matter content and a higher ammonium nitrogen content. The content of P was similar, whilst K content was similar for undigested pig slurry and digested slurry, but higher for cattle slurry. Organic biogas plants in Denmark are envisaged to run primarily on biomass from organic farms; thus, concern about contaminants should be minimal.

Ensuring a sufficient and timely nitrogen supply is critical for securing sufficient yields. This can occur through an increased proportion of nitrogen fixing crops and cash crops; however, a major challenge in organic systems is to match N supply with crop demand whilst simultaneously minimising nutrient loss (Pang and Letey 2000). Contrary to nitrogen that is organically bound, N in ammonium form is readily available for plant uptake; therefore, biogas slurry can provide a viable option for crops where an early and timely supply of nitrogen is important.

Recycling of non-farm organic waste

Central concerns related to the use of non-farm organic wastes as fertilisers in agriculture are particularly about ecosystem and human health effects of contaminants and odour issues. Other issues are often of a technological or economic nature, in particular whether there is a sufficient waste supply to warrant a cost-effective investment in treatment technology and transportation to farmers' fields. In line with this, the potential use of non-farm organic waste products in agriculture also depends strongly upon farmers' willingness to use the products. Analysing Denmark's non-farm waste production exemplifies the potential that organic waste might hold for organic agriculture in the future. Denmark's total non-farm waste production in 2009 was 13.9 million tons (Danish Ministry of the Environment 2011). Table 3 presents a breakdown of the available amounts and the theoretical nutrient supply potential of the organic fraction of different types of non-farm waste in Denmark.

[5] For specific scenarios, please see Fog (2010) and Tersbøl (2008).

Table 3 Theoretical nutrient supply potential by non-farm organic waste type in Denmark

	DM (t)	N (t)	P (t)	K (t)
Household source-segregated organic waste[a] (currently recycled)	14,865	282	34	189
Household waste[a], organic fraction[a] estimate (currently incinerated)	228,800	4,347	526	2,906
Garden and park waste (private and public)	409,635	2,222	394	3,892
Service sector organic waste[a]	9,756	185	22	124
Industrial sector organic waste[a]	35,495	53	9	93
Sewage sludge	132,600	6,312	4,150	716
Total (t)	831,151	13,402	5,137	7,919
Supply to organic agriculture[b] (kg/ha)[b]	4,790	77	30	46

Sources: (1) waste quantities: Danish Ministry of the Environment 2011; Danish Ministry of the Environment 2009; Personal communication, Petersen 2011; (2) nutrient contents: Boldrin 2009; Boldrin and Christensen 2010; Boldrin et al. 2011; Danish Ministry of the Environment 2009

[a] Based on the nutrient content of the vegetable food waste fraction of household waste

[b] Based on a theoretical distribution of total nutrients from organic waste streams to all organic land in Denmark (173,517 ha)

The values in Table 3 provide a theoretical nutrient supply potential, with the hectare distribution based upon a total supply to current organic agriculture. It is important to note that some of the potential nutrient streams are already partially recycled in Denmark, e.g. to private gardens, landscaping or conventional agriculture. However, Table 3 still demonstrates that there is an untapped nutrient potential from non-farm waste types. In particular, there is a large potential in uncollected household organic waste and garden and park waste for nitrogen and potassium and in sewage sludge for nitrogen and phosphorus.

Whilst an increase in recycling of animal wastes, slurry and biogas residues (described in the above sections) adheres to the notion of non-reliance on conventional agriculture, we recognise that a large proportion of nutrients recycled from non-farm organic wastes such as sewage sludge or household waste will inevitably emanate from conventional agriculture. It might therefore be considered paradoxical to recommend their usage in organic agriculture. The question is whether the recycling of non-farm organic wastes actually represents a real reliance on conventional nutrients (compared to reliance on conventional animal manure) or a sensible reuse of a product which would most likely be incinerated? 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. In the following sections, we will discuss issues related to the potential use of non-farm waste types in organic agriculture.

Source-segregated organic waste

Current EU organic regulations permit the conditional use of source-segregated household waste (European Communities 2007). In Denmark, only a small percentage of the organic fraction of household domestic waste is source separated and recycled (12 %). Source-segregated household waste is either digested in a biogas plant or composted. The large proportion of non-segregated organic waste in Denmark, which is currently incinerated for energy recovery in combined heat and power plants, holds a future potential for treatment and potential use in agriculture, as evident in Table 3. However, in order for this to occur requires a significant adaptation of current refuse collection infrastructure, in particular for private households

Source-segregated organic waste as a soil amendment has typically been investigated under the broad term of municipal solid waste (MSW). Although there is no common definition of MSW, the term generally includes solid waste from households, businesses and institutions (Gerba et al. 2011), although Hargreaves et al. (2008) refer to MSW as being largely made up of kitchen and yard waste. Hence, a review of the properties of source-separated organic waste, or MSW, should take heed of the type of composting or biogas feedstock used and the proportions, the treatment facility design, and the composting procedure and maturation period (Hargreaves et al. 2008).

Hargreaves et al. (2008) conducted a comprehensive review of the use of composted municipal solid waste in agriculture. The authors review the effects of composted MSW on soil physical, biological and chemical properties. Whilst the review shows that MSW compost has a potential as a beneficial recycling tool, the authors stress that, due to the large variability in compost content, MSW composts should be consistently monitored. Monitoring should be conducted using standardised procedures to determine bioavailability of nutrients, metals and trace elements, and a measure of the content of organic pollutants (Hargreaves et al. 2008). Farrell and Jones (2009) conclude in their review that composts from MSW and mechanical biological treatment residues are rich in plant-available nutrients, although in some cases, the inorganic salt levels might be too high.[6] They thus find that MSW composts potential to improve soil quality make them ideal for agriculture, although correct measures should be taken to mitigate environmental damage and improve public acceptance.

Smith (2009a) reviewed studies concerning the bioavailability of heavy metals in MSW composts and sewage sludge. The review demonstrates that the total heavy metal content of composted source-separated MSW is lower than that of sewage sludge. However, it is important to note that the phosphorous content of sewage sludge is typically higher than that of composted MSW; therefore, consideration should be given to the ratio of P to heavy metals when using these wastes as fertilisers. Furthermore, the heavy metal concentrations of different types and sources of organic waste, presented by Smith (2009a), demonstrate that source-segregated waste had markedly lower concentrations than mechanically separated MSW, a finding resonated in a review conducted by Farrell and Jones (2009)

Comparing heavy metal concentrations reviewed by Smith (2009a) with the limits set by the organic regulations (for content of composted or digested household waste) reveals that some green waste and source-segregated wastes can fall below the current thresholds, although this is not always the case for all waste sources (Smith 2009a). Heavy metals will accumulate slowly in soils following long-term application of composts; however, the review found little evidence of phytotoxic effects or accumulation of heavy metal in crop tissue that may pose a threat to human health from compost or compost-amended soil. Smith (2009a) concludes that 'risks to the environment, human health, crop quality and yield, and soil fertility, from heavy metals in source-segregated MSW or greenwaste-compost are minimal'. Farrell and Jones (2009) reviewed research of the content of organic contaminants in composted MSW and conclude that, whilst composting provides a critical step in treatment for organic contaminant removal, a clear understanding of various aspects of how composting affects organic contaminants is lacking.

Sewage sludge

In Denmark, sewage sludge (biosolids) is collected from municipal and private wastewater treatment plants. Approximately 800,000 tons of sludge (in wet weight) was produced by wastewater treatment plants in 2008, 56 % of which was recycled to agricultural land (conventional), 43 % incinerated (ashes typically recycled into cement or road construction materials) and 1 % landfilled (based on statistics from 2002) (Danish Ministry of the Environment 2011). Prior to the land application of sludge, it is either aerobically or anaerobically digested and then dewatered using a number of different methods (Jensen and Jepsen 2005).

Sewage sludge is currently not permitted in organic farming systems in the EU due to concerns about pathogens, viruses and the possible content of potentially toxic elements (European Communities 2007; Möller and Stinner 2010). Like other types of organic wastes, sewage sludge can be a source of nutrients to enhance soil fertility (Krogh et al. 2001). In particular, sewage sludge has a high content of phosphorous, making it a potentially valuable resource, given increasing concerns about 'peak-phosphorous' (Cordell et al. 2009). For example, Table 3 shows that the phosphorous supply potential of sludge in Denmark is considerable. However, concerns about the potential heavy metal and organic contaminant contents of sewage sludge have, until now, restricted its use in agriculture in general in many countries, whilst in other countries, e.g. Denmark, a relatively high proportion of the sewage sludge is land applied as any other organic fertiliser, complying with low legal thresholds for heavy metals and other contaminants.

[6] Particularly when used as a substrate for plant propagation.

The primary risks posed by sewage sludge comprise heavy metals[7] and organic contaminants.[8] Smith (2009b) reviewed the concentration data for organic contaminants (OCs) in sewage sludge and assessed the potential environmental and health impacts of organic contaminants in sewage sludge. He notes that according to the European Commission (2006) there are no recorded cases of human, animal or crop contamination due to the use of sludge on agricultural soils following the provisions of Directive 86/278/EEC. Despite the international support for recycling sludge to land, the acceptance of this practice among different European countries varies considerably and has declined markedly in some cases, despite the lack of scientific evidence indicating that it is harmful in any way (Smith 2009b). Smith's review (Smith 2009b) indicates that: 'the presence of a compound in sludge, or of seemingly large amounts of certain compounds used in bulk volumes domestically and by industry, does not necessarily constitute a hazard when the material is recycled to farmland'. Concern has also been raised about 'emerging' organic contaminants, which might be present in sewage sludge. Clarke and Smith (2011) conducted therefore a review of emerging OCs in biosolids (sewage sludge) of a selection of chemicals of potential concern for land application based upon human toxicity, evidence of adverse effects on the environment and endocrine disruption. Whilst they maintain the view that the most sustainable option for biosolid use is land application, they stress that 'continued vigilance in assessing the significance and implications of 'emerging' OCs in sludge is necessary to support and ensure the long-term sustainability and security of the beneficial agricultural route for biosolids management' (Clarke and Smith 2011).

A large assessment of the risk of using sewage sludge as a fertiliser and soil conditioner on agricultural lands was recently conducted by the Norwegian Scientific Committee for Food Safety (Eriksen et al. 2009). The assessment focussed on heavy metals and organic contaminants as well as potential pharmaceutical contaminants. Based on their findings, the assessment panel 'considers the use of sewage sludge to constitute a low risk to the soil ecosystem' (Eriksen et al. 2009). The panel recommended though that as the use of sludge has the potential to increase the concentration of inherent toxic metals, such as cadmium and mercury, the use of sludge on agricultural land should be monitored.

[7] Heavy metals of concern are primarily cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni), zinc (Zn), copper (Cu) and chromium (Cr).

[8] For an overview of organic contaminants, see Table 2 in Smith (2009b).

Other organic waste types

Whilst the potential of sewage sludge has been discussed above, there is also a future potential for new sanitation systems that can source separate wastewater and thus allow for urine and blackwater to be harvested separately and used as a nutrient source after treatment (Winker et al. 2009). The design of integrated ecological waste management systems to recycle urine from urban areas is technically feasible and can lead to increased recycling of nutrients to agricultural land (Magid et al. 2006). However, the implementation of such systems should be cost-effective as well as socially acceptable, both by urban populations as well as farmers. The collection of human urine, which requires a certain type of toilet and collection system, occurs only to a very limited extent in Denmark. Therefore, a future recycling of urine would require significant infrastructural changes. Products derived from domestic wastewater streams can contain organic micropollutants and thus require treatment (Winker et al. 2009). Human urine does not generally contain pathogens that can be transmitted through the environment; however, one inevitable source of pathogens in urine collected from the urine diverting toilets is cross contamination from faeces (Magid et al. 2006).

Garden and park waste is a waste type collected systematically in Denmark which can be recycled following either home or central composting (Boldrin 2009). The amount of nutrients recycled from municipal collection of both garden and park waste (Table 3) demonstrates a considerable potential. The majority of produced compost is typically redistributed to home owners for garden use, whilst it is also increasingly being used by professional landscapers and gardeners (Boldrin 2009). Utilisation in organic agriculture will therefore compete with an existing market for garden park compost, which may drive prices to an unrealistic level for organic farmers.

Nygaard Sørensen and Thorup-Kristensen (2011) conducted an investigation of the fertiliser effects of 'mobile' green manures. Mobile green manures are typical green manures which, instead of being ploughed into the same field, are harvested and applied to other fields. They found that it is possible to produce mobile green manures with a high concentration of sulphur (S), P, K and B. Additionally, they found that the C/N ratio of the green manure had a strong influence on yields. Amendments with a high C/N ratio (>20) decreased yields when compared to inputs with a lower C/N ratio. If garden park waste, which typically has a high C/N ratio, should be used as a fertiliser, it would most likely require the removal of the high C/N ratio fraction (wood material), which can also be useful as biomass fuel. It should be noted though that while mobile green manures may include legumes, which add supplementary nitrogen by fixation, they do not represent an additional input of the other nutrients at the farm level; rather, they can be used to shift nutrient availability between fields.

Acceptability of non-farm organic waste use in organic agriculture

Technical and legislative requirements for the future utilisation of theoretically available organic nutrients to farmers in Denmark constitute one part of the barrier for increased use of these resources. The social acceptability, both for organic farmers and consumers, of the use of organic wastes is an important factor to understand and address. It would be of scant use should organic farmers be unwilling to use organic wastes of certain origin, despite possible consumer acceptance of the use of organic wastes as fertilisers. Current food safety concerns, for example regarding multi-resistant bacteria, do little good in enhancing an increased acceptability and use of organic wastes amongst consumers and farmers alike. It is furthermore essential to discuss how the land application of organic waste products aligns with the principles of organic agriculture. This section seeks to address these questions and will deal with the various waste types individually.

Biogas residue

From a plant nutrition perspective, the potential use of biogas residue as a crop fertiliser is considered positive, although the content of pollutants should be closely monitored (Arthurson 2009). However, from an organic principle perspective, the acceptability of biogas slurry as a suitable organic fertiliser has been discussed, primarily based on the notion that biogas slurry has a very high mineral N content which might be contrary to the principles of organic agriculture of building healthy soils (rather than feeding the plant) (Tersbøl 2008). However, given the increased focus on biogas production in organic systems in the past 5 years, coupled with recognition of current and future challenges related to nutrient and energy supply, the use of biogas slurry in organic farming in Denmark is gaining acceptance. This increased acceptance can also be attributed to the potential yield benefits biogas residue might provide.

Sewage sludge

Although we are fully aware of the stance taken by organic agriculture regarding sewage sludge, we would like to raise the question of whether all sewage sludge should, in future, still be disregarded as a nutrient source in organic systems. Legal requirements about the quality and use of sludge are stringent, particularly following concerns about the concentration of organic contaminants. The European Commission's opinion is that the best environmental use of sewage sludge is as an agricultural fertiliser, provided that its use does not pose a threat to human and animal health as well as the environment (Smith 2009b).

As discussed above, nutrients in sewage sludge (and household waste) might by in large come from conventional agriculture, although ideologically, the use of sewage sludge aligns with the organic ideology of working with closed cycles. However, the application of the precautionary principle in organic agriculture so far prevents the use of sewage sludge. The precautionary principle is a broadly applied term in environmental regulation. According to EU legislation, the precautionary principle may be invoked where urgent measures are needed in the face of a possible danger to human, animal or plant health, or to protect the environment where scientific data do not permit a complete evaluation of the risk (Commission of the European Communities 2000). This principle is applied mainly where there is a danger to public health. For example, it may be used to stop distribution or order withdrawal from the market of products likely to constitute a health hazard. Thus, according to the EU, there can be no question of merely taking a negative attitude towards risk.

The organic principle of care, one of the four main principles of organic agriculture, states that: 'Organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment' (Luttikholt 2007). Indeed, the precautionary principle is central to organic agriculture concerning the management of risk, for example preventing the use of GMO. The precautionary principle places a burden of proof on those who create potential risks and requires that activities should be regulated even if it cannot be shown that these activities are likely to cause potential harm (Sunstein 2003). Sunstein (2003) challenges the use of the precautionary principle as a regulator of risk, stating that, whilst the use of the principle does not lead us in a bad direction, the problem is it leads us in no direction at all, primarily claiming that the principle 'is literally paralysing—forbidding inaction, stringent regulation and everything in between'.

Although our aim is not to debate the merits and pitfalls of the precautionary principle, we feel it is particularly important to assess the implications of its use. For example, there is a tendency to neglect the system effects of invoking the precautionary principle, i.e. that the decision not to utilise a resource such as sewage sludge will have unintended global effects such as increased greenhouse gas emissions or environmental degradation, e.g. due to phosphorus mining and sludge incineration, and the long-term use of a finite resource (phosphorus). As stated above, the precautionary principle should be applied where scientific data do not permit a complete evaluation of risk. While a complete risk assessment cannot be made, since there are some questions that still need attention (i.e. emerging contaminants that need addressing), there is an overwhelming body of evidence indicating that recycling of sewage sludge on farmland is not constrained by concentrations of inorganic or organic contaminants found in contemporary sewage sludge.

A survey of the Danish public's perception of sewage sludge (with 1,028 respondents) was conducted in 2011. Approximately two thirds of the respondents agreed with the statement that sewage sludge should be recycled through land application, whilst 70 % of respondents felt confident that sewage sludge, fulfilling legislative requirements, could be recycled without risks to humans, animals or the environment (BGORJ 2011). These findings might indicate that consumer's concern regarding the use of sludge need not be a barrier to an increased use of sludge as a nutrient source.

Conclusion and final remarks

The decision to phase out conventional nutrients in Danish organic agriculture might represent a landmark in the development of organic agriculture. There are significant lessons which can, both now and in future, be learnt from this decision, not just for Danish organic agriculture but also for the international organic sector. The reasons behind the organic sectors' decision are not unique in organic agriculture internationally, although it is difficult to quantify exactly the reliance of organic agriculture on conventional nutrient supply in other countries. Consideration should thus be given as to whether Denmark should stand alone following this decision or whether other countries should follow suit. There are also significant challenges ahead as a consequence of such a decision. Ensuring a sustainable nutrient supply to organic farms in the future will require a rethinking of farmers' strategies and further require support from all levels in society. As demonstrated in this article, finding alternative strategies to ensure nutrient supply will require a tapestry of small solutions, which in unison can ensure that organic agriculture continues to grow whilst ensuring the integrity of the organic sector.

One of the forefathers of organic agriculture, Sir Albert Howard, was a very strong proponent of the recycling of organic waste (Heckman 2006). One element of the tapestry of solutions is to review the volume and type of nutrient sources available in alternative, non-farm organic waste streams. Realising the potential on offer will require technological and infrastructural support to varying degrees to facilitate the collection, treatment and redistribution of organic wastes. Furthermore, for some waste types, there is a need for discussion, and perhaps a rethinking, about the acceptability of use of such resources. For example, whether recycled nutrients from sewage sludge and organic household waste should be viewed as a reliance on conventional nutrients. A pessimistic view of the decision to ban conventional nutrients might be that it threatens the growth of the organic sector. However, the challenges that arise from this decision do not seem insurmountable, and in the long term, seeking to align organic practices with the organic principles is very important.

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