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# Disposal of Biosolids through Land Application: Concerns and Opportunities

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Application to cropland as a soil amendment is the predominant method to dispose of biosolids, an organic waste of sewage sludge processed by dehydration, stabilization, and sterilization [1]. Sewage sludge has relatively high nutrient contents, containing N 30–60 g $kg^{-1}$, P 18–36 g $kg^{-1}$, K 3–6 g $kg^{-1}$, and organic carbon (OC) 320–370 g $kg^{-1}$ dry solid matter [2]. Nevertheless, unprocessed sewage sludge directly from domestic wastewater treatment operations is soupy and unstable. Prior to land application, raw sludge is commonly treated by anaerobic/aerobic digestion, belt filter pressing, and/or alkaline stabilization to separate water, improve texture, reduce offensive odor, destroy pathogens, and enhance its hand liability [3]. Depending on wastewater sources and sludge treatment methods, biosolids demonstrate varied quality in terms of nutrient contents, trace metal contents, pathogen presence, odorants, and organic contaminants. For example, Christie et al. [4] reported that British biosolids from stabilizing sewage sludge (dry solids 300–350 g $kg^{-1}$) with cement kiln dust at 65:35 fresh w/w and windrow composting the mixture for 50 d had a liming value of 300 g $kg^{-1}$ $CaCO_3$ equivalent and contained 7.2, 2.3, and 19.5 g $kg^{-1}$ N, P, and K, respectively. Biosolids from wastewater treatment plants in Washington D.C. and Maryland using lime stabilization demonstrated pH 11.9–12.5, $CaCO_3$ equivalency 219–520 g $kg^{-1}$, and OC, Kjehldahl N, total P, and K contents 216–292, 19.7–42.4, 5.9–14.3, and 0.5–4 g $kg^{-1}$, respectively [5]. Class A biosolids contain pathogens below detectable levels: the density of fecal coliform is less than 4000 or the density of *Salmonella* sp. bacteria is less than 3 most probable numbers per 4 dry grams of biosolids at the time of application. Class B biosolids contain low but detectible, compliant levels of pathogen upon application [6]. In the U.S., land application of biosolids is regulated by the federal rules described in 40 CFR Part 503 [7]. To minimize the potential threats to public health, the rules govern the use of biosolids as a soil amendment to meet metal limits, pathogen reduction standards, site restriction, and crop harvesting restrictions [6]. Biosolids shall be applied at or below agronomic rates to land at least 10 m away from a water body [6]. The ceiling and monthly average concentrations of the nine toxic elements As, Cd, Cu, Pb, Hg, Mo, Ni, Se, and Zn in land-applied biosolids and their annual and cumulative loads to soil through land application are strictly capped (Table 1). There are no pathogen-related restrictions for Class A biosolids application, but land application of Class B biosolids is subject to buffer requirements, public access, and crop harvesting restrictions [7].

There are no rules in 40 CFR Part 503 to regulate concentrations of organic contaminants in biosolids. When research was conducted to evaluate the safety of biosolids land application, 11 organic chemicals that were directly hazardous to human health were surveyed for their presence and concentrations in sewage sludge (Table 2). Since merely 3 of the 11 compounds were detected in the late 1980 survey, with trichloroethylene found in 1% and aldrin/dieldrin and benzo(a) prene in 3% of the biosolids surveyed at less than 1/1000 of the proposed regulatory limits, it was decided that regulations on organic contaminants in biosolids for land application should not be included in 40 CFR Part 503. The absence of organic contaminant regulations, however, does not signify negligence of the federal regulatory rules. This fact is clearly illustrated by the initial proposal to and five years later the final decision not to include concentration limits for dioxin and similar compounds in biosolids in the Part 503 Rule [8]. As a matter of fact, a wide range of organic chemicals have been detected in biosolids with the advances of environmental analytical chemistry. These chemicals cover antimicrobials, synthetic musks, pesticides, flame retardants, surfactants, phthalates, bisphenols, hormones, steroids, and perfluorochemicals [9]. Present at trace concentration levels in biosolids, these compounds do not directly influence human health but may have significant impacts on the ecosystem. Via surface runoff, these trace organic chemicals can be easily carried off the application sites. Substantially elevated concentrations of steroid hormones in runoff water from biosolids-fertilized land had been observed [10]. It is well-known that endocrine-disrupting compounds (EDCs) and hormones have significant adverse effects on aquatic life. Research is warranted to assess the interactive toxicological effects of these chemicals, to identify safe alternatives in industry, and to develop effective sludge treatment methods to eliminate these chemicals [11].

Due to quality improvement of industrially discharged wastewater, the concentrations of toxic elements in biosolids have significantly reduced over the past thirty years [2]. The median concentrations of As, Cd, Cu, Pb, Hg, Ni, Se, and Zn in sewage sludges from 177 wastewater treatment plants in Pennsylvania were 3.6, 2.3, 511, 64.9, 1.5, 22.6, 4.3, and 705 mg $kg^{-1}$ (dry sludge mass), respectively [2], far below the ceiling concentration limits (Table 1). The total concentrations of these trace elements in Delaware lime-stabilized biosolids were measured at 11.4, 1.1, 269, 34.7, 0.0, 16.0, 0.4, and 550 mg $kg^{-1}$, respectively [12]. Despite the overall quality improvement of biosolids, application of the material to land as a fertilizer is not widely accepted by the public [13]. Citizens expressed concerns on potential impacts of biosolids land application on health, quality of life, and natural resources. In the U.S., health complaints related to sludge exposure from biosolids land application were filed at roughly once a month incidence. These concerns and complaints, however, had led to banning or restrictions of biosolids land application in a number of counties and municipalities [13]. Investigations revealed that the complaints were mainly from the residents who lived near sites with surface application of Class B biosolids [14]. Illness symptoms of sludge exposure include headache, skin rashes, nosebleeds, burning eyes, irritated throat or nose, flu-like symptoms, and fatigue. The illness was likely a result of exposure to sludge odorants (e.g., hydrogen sulfide, methanethiol, dimethyl sulfide, ammonia, and amines) and airborne particles that carried endotoxins (microbial byproducts) and pathogens (e.g., *Staphylococcus aureus*)

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| Pollutant | Pollutant concentration, mg kg$^{-1}$ | | Pollutant loading rate, kg ha$^{-1}$ | |
|---|---|---|---|---|
| | Ceiling | Monthly average | Annual | Cumulative |
| Arsenic | 75 | 41 | 2.0 | 41 |
| Cadmium | 85 | 39 | 1.9 | 39 |
| Copper | 4300 | 1500 | 75 | 1500 |
| Lead | 840 | 300 | 15 | 300 |
| Mercury | 57 | 17 | 0.85 | 17 |
| Molybdenum | 75 | - | - | - |
| Nickel | 420 | 420 | 21 | 420 |
| Selenium | 100 | 100 | 5.0 | 100 |
| Zinc | 7500 | 300 | 140 | 2800 |

**Table 1:** Quality standards of biosolids for land application [7].

| Pollutants | Limiting pathway | Pollutant limit mg kg$^{-1}$ | Conc. in sludge, μg kg$^{-1}$ | |
|---|---|---|---|---|
| | | | 1970s† | 1980s‡ |
| Aldrin/Dieldrin | Adult eating animal products | 2.7 | 6.4 (16%)¶ | 1.9 (3%) |
| Benzo(a)pyrene | Child eating biosolids | 15 | 138 (21%) | - (3%) |
| Chlordane | Child eating biosolids | 86 | 6.4 (16%) | - (3%) |
| DDT§ | Adult eating fish/drinking water | 120 | - (0%) | - (0%) |
| Heptachlor | Adult eating animal products | 7.4 | 6.4 (16%) | - (0%) |
| Hexachlorobenzene | Adult eating animal products | 29 | 155 (16%) | - (0%) |
| Hexachlorobutadiene | Adult eating animal products | 600 | 23 (5%) | - (0%) |
| Lindane | Child eating biosolids | 84 | 6.4 (16%) | - (0%) |
| Dimethylamine | Child eating biosolids | 2.1 | 57 (5%) | - (0%) |
| Toxaphene | Adult eating animal products | 10 | 6.4 (16%) | - (0%) |
| Trichloroethylene | Child eating biosolids | 10000 | 8139 (84%) | - (1%) |

†Averages for sludge in 40 cities in the late 1970s.
‡Averages from the National Sewage Sludge Survey conducted in the late 1980s.
§Dichlorodiphenyl trichloroethane
¶Numbers in parentheses are the percentage of wastewater treating plants in which a compound was detected.

**Table 2:** Organic chemicals evaluated for safety of biosolids land application [11].

[15]. Air transport is the major path for sludge contaminants to disperse and therefore, the health impacts of biosolids land application vary with sludge quality, application method, distance from the site, exposure duration, and wind speed [14]. Modeling studies indicate that individuals within 100 m from the application site may experience the serious risk [16]. Spreading of deodorized Class A biosolids over land more than 100 m distant from residential areas followed by soil incorporation should minimize the human exposure and health impacts. Pre-treatment of sludge with hypochlorite or ferrate (VI) had been proposed to destroy sludge odor [17,18].

Safe application of biosolids as a soil amendment requires control of the organic waste in odor emissions, trace elemental concentrations, air-transport of pathogens, and runoff of EDCs. Practical, innovative approaches are needed to treat sewage sludge into odor-minimal, metal-unlabile, pathogen-free, drifting-resistant, and EDCs-null biosolids.

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