Organic Plus, Deliverable 5.12, Mini Report Topic 2.8

Written by Maria Alejandra Arias Escobar, September 2022

Barriers of recycled fertiliser use in organic farming – the presence of micropollutants and potential reduction treatments

Introduction

One of the key challenges of organic farming is the supply of sufficient nutrients for crop production. Organic farmers rely on soil fertility management practices such as biological nitrogen fixation by legumes, crop rotation design, and crop residue management. This is complemented with recycled, regenerated and/or added organic materials and nutrients. The most important fertiliser sources are (1) animal manures and by-products, (2) plant-based products and composts, and (3) different permitted commercial fertilisers and soil conditioners. Organic arable farms, especially those lacking livestock, have often a deficit of macronutrients, and they need to be supplied from external sources (Løes et al., 2017; Magid et al., 2020).

Some of the off-farm fertilisers currently authorized in organic production originate from conventional agricultural systems: manure, animal by-products (e.g., meat and bone meal, keratins, or blood), and plant-based products (e.g., composted, or fermented household waste; residues of the oil, sugar, or plant starch industry) (Regulation (EU) 2021/1165). These by-products can be problematic for the organic sector, because the conventional environmental and animal welfare practices (e.g., high animal density in reduced space, high use of antibiotics) do not follow the organic farming principles. In addition, micropollutants, also known as emerging contaminants, are introduced by applying materials of animal and plant origin. There is a wide and expanding array of anthropogenic and natural substances which include pharmaceuticals, steroid hormones, microplastics, industrial chemicals, pesticides, and many other emerging compounds (e.g., phthalates and phenolics).

Therefore, the organic farming sector in Europe has decided to gradually phase out the use of conventional manure and other problematic by-products (ORGANIC PLUS; RELACS) . Alternative fertiliser sources are needed to fill this gap and to avoid the risk of soil nutrient depletion and yield reduction. Several organic materials have been suggested to substitute conventional manure, that is (1) digestates from biogas plants, and (2) biowaste, i.e., vegetable and source separated organic wastes. This is a compelling idea, because it follows the principle of closing the nutrient cycle; yet, as with the use of conventional manure, there could be also a relocation of pollutants into the soil and plant system of organic farms. Indeed, farmers are constantly requesting advanced information on potential risks when using different "wastes" as nutrient sources. There are specific processes to treat pollutants in by-products prior to field application. Currently, composting, vermicomposting, anaerobic digestion, and other mechanical methods (e.g., thermal treatments, carbon filtration) are the practised treatments in organic farming to reduce or eliminate hazardous substances in by-products. Table 1 lists the materials that are permitted as nutrient source in organic farms (*EU 2021/1165)*. Micropollutants and pathogenic organisms reported to be found in the specific materials are also listed.

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This report aims to support stakeholders in their decision to estimate the impact of alternative products and its contaminants in organic farming. Reviewed information on the following question is summarized: (1) Which pollutants are most likely introduced into organic farming through recycled fertilisers? and (2) can the currently practised treatments in organic farming reduce the amount and toxicity of pollutants?

Table 1. Materials permitted for organic farming and possible pollutants contained in these materials.

Material	Specific conditions	Micropollutants found in materials
Farmyard manure	Mixture of animal excrements and vegetable matter (animal bedding and feed material) Dried / Dehydrated (poultry)	**Pharmaceuticals**: analgesics and anti-inflammatories, anticonvulsants, antihelminthics, antimicrobials, antiseptics; beta-blockers, hormones, inhibitors, lipid regulators; **parabens**; **plasticisers (BPA)**; **Microorganisms**: *E. coli*; Faecal coliforms; Faecal enterococci; Faecal streptococci; Heterotrophic bacteria; Total coliforms; **Pathogens** (Ghirardini et al., 2020)
Animal excrements (farmyard manure and poultry manure)	Composted	
Liquid animal excrements	Fermented and/or appropriately diluted	
Source separated vegetable and animal household waste	Composted or fermented (anaerobic digested)	**Persistent organic compounds** (Brändli et al., 2005) **Pathogens**: Salmonella enterica, Esscherichia sp., Enterobacteriaceae, Pseudomonas, Enterococcus, Clostridium, Listeria (Sundberg et al., 2011)
Vermicompost		-
Guano		-
Mixture of vegetable matter from retail, household waste production	Composted Fermented (anaerobic digested)	Pesticides* from conventional farming
Biogas digestate (from animal by-products co-digested with material from plant / animal origin)	Anaerobic digestion	Heavy metals; food-borne pathogens; antibiotic resistant bacteria; stimulants; pesticides, antifungal food preservatives; pharmaceuticals (Golovko et al., 2022)
Products and by-products of plant origin	(e.g., oilseed cake meal, cocoa husks, malt culms)	Pesticides *

*Not verified with literature source, but noted from specialists

Groups of micropollutants present in recycled fertilisers

Micropollutants (MPs) can be defined as anthropogenic chemicals that occur in the environment well above a (potential) natural background level due to human activities but with concentrations remaining at trace levels ranging from a few ng/L to several µg/L (Luo et al., 2014). Table 2 listed the most relevant micropollutants and other categories of concerning pollutants potentially present in recycled fertilisers.

Table 2. List of relevant groups and corresponding micropollutants, and other categories of contaminants occurring in recycled fertilisers

Group	Micropollutants
Metallic trace elements	Sb, Al, As, Ba, Pb, B, Cd, Cu, Co, Hg, Mo, Ni, Se, Ag, Tl, Sn, U, V, Zn
Persistent organic contaminants (POPs)	PFOS Perfluorooctanesulfonates PCBs Perfluorooctanesulfonates OCP Organochlorine Pesticides PFAS Per- and Polyfluoralkyl substances PAHs Polycyclic aromatic hydrocarbons HCH Hexachlorocyclohexane DDT Dichloro Diphenyl Trichloroethane PBDE Polybrominated Diphenyl Ethers HCB Hexachloorobenzene
Pharmaceuticals	Analgesics, antibiotics, anti-inflammatories, antidepressants, beta-blockers, antiulcers, lipid regulators, anti-epileptics, antihistamines
Other categories of contamination	
Resistant genes	
Microplastics	
Pathogens	Salmonella, E. coli, Enterobacteriaceae, Noroviruses, Hepatitis A virus (HAV)

Metallic trace elements: a group of environmental chemicals that are ubiquitous and non-biodegradable; some of them are heavy metals. Metallic trace elements biomagnify (or increase their concentration in the tissues of organisms) as it travels up the food chain, owing to these characteristics. The presence of these chemicals in the environment has been associated with numerous adverse effects on humans and animals (Wu et al., 2016). Some states (e.g., Sweden, Finland, Denmark) report a reduction of 90% of heavy metals in municipal waste waters after 1979 due to environmental programs and statutory limits on metals in sludge and soil (Kirchmann et al., 2017).

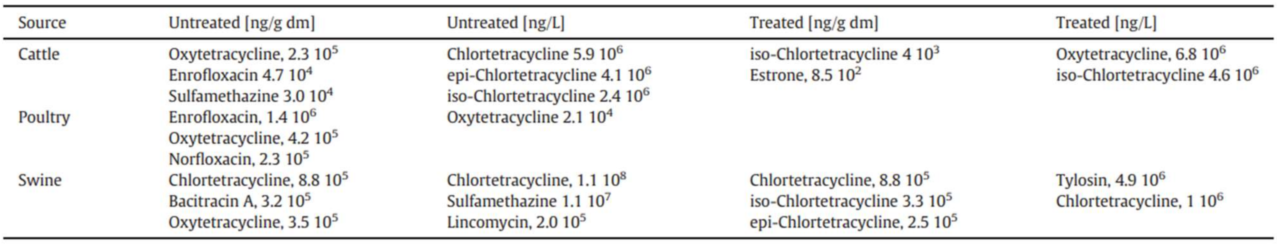
Persistent organic compounds (POPs) include a series of intentionally or non-intentionally produced toxic substances that are very resistant to chemical or biological degradation (direct or indirect photolysis, hydrolysis, and microbial transformation). POPs are divided into three major subgroups: (i) Organochlorinated pesticides that have been deliberately used in agriculture, for example endosulfan, lindane, Dichlorodiphenyltrichloroethane (DDT), dieldrin, chlordane, pentachlorophenol (PCP), Dichloro diphenyl dichloroethane (DDE), dicofol, heptachlor, mirex, etc. (ii) Industrially produced chemicals including polychlorinated naphthalenes (PCNs), polychlorinated biphenyls (PCBs), hexachlorobenzenes (HCBs), polybrominated diphenyl ethers (PBDEs), and poly perfluorinated compounds (PFCs), polybrominated biphenyls (PBBs). (iii) Unintentionally produced as industrial by-products include HCBs, polychlorinated dibenzo-p-dioxin/ polychlorinated dibenzofuran

(PCDD/ PCDF) and PCNs (Mishra et al., 2022). These compounds can persist several years to decades in the environment and therefore POPs may be deposited in water and sediments, enter the food chain, bioaccumulate and biomagnify. This affects plants, animals, human health, and the environment (Russell, 2005).

Pharmaceutical compounds are biologically active substances used in both human and veterinary medicine. They are applied for therapeutic and preventive purposes and are additionally used in animal husbandry and food production as growth stimulants (Gworek et al., 2021). The major source of emitting the drug active substances is the pharmaceutical industry. Another source is wastewater and sewage sludge from municipal wastewater treatment plants, where drugs excreted by humans in households, hospitals, and other therapeutic facilities accumulate. The third source is soil fertilisation with organic fertilisers, including manure and slurry, or with other natural fertilisers containing animal excreta (Gworek et al., 2021). The active substance of several pharmaceuticals can be degraded by biological treatment of wastewater, water bodies, and soils, and by abiotic reactions. While potentially harmful effects of drugs are reduced during treatment, in some cases, breakdown products have a similar toxicity as the parent substance (Halling-Sørensen et al., 2002). Other pharmaceutical residues can be resistant to degradation, highly soluble in water and complex when mixed with other compounds. Antibiotics are an important group of pharmaceuticals reported to be widely used in animal production. Table 3 summarizes concentrations of antibiotics and other pharmaceuticals among different manures treated or untreated (Ghirardini et al., 2020). Table 4 shows a group of commonly human-consumed antibiotics and found in sewage sludge and biosolids (Cycoń et al., 2019). Common treatments reported by the authors include lagooning, composting, anaerobic digestion, pelletization and alum treatment (addition of aluminium sulphate for reduction of ammonia emissions, and bacterial pathogens e.g., Campylobacter and Salmonella). Yet, bioaccumulation of pharmaceuticals in organisms and in the trophic chain, and antibiotics in soil affecting higher organisms are issues that are still under investigation.

Antibiotic resistant genes (ARGs) and antibiotic resistant bacteria (ARB) confer resistance to a wide range of antibiotics. They occur naturally and may date back tens of millions or billions of years. ARGs in natural environments are highly integrated and tightly regulated in specific bacterial metabolic networks (Hu et al., 2017). However, the antibiotic selection pressure conferred using antibiotics in both human medicine and agriculture practice leads to a significant increase of antibiotic resistance and a steady accumulation of ARGs in bacteria.

Table 3. Summary of antibiotic substances and pharmaceuticals and maximum concentration as found in different manures and treatments (Ghirardini et al., 2020)



Source	Untreated [ng/g dm]	Untreated [ng/L]	Treated [ng/g dm]	Treated [ng/L]
Cattle	Oxytetracycline, 2.3 10^5 Enrofloxacin 4.7 10^4 Sulfamethazine 3.0 10^4	Chlortetracycline 5.9 10^6 epi-Chlortetracycline 4.1 10^6 iso-Chlortetracycline 2.4 10^6 Oxytetracycline 2.1 10^4	iso-Chlortetracycline 4 10^3 Estrone, 8.5 10^2	Oxytetracycline, 6.8 10^6 iso-Chlortetracycline 4.6 10^6
Poultry	Enrofloxacin, 1.4 10^6 Oxytetracycline, 4.2 10^5 Norfloxacin, 2.3 10^5			
Swine	Chlortetracycline, 8.8 10^5 Bacitracin A, 3.2 10^5 Oxytetracycline, 3.5 10^5	Chlortetracycline, 1.1 10^8 Sulfamethazine 1.1 10^7 Lincomycin, 2.0 10^5	Chlortetracycline, 8.8 10^5 iso-Chlortetracycline 3.3 10^5 epi-Chlortetracycline, 2.5 10^5	Tylosin, 4.9 10^6 Chlortetracycline, 1 10^6

Table 4. Frequent antibiotics consumed by humans as found in sewage sludge and biosolids. Adapted from (Cycoń et al., 2019)

	Sewage sludge		Biosolids	
Class	**Antibiotic**	**Concentration µg kg DW**	**Antibiotic**	**Concentration µg kg DW**
Diaminopyrimidines	Trimethoprim	133		
Fluoroquinolones	Ciprofloxacin	426 (8.905)		
Lincosamides			Lincomycin	2,6
Macrolides	Azithromycin	1,3 - 158	Azithromycin	
			Erythromycin	14 (6.500)
Sulfonamides	Sulfadimethoxine	0-20 (22,7)		650
Tetracyclines	--	8.326	Oxytetracycline	743,6 (8.700)

Potential treatments for elimination and or reduction of pollutants in by-products

Permitted technologies in organic farming are based on biological and mechanical processes and have been used to treat against different hazardous components from by-products, while maintaining their fertiliser value. The technologies are environmentally friendly, and often require low maintenance at low costs. In this section composting, vermicomposting, and anaerobic digestion are described, which are the current permitted biological treatments in organic agriculture. Also, the results of different studies are described, where those technologies have been assessed as a treatment for degradation and/or elimination of micropollutants, antibiotic resistant genes, and pathogens.

Composting is the decomposition of organic matter by microorganisms (mainly bacteria, fungi, and actinomycetes) under controlled conditions. The organic material undergoes a characteristic thermophilic stage (45 – 65º C) that allows sanitization of the waste by the elimination of pathogenic microorganisms (Lung et al., 2001). Numerous studies have shown that composting has substantial potential for bioremediation from polluted substrates through sustaining microbial populations, which degrade different contaminants (e.g., Cai et al., 2007; Guo et al., 2020; Sinha et al., 2008).

Composting has a potential to decrease hazardous effects of **heavy metals**. Wei et al (2020) reported a decrease of Cu^{2+}, Zn^{2+}, Ni^{2+}, Pb^{2+}, Cr^{3+} and Cd^{2+} concentration by adding humin from compost, but the removal rates were relatively low (<30% on average). The authors suggest that heavy metal resistant bacteria from composting have better metal binding capacities than humin. The combination of humin and bacteria could stimulate the biosorption of heavy metals with 60-80% removal rates and improve the bacterial biomass and diversity. In another study, the inoculation of composts with certain fungi species (e.g., *Phanerochaete* *chrysosporium*) have shown to be beneficial for the conversion of heavy metals (Cd, Pb, and Cu) from active to stable forms (Chen et al., 2019). The composting process, however, is generally marked by an increase in metal concentrations due to the evident reduction of compost mass by decomposition (i.e., loss of matter) (Grasserová et al., 2020).

Composting may also reduce the concentration of **polycyclic aromatic hydrocarbons (PAHs)** in organic material. Co-composting with the addition of bulking agents have been studied for the bioremediation of contaminated sewage sludge with PAHs. Cai et al., (2007) found that in 65-day-old composted sewage sludge-rice straw PAHs were below the limits as legislated in the EU and USA. The 2,3-ring accounted for more than 65% of PAHs and 5,6-ring for less than 10%. Removal rates ranged from 64% to 94% PAHs among treatments. Aerated composting (the static piles) was most efficient to remove PAHs. Mixing sewage sludge with green forest waste (3:2 ratio) was effective to degrade PAHs during co-composting with a removal efficiency of 75% and a residual PAHs concentration of 1.81 mg/kg after 50 days of composting.

Co-composting of sewage sludge and rice straw was also tested to degrade **pharmaceutical compounds.** Here, the C/N ratio determined degradation rates with an optimum at C/N ≈ 20. Azithromycin, irbesartan, fluoxetine, and citalopram were biodegraded, whereas telmisartan and venlafaxine were not affected. The azithromycin levels were reduced by up to 50%, citalopram was reduced by 10%, and fluoxetine was completely biodegraded after 15 days. These results suggest that composting might be an efficient process to reduce and degrade pharmaceutical compounds (Iranzo et al., 2018).

Composting may assist in the degradation process of **antibiotics**. Zhang et al. (2019) showed that in a mixture of swine manure, poultry manure, and sawdust, 65% of the detected veterinary antibiotics were removed after composting for 171 days. This reduction mainly occurred at the thermophilic phase in the second week, followed by a long stable stage with little difference. The removal rates for lincomycin, trimethoprim and the macrolides during the composting were >90%, while those for the sulfonamides, tetracyclines and fluoroquinolones were less than <64%. The dissipation of antibiotics during the composting was related to the change of compost physicochemical properties, especially moisture and C/N ratio. Yet, the authors suggest that application of composted manure into soils may present a risk of antibiotic resistance to soil microbial ecosystems.

Composting has been shown to be effective in reducing **ARGs**. Selvam et. al. (2012) studied tetracycline, sulfonamide, and fluoroquinolone resistance genes during the composting of swine manure spiked with different levels of antibiotics, and found that after 56 days of composting, most of the selected ARGs, were undetectable in the composting mass. Liu et al., (2020) states ARGs from pig manure, especially Tetracycline RGs, can be reduced through microbial processes during co-composting with wheat straw and sawdust. Those processes are linked to the bacteria *Pseudomonas, Pseudoxanthomonas, Pusillimonas, Aquamicrobium, Ureibacillus, Lysinibacillus Bacillus and Brachybacterium*. The authors suggest that close monitoring and management of key parameters, such as pH and temperature, to ensure bacteria growth, may present an opportunity for ensuring effective ARG removal.

Vermicomposting is a bio-oxidation and stabilization process of organic material by both, earthworms (*Eisenia fetida, Eisenia tetraedra, Lumbricus terrestris, Lumbricus rubellus and Allobophora chlorotica*) and microorganisms and without a thermophilic stage. The earthworms are the agents of turning, fragmentation, and aeration of the organic material (Dominguez et al., 1997). Earthworms indirectly facilitate the conversion of organic contaminants by promoting microbial and enzyme activities. To date vermicomposting is not fully adapted to the industrial scale. Since the temperature of the organic material always stays in the mesophilic range (15º - 40º C), pathogen removal is not guaranteed (Grasserová et al., 2020) .

Temperature range in vermicomposting, however, may be favorable for the development of mesophilic microorganisms that have been correlated to the degradation of POPs (Mishra et al., 2022) . Grasserová et. al. (2020) , reviewed the advantages of combining composting and vermicomposting to break down and remove pollutants from organic waste. The authors evidenced that composting alone is efficient when degrading PAHs, yet degradation may occur in the final maturation phase which can take up to 300 days. They suggest that the composting-vermicomposting process could decrease removal period of PAHs.

In addition, earthworms can directly remove **heavy metals, pesticides, and PAHs** from the soil. They “absorb” the dissolved chemicals through the moist ‘body wall’ in the interstitial water and ‘ingest’ by mouth, while the soil passes through the gut. They either ‘bio-transform’ or ‘biodegrade’ the chemical contaminants rendering them harmless in their bodies (Sinha et al., 2008). Therefore, vermicomposting can significantly decrease the mobility of heavy metals by increasing the residual fractions. Sewage sludge vermicomposted with *Eisenia fetida* and adding bulking agents (soil, straw, fly and sawdust) accelerated the stabilization of sludge and eliminated its toxicity. Heavy metals (As, Cr, Cd, Cu, Fe, Mn, Ni, Pb and Zn) decreased after vermicomposting as compared to the control without amendment. (He et al., 2016).

Anaerobic digestion (AD) is a biochemical process where several groups of microorganisms degrade organic materials at temperatures promoting either mesophilic or thermophilic bacteria. A gaseous mixture of mainly methane and carbon dioxide (“biogas”) is produced during degradation, and a digestate, a nutrient rich semi-solid or liquid product remains (Font-Palma, 2019). This process simultaneously inactivates **pathogens** in the feedstock material. Ma et al. (2022) conducted a meta-analysis, indicating that AD had significant effect on pathogen inactivation of fecal coliforms, *E.coli* and salmonella.

Three anaerobic digestates and biofertilisers based on food waste from biogas plants in Sweden were analysed for **heavy metals, pathogens, and pharmaceutical compounds** (Golovko et al., 2022). The authors found lower concentrations of heavy metals in the digestate (Cd, Cr, Cu, Pb, Hg, Ni, Zn) than the permitted level. This suggests that concentrations were well monitored and controlled by the producers, probably owing to the presence of clear statutory limits. However, the authors did not compare the feed material before entering the process of digestion to the final digestate. Also, six microorganisms (*viz. E. coli, enterococci, Salmonella spp., C. perfringens*, MRSA, ESBL-resistant *E. coli*, and ESBL-CARBA resistant *Enterobacteriaceae*), showed low or no concentrations in the anaerobic digestate (biofertiliser), while the spore-forming *B. cereus* was found at high concentrations. In total, 133 compounds were investigated and 48 detected at least once.

The highest concentrations found were for pyroxidine and nicotine, with average cumulative concentrations of 200 and 8500 ng/g dw, respectively. Thirteen out of 58 pesticides investigated were detected, in concentrations ranging from 2.0 ng/g dw for chloridazon to 840 ng/g dw for imazalil.

AD has reportedly reduced and removed **antibiotics and ARGS.** The removal pathway for β-lactams, macrolides, tetracyclines, fluoroquinolones and trimethoprim was adsorption, whereas the pathway for sulfonamides was biodegradation. The adsorption rate of different antibiotics in the AD system might differ depending on the solid content of the substrate, i.e., increasing rates of total solids may decrease the degradation rate of antibiotics because they are adsorbed to the solids. Therefore, the use of the liquid component may be safer than the solid fraction because the latter needs to be further treated before used as fertilizer. Note that the use of digestate as fertiliser without treatment could introduce antibiotics and ARGs to the environment. In addition, antibiotics may reduce biogas production, depending on type, concentration, and prevalence of antibiotics in the substrate, because biogas-producing microbes are inhibited (Gurmessa et al., 2020).

As Gurmessa et al. (2020)Gurmessa et al. (2020) suggest, the approach of using AD is useful to reduce antibiotics and ARGs from animal manure but still needs to consider in depth the different stages of manure management as opportunities for intervention. The first step should start from pre-AD manure handling. At this stage, stripping-off water and improving storage play a role against removal of antibiotics and ARGs, both at onsite and off-site, when it later enters AD. Second, before it enters the AD, it is recommended to incubate at a high temperature for a certain period. However, optimizing the temperature without compromising biogas production potential requires further study since evidence are lacking on the range of temperature required to potentially remove VAs at the lowest possible cost. The third stage is AD. The focus here needs to be optimizing the temperature for effective removal of antibiotics and ARGs and biogas production. In the single temperature-phased AD, thermophilic condition is frequently reported to have positive effect on removal of antibiotics and ARGs, while mesophilic conditions may be more effective for biogas production.

Other technologies that can be used as a post-(biological) treatment are for example thermochemical conversion of biomass or pyrolysis, which produces biochar. As reported elsewhere (Pathy et al., 2021), the rather larger surface area due to its porous structure, makes biochar a promising biosorbent. Hence, biochar has been extensively used in the field of bioremediation for removing antibiotics, dyes, oils, pesticides, organic pollutants and heavy metals.

There is also to consider that once the recycled fertilisers are disposed into soils, the behavior of the micropollutants depends on different biotic and abiotic processes that may influence on their decay. As an example, it has been observed that after application of manure into the soil, common microorganisms (*E.coli, Salmonella, Listeria*) decline rapidly (Ghirardini et al., 2020). However, it can also occur that some compounds are very persistent in the soil. The antibiotic oxytetracycline demonstrates a high persistence in pig slurry-amended soil. This compound has a strong potential to absorb on solid matter which makes it unavailable for microbial attack, but at the same time it remains in the soil without being mobilized in the aqueous phase (this means that it is not present in the runoff or tile drainage induced by rain) (Ghirardini et al., 2020). This means that the subsequent application of the same type of manure on the same soil over the years will cause it to accumulate.

Therefore, some experts as Kümmerer et al. (2019) proposed that additionally to the optimization of treatments to tackle the chemical pollution problem, there is an increasing necessity of an input prevention, that means more and better controlling and a real reinvention of green and sustainable chemistry in a way that treatments and the environment can cope successfully with the challenge of pollutants and hazardous substances.

Conclusion

The use of recycled fertilisers from animal manure, other animal by-products, source-separated organic waste, and other vegetable residues, can introduce a wide range of micropollutants into the soil environment of the organic farms. However, as indicated by several studies, the biological processes of composting, co-composting (i.e., addition of bulking agents), vermicomposting, and anaerobic digestion can assist in the reduction, elimination, and /or immobilization of heavy metals, pharmaceutical compounds, POPs, pathogenic agents, and ARGs.

The wide range of pollutants, with different physical and chemical characteristics, that respond differently to environmental factors, pose an important challenge: their properties dictate if they can be degraded by biological processes. Organic micropollutants except for POPs are potentially more susceptible to degrade by biological processes than inorganic micropollutants (e.g., heavy metals). POPs are very persistent in the environment with multi-year degradation periods due to their unique characteristics including semi-volatility, long half-lives, recalcitrance, harmful toxicological impact, long-range transport, transformation, and bioaccumulation.

There is not a single treatment that degrades every pollutant. However, the presented biological techniques appear to have potential for the reduction and immobilization of some pollutants. Additionally, biological treatments could be complemented with pre- and post-managements or treatments for further elimination of pollutants.

The identification of persistent compounds is key to avoid further pollution of the soil-plant environment in cropping systems. Setting permitted concentration levels for persistent compounds and micropollutants would be a control measure that is useful for recycled fertiliser certification.

There is substantial research regarding micropollutants and hazardous substances in the environment. It is important to focus research on organic farming systems to elucidate the risks of and solutions for using recycled fertilisers. Also, the acceptance of alternative by-products by organic farmers and consumers needs to be assessed. This will probably require compromises to supply sufficient plant nutrients to sustain yields in organic farming, and to overcome the challenges of micropollutants.

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