Synthetically Produced Organic Compounds

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Background

When domestic sewage is transported and conveyed to a wastewater treatment plant, it is treated to separate liquids from the solids, which produces a semi-solid, nutrient-rich product known as "sewage sludge". The terms "biosolids" and "sewage sludge" are often used interchangeably by the public; however, the U.S. Environmental Protection Agency (EPA) and wastewater treatment facilities typically use the term "biosolids" to mean sewage sludge that has been treated to meet the requirements in the EPA's regulation entitled, "Standards for the Use or Disposal of Sewage Sludge," promulgated at 40 CFR Part 503, and intended to be applied to land as a soil conditioner or fertilizer.

Biosolids are primarily composed of water and organic (carbon-rich) materials. Biosolids contain macronutrients like nitrogen, phosphorus and potassium as well as micronutrients like copper, zinc and iron. Additionally, biosolids contain inert (no carbon) solids like sand, trace elements and, depending on the level of treatment, low concentrations of microorganisms. Biosolids that comply with state and federal regulations are considered safe for the environment and protective of human health and may be beneficially used for land application as a fertilizer and soil amendment, as well as for use in composted products.

Biosolids are recycled on farms and forests throughout the United States and in most developed countries worldwide. As of 2023, the EPA estimates about 60% of the total biosolids produced annually in the United States are applied for beneficial uses, while the remainder is either incinerated or disposed of in landfills.

In Virginia, the Department of Environmental Quality (DEQ), reports 37,786 acres received biosolids applications in 2024, an increase from 36,145 acres in 2023. Despite this, the acreage where biosolids are recycled represents less than 1% of all agricultural land in Virginia.

What are Synthetically Produced Organic Compounds

Organic compounds contain carbon atoms bonded to at least one hydrogen, oxygen, or nitrogen atom. These chemicals, whether naturally occurring or manufactured by humans, are typically present in very low concentrations in environmental samples such as soil, water, and air.

Modern society depends heavily on organic chemicals for a wide range of applications, including food additives, cleaning products (detergents, dry-cleaning agents), personal care products (toothpaste, soaps, shampoos), cosmetics, pharmaceuticals, pesticides, and transportation-related uses (gasoline, diesel, asphalt). In many ways, these chemicals are foundational to today's world.

Synthetically produced organic compounds can become environmental pollutants because of their persistence and potential to bioaccumulate in organisms. Some are associated with harmful effects on ecosystems and human health, even at low concentrations (Shin et al., 2022). Many are known or suspected to be carcinogenic, mutagenic, or endocrine-disrupting chemicals (Ghahari et al., 2021).

These compounds can enter the environment through industrial discharges to air and water, the routine use of everyday products, and via land-applied manures, biosolids, and industrial sludges. The use of pharmaceuticals, personal care products (PPCPs), and household detergents represent the most direct and significant pathways for exposure to trace organic compounds for humans (Thakur and Pathania, 2020; Ghahari et al., 2021).

Organic chemicals reach wastewater treatment plants from a variety of sources, including businesses, industries, agricultural runoff, stormwater, and household wastewater.

Categories, Treatment, and Environmental Fate of Trace Organic Compounds

Common categories of organic chemicals include:

- Polycyclic Aromatic Hydrocarbons (PAHs): Produced mainly by the burning of fossil fuels such as coal, oil, gasoline, and wood.
- Polychlorinated Dibenzo-p-dioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) (commonly called dioxins): Emitted from incineration and some chemical manufacturing processes.
- Polychlorinated Biphenyls (PCBs): Result from leaks in electrical transformers and improper disposal of PCB-containing products.
- Polychlorinated n-alkanes (PCAs) or chlorinated paraffins: Used as lubricant additives, plasticizers, flame retardants, and paint additives.
- Pesticides and Herbicides: Enter the environment through agricultural practices and urban pest and weed control.
- Polybrominated Diphenyl Ethers (PBDEs): Used as flame retardants and may leach from plastic products.
- Bis (2-ethylhexyl) Phthalate (DEHP): Found in plastics, tablecloths, floor tiles, scented candles, and air fresheners.
- Alkylphenols: Common in detergent products.
- Pharmaceuticals and Personal Care Products (PPCPs): Include antibiotics, hormones, synthetic steroids, and cosmetics.
- Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS): Fluorinated compounds used to repel oil and water in products such as carpet and clothing treatments and firefighting foams.

During Wastewater Treatment:

- Many organic chemicals degrade through physical, chemical, and biological processes at the treatment treatment facilities.
- Highly volatile compounds (e.g., benzene, toluene, trichloroethane) are often lost to the air during treatment or shortly after land application, making them unlikely to persist in soils or pose health risks (Semblante et al., 2015).
- Other compounds persist in the solid fraction generated during wastewater treatmet but are biodegraded by microbial processes during aerobic and anaerobic digestion (Ghahari et al., 2021).
- Some synthetically produced organic compounds like PCBs and dioxins have largely been phased out and are no longer a major concern in biosolids.

- New emerging contaminants like PPCPs show varied biodegradability: for instance, certain bacteria can completely degrade 17-ethinyl estradiol (a birth control hormone), while others achieve partial breakdown (Larcher et al., 2013).
- Innovative treatments like myco-remediation (using white-rot fungi), advanced oxidation processes, membrane filtration, chemical coagulation, and green nanotechnologies are being developed to capture or degrade these contaminants (Stiebeling and Labes, 2022; Naguib et al., 2024).

After Land Application:

- Many organic chemicals continue to break down in soil over time.
- Sorption to soil particles and organic matter reduces their bioavailability.
- Soil heating can accelerate degradation.
- Microbial activity in soil plays a major role in breaking down residual organic compounds (Gao et al., 2022).
- Adding activated charcoal or biochar to soil has been shown to effectively adsorb organic chemicals and limit their availability (Qiu et al., 2022).
- Composting biosolids is one of the most effective methods for degrading organic chemicals through mineralization, co-metabolism, and nonspecific oxidation reactions (Xia et al., 2005; Semblante et al., 2015; Lin et al., 2022).

The specific chemical structures and properties of organic chemicals greatly influence their persistence, degradation, transformation, and movement in the environment. These factors determine how bioavailable the chemicals are for uptake by microbes and plants, and how likely they are to pose a risk to human health (Kumar et al., 2022).

For example, while many studies have shown that the degradation of organic chemicals in soil can significantly reduce their bioavailability for plant uptake, certain compounds, such as carbamazepine and triclosan, have still been detected in plant tissues (Wu et al., 2015). This persistence may be due in part to the behavior of their breakdown products. Some degradation products may not bind as well to soil products as their parent compound, increasing the likelihood of plant uptake (Paz et al., 2016).

Risk Assessment

The U.S. EPA has conducted extensive screenings of organic chemicals in biosolids and evaluated their potential risks to the environment and human health. The impact of these chemicals was assessed primarily in terms of their potential to cause cancer through long-term exposure.

Results from early risk assessments indicated that specific regulation of these organic chemicals in land-applied biosolids was not necessary for three main reasons (U.S. EPA, 1995):

1. Many pollutants were detected at very low levels in biosolids, as shown by the National Sewage Sludge Survey.
2. Certain pollutants had already been banned, restricted, or were no longer in use in the United States.
3. Concentrations of organic chemicals present in biosolids did not exceed toxicity thresholds based on exposure assessments.

In the early 2000s, the U.S. EPA conducted a second round of screenings to evaluate pollutants of concern, including dioxin-like compounds such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and dioxin-like coplanar PCBs in land-applied biosolids. The risk assessment concluded that these compounds did not pose a significant threat to human health or the environment, and that existing regulations already provided adequate protection to limit exposure (U.S. EPA, 2003).

In addition to EPA's assessments, current research suggests that human exposure to newer classes of organic chemicals, such as pharmaceuticals and personal care products (PPCPs), through consumption of crops grown in biosolids-amended soils is likely very low and poses minimal risk (Wu et al., 2015). For example, Sindhu et al. (2019) conducted a risk assessment on the antibiotics ciprofloxacin and azithromycin after land application and found that their hazard quotients were below 1, indicating no significant health risk from exposure.

Nevertheless, given the wide range of organic compounds that could potentially be present in biosolids, research and risk assessments on unregulated compounds should continue. Prioritization should consider occurrence, mobility, persistence, bioaccumulation potential, and human toxicity (Warke and McAvoy, 2024). Based on biennial reports and National Sewage Sludge Surveys, the EPA has compiled a list of chemicals and structural classes found in biosolids (Richman et al., 2022) and has begun characterizing these chemicals as high or low priority for further detailed risk analysis, based on factors such as concentration, mobility, persistence, and toxicity.

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