Organic 3.0 and the use of recycling fertilizers from wastewater

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Key words: Soil Fertility, Nitrogen, Phosphorus, Micronutrients, Struvite, Microalgae

Abstract

The depletion of fossil nutrient reserves and the intrinsic nature of farms as open entities through which nutrients flow, will require introducing more recycling fertilizers in Organic Agriculture (OA). Processes exist to safely recover nutrients from wastewater, and some products have been considered suitable for Organic 3.0. While the safety issue has the highest priority, characterization of fertilizer behaviour in soil is also an important aspect that requires appropriate testing methods. Phosphorus (P) can be recovered in forms that are compatible with the principles of OA, however, nitrogen (N) and micronutrient recovery has not received much attention and remains challenging.

Acknowledgments

Our work is supported by the Austrian Research Promotion Agency (FFG) through the Research Studio Austria FERTI-MINE [Project number: 844744].

Introduction

Organic agriculture (OA) started in the early 20th century deemed as a more sustainable alternative to conventional practices (Organic 1.0; 1900 - 1970). It is a growing sector with a set of standards that were established over the past 40 years (Organic 2.0; 1970 - 2015). Organic 3.0 (2015-) was characterized as "innovation with research" (Rahmann et al. 2016) while the objective was set to "warrant sustainable agriculture and nutrition beyond the niche" (Niggli et al. 2015).

Soil fertility management in OA focuses on the interplay of various ecosystem components through the management of soil physical, chemical and biological properties, crop rotation, biodiversity, etc. Notwithstanding the necessity to make use of ecosystem processes to enhance soil fertility (Bender et al. 2016), nutrients must be replenished if yield is declining and other management practices cannot solve the problem alone. Farms being open entities which thrive by selling products with the nutrients they contain, macro- and micronutrients are gradually transferred to urban centres even when animal manures and other farm wastes are recycled. Although N can be fixed from atmospheric N_2 by legumes, this practice has its cost in particular for stockless organic farms which may grow legumes mainly for N fixation, possibly reducing the proportion of marketable crops in the rotation. Scarcity of macro- and micronutrient fossil reserves (de Haes et al. 2012) will require that the agricultural sector increases nutrient recycling from municipal solid waste and wastewater. Municipal sewage sludge (MSS) is the major residual nutrient stream, but it is often not readily applicable as fertilizer, as it may contain a multitude of organic and inorganic contaminants.

The use of new (mainly P-) fertilizers recycled from MSS in OA is discussed in strategic documents about Organic 3.0 (Niggli et al. 2015; Rahmann et al. 2016). Precipitation products such as struvite, or calcined P from MSS ash may be considered compatible with the principles of OA (European Commission 2016; Wollmann and Möller 2015). More generally "all human waste products could

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be authorized if their production processes effectively eliminate human pathogens and minimize the presence of contaminants" (European Commission 2016).

After discussing important principles and prerequisites concerning fertilizer use in OA this paper shortly presents recent developments in nutrient recovery from wastewater and discusses their potential for OA. In addition to P we also address other nutrients that may be recovered concomitantly, or separately with complementary processes.

Prerequisites for authorization of fertilizers in OA

The main criteria for the adoption of (recycling) fertilizers in OA may be categorized as follows:

1) Fossil *vs.* renewable raw materials: Renewable raw materials are prioritized over fossil products such as guano or phosphate rock. This is an important argument in favour of recycled fertilizers from wastewater.
2) Nutrient recovery efficiency: Overall, the number of recovered nutrients and their recovery rate should be as high as possible (Wollmann and Möller 2015).
3) Safety: Pathogens, trace element and organic pollutants must be avoided.
4) Solubility in water: Water-soluble fertilizers are generally avoided in OA. Beyond the risk of nutrient leaching, arguments include that a high nutrient concentration in the soil solution has a negative impact on soil ecology.
5) Use of energy and chemicals: In the context of recycling fertilizers, chemicals used for re-dissolution of P from sludge is a matter of concern (Wollmann and Möller 2015). Regarding calcined P from MSS ash, energy consumption may be acceptable because mining and transport of rock P is roughly equally energy intensive (European Commission 2016).
6) Organic *vs.* inorganic inputs: Considering the central position given to soil organic matter (SOM) management in OA, organic resources are very important. If inorganic fertilizers such as slags and rock powders are common, organic wastes should be used directly where possible instead of their calcined products unless the thermal treatment is a means to guarantee product safety (European Commission 2016).
7) Certified organic *vs.* conventional origin: Manure from organic farms is preferred for crop fertilization although in practice nutrient transfer from conventional farms (manure, feed, straw bedding) can be substantial. Nutrients in recycling fertilizers will originate from organically managed farms proportionally to the organic market share. In this respect their use would be compatible with the principles of OA.

Overall, the principle of ecology favours nutrient recovery and recycling (1, 2), prioritizes the direct use of organic resources (6) as well as processes that require low amounts of energy and chemicals (5). Several key prerequisites (3, 4, 5) can be related to the principles of health and of care which aim at avoiding harm to / fostering health of people, animals and the environment. As evident in recent documents (European Commission 2016; Wollmann and Möller 2015) decisions will be made according to the best compromises between all those criteria.

Fertilizers from wastewater

Standard procedures in wastewater treatment plants (WWTPs) are based on N elimination by denitrification and P precipitation with iron or aluminium salts, which renders P highly insoluble in MSS. Nowadays an increasing number of processes are becoming available to produce fertilizers recovered from wastewater streams. Including struvite as a state of the art reference, examples of promising approaches are listed in Table 1 with a focus on recent developments, N recovery, and products exhibiting good nutrient availability to plants.

Table 1: Examples of technologies for nutrient recovery from wastewater

Process	**Product**	**Nutrients recovered**	**Potential limitations**	**Reference**
Struvite precipitation in (dewatered) sludge	Struvite ($MgNH_4PO_4$)	P: < 5-65% of total load [a]	Needs addition of Mg Only little N recovered [b]	Wollmann and Möller (2015)
Thermo-chemical MSS ash treatment with Na and/or K additives	Contaminant depleted NaCaP bearing ash	P: ca. 90% of total load [a] Cu, Zn	Cr and Ni not removed No N recovery High energy consumption	Herzel et al. (2016)
NH_3 volatilization + acid stripping	$(NH_4)_2SO_4$	N	Soluble fertilizer Use of sulfuric acid	Evans (2007)
Microalgal nutrient recovery	Microalgal biomass	N & P: up to 100% [a, b] Likely other nutrients	Pathogens and trace elements not investigated Unsuitable for cold climate Lab-scale development stage	e.g. Vasconcelos Fernandes et al. (2015)

[a] Proportion of total P entering the wastewater treatment plant. It depends on the process, e.g. for P precipitation with or without re-dissolution from the solid phase of the sludge.

[b] The wastewater has roughly a 10 : 1 N : P mass ratio. N and P are being recovered stoichiometrically by microalgae. Struvite has a 0.5 : 1 mass ratio and as such can't be used to recover N.

The precautionary principle of care and the safe use of recycling fertilizers

The main prerequisite to adoption lies in the safe use of recycling fertilizers (European Commission 2016; Jedelhauser et al. 2015; Løes 2016). Thermo-chemical treatments of MSS ash for P and micronutrient recovery (Table 1) are possibly the most reliable in this respect. Microalgae as an emerging alternative still must be investigated in that respect (Table 1). In future, however, recycling fertilizers that are authorized under the general fertilizer regulations may already match the safety criteria for OA (see discussion in European Commission 2016).

Characterization of P availability from heterogeneous recycling fertilizers

According to Jedelhauser et al. (2015) fertilizer efficiency is the second most important criterion for adoption in OA by organic farmers. However, OA only allows the use of sparingly water-soluble fertilizers. To properly characterize such behaviour, we are proposing an approach combining (1) the assessment of water solubility and (2) an uptake-based method in which P solubilization is driven by depletion from P in solution by an infinite sink. While the first method describes the immediate solubility (which should be low in OA) the second method mimics the kinetics of P release and measures total P available in response to plant uptake (which should be high according to the plant´s demand). Our preliminary results demonstrate the suitability of this approach (Duboc et al. in peparation).

The case of N recovery and the use of soluble fertilizers

While recycling P fertilizers have received much attention, N recovery is less discussed. Struvite is not appropriate for N recovery due to an N:P stoichiometric mismatch between the wastewater and struvite. Nutrient recovery with microalgae could solve that issue but still must be developed beyond lab scale (Table 1). Although soluble fertilizers are not eligible, animal manures and slurries which are commonly used in OA have a substantial proportion of their N in solution as NH_4^+ and NO_3^-. This may leave an open door for the use of soluble fertilizer such as ammonium sulphate produced in WWTPs (Table 1) in the future as a complement to biological N fixation.

Nutrients and society –technology as a prerequisite to close the cycles

The almost unavoidable presence of pathogens and contaminants has gradually resulted in the exclusion of wastewater as a nutrient source for agriculture. Reverting this trend will require appropriate technologies in order to guarantee product safety. The envisaged implementations of P recycling schemes tend to favour centralized treatment of MSS through incineration and post-treatment of ash. On the longer term, however, small-scale decentralized processes may also fill niches with customized solutions for e.g. (1) contrasting socio-economic and geographic contexts, (2) efficient recovery of multiple nutrients or (3) tailoring of fertilizer properties and related nutrient availability for different requirements and markets. De-centralized technological approaches will also offer opportunities for more sustainable local and regional solutions that address the economic and societal needs of farmers and municipalities, e.g. by creating new employment and participation opportunities for disadvantaged population groups.

Conclusion

Among the principles of OA, the principle of care sets key prerequisites for adoption of recycling fertilizers from wastewater in OA. However, these prerequisites may already be met by the criteria for registration in general fertilizer regulations. Fertilizer efficiency and solubility are equally important aspects. Novel methods of fertiliser characterization and evaluation are considered important tools to facilitate the acceptance of new recycled fertilizer products in OA. In future, fertilizers from wastewater and other secondary raw materials should be given priority over those produced from fossil resources, thereby bringing OA closer towards its objective to foster agricultural sustainability beyond the niche.

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