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Are Agricultural Soils Dumps for Microplastics of Urban Origin?

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Due to their ubiquitous distribution and chemical composition, microplastics (MPs) are increasingly being recognized as a global concern. While it is widely acknowledged that MPs in the ocean are a serious issue with potentially negative effects on marine organisms, information about MPs in terrestrial and freshwater environments is fragmentary.

Based on new MP emission estimates in industrialized countries, we suggest that widespread application of sewage sludge from municipal wastewater treatment plants (WWTPs) to farmlands is likely to represent a major input of MPs to agricultural soils, with unknown consequences for sustainability and food security.

Terrestrial emissions are the dominant source of MPs, including those conveyed to receiving waters by WWTP outfalls. Recent reports based on product life cycle data[1−3] offer the first quantitative insights into national MP emission inventories. MPs originate predominantly from automobile tire wear, household and laundry dust, industrial processes (e.g., blasting and deflashing of plastics), and through deterioration of surfaces made of or coated with plastic, for example, artificial turf and polymeric paint. Most of these emissions occur in urban and residential areas. In developed regions, municipal/industrial effluents and even diffuse urban runoff are eventually conveyed to WWTPs. During wastewater treatment, over 90% of MPs are retained in sewage sludge.[4] Effectiveness of MP retention is dependent on particle density and size. MPs with a density greater than water are almost completely retained in sewage sludge during primary and secondary treatment. Tertiary filtration treatment effectively removes larger floating particles, while smaller and lighter particles, expectedly, are released with wastewater effluents.

The use of sewage sludge as fertilizer for agricultural applications is often economically advantageous and is common in many developed regions. In Europe and North America about 50% of sewage sludge is processed for agricultural use. Using national data on farm areas, population and sewage sludge fate (http://ec.europa.eu/eurostat), with estimates of MP emissions[1−3] and applying broad but conservative uncertainty ranges, we estimate that between 125 and 850 tons MP/million inhabitants are added annually to European agricultural soils either through direct application of sewage sludge or as processed biosolids. This is at least equal to, and probably much higher than our estimate of 110 to 180 tons MP/million inhabitants emitted annually to surface waters based on refs 1−3. In Europe, in fact, between 1270 and 2130 tons MPs/million inhabitants are released to urban environments, annually. Conservatively assuming that 10−90% of MPs produced from road wear and debris from building coating are collected by sewers, between 360 and 1980 tons MPs are expected to reach municipal WWTPs. Here, an uncertain fraction of MPs from car tire debris (conservatively, 20−80%) and >90% of MPs from personal care products are likely to be retained in sludge,[4] giving a total input of between 250 and 1700 tons/million inhabitants each year. Sludge application to agricultural land was calculated as the sum of direct application and application of processed biosolids, excluding the fraction of wastewater sludge incinerated, disposed in landfills or subject to other nonagricultural uses. These figures are highly conservative as sludge is only ever applied to a small percentage of agricultural land.

There is a broad range of sludge application rates and intensities to European agricultural land (Figure 1). Application rates (estimated as compost plus direct application) range from 0 to 91%, with an average of 43%. This equates to average and maximum areal per-capita loadings of 0.2 and 8 mg MP/ha/yr. MPs inputs estimated here possibly reflect the situation in other countries with similar socioeconomic conditions and/or similar use of plastics (e.g., in Asia and the Americas). A rough extrapolation from data in refs 1−3 produces a total yearly input of 63 000−430 000 and 44 000−300 000 tons MPs to European and North American farmlands, respectively. This would be an alarmingly high input. Comprehensively, this exceeds the total accumulated burden of 93 000−236 000 tons MPs currently estimated to be present in surface water in the global oceans.[5]

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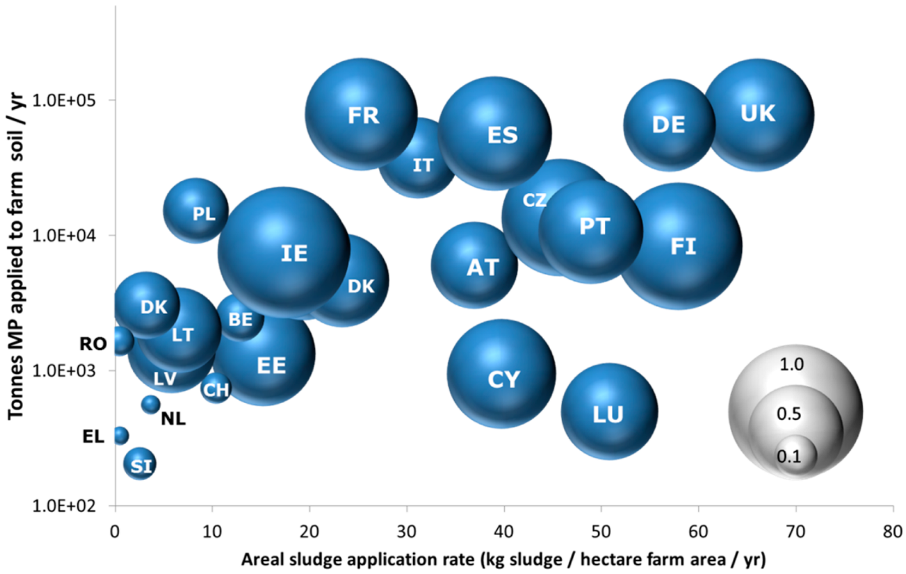

Figure 1. Estimated rates and intensities of MP application to European agricultural lands. In countries with elevated sludge application rates per unit area of farmland (such as, for example UK) the level of MPs accumulated in treated soils is expectedly potentially higher than in countries with similar use of sludge but lower application intensity (e.g., France). National MP upper application rates were estimated as sludge production multiplied by agricultural application rate multiplied by MP emission per inhabitant multiplied by total population. Areal application rates were estimated as sludge production multiplied by agricultural application rate then divided by total farm area. Bubbles represent individual countries (Austria (AT), Belgium (BE), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Slovenia (SI), Spain (ES), United Kingdom (UK)), and bubble sizes represent the fraction of sludge either applied directly to agricultural areas or in the form of processed biosolids.

Regulations generally prohibit use of sludge containing an excess of harmful substances (including heavy metals and some organic substances). Neither the relevant European (EU 86/278/EEC) nor U.S. (Code 503) regulations mention MPs. We expect that none of the common processing steps (e.g., drying, pasteurization, composting, etc.) to produce biosolids from WWTP sludge for agricultural use will remove the MP load. Reports are emerging about the occurrence and impacts of MPs in soil, both from breakdown of plastics and sludge additions. Reproduction of worms was recently shown to be impacted at MP exposure levels possibly representative of those in agricultural soils receiving sewage sludge application.[6]

Assessing potential impacts for agricultural sustainability and human health is far from easy. MPs can potentially impact soil ecosystems, crops and livestock either directly or through the toxic and endocrine-disrupting substances added during plastics manufacturing. These substances include short/medium-chain chlorinated paraffins (candidates for inclusion in the Stockholm Convention) and plasticizers, which can represent up to 70% of the weight of plastics. Endocrinologically active alkylphenols, such as bisphenols, and flame retardants including several banned brominated compounds comprise up to 3% by weight of some plastics. During use, plastic polymers efficiently accumulate other harmful pollutants from the surrounding environment, including a number of persistent, bioaccumulative and toxic substances, e.g. PCBs, dioxins, DDTs and PAHs. Many studies on these topics can be found in previous issues of ES&T.

It is striking that transfers of MPs (and the hazardous substances bound to them) from urban wastewater to farmland has not previously been considered by scientists and regulators. Studies assessing the scale of contamination of agricultural soils by MPs are notable for their absence while farm soils may arguably represent one of their largest environmental reservoirs. International monitoring programs, additional research into ecological effects, and awareness raising among farmers, wastewater treatment operators and the general public are all urgently needed to frame the problem more accurately. Analysis of risks and potential impacts of MPs on agricultural sustainability and human/livestock health must be prioritized to ensure a safe reuse of municipal waste. From a broader perspective, these analyses are critical for safeguarding circular economy objectives including those in which biological nutrients in waste products can be safely and sustainably reintroduced into natural and farm ecosystems.

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Notes

The authors declare no competing financial interest.

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