



Research Paper



Investigating the sources and fate of per- and polyfluoroalkyl substances (PFAS) in food waste compost

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ABSTRACT

Composting municipal food waste is a key strategy for beneficially reusing methane-producing waste that would otherwise occupy landfill space. However, land-applied compost can cycle per- and polyfluoroalkyl substances (PFAS) back into the food supply and the environment. We partnered with a pilot-scale windrow composting facility to investigate the sources and fate of 40 PFAS in food waste compost. A comparison of feedstock materials yielded concentrations of \sum PFAS under 1 ng g^{-1} in mulch and food waste and at 1380 ng g^{-1} in leachate from used compostable food contact materials. Concentrations of targeted \sum PFAS increased with compost maturity along the windrow ($1.85\text{--}23.1 \text{ ng g}^{-1}$) and in mature stockpiles of increasing curing age ($12.6\text{--}84.3 \text{ ng g}^{-1}$). Among 15 PFAS quantified in compost, short-chain perfluorocarboxylic acids (PFCAs) – C5 and C6 PFCAs in particular – led the increasing trend, suggesting biotransformation of precursor PFAS into these terminal PFAS through aerobic decomposition. Several precursor PFAS were also measured, including fluorotelomer carboxylic acids (FTCAs) and polyfluorinated phosphate diesters (PAPs). However, since most targeted analytical methods and proposed regulations prioritize terminal PFAS, testing fully matured compost would provide the most relevant snapshot of PFAS that could be land applied. In addition, removing co-disposed food contact materials from the FW feedstock onsite yielded only a 37 % reduction of PFAS loads in subsequent compost, likely due to PFAS leaching during co-disposal. Source-separation of food contact materials is currently the best management practice for meaningful reduction of PFAS in food waste composts intended for land application.

1. Introduction

The United Nations Environment Programme (UNEP) estimates that 931 million tons of food (as much as 17 % of food produced globally) became waste at retail and consumer levels in 2019 (UNEP, 2021). The World Bank further estimates that, even though an average 44 % of global municipal solid waste (MSW) is food and green waste, only 5.5 % of global MSW is composted (The World Bank, 2023). In the United States (US), the Environmental Protection Agency (EPA) estimates that only 5 % of the 62.2 million tons of municipal food waste (FW) generated in 2018 was composted. Meanwhile, approximately 60 % of US municipal FW (24 % of all landfilled waste) occupied landfill space (EPA, 2023a), contributing to methane emissions and excess nutrients in landfill leachate (EPA, 2022a; Lucero-Sorbazo et al., 2022). In fact, the UNEP estimates that wasted food accounts for 8–10 % of global greenhouse gas emissions (UNEP, 2021).

Composting is a method of FW recycling that can divert this organic fraction of MSW from landfills while reducing greenhouse gas emissions

and creating a nutrient-rich fertilizer for beneficial reuse (EPA, 2022a; Huang et al., 2022). Promoting composting programs is integral to accomplishing goals set forth by the UNEP and US EPA to halve food waste by 2030 (EPA, 2022b; UNEP, 2023), and many states and municipalities are already adopting their own far-sighted policies for food-waste diversion (Interreg Europe, 2021; Sandson et al., 2019; US Composting Council, 2023). With increasing evidence that per- and polyfluoroalkyl substances (PFAS) are likely present in most composts, however, there is concern that the land application of compost will cycle PFAS back into the food supply and environment (Choi et al., 2019; Lazcano et al., 2020; Munoz et al., 2021).

PFAS are a class of anthropogenic compounds known as “forever chemicals” due to their persistence in the environment and potential for adverse health effects in all living organisms (W. Liu et al., 2019; Panieri et al., 2022). The extensive global use of PFAS in both consumer and industrial products for over 50 years has resulted in their widespread contamination of waste streams and the environment (Brusseu et al., 2020; Faust, 2022; Masoner et al., 2020; Zhang et al., 2023), and an

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increasing awareness of their impact on humans (D'eon et al., 2009; Lee and Mabury, 2011). Consumption of food and drinking water is currently considered the primary route of exposure to PFAS for most humans (Ericson et al., 2008; Haug et al., 2011; Hu et al., 2016), and studies have demonstrated that PFAS can migrate into nearby water systems and into the edible parts of plants when land applied (Bizkarguenaga et al., 2016; Costello and Lee, 2020; Ghisi et al., 2019; Z. Liu et al., 2019; Sungur et al., 2020; Wang et al., 2020).

Concentrations of PFAS in the order of parts per billion (ppb) have been detected in composts across the world (Brändli et al., 2006; Lazcano et al., 2020; Munoz et al., 2021; Sivaram et al., 2022; Sungur et al., 2020). In the U.S., 17 PFAS were monitored in the range of 2.38 to 75.9 ng g⁻¹ in MSW composts (Choi et al., 2019). Interestingly, Choi et al. (2019) found that FW compost that accepted food contact materials (FCMs) had consistently higher concentrations of \sum_{17} PFAS (28.7–75.9 ng g⁻¹) compared to composts of just food or yard waste (2.38–7.60 ng g⁻¹). Similarly, manure composted with FCMs yielded 209–455 ng g⁻¹ of \sum_{13} PFAS, while manure alone contained only 3.7 ng g⁻¹ of \sum_{13} PFAS (Goossen et al., 2023).

PFAS have also been measured (at concentrations up to parts per million) in unused paper and other plant-fiber FCMs that are marketed as compostable and/or biodegradable and are often co-disposed with FW for composting. These studies are finding that single-use plant-fiber FCMs, intended as an eco-friendly replacement to single-use plastics, are often intentionally processed with non-biodegradable PFAS for the purpose of grease- and water-resistance, in addition to trace contamination of PFAS from source material and manufacturing (Peters et al., 2019; Rice et al., 2020; Schwartz-Narbonne et al., 2023; Timshina et al., 2021; Trier et al., 2011). While PFAS presence in FCMs is potentially a major route for direct human exposure via leaching into food and drinks, these products can also contribute to the global PFAS cycle and long-term ambient exposure for all organisms when they are co-disposed with FW for composting (Ramírez Carnero et al., 2021; Susmann et al., 2019; Timshina et al., 2021; Trier et al., 2011; Yuan et al., 2016).

Since becoming aware of this expanding problem of PFAS in FCMs, organizations such as TÜV AUSTRIA and the US-based Biodegradable Products Institute (BPI) require that testing finds under 100 parts per million (ppm) of total organic fluorine (TOF) for a product to be certified compostable and/or biodegradable (BPI, 2023; TÜV AUSTRIA, 2022). Some governments have also banned the use of FCMs that exceed 100 ppm of TOF (Safer States, 2023), prohibited the application of specific PFAS to paper FCMs (Boucher, 2020; McDaniel, 2023; OECD, 2020; O'Keeffe, 2023), or even banned FCMs from municipal compost streams altogether (Certa, 2021; Choi et al., 2019). While manufacturers of compostable products race to develop safer alternatives for water- and grease-resistant FCMs (Ecology, 2021; Glenn et al., 2021; OECD, 2020; Semple et al., 2022) and PFAS-laden FCMs are still widely composted, waste managers and regulators need to know how to reduce PFAS in FW compost.

Though broader PFAS restrictions are on the horizon for countries in the Organisation for Economic Co-operation and Development (OECD), current manufacturing restrictions, health advisories and environmental screening guidelines in the US and abroad prioritize PFAS that have the most evidence for toxicological concern, widespread occurrence, and can be measured with typical targeted analytical methods (EPA, 2023b, 2023c, 2023d, 2022c; OECD, 2023). Most prioritized PFAS are perfluoroalkyl acids (PFAAs), which are often described as “terminal PFAS” because they are not likely to further degrade under typical environmental conditions, persisting in the environment indefinitely (ITRC, 2022). Precursor PFAS, however, can transform into intermediate and terminal PFAS in the environment via aerobic microbial activity (Butt et al., 2014; Lee et al., 2010). Thus, understanding the fate of PFAS through the composting process is critical for developing relevant testing protocols for evaluating PFAS compliance if regulations are enacted.

This study investigated the sources and fate of 40 PFAS in a pilot-

scale municipal FW composting facility managing a single windrow. The relative contributions of PFAS from feedstock materials (mulch, FW, and FCMs) were compared, and windrow compost was sampled periodically to monitor for potential PFAS profile transformation throughout the composting process. To test the hypothesis that removing FCMs from FW compost feedstock will significantly reduce PFAS in the compost, facilitators began removing co-disposed FCMs from the feedstock after baseline sampling of windrow compost. Both windrow and mature composts were also batch-leached to explore the potential for PFAS to migrate into the surrounding environment when in contact with moisture/during rain events. Concentrations of PFAS measured in mature compost stockpiles were assessed in relation to risk-based human exposure thresholds most recently proposed by the US EPA. Finally, implications for future regulations of PFAS in FCMs and FW compost are discussed, and best management practices are suggested.

2. Materials and methods

2.1. Description of composting facility and study design

This pilot-scale composting facility collects FW from both local households and small businesses, such as restaurants and coffee shops. The FW is largely kitchen waste, but may include some garden waste from households. Prior to this study, they included compostable plant-fiber FCMs such as paper plates, bagasse clamshells, and plant-plastic cups in their compost, as these products are typically co-disposed with FW at the source. This blend of food and FCM waste is added to the beginning of the windrow where it is mixed with locally-sourced mulch at an approximate ratio of 60 % mulch to 40 % FW/FCM by volume. FCMs are estimated to make up only 2–5 % of total feedstock volume. The composting practices at this facility are based on standard aerobic composting practices which optimize decomposition, pathogen control, and nutrient balance through several stages (Abdool-Ghany et al., 2023; Papale et al., 2021). The waste is turned weekly and shifted down the windrow as it decomposes, with a turnover period of approximately 1.5 months from the beginning to the end of the windrow. Temperatures mid-windrow reach 60–70 °C during the thermophilic phase. Once the active phase of aerobic decomposition is complete, compost at the end of the windrow cools to 35–50 °C. At this stage, that segment of compost is stockpiled in another location for curing and storage before it is land applied. Stockpiles are further turned until they cool to around 25 °C – a temperature safe for insects to aid in the final curing phase lasting about six months before it is ready for land-application. These stockpiles in various stages of curing are herein referred to as “mature compost stockpiles”.

Initial windrow compost samples were collected twice to establish baseline concentrations of PFAS in the compost when co-disposed FCMs were integrated into the windrow. During each collection, windrow compost was sampled at five equally spaced intervals along the windrow (W1–W5), representing increasing compost maturity (see Fig. 1 for sampling scheme illustration). Facility staff then began manually separating and accumulating the FCMs out of the FW feedstock upon its arrival to the facility. This composite sample of separated FCMs, in addition to representative composite samples of food scraps and mulch, was analyzed to compare the contribution of PFAS from these feedstock materials to the compost. Windrow compost was then collected eight more times over a period of three months (every 9–12 days) to assess whether concentrations of PFAS would decrease after FCM removal. This practice does not eliminate food contact with FCMs prior to composting but represents a management practice which does not rely on a change in consumer behavior. See Table S1 for a list of all samples analyzed in this study, their collection dates, and corresponding physical parameters (pH, moisture content, and organic matter content).

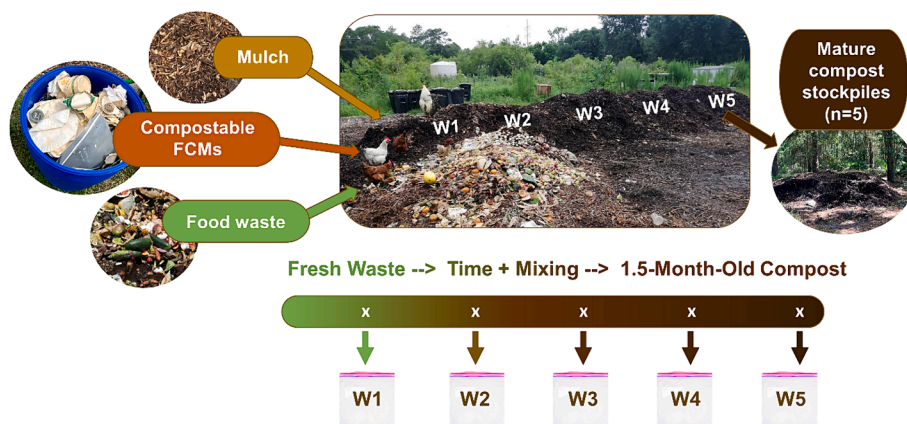


Fig. 1. Schema of composting process and sampling strategy at collaborating food-waste composting facility.

2.2. Sample collection and preparation

2.2.1. Mulch, windrow compost, and mature compost

Triplicate samples of mulch feedstock (one from the middle and each end of the pile) and, in a similar manner, five samples of mature compost (one from each of the five stockpiles collected in triplicate, for a total of 15 mature compost samples) were collected. The mulch is locally sourced from untreated wood, and it was sampled from an onsite stockpile before mixing with FW feedstock. Mature stockpiles are differentiated by age; M12 was 12 months old, while M6, M3, M2, and M1 were six, three, two and one month old, respectively. Singular composite windrow compost samples were collected 10x over a period of 3 months (May – August 2021) at 5 equally spaced intervals along the windrow (for a total of 50 windrow samples) to simulate a timeline of compost shifting through the windrow. Windrow compost intervals W1–W5 correspond to increasing decomposition and maturity of the composting waste. Each sample of mulch and compost was a composite of twelve scoops taken at a depth of six inches below the pile surface and all together filling approximately half of a gallon Ziplock bag (see Fig. S1 for illustration of composite sampling scheme). Samples were scooped using a stainless-steel trowel and temporarily stored in Ziplock bags at $-20\text{ }^{\circ}\text{C}$ until further processing. The trowel was sonicated in DI water and cleaned with methanol 3x before each sampling trip and rinsed with DI water between each individual sample collection in the field. Mulch and compost samples were air-dried under a fume hood on PFAS-free foil at ambient temperatures and gently homogenized in a blender before aliquoting for tests.

2.2.2. Separated FCMs

FCMs were manually separated out of the FW feedstock upon its delivery to the facility and accumulated in a covered HDPE container onsite. The resulting composite sample included approximately 100 pieces of FCMs (totaling approximately 3,600 g dry wt), including clamshells, plates, cups, pizza boxes, napkins, and paper towels (Fig. S2). Though napkins and paper towels are not typically considered FCMs, they were included here because they are often co-disposed with FW for composting. Compostable plastics and non-compostable materials such as polystyrene were avoided; only plant-fiber materials such as paper and sugarcane bagasse were included. At the laboratory, FCMs were laid out on a PFAS-free foil surface and air-dried overnight. The next day, the FCMs were weighed and placed in a methanol-rinsed HDPE container for leach testing as one large composite sample. Due to their bulk and variety, it was not feasible to methanol-extract a representative sample of FCM feedstock. Instead, PFAS concentrations for FCMs were obtained from their leachate, and (conservatively) compared directly to solvent-extracted PFAS concentrations for mulch and FW samples.

2.2.3. Food waste (FW)

To avoid PFAS contamination from co-disposal with FCMs, a control sample of kitchen food-scrap waste (pre-disposal) was crowdsourced. Like the bulk of FW material observed at the facility, this included a variety of fruit and vegetable scraps, coffee grounds, stale bread, egg shells, and herbs. FW was collected by eight individuals into Ziplock bags and was frozen at $-20\text{ }^{\circ}\text{C}$ until further processing. In preparation for PFAS extraction, FW was thawed, mixed with a stainless-steel trowel in an HDPE bin, size-reduced in a glass blender, and mixed again. Nine composite replicates (taking small scoops from different sections of the slurry) were then aliquoted into 50 mL centrifuge tube, frozen at $-80\text{ }^{\circ}\text{C}$, lyophilized overnight, sealed with Parafilm and kept frozen at $-20\text{ }^{\circ}\text{C}$ until extraction. One-gram aliquots were transferred into 15 mL centrifuge tubes for extraction.

2.3. Soil pH, moisture, and organic matter content

Soil pH was determined according to EPA Method 9045D for mulch and composts. Moisture content was determined post air drying for FW, mulch, and composts using EPA Method 1684, and all corresponding PFAS concentrations were normalized to dry weight. FCMs were considered fully air-dried. Organic matter content was estimated using the loss on ignition (LOI) method at $440\text{ }^{\circ}\text{C}$ (EPA, 2002).

2.4. PFAS extraction

Total measurable PFAS were extracted using a solids methanol extraction, as adapted from Ahmadireskety et al. (2021), with matrix-specific variations. Leach testing was performed according to a modified EPA Method 1316 and PFAS extraction of leachates was adapted from Liu et al. (2021). See Supplementary Information for details regarding standards and reagents (S1.1, Table S2, and Table S3) and PFAS extraction (S1.2 and S1.3).

2.5. Analysis

Samples were analyzed for 40 PFAS via ultra-high-pressure liquid chromatography tandem mass spectrometry (UHPLC-MS/MS). Chromatographic separation was achieved using a Thermo Vanquish UHPLC system (Waltham, MA, USA) with a Phenomenex Gemini C18 column and a gradient elution comprised of water and methanol mobile phases, both with 5 mM ammonium acetate. The Thermo Quantis triple quadrupole mass spectrometer was operated in negative selected reaction monitoring polarity (SRM) mode. Additional details regarding instrument parameters and analyte scan parameters are provided in Table S4 and Table S5, respectively. Supplementary Information S1.4 and S1.5 provide further details on quality control and procedures during sample collection, extraction, instrumental analysis, and data analysis.

3. Results and discussion

The aims of this study were 1) to identify which feedstock(s) contributed the most PFAS to FW compost, 2) to observe potential PFAS profile transformation as compost matures via aerobic decomposition, 3) to evaluate the magnitude of PFAS that may be land-applied via mature FW compost 4) to explore the leachability of PFAS present in the compost, 5) to test whether onsite removal of co-disposed FCMs by facilitators is an effective strategy for reducing PFAS in mature compost, and 6) to evaluate the profile and magnitude of PFAS in mature FW compost in relation to risk-based thresholds proposed by the US EPA. Individual PFAS concentrations for all samples/matrices are detailed in Table S6 and average concentrations and detection frequencies (DF) are summarized in Table S7. For samples extracted in replicate, only PFAS present at concentrations above the limit of quantitation (>LOQ) in all replicates were reported in summary tables and figures. All reported concentrations were normalized to the weight of solid sample leached or solvent-extracted. For samples whose moisture content was determined, concentrations were further normalized to dry weight.

3.1. Comparing PFAS in FW compost feedstocks

Average concentrations of 40 PFAS (Σ_{40} PFAS) measured in feedstock materials are compared in Fig. 2a. Among 40 PFAS analyzed, three were measured in all mulch replicates ($n = 3$) – perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), and 6:2 fluorotelomer phosphate diester (diPAP), with combined concentrations below 1 ng g^{-1} . Several PFAS were detected in FW, but none were present in all replicates ($n = 6$), and all concentrations were < LOQ. In contrast, eight PFAS were measured > LOQ in FCM leachate ($n = 3$) at an average Σ_{40} PFAS of 1380 ng g^{-1} (three orders of magnitude greater than in mulch and FW): perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), 6:2 fluorotelomer carboxylic acid (FTCA), 5:3 FTCA, 6:2 diPAP, 6:2/8:2 diPAP, and 8:2 diPAP.

The most abundant PFAS measured in FCM leachate were PFAAs (Fig. 2b). PFAAs are typically categorized by their functional group (into perfluorocarboxylic acids, or PFCAs, and perfluorosulfonic acids, or PFSAs) and by the length of their carbon–fluorine chain. Short-chain

PFAAs (≤ 7 carbons for PFCAs and ≤ 5 carbons for PFSAs) are typically considered more water-soluble and thus more mobile in the environment, while long-chain PFAAs often accumulate in soils and sediments (ITRC, 2022). Concentrations of PFOS (a PFSA) averaged 0.06 ng g^{-1} in mulch and < LOQ in FW and FCMs. Concentrations of three PFCAs (C5–C7) in FCM leachate, on the other hand, averaged 1340 ng g^{-1} , with PFPeA (C5) and PFHxA (C6) accounting for an average 87 % of Σ_{40} PFAS.

It is important to note here that a potential unintended consequence of a 3-day batch leaching test of soiled plant-fiber products in outdoor conditions ($25\text{--}28 \text{ }^\circ\text{C}$) was biotransformation of precursor PFAS, potentially inflating concentrations of PFCAs observed. In addition, the contact time of the co-disposed FCMs and FW moisture and microbes prior to the composting facility is unknown. In other words, it is plausible that we may have measured biotransformation products of precursor PFAS that our method may not otherwise have been able to measure, though future studies should confirm the plausibility PFAS biotransformation during leaching tests. Then again, comparing concentrations of PFAS found in FCM leachate to that of solvent extracted PFAS in mulch and FW is conservative, as it underestimates PFAS in the FCM feedstock that did not leach with water. Nonetheless, five potential PFAA precursors were measured in all FCM replicates: average combined concentrations of 6:2, 6:2/8:2, and 8:2diPAPs were under 3 ng g^{-1} , while combined concentrations of 6:2 and 5:3 FTCA averaged 181 ng g^{-1} , accounting for most of the remaining 30 % of Σ_{40} PFAS in FCM leachate.

Although the profile of PFAS observed in FCM leachate is not necessarily representative of the total and original profile those FCMs would have contributed to our windrow, it is consistent with literature regarding PFAS commonly applied to new FCMs and their biodegradation products. Both short-chain PFCAs and PFCA precursors are approved for application to FCMs for the purpose of water and grease resistance (Schneider et al., 2017; Trier et al., 2011; US Food and Drug Administration, 2022). PAPs, specifically, are used extensively in FCMs. Though relatively low concentrations of PAPs were measured in FCM leachate, intermediate PFAS (6:2 FTCA and 5:3 FTCA) and terminal PFCAs measured are all potential biotransformation products of PAPs (Bizkarguenaga et al., 2016; Butt et al., 2014; Lee et al., 2010). Schultes et al. (2019) also finds that short-chain PFCAs can be the most abundant

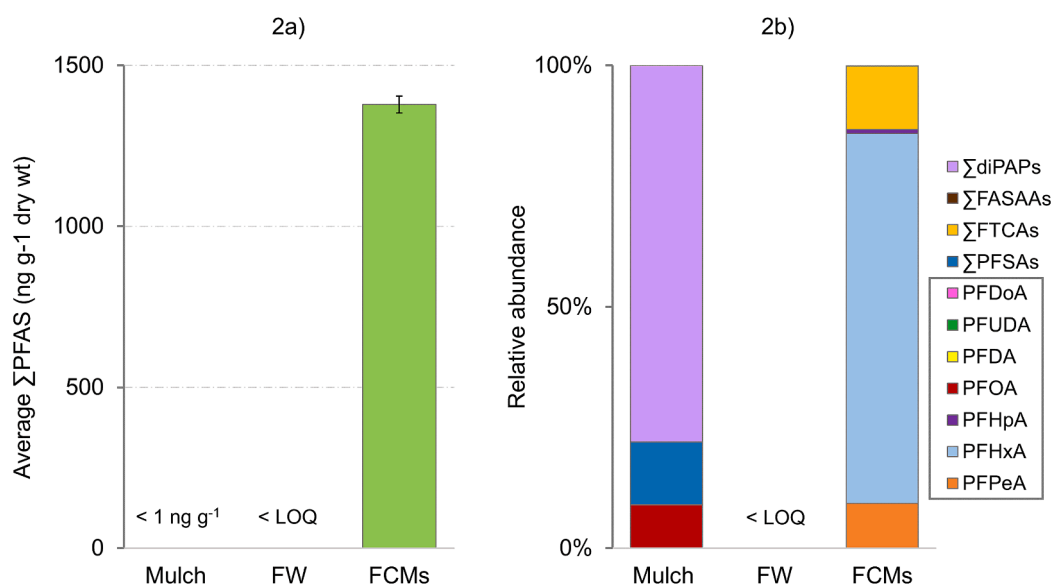


Fig. 2. Bar charts comparing average Σ_{40} PFAS (a) and relative abundance of individual PFCAs (boxed) and other PFAS subclasses (b) in the food waste (FW) compost feedstock materials. Food contact materials (FCMs) tested here are all plant-based products often co-disposed with FW for composting. Due to their bulk and variety, FCMs were batch-leached, and concentrations of PFAS in FCM leachate were conservatively compared to solvent-extracted concentrations of PFAS in mulch and FW. Error bars represent the standard deviation of Σ_{40} PFAS across sample replicates.

PFAS measured in new FCMs, even as TOF measurements of the same materials pre- and post- solvent extraction show that a majority of TOF often remains on paper-based FCMs after extraction, likely in the form of PFAS-containing polymers that can release transformation products. Other studies corroborate that plant-fiber FCMs marketed as eco-friendly and/or compostable can have PFAS concentrations higher than those in most other FCMs (Schwartz-Narbonne et al., 2023; Yuan et al., 2016).

PFAS can incorporate into FW compost feedstock materials at any point in their lifecycle. Food products and trees used for mulch can accumulate PFAS if they are grown with PFAS-containing soils and water (Ghisi et al., 2019), during processing, packaging, use and co-disposal (Ramírez Carnero et al., 2021; Thakali et al., 2022), or even via aerial deposition (Brändli et al., 2006; Pfothenhauer et al., 2022). In this study, the mulch was locally sourced from virgin untreated wood and the FW was crowd-sourced directly from local kitchen waste to avoid contamination from co-disposal with FCMs. Mulch and FW from other sources may contain higher concentrations of PFAS than those measured in this study. For example, Thakali et al (2022) measured up to 7.6 ng/g PFAS in food waste sampled from waste receptacles, likely co-disposed with FCMs. PFAS may also enter the compost from residual contamination of the bins re-used to transport food waste to the facility, water added during composting, or tarps used to cover curing mature compost. Nonetheless, these concentrations are expected to be negligible compared to what we measured in FCM leachate and what other studies report for potential total loads of PFAS in unused plant-fiber FCMs.

3.2. PFAS concentrations along the windrow

Single composite samples of windrow compost ($n = 50$) were collected 10 times over a period of three months at five intervals along the windrow (W1-W5) to simulate a timeline of potential PFAS transformation (See Fig. 1 for sampling schema). Among 40 PFAS analyzed, 15 were detected in at least one windrow sample: two PFSAs, seven PFCAs, 5:3 FTCA, N-ethyl perfluorooctane sulfonamido acetic acid (N-EtFOSAA) and three diPAPs. Within each of the 10 collections, Σ_{40} PFAS increased as compost matured along windrow intervals W1-W5 ($r =$

0.91, $p = 2.2e-16$, Fig. S3), with an average increase from 1.85 to 23.1 ng g⁻¹ (Fig. 3a).

PFCAs clearly lead the increasing trend, and, by the end of the windrow (W5), the PFAS profile resembles the profile in FCM feedstock leachate (Fig. 3b). The same two short-chain PFCAs (PFPeA and PFHxA) account for an average 91 % of Σ_{40} PFAS at W5. Combined PAP concentrations do not follow a visually evident trend, but a correlation analysis suggests a modest decrease with compost maturity within the windrow ($r = -0.49$, $p = 0.00036$, Fig. S4). FCMs are likely the main source of PAPs in the compost, but mulch may also contribute some 6:2diPAP. Two potential intermediate PFAS – 5:3 FTCA and N-EtFOSAA – tend to occur towards the middle and end of the windrow (see Fig. S5). N-EtFOSAA was not measured in FCM leachate, but it could be a biotransformation product of N-ethyl perfluorooctane sulfonamidoethanol (N-EtFOSE), and an eventual precursor to PFOS. N-EtFOSE, not monitored in this study, was historically used in paper coatings, and it tends to transform more quickly due to its volatile nature (Rhoads et al., 2008).

The increase of Σ_{40} PFAS along the windrow is likely, in part, a result of concentration as the compost volume decreases through aerobic decomposition (Breitenbeck and Schellinger, 2004). However, volume reduction alone should cause a proportional increase in all PFAS measured. Additional confounding factors not controlled in this study, including the inherent daily and seasonal variability in the volume and composition of the FW/FCMs waste, rain events that led to leaching of PFAS out of the compost pile, and potentially variable extraction efficiency in different windrow samples (See 3.4 discussion), could affect the profile and magnitude of PFAS measured in the compost. Ultimately, the consistent increase of intermediate and terminal PFAS as compost matures, and the lack of a corresponding increase in precursor PFAS, suggests precursor PFAS transformation throughout the windrow is the greater driver of the increasing trend.

3.3. PFAS concentrations in mature compost stockpiles

Five mature compost stockpiles (also shaped like windrows) were sampled in triplicate composite samples ($n = 15$) at the beginning, middle and end of each stockpile, to observe the range of PFAS

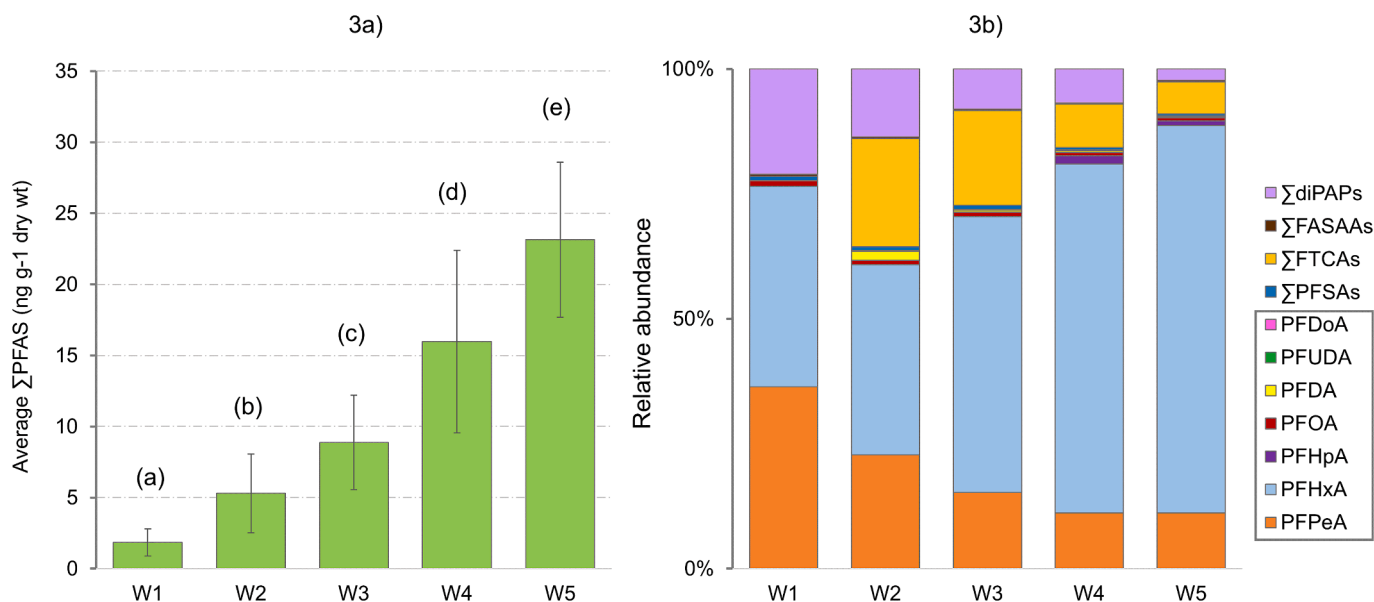


Fig. 3. Bar charts comparing Σ_{40} PFAS (a) and relative abundance of individual PFCAs (boxed) and other PFAS subclasses (b) in windrow compost. Five intervals along the windrow (corresponding to W1-W5 on the chart) were collected 10 times over a period of three months. Each bar represents an average of Σ_{40} PFAS measured > LOQ across 10 collections and error bars represent the standard deviation of Σ_{40} PFAS across 10 collections. See Table S7 for detection frequencies, since some PFAS depicted in averages were not present in samples from all collections. Labels (a)-(e) correspond to compost age groups that were significantly different from each other according to the Dunn pos-hoc test ($p < 0.05$). See Table S8 for all relevant p-values.

stockpiled over time. The same 15 PFAS detected in windrow compost were also detected in at least one mature triplicate, with average Σ_{40} PFAS ranging from 12.6 ng g⁻¹ in the youngest stockpile (M1) to 84.3 ng g⁻¹ in the oldest (M12) (Fig. 4a). PFAS profiles in mature composts were consistent with profiles in FCM leachate and in compost at the end of the windrow (W5). PFPeA and PFHxA account for 86–97 % of Σ_{40} PFAS in all mature composts (Fig. 4b) and drive the major trend: after the initial and more rapid increase of Σ_{40} PFAS within the windrow, Σ_{40} PFAS continues to increase as mature compost cures, even up to a year later ($R = 0.75$, $p = 0.0012$, Fig. S6), likely due to continued biotransformation of precursor PFAS into terminal PFAS. Concentrations of the other 12 PFAS measured are also similar in magnitude to those in windrow composts. Notably, 5:3 FTCA is not present in the oldest stockpile (M12), which could indicate its complete transformation into terminal PFAS.

The magnitude and profile of PFAS measured here is comparable to what Choi et al. (2019) reported in FW composts from seven different facilities: PFHxA was the most abundant PFAS, followed by other short-chain PFCAs, and concentrations 17 PFAAs ranged from 28.7 to 75.9 ng g⁻¹. In commercially-available composts of variable origin, concentrations of measured PFAS tend to range lower than those of FCM-containing FW composts (0.1–19 ng g⁻¹), but the profile is similar: short-chain PFCAs dominate (Lazcano et al., 2020; Sivaram et al., 2022). Furthermore, PFCA concentrations are likely to increase over time under environmental conditions if precursors are present, as demonstrated by an increase of short-chain PFCAs with total oxidizable precursor (TOP) assays (Choi et al., 2019; Lazcano et al., 2020; Sivaram et al., 2022) and by observations of recurring PFCAs in soil columns spiked with precursor PFAS (Weidemann et al., 2022) and land-applied composts in the field (Röhler et al., 2021). The detection of 6:2 fluorotelomer sulfonate and 6:2 diPAP in composts whose PFCA concentrations increased after the TOP assay (Choi et al., 2019) further supports our hypothesis that most of the PFAS in mature compost could be attributed to FCM

presence in the compost feedstock. Still, the limited scope of our targeted analytical method (monitoring only 40 PFAS out of the 9,000 + that exist) cannot account for all possible precursors, as confirmed by the non-targeted exploration of Munoz et al. (2021). This study estimates that most targeted methods, depending on how many of the more common precursor it included, could be underestimating PFAS concentrations in MSW compost by 40- to 160-fold.

3.4. Leachable PFAS in windrow and mature composts

Batch leaching tests were employed to explore the potential mobility of PFAS in windrow ($n = 50$) and mature ($n = 15$) composts from contact with FW moisture and rainwater during the composting process, as well as the potential availability of the PFAS for plant uptake upon land-application of mature composts. Four PFCAs (C5–C8) were measured in compost leachates, but overall trends mirror those of solvent-extracted PFAS: average Σ_{40} PFAS increase across the windrow (<LOQ–17.8 ng g⁻¹; Fig. S7a) and with mature compost curing age (9.82–57.1 ng g⁻¹; Fig. S7b). As expected, all but PFOA are short-chain PFCAs, which are typically more hydrophilic and mobile than long-chain PFCAs (Li et al., 2020). As in FCM leachate and compost solvent extracts, PFHxA is the most abundant PFAS measured in compost leachates, accounting for 98–100 % and 64–85 % of PFAS measured in windrow and mature leachates, respectively.

Only two of the four PFCAs (PFHxA and PFOA) measured in mature compost leachate were also measured in windrow compost leachates. This is likely a result of several factors, including the magnitude of PFAS available for leaching, potential heterogeneity in the composite sample, the variable partitioning behavior of individual PFAS, and the effect of background matrix on extraction efficiency and instrumental/data analysis. For example, compost is high in organic matter (ranging from 65 to 92 % across windrow and mature composts; Table S1), which is known to adsorb PFAS and reduce their leachability (Lazcano et al.,

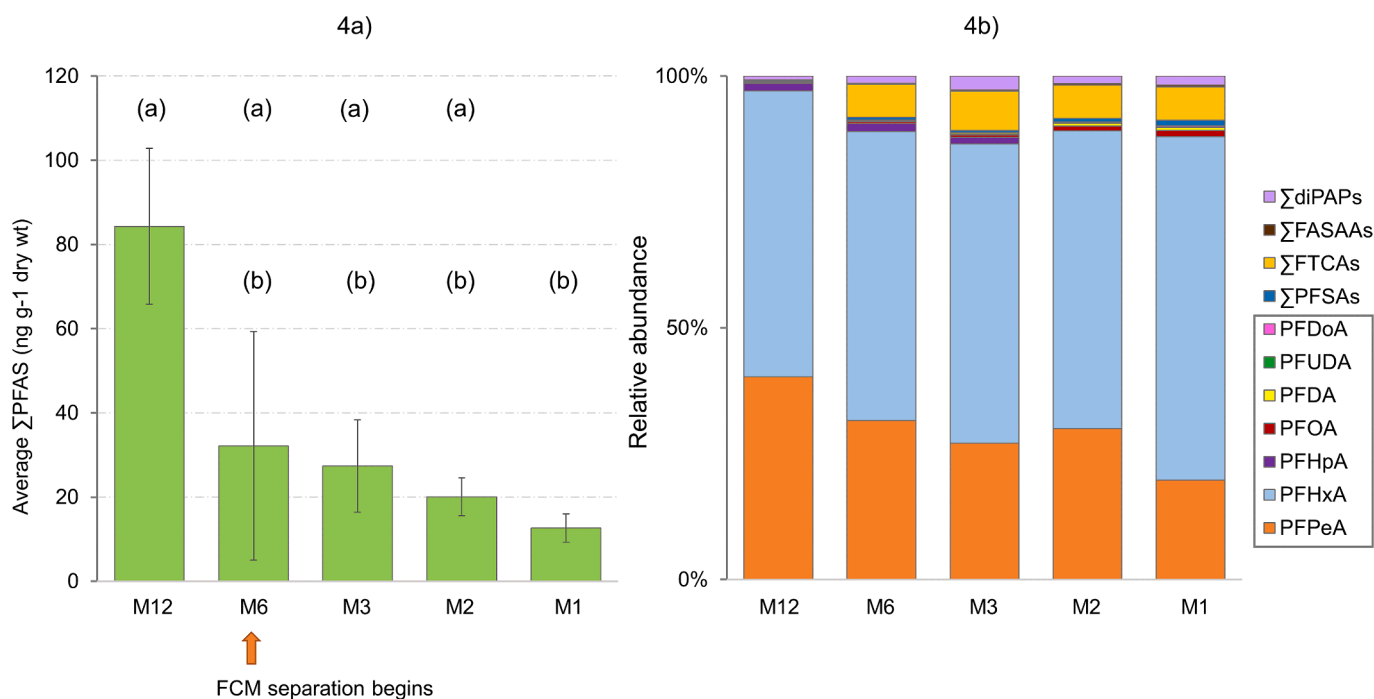


Fig. 4. Bar charts comparing Σ_{40} PFAS (a) and relative abundance of individual PFCAs (boxed) and other PFAS subclasses (b) in five mature compost stockpiles of decreasing curing age, in chronological order of when they were stockpiled. Stockpiles M12, M6, M3, M2, and M1 are 12, 6, 3, 2 and 1 month old, respectively. Each bar represents an average of Σ_{40} PFAS measured > LOQ across three distinct samples from different parts of that stockpile. Error bars represent the standard deviation of Σ_{40} PFAS within each triplicate, correlating to variation in PFAS distribution throughout the pile. Labels (a) and (b) indicate compost age groups that were significantly different from each other according to the Dunn post-hoc test ($p < 0.05$). Only groups M12 and M1 were significantly different. See Table S8 for all relevant p-values.

2020). In the laboratory, visual clarity of sample extracts and resulting mass spectra improved with advancing compost maturity. Similarly, variability of the percent of total measured PFAS that leached in each compost age group decreased with increasing compost maturity. Leached Σ_{40} PFAS constituted 38–104 % (excluding outliers) of solvent-extracted PFAS in windrow compost and 54–96 % in the more decomposed and homogenous mature compost (Fig. S8). Leaching fractions above 100 % could be the result of both sample heterogeneity and the potential of precursor PFAS transformation during leaching tests. For example, leached PFHxA (a terminal PFAS and the only PFAS consistently measured in both windrow and mature compost leachates) constituted 61–149 % (excluding outliers) and 69–103 % of solvent-extracted PFHxA in windrow and mature composts, respectively (Fig. S9).

Since PFHxA is the most abundant PFAS among all samples, its tendency for liquid partitioning complicates our interpretation of trends correlating increased PFHxA with increasing age. Compost sampling for this study took place from May to October, during which frequent rain events of variable intensity could have released a leachable fraction of the short-chain PFCAs present in the compost. These leaching tests demonstrate that, under the worst-case leaching scenario of complete inundation with rainwater, over half of short-chain PFCAs in compost are readily mobile into the surrounding environment. Further research is needed to better understand the leaching behavior of PFAS during composting.

3.5. Did onsite separation of co-disposed FCMS reduce PFAS in compost?

At the beginning of this study, we hypothesized that manual removal of co-disposed FCMS from the FW upon delivery to the composting facility will be sufficient to significantly reduce measurable PFAS in both windrow and mature compost over time. If onsite removal of FCMS could be proven effective, the need for changing consumer behavior could be avoided. Although FCMS represent a relatively small fraction of the feedstock (2–5 % by volume, according to the facility operator's estimate), this study corroborates that they contribute disproportionately to the PFAS content in FW compost. We were surprised, however, to not observe an equally indisputable decrease of Σ_{40} PFAS in both windrow and mature composts following FCM removal from the feedstock.

Onsite FCM separation began after two initial windrow collections established baseline concentrations of PFAS in the windrow. Separation began amidst stockpiling M6, which could account for the half-fold decrease in average Σ_{40} PFAS between stockpiles M12 and M6, the relatively large standard deviation of Σ_{40} PFAS across stockpile M6, and the decrease in Σ_{40} PFAS in subsequent stockpiles M3, M2 and M1 (Fig. 4). However, as aforementioned, compost age correlates closely with increasing Σ_{40} PFAS in mature stockpiles regardless of FCM separation timing (see Fig. 4 and Fig. S5), likely due to compost volume reduction and the biotransformation of precursor PFAS over time. Additionally, the Σ_{40} PFAS was only found to be significantly different between stockpiles M12 and M1, and not significant between M12 and M6 (Kruskal-Wallis, $p < 0.05$; Fig. 4). In windrow compost, a strong negative correlation was observed between the number of days since FCM separation began and Σ_{40} PFAS ($r = -0.8$; $p = 0.0058$; Fig. S10). Ultimately, separating FCMS did not reduce Σ_{40} PFAS to concentrations found in food and mulch alone. Average Σ_{40} PFAS measured across the windrow were reduced by only approximately 37 % between the first and final collection, suggesting that FW contact with PFAS-containing FCMS prior to its arrival to the composting facility (i.e. during use, co-disposal and en-route to the facility) contributes significant concentrations of PFAS to FW compost.

The composting facility in this study collects food waste from households and businesses on a weekly basis, which could allow up to a week of contact time between co-disposed FW and FCMS. FCMS co-disposed with FW are exposed to both moisture and higher

temperatures (especially in Florida), two conditions known to facilitate PFAS migration into foods. In addition, the short-chain PFAAs abundant in FCMS are known to migrate more easily with moisture (Ramírez Carnero et al., 2021). Moreover, the manual labor required to screen for and remove FCMS onsite would be impractical for most facilities and quality control is difficult when some FCMS begin to disintegrate from contact with moisture during co-disposal. Considering this leaching potential during co-disposal, as well as the unfeasibility of onsite removal of FCMS, source-separation is desirable.

3.6. Implications for potential PFAS regulations

Regardless of the causes of the profile transformation in maturing compost, the implication for formulating and enforcing regulatory thresholds is clear: the stage at which a compost is tested matters if regulations and testing methods are largely focused on PFAAs. This study demonstrated that precursor PFAS not measured with targeted analysis can continue transforming into PFAAs for at least a year, increasing measurable PFAAs over time. Testing compost when it is ready to land-apply would be most accurate, although most current targeted methods will not be able to measure every precursor PFAS that may transform into short-chain PFAAs after land application (Röhler et al., 2021; Weidemann et al., 2021). In addition, composite sampling protocols may be necessary to accurately reflect the range of concentrations present in compost, as evidenced by the relatively high standard deviation of PFHxA throughout mature stockpiles (Table S7 summary statistics). Background PFAS concentrations in soils would also need to be considered, depending on a facility's proximity to other PFAS sources (Brusseau et al., 2020), as well as other on-site sources such as the water used, the collection bins, and potential feedstock contamination with materials not explicitly accepted by the composting facility.

Though there are currently no regulations for PFAS in compost in the US, the US EPA has put forth provisional risk-based Regional Screening Levels (RSLs) for eight PFAS (see Table S9 for EPA RSLs) (EPA, 2023c). Of the 15 PFAS measured in mature compost stockpiles intended for land-application, PFHxA, PFOA, perfluorobutanesulfonic acid (PFBS), and PFOS are addressed in the EPA RSLs (updated May 2023). We chose to reference RSL values corresponding to a target hazard quotient (THQ) of 0.1, since compost contains a mixture of the targeted PFAS (EPA, 2023e). All four PFAS are present with 100 % detection frequency in mature compost, but they do not exceed industrial or residential direct human exposure limits. However, leachability-based soil screening thresholds designed to protect groundwater were exceeded by Σ PFOS and PFHxA in 100 % of mature compost replicates and by PFOA in 93 % of mature compost replicates. Though authorization for PFOS and PFOA use in FCMS was revoked in the US in 2016 (US Food and Drug Administration, 2022), their relatively low concentration could be attributed to legacy background presence or to precursor transformation. Some states are proposing soil screening levels and standards for groundwater and surface water protection for additional PFAS (ITRC, 2023). For example, PFHpA concentrations in mature compost stockpile M5 would exceed soil standards in place to protect drinking water in Hawaii and Massachusetts.

Since it has become clear that FCMS are the greatest source of PFAS in FW compost, banning PFAS in FCMS and prohibiting PFAS-containing FCMS from composting are key strategies for meeting potential limits for PFAS in FW compost. The widely accepted 100-ppm limit for TOF in FCMS is a reasonably simplified standard for differentiating intentional PFAS application from ubiquitous background PFAS presence, but it does not account for the variable efficacies of individual PFAS. For this reason, both TÜV AUSTRIA and the Biodegradable Products Institute require a signed statement that no PFAS were intentionally used in the product in addition to TOF testing (BPI, 2023; TÜV AUSTRIA, 2022). Curtzwiler et al., (2021) proposes that Limits of Performance (LOPs) experimentally developed for individual PFAS are the most relevant thresholds to distinguish intentional PFAS application from non-

intentional PFAS background. LOP concentrations for avocado oil placed on paper packaging treated with C4, C6, C8, or C10 PFCAs decreased with PFAS carbon chain length, ranging from 37 ppm for PFDA (C10) to over 1238 ppm for PFBA (C4). Moreover, it is unclear how 100 ppm of TOF in FCMs would translate to concentrations of PFAS in compost that included those FCMs or concentrations of PFAS that are able to migrate from the FCMs into food or drink. Future research should evaluate the toxicological relevance of the 100-ppm threshold, both for direct human exposure and for environmental release through composting or landfill disposal.

3.7. Conclusions

A comparison of Σ_{40} PFAS among feedstock materials (mulch, FW and FCMs) confirmed that FCMs are typically the greatest PFAS source in FW compost, with concentrations up to three orders of magnitude greater than those in mulch and FW alone. The similarity in profile of Σ_{40} PFAS in FCMs and composts further supports the hypothesis that FCMs are the predominant source of PFAS in FW compost. However, our effort to remove FCMs from the compost feedstock onsite yielded only a 37 % decrease of PFAS in subsequent composts, likely due to the biotransformation and leaching potential of PFAS from FCMs while they are co-disposed with moisture- and microbe-rich FW. Other factors such as compost age, volume reduction due to decomposition, pre-separation contact time, variability in waste content and variability of rain events could have affected our measurement of PFAS in the compost over time. In future work, we aim to improve PFAS extraction methodology (extracting less material and implementing additional cleanup steps) and expand the suite of PFAS in our analytical method as additional PFAS standards become available to get a fuller picture of the PFAS landscape in compost.

Regarding potential regulations, banning PFAS-containing FCMs from composting waste streams and the continued effort of FCM manufacturers to implement PFAS alternatives are crucial for reducing PFAS loads in FW compost. If PFAS limits were to be established for composts, sampling compost when it is fully cured and ready for land-application would yield the most relevant PFAS measurements because precursor PFAS transformation into PFAAs we are able to measure increases with compost maturity. The continued transformation of unknown precursor PFAS after land-application should also be considered.

Finally, consumers, regulators and waste managers should consider the long-term impact of including PFAS-laden FCMs in land-applied compost regardless of potential PFAS regulations. The persistence of PFAAs under environmental conditions, combined with their continued use, environmental release, and long-range mobility, suggests a potentially indefinite increase of PFAS loads in the environment and organisms over time (Stoiber et al., 2020). Because large-scale environmental remediation of PFAS, particularly short-chain species, is costly and impractical with current technology (Ateia et al., 2019; Li et al., 2020), prevention of PFAS release at the source is preferred. Until PFAS are phased out of FCMs, source-separation of FCMs from the composting waste stream is the best management strategy for the long-term reduction of PFAS release into the environment via municipal FW compost.

CRediT authorship contribution statement

Alina S. Timshina: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Nicole M. Robey:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. **Allison Oldnettle:** Investigation, Visualization, Writing – review & editing. **Stephan Barron:** Investigation, Resources. **Qaim Mehdi:** Data curation, Formal analysis, Software, Writing – review & editing. **Allison Cerlanek:** Investigation, Visualization, Writing – review & editing. **Timothy G. Townsend:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing –

review & editing. **John A. Bowden:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: John A. Bowden reports financial support was provided by US Environmental Protection Agency. John A. Bowden reports financial support was provided by Hinkley Center for Solid and Hazardous Waste Management. Timothy G. Townsend reports financial support was provided by US Environmental Protection Agency. Timothy G. Townsend reports financial support was provided by Hinkley Center for Solid and Hazardous Waste Management. Co-author Stephan Barron is the owner and operator of the composting facility from which samples for this study were collected. We felt that it was important to include Stephan as a co-author because he had to facilitate our access to sample collection and provide information about his composting process, which was then incorporated into the manuscript. Stephan was not involved in any way in sample processing, data analysis and interpretation, or manuscript writing. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Processed data is included in the [Supplementary Information](#) to this manuscript, and raw data can be made available upon request.

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Appendix A. Supplementary data

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1 **Investigating the Sources and Fate of Per- and Polyfluoroalkyl Substances**
2 **(PFAS) in Food Waste Compost**

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13 **Supplemental Information**

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52 **S1. MATERIALS AND METHODS**

53

54 S1.1 Standards and reagents

55 Optima-grade water, methanol, ammonium hydroxide, ammonium acetate, and acetic acid, as
56 well as HPLC-grade methanol for cleaning, were purchased from Fisher Scientific (Waltham,
57 MA, USA). Isotopically-labeled compounds (Table S2) used as internal standard (IS) were
58 purchased from Wellington Laboratories Inc., while native (non-labeled) standards for each of
59 the 40 PFAS monitored (Tables S3) were obtained from either Wellington Laboratories Inc. or
60 Oakwood Products Inc. (Estill, SC, USA). Supelco ENVI-Carb (120-400 mesh) was purchased
61 from Supelco (Sigma-Aldrich, Bellefonte, PA).

62 S1.2 PFAS solvent extraction

63 An aliquot from each sample was weighed (10.0 ± 0.5 g for mulch and composts and 1 g for
64 food waste; FW), added to 50-mL polypropylene centrifuge tube, and spiked with IS (30 μ L for
65 mulch and composts and 50 μ L for FW). Extraction was performed in two rounds as follows:
66 0.3% methanolic ammonium hydroxide was added to each sample (30 mL for mulch and
67 compost and 3 mL for FW in the first round; 15 mL and 1 mL in the second round); each sample
68 was vortexed for 30 sec, sonicated for 30 min, rotated for 30 min, and centrifuged at 4,000 rpm
69 for 10 min; the supernatant was pipetted into a clean centrifuge tube, where the two supernatants
70 were combined. For mulch and composts, the combined supernatants were cleaned with 50 ± 5
71 mg of ENVI-Carb graphitized activated carbon (120-400 mesh) and transferred to a new 15 mL
72 centrifuge tube twice, before and after evaporation, to remove interference and precipitation
73 before final concentration to (2 mL) using a Biotage TurboVap II. FW supernatants were first
74 diluted to 50 mL with Optima water and cleaned via solid phase extraction (SPE), before being
75 cleaned with 10 ± 1 mg of ENVI-Carb and evaporated to 1 mL.

76 S1.3 Leachable PFAS extraction

77 According to a modified EPA Method 1316, samples were rotated with PFAS-free water (DI
78 water) in HDPE containers for 72 hours at a liquid-to-solid ratio of 10. All compost leaching
79 tests were performed at the recommended room temperature ($20 \pm 2^\circ\text{C}$). Due to the large size of
80 the container for food contact material (FCM) leaching, this leaching test was performed outside

81 at approximately 25-28°C. FCM leachate was passed through a sieve to separate a liquid sample
82 from the bulk mass of plant-fiber pulp. Leachate pH was recorded, and composite aliquots were
83 stored at -20°C until extraction. Leachate extraction was adapted from Y. Liu et al., 2021.
84 Aliquots of leachates (25 mL for FCMs and 50 mL for composts) were adjusted to a pH of 4-5
85 with glacial acetic acid, spiked with IS, vortexed and centrifuged at 4,000 rpm. Polymeric weak
86 anion exchange cartridges (Phenomenex Strata-X-AW 100 µm, 500 mg/6 mL) were conditioned
87 with 0.3% methanolic ammonium hydroxide (4 mL), methanol (3 mL), and a buffer solution
88 with ammonium acetate/acetic acid (4 mL; pH = 4). After samples were loaded at a rate of 1
89 drop per second, cartridges were washed with the buffer solution (4 mL) and eluted in three
90 stages with methanol (2 mL) and 0.3% ammonium hydroxide in methanol (3 mL twice). Optima
91 water method blanks were included both during leaching and during SPE. Extracts were then
92 cleaned with Envi-Carb (50 ± 5 mg) and evaporated to 1 mL. Aliquots of all final extract (100
93 µL) were transferred into autosampler vials for analysis.

94 S1.4 PFAS quality control during sample collection, extraction, and analysis

95 When possible, new containers from brands previously tested for background PFAS
96 contamination with our method were used for sample collection (Ziplock bags), small-scale
97 leaching tests (2-L HDPE bottles) and SPE/solids extractions (15 and 50 mL polypropylene
98 centrifuge tubes). Large HDPE containers used for FCM leach-testing were thoroughly washed
99 with Liquinox soap and rinsed with methanol three times before each use. Smaller tools used for
100 sample processing in the laboratory, such as the glass blender, stainless steel trowels and scoops,
101 were wash with Liquinox soap, sonicated in deionized water for 10 min, and thoroughly rinsed
102 with HPLC methanol and Kimwipes in between each sample. PFAS-free foil (All Foils Ultra
103 High Vacuum (UHV) Foil) was used to hold samples and to line benchtop surfaces during all
104 activities. Samples and extracts were always stored at -20 or 4°C when not in active processing.
105 To test for ambient contamination during compost sampling, HDPE bottles filled with Optima
106 water were opened in the field on three separate sampling trips. Methanol rinsate blanks were
107 collected from cleaned blender and bins on three different sampling preparation days. Method
108 blanks were spiked with IS, extracted and analyzed for leaching tests (one Optima water rotated
109 for every 10 compost samples), leachate SPE (an additional Optima water blank per 10 samples),
110 and for solids extractions (one Optima methanol blank per 10 samples). To evaluate extraction

111 efficacy, nine quality control (QC) samples were prepared from pooled and homogenized
112 mixtures for both compost and compost leachate. Three QCs were spiked with both native and
113 labeled standard mixtures before extraction, three QCs were spiked with only labeled standard
114 before extraction, and three QCs were spiked with both native and labeled standard after
115 extraction.

116 During analysis, methanol instrument blanks were run after every five samples to check for
117 carryover. A 12-level calibration curve (spanning from 10 to 20,000 ng L⁻¹) was analyzed with
118 each of the three sample runs. To monitor retention time shifting, calibration levels were
119 randomized, and a mid-level calibration solution was repeated 3x throughout each sequence.

120 S1.5 Data analysis

121 QuanBrowser (Xcalibur) software was used for the integration of chromatographic peaks. The
122 most abundant transition was integrated for quantitation, and a second transition was observed
123 (when possible) for confirmation. Linear calibration curves constructed for the quantitation of
124 native PFAS consisted of at least 5 levels, but up to 11 levels, depending on the LOQ of each
125 individual PFAS. For PFAS without a direct isotopically-labeled IS, an IS similar by structure
126 and/or retention time was selected for semi-quantitation (Table S3a). Peaks were considered
127 above the limit of detection if they were $\geq 3x$ the signal-to-noise ratio (S/N). Each limit of
128 quantitation (LOQ) was determined as the concentration of that PFAS in the lowest calibration
129 curve level with a peak $\geq 10x$ the S/N. Concentrations above the highest calibration curve level
130 were estimated using the calibration curves (Table S6, indicated in bold), in accordance with this
131 study's goal of describing relative changes in PFAS concentration, rather than pinpointing exact
132 concentrations in an environmental matrix in constant flux.

133 Extraction efficiency was determined by dividing mean peak areas of standards spiked into
134 triplicate QC samples before and after extraction. Accuracy was determined by comparing ng
135 PFAS per sample recovered experimentally to known concentrations spiked. Precision, or
136 relative standard deviation, was determined for PFAS in QC triplicates spiked before extraction.
137 Recovery and precision values for labeled standards can be found in Table S2. Table S3b
138 contains LOQ, recovery, accuracy, and precision, for native PFAS, where applicable. All
139 reported PFAS have a QC sample precision of $<25\%$ and R² values >0.995 . PFBA was

140 excluded from reporting due to insufficient calibration curves and high matrix interference,
141 though it was likely present in FCM leachate and composts. Extraction blank contamination from
142 6:2diPAP was subtracted from corresponding samples (only FCM leachate) and two PFAS, 7H-
143 PFHpA and 6:2FTS, were excluded from reporting due to more extensive blank contamination.
144 No other reported PFAS were observed in blanks. For samples extracted in replicate, only PFAS
145 present at concentrations above instrumental LOQ in all replicates were reported in summary
146 tables and figures. All reported concentrations were normalized to the weight of solid sample
147 leached or extracted. For samples whose moisture content was determined, concentrations were
148 further normalized to dry weight.

149 Statistical analyses were accomplished using R (version 4.2.3). After determining that all data
150 sets were non-parametric via the Shapiro-Wilk test, non-parametric tests were employed. The
151 Kruskal-Wallis test was used to compare \sum PFAS measured among different ages of compost.
152 When a statistically significant difference ($p < 0.05$) was determined by the Kruskal-Wallis test,
153 the Dunn post-hoc test was applied to identify which compost age groups were significantly
154 different from the others. Table S8 details p-value results of significance testing among Σ_{40} PFAS in
155 windrow composts and in mature composts. The Spearman correlation was used to understand how
156 \sum PFAS measured changed with compost age and with time after FCM separation began.

157

158 **TABLES**

159 **Table S1.** Sample descriptions and physical characterization: dates collected, soil pH, post-air-drying
 160 moisture content (%), organic matter content (OM, % dry wt), leachate pH and other description where
 161 applicable.
 162

163 Table S1a. Compost feedstock samples

Sample ID	Date of collection	Soil pH	Moisture (%)	OM (% dry wt)	Leachate pH	Description
Mulch A		6.49	27.8	95.0		
Mulch B	8/27/2021	6.37	23.9	96.2	--	--
Mulch C		6.19	27.3	96.2		
Food waste A						
Food waste B						
Food waste C	3/21/2022	--	Lyophilized before extraction	--	--	--
Food waste D						
Food waste E						
Food waste F						
FCM leachate A		--		--		
FCM leachate B	9/11/2021	--	Fully air-dried before extraction	--	5.32	~100 pieces, 3,600 g total wt
FCM leachate C		--		--		

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166 Table S1b. Windrow compost samples

Sample ID	Date of collection	Soil pH	Moisture (%)	OM (% dry wt)	Leachate pH
Collection 1-W1		5.69	15.3	90.5	5.85
Collection 1-W2		7.00	9.8	76.7	6.44
Collection 1-W3	5/24/2021	7.09	10.1	80.3	6.68
Collection 1-W4		7.23	10.1	72.6	6.87
Collection 1-W5		7.17	10.8	74.1	6.97
Collection 2-W1		6.19	11.1	83.2	6.07
Collection 2-W2		6.33	11.5	82.9	6.18
Collection 2-W3	6/2/2021	6.91	13.4	78.7	6.52
Collection 2-W4		7.06	10.7	76.5	6.64
Collection 2-W5		7.29	11.3	75.6	7.03
Collection 3-W1		6.32	18.1	91.2	5.87
Collection 3-W2		6.78	16.0	83.6	6.22
Collection 3-W3	6/11/2021	6.92	14.5	85.6	6.39
Collection 3-W4		7.11	11.4	84.8	6.71
Collection 3-W5		6.98	11.0	80.5	6.66

Collection 4-W1		6.01	15.6	87.5	6.01
Collection 4-W2		7.61	22.7	84.1	6.41
Collection 4-W3	6/22/2021	7.37	12.9	77.6	6.62
Collection 4-W4		6.83	13.0	81.3	6.56
Collection 4-W5		7.24	11.2	75.7	6.72
Collection 5-W1		7.35	18.6*	84.6*	6.53
Collection 5-W2		7.00	18.2	84.0	6.47
Collection 5-W3	7/2/2021	7.57	33.6	82.7	6.51
Collection 5-W4		7.64	12.9*	78.0*	6.92
Collection 5-W5		7.81	16.3	75.2	6.96
Collection 6-W1		6.76	32.6	85.8	6.46
Collection 6-W2		7.51	16.6	74.5	6.61
Collection 6-W3	7/12/2021	8.14	35.7	77.2	6.77
Collection 6-W4		7.94	13.2	75.5	6.92
Collection 6-W5		8.34	37.2	76.2	6.91
Collection 7-W1		6.85	11.2	86.5	6.20
Collection 7-W2		7.31	16.3	86.0	6.64
Collection 7-W3	7/23/2021	7.62	16.1	78.9	6.57
Collection 7-W4		7.77	11.3	75.5	6.77
Collection 7-W5		8.32	38.3	76.8	6.90
Collection 8-W1		7.27	13.9	86.0	6.24
Collection 8-W2		7.48	11.0	79.1	6.33
Collection 8-W3	8/3/2021	7.58	14.5	76.9	6.62
Collection 8-W4		7.69	11.8	71.1	6.76
Collection 8-W5		8.06	12.8	75.5	6.86
Collection 9-W1		6.44	27.0	86.5	6.08
Collection 9-W2		7.69	24.5	81.8	6.58
Collection 9-W3	8/13/2021	7.70	15.7	80.3	6.62
Collection 9-W4		7.68	13.9	81.8	6.83
Collection 9-W5		8.08	22.7	77.4	6.78
Collection 10-W1		6.69	22.5	64.5	6.06
Collection 10-W2		7.20	20.0	85.0	6.18
Collection 10-W3	8/27/2021	7.39	24.0	81.2	6.58
Collection 10-W4		7.58	20.7	82.4	6.68
Collection 10-W5		7.90	28.4	81.9	6.66

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173 Table S1c. Mature compost samples

Sample ID	Date of collection	Soil pH	Moisture (%)	OM (% dry wt)	Leachate pH	Approximate date stockpiled; age in months
Mature 12-A		6.78	45.9	68.7	6.82	
Mature 12-B	8/27/2021	6.96	55.5	65.6	6.91	Aug. 2020; 12 months
Mature 12-C		6.78	51.3	66.0	6.82	
Mature 6-A		8.21	36.2	71.9	6.93	
Mature 6-B	10/1/2021	7.45	37.4	72.1	6.83	Apr. 2021; 6 months
Mature 6-C		7.44	38.7	68.6	7.09	
Mature 3-A		7.93	38.2	67.8	6.74	
Mature 3-B	10/1/2021	8.00	29.9	68.6	6.89	July 2021; 3 months
Mature 3-C		8.05	20.7	67.7	6.86	
Mature 2-A		8.21	31.3	68.0	6.88	
Mature 2-B	10/1/2021	8.22	34.8	72.2	6.87	Aug. 2021; 2 months
Mature 2-C		8.09	38.9	71.6	6.85	
Mature 1-A		8.11	23.1	78.5	6.94	
Mature 1-B	10/1/2021	8.04	19.4	72.7	6.92	Sept. 2021; 1 month
Mature 1-C		8.13	35.7	70.6	6.88	

174 Sample characterization was conducted after samples were thawed and air-dried in a fume hood in
 175 preparation for PFAS extractions. Soil pH was determined according to EPA Method 9045D, with 80 mL
 176 of reagent water per 20 g solid to adjust for the hygroscopic material. Moisture content was determined
 177 using EPA Method 1684, and all corresponding PFAS concentrations were normalized to dry weight.
 178 Organic matter (OM) was estimated by loss on ignition at 400°C. Each composite windrow sample was
 179 analyzed as one, while composite samples of mature compost, and feedstock materials were analyzed in
 180 replicate (indicated with A, B, C, etc). Due to insufficient sample for testing, MC and OM values
 181 indicated with an asterisk (*) were estimated by averaging MC and OM values for the other nine windrow
 182 samples corresponding to the same windrow interval.

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Table S2. List of labeled PFAS standards: analyte names, abbreviations, exact amounts added to all samples, extraction efficiency and precision.

Labeled PFAS	Abbreviation	Mulch and compost solvent extractions	Compost leachate extractions	FW and FCM leachate	Compost composite		Food waste composite	
		Amount added per sample (ng)			Recovery (%)	Precision (%)	Recovery (%)	Precision (%)
Perfluoro-n-[13C4]butanoic acid	M4PFBA	2.38	2.38	2.14	60.7	5.05	75.9	34.4
Perfluoro-n-[13C5]pentanoic acid	M5PFPeA	2.38	2.38	2.14	62.3	2.14	84.9	20.0
Perfluoro-n-[13C2]hexanoic acid	M5PFHxA	2.38	2.38	2.14	58.6	6.06	74.9	17.8
Perfluoro-n-[13C4]heptanoic acid	M4PFHpA	2.38	2.38	2.14	55.4	10.8	85.3	11.5
Perfluoro-n-[13C4]octanoic acid	M8PFOA	2.38	2.38	2.14	55.7	5.53	80.0	22.1
Perfluoro-n-[13C8]nonanoic acid	M9PFNA	2.38	2.38	2.14	52.9	11.0	94.4	23.1
Perfluoro-n-[13C6]decanoic acid	M6PFDA	2.38	2.38	2.14	67.7	4.72	78.7	13.3
Perfluoro-n-[13C7]undecanoic acid	M7PFUdA	2.38	2.38	2.14	62.8	3.65	71.9	12.6
Perfluoro-n-[13C2]dodecanoic acid	M2PFDoA	2.38	2.38	2.14	63.9	3.08	73.6	10.3
Perfluoro-n-[13C2]tetradecanoic acid	M2PFTeDA	2.38	2.38	2.14	60.4	1.35	71.4	11.9
Perfluoro-1-[13C3]butanesulfonic acid	M3PFBS	2.21	2.21	1.99	47.7	13.7	83.1	15.9
Perfluoro-1-[13C3]hexanesulfonic acid	M3PFHxS	2.25	2.25	2.02	60.8	6.30	82.9	12.4
Perfluoro-[13C8]octanesulfonic acid	M8PFOS	2.28	2.28	2.05	55.4	22.2	89.3	26.3
Perfluoro-1-[13C8]octanesulfonamide	M8FOSA	2.38	2.38	2.14	50.8	8.28	65.3	22.9
N-ethyl-d5-perfluoro-1-octanesulfonamidoacetic acid	d5-N-EtFOSAA	2.38	2.38	2.14	61.9	10.0	74.5	13.1
4:2 fluorotelomer-[13C2]sulfonic acid	M2-4:2FTS	2.23	2.23	2.00	51.7	17.5	87.3	16.7
6:2 fluorotelomer-[13C2]sulfonic acid	M2-6:2FTS	2.26	2.26	2.03	53.1	4.79	89.9	28.0
8:2 fluorotelomer-[13C2]sulfonic acid	M2-8:2FTS	2.28	2.28	2.05	70.1	3.65	85.1	9.50

Labeled standards were purchased from Wellington Laboratories Inc. Recovery was determined by comparing mean peak areas of isotopically labelled standards spiked into triplicate quality control samples before and after extraction. Precision was determined as the relative standard deviation of peak areas of isotopically labelled standards spiked into triplicate quality control samples before extraction.

Table S3. List of native PFAS: identification and quality control

Table S3a. Native analyte names, abbreviations, chemical formulas, and corresponding internal standards.

PFAS Subclass	PFAS	Abbreviation(s)	Formula	Internal Standard
PFCA	Perfluorobutanoic acid	PFBA	C ₄ HF ₇ O ₂	M4-PFBA
	Perfluoropentanoic acid	PFPeA	C ₅ HF ₉ O ₂	M5-PFPeA
	Perfluorohexanoic acid	PFHxA	C ₆ HF ₁₁ O ₂	M5-PFHxA
	Perfluoroheptanoic acid	PFHpA	C ₇ HF ₁₃ O ₂	M4-PFHpA
	Perfluorooctanoic acid	PFOA	C ₈ HF ₁₅ O ₂	M8-PFOA
	Perfluorononanoic acid	PFNA	C ₉ HF ₁₇ O ₂	M9-PFNA
	Perfluorodecanoic acid	PFDA	C ₁₀ HF ₁₉ O ₂	M6-PFDA
	Perfluoroundecanoic acid	PFUdA	C ₁₁ HF ₂₁ O ₂	M7-PFUdA
	Perfluorododecanoic acid	PFDoA	C ₁₂ HF ₂₃ O ₂	M2-PFDoA
	Perfluorotridecanoic acid	PFTTrDA	C ₁₃ HF ₂₅ O ₂	M2-PFDoA
	Perfluorotetradecanoic acid	PFTeDA	C ₁₄ HF ₂₇ O ₂	M2-PFTeDA
	Perfluorohexadecanoic acid	PFHxDA	C ₁₆ HF ₃₁ O ₂	M2-PFTeDA
	Perfluorooctadecanoic acid	PFODA	C ₁₈ HF ₃₅ O ₂	M2-PFTeDA
PFSA	Perfluoropropanesulfonic acid	PFPrS	C ₃ HF ₇ O ₃ S	M3-PFBS
	Perfluorobutanesulfonic acid	PFBS	C ₄ HF ₉ O ₃ S	M3-PFBS
	Perfluoropentanesulfonic acid	PFPeS	C ₅ HF ₁₁ O ₃ S	M3-PFHxS
	Perfluorohexanesulfonic acid	PFHxS	C ₆ HF ₁₃ O ₃ S	M3-PFHxS
	Perfluoroheptanesulfonic acid	PFHpS	C ₇ HF ₁₅ O ₃ S	M8-PFOS
	Sodium perfluoro-3-methylheptanesulfonate	Br-PFOS	C ₈ F ₁₈	M8-PFOS
	Perfluorooctanesulfonic acid	L-PFOS	C ₈ HF ₁₇ O ₃ S	M8-PFOS
	Perfluorononanesulfonic acid	PFNS	C ₉ HF ₁₉ O ₃ S	M8-PFOS
	Perfluorodecanesulfonic acid	PFDS	C ₁₀ HF ₂₁ O ₃ S	M8-PFOS
	Perfluorododecanesulfonic acid	PFDoS	C ₁₂ HF ₂₅ O ₃ S	M8-PFOS
H-PFCA	7H-Dodecafluoroheptanoic acid	Oak 6 (7H-PFHpA)	C ₇ H ₂ F ₁₂ O ₂	M4-PFHpA
FTCA	6:2 fluorotelomer carboxylic acid	FHEA (6:2 FTCA)	C ₈ H ₃ F ₁₃ O ₂	MFHEA
	5:3 fluorotelomer carboxylic acid	FPePA (5:3 FTCA)	C ₈ H ₅ F ₁₁ O ₂	M4-PFHpA
	8:2 fluorotelomer carboxylic acid	FOEA (8:2 FTCA)	C ₁₀ H ₃ F ₁₇ O ₂	MFOEA
	7:3 fluorotelomer carboxylic acid	FHpPA (7:3 FTCA)	C ₁₀ H ₅ F ₁₅ O ₂	M8-PFOA
FTUCA	8:2 fluorotelomer unsaturated carboxylic acid	FOUEA (8:2 FTUCA)	C ₁₀ H ₂ F ₁₆ O ₂	M9-PFNA
FASA	Perfluoro-1-octanesulfonamide	FOSA	C ₈ H ₂ F ₁₇ NO ₂ S	M6-PFDA
FASAA	2-perfluorooctanesulfonamido acetic acid	FOSAA	C ₁₀ H ₄ F ₁₇ NO ₄ S	d5-N-EtFOSAA
	N-ethyl perfluorooctane sulfonamido acetic acid	N-EtFOSAA	C ₁₂ H ₈ F ₁₇ NO ₄ S	d5-N-EtFOSAA
FTS	4:2 fluorotelomer sulfonic acid	4:2FTS	C ₆ H ₅ F ₉ O ₃ S	M2-4:2FTS
	6:2 fluorotelomer sulfonic acid	6:2FTS	C ₈ H ₃ F ₁₃ O ₃ S	M2-6:2FTS
	8:2 fluorotelomer sulfonic acid	8:2FTS	C ₁₀ H ₅ F ₁₇ O ₃ S	M2-8:2FTS

	10:2 fluorotelomer sulfonic acid	10:2FTS	C ₁₂ H ₅ F ₂₁ O ₃ S	M2-8:2FTS
PAP	6:2 fluorotelomer phosphate diester	6:2diPAP	C ₁₆ H ₉ F ₂₆ O ₄ P	M2-PFTeDA
	6:2/8:2 fluorotelomer phosphate diester	6:2/8:2diPAP	C ₁₈ H ₈ F ₃₀ NaO ₄ P	M2-PFTeDA
	8:2 fluorotelomer phosphate diester	8:2diPAP	C ₂₀ H ₉ F ₃₄ O ₄ P	M2-PFTeDA
	Sodium bis-[2-(N-ethylperfluorooctane-1-sulfonamido)ethyl] phosphate	diSAmPAP	C ₂₄ H ₁₈ F ₃₄ N ₂ NaO ₈ PS ₂	M2-PFTeDA

Oak 6 standard was obtained from Oakwood Products Inc. and all other standards were obtained from Wellington Laboratories Inc.

Table S3b. Native PFAS: limit of quantitation in picograms (LOQ; pg), recovery (%), accuracy (%), and precision (%) for each native analyte, where applicable.

PFAS	Run 1:				Run 2:				Run 3:
	LOQ (pg)	Recovery (%)	Accuracy (%)	Precision (%)	LOQ (pg)	Recovery (%)	Accuracy (%)	Precision (%)	LOQ (pg)
PFBA	5.35	--	--	--	10.9	--	--	--	52.8
PFPeA	10.9	99.4	--	7.44	10.9	93.6	--	2.40	1.01
PFHxA	1.01	100	95.5	8.25	1.01	106	--	4.29	1.01
PFHpA	2.07	93.4	71.4	21.3	2.07	64.1	81.3	4.28	0.50
PFOA	0.50	86.0	13.0	12.0	0.50	60.5	98.9	4.90	1.01
PFNA	1.01	--	--	--	1.01	52.6	95.0	2.61	1.01
PFDA	1.01	--	--	--	1.01	69.8	90.0	2.53	1.01
PFUdA	1.01	--	--	--	0.50	63.1	93.1	2.56	0.50
PFDoA	0.50	--	--	--	0.26	65.2	90.2	2.21	0.26
PFTTrDA	1.01	--	--	--	1.01	63.5	91.3	3.58	1.01
PFTeDA	0.50	--	--	--	1.01	61.7	99.3	3.23	0.26
PFHxDA	0.91	--	--	--	0.45	--	--	--	0.24
PFODA	0.45	--	--	--	0.24	--	--	--	0.24
PFPrS	1.85	--	--	--	0.45	--	--	--	0.91
PFBS	0.90	--	--	--	0.44	46.1	76.6	7.04	0.90
PFPeS	0.95	--	--	--	0.95	54.5	87.1	19.8	0.95
PFHxS	0.93	--	--	--	0.93	71.0	81.7	19.4	1.89
PFHpS	1.97	--	--	--	0.97	67.7	81.2	27.1	5.10
Br-PFOS	0.91	--	--	--	0.91	82.0	45.6	31.9	0.91
L-PFOS	1.51	--	--	--	1.51	67.6	47.9	18.3	1.51
PFNS	5.15	--	--	--	0.98	69.5	84.5	21.1	1.99
PFDS	2.00	--	--	--	0.98	71.8	77.6	27.3	0.98
PFDoS	4.56	--	--	--	0.86	--	--	--	0.42
Oak 6 (7H-PFHpA)	0.91	--	--	--	0.91	--	--	--	0.91
FHEA (6:2 FTCA)	49.9	--	--	--	10.3	--	--	--	10.3

FPePA (5:3 FTCA)	4.81	--	--	--	4.81	--	--	--	1.86
FOEA (8:2 FTCA)	97.9	--	--	--	49.5	--	--	--	5.02
FHpPA (7:3 FTCA)	4.85	--	--	--	4.85	--	--	--	1.88
FOUEA (8:2 FTUCA)	5.10	--	--	--	0.96	--	--	--	0.96
FOSA	5.35	--	--	--	1.01	60.4	86.2	4.67	1.01
FOSAA	4.53	--	--	--	0.86	--	--	--	0.86
N-EtFOSAA	2.07	--	--	--	1.01	68.2	70.0	2.70	1.01
4:2FTS	0.95	--	--	--	0.47	49.0	33.4	39.6	0.47
6:2FTS	1.97	--	--	--	0.96	53.1	50.8	24.3	0.47
8:2FTS	5.14	--	--	--	0.97	67.1	26.0	41.9	0.97
10:2FTS	4.41	--	--	--	0.83	--	--	--	0.83
6:2diPAP	1.79	--	--	--	0.43	--	--	--	1.79
6:2/8:2diPAP	4.60	--	--	--	1.78	--	--	--	1.78
8:2diPAP	4.76	--	--	--	0.90	--	--	--	0.90
diSAmPAP	0.89	--	--	--	0.43	--	--	--	0.43

Due to abundance of samples, they were analyzed on the instrument in three separate batches. Run 1 included all compost leachates, Run 2 included mulch and compost solids extracts, and Run 3 included FCM leachate and FW. Recovery was determined by dividing mean peak areas of isotopically labelled standards spiked into triplicate quality control (QC) samples before and after extraction. Accuracy was determined by calculating the error rate of the value we measured in QC samples spiked with standards before extraction as compared to the known concentration we spiked in. Precision was determined as the relative standard deviation of peak areas of isotopically labelled standards spiked into triplicate QC samples before extraction.

Table S4. Instrumental parameters

LC Conditions – Thermo Scientific Vanquish UHPLC	
Column	Gemini Phenomenex 100 x 2 mm 3 μ m
Mobile phases	Methanol [A] and water [B] both containing 5mM ammonium acetate
Gradient elution	0-1 min 90-30% B, 1-3.5 min 30-18% B, 3.5-4.5 min 18-16% B, 4.5-5.5 min 16-10% B, 5.5-8 min 10-5% B, 8-8.5 min 5-1% B, 8.5-10 min 1-90% B, 10-12 min 90% B
Flow rate	0.5 mL min ⁻¹
Column temperature	40°C
Autosampler temperature	4°C
Injection volume	10 μ L

Mass Spectrometric Ion Source Parameters – Thermo Quantis	
Ion source type	H-ESI
Spray voltage	Static
Negative ion (V)	-3000
Sheath gas (Arb)	60
Aux gas (Arb)	5
Sweep gas (Arb)	5
Ion transfer tube temp (°C)	325
Vaporizer temp (°C)	350

Table S5. Analyte scan parameters

Table S5a. SRM scan parameters for labeled PFAS

Analytes (abbreviation)	Precursor Ion (<i>m/z</i>)	Fragment Ion (<i>m/z</i>)	Collision Energy (V)	RF Lens (V)
M4PFBA	217.05	172.11	8.75	73
M5PFPeA	267.99	222.97	7.91	83
M5PFHxA	318.04	273.11	7.82	88
M4PFHpA	366.99	322.04	9.34	102
M8PFOA	421.05	376.04	9.34	114
M9PFNA	471.99	426.97	8.79	119
M6PFDA	518.95	474.04	10.39	136
M7PFUdA	570.05	525.13	9.55	150
M2PFDoA	615.05	570.04	10.9	156
M2PFTeDA	715.04	670.04	11.61	184
M8FOSA	506.038	77.97	31.2	299
d3-N-MeFOSAA	573.04	419.04	21.76	208
d5-N-EtFOSAA	589.09	419.04	19.36	195
M3PFBS	302.05	79.97	32.59	206
M3PFHxS	402	79.917	39.29	299
M8PFOS	507.05	80.07	42.66	191
M2-4:2FTS	329	308.97	19.28	189
M2-6:2FTS	429.1	409.04	21.93	173
M2-8:2FTS	529.09	509.04	26.19	299

Table S5b. SRM scan parameters for native PFAS listed in order of retention time (including both first and second transition, if applicable)

Analytes (abbreviation)	Precursor Ion (<i>m/z</i>)	Fragment Ion (<i>m/z</i>)	Collision Energy (V)	RF Lens (V)
PFBA	212.95	168.917	8.5	74
PFPrS_1	248.912	79.97	29.3	184
PFPrS_2	248.912	119.042	22.02	184
PFPeA	263.038	219.042	5.25	80
PFBS_1	299.012	79.97	32.76	193
PFBS_2	299.012	99.012	29.22	193
7H-PFHpA_1	345	281.042	9.8	99
7H-PFHpA_2	345	131	24.17	99
PFHxA_1	313	269.131	8.16	87
PFHxA_2	313	118.988	17.85	87
4:2FTS_1	327.05	306.899	18.56	160

4:2FTS_2	327.05	80.988	28.63	160
PFPeS_1	349	80.06	34.23	231
PFPeS_2	349	98.94	32.09	231
PFHpA_1	362.95	319.042	8.66	103
PFHpA_2	362.95	169.042	16.5	103
FHEA_1	377	293.042	13.59	103
FHEA_2	377	312.97	6.18	103
PFHxS_1	399	80.06	37.01	232
PFHxS_2	399	98.958	35.12	232
FPePA_1	341.038	237.042	12.71	122
FPePA_2	341.038	216.97	23.49	122
PFOA_1	413	369.024	7.11	98
PFOA_2	413	169.042	16.46	98
6:2-FTS_1	427.038	407.042	22.4	162
6:2-FTS_2	427.038	81.042	31.37	162
PFHpS_1	449	80.042	40.38	299
PFHpS_2	449	99.03	39.63	299
BrPFOS_1	499	129.917	41.18	285
BrPFOS_2	499	80.042	43.8	285
FHpPA_1	441.038	337.113	11.15	148
FHpPA_2	441.038	316.917	20.63	148
PFNA_1	463	419.06	9.3	127
PFNA_2	463	219.042	16.08	127
FOEA_1	477.05	393.071	13.21	120
FOEA_2	477.05	413.042	5.59	120
PFOS_1	498.9	79.97	41.48	299
PFOS_2	498.9	98.97	42.62	299
FOUEA_1	457.05	393.042	11.91	135
FOUEA_2	457.05	343.042	39.71	135
FOSAA_1	556	497.988	27.83	299
FOSAA_2	556	419.012	24.38	299
8:2FTS_1	527	506.958	26.44	299
8:2FTS_2	527	486.988	31.96	299
FOSA_1	498.05	78.042	32.17	265
FOSA_2	498.05	169.03	29.22	265
PFDA_1	513.05	468.97	9.68	128
PFDA_2	513.05	219.042	16.96	128
PFNS_1	549	79.988	45.65	299
PFNS_2	549	98.988	42.11	299
N-EtFOSAA_1	584.05	418.917	19.7	189
N-EtFOSAA_2	584.05	526.042	19.36	189
PFDS_1	599	98.887	46.41	299

PFDS_2	599	79.97	47.21	299
PFUdA_1	563	518.899	10.14	139
PFUdA_2	563	269.042	18.56	139
PFDoA_1	612.95	568.917	10.56	146
PFDoA_2	612.95	319.042	18.4	146
10:2FTS_1	627.05	606.97	30.06	299
10:2FTS_2	627.05	586.899	34.7	299
PFDOS_1	699	80.054	51.93	251
PFDOS_2	699	379.958	55	251
PFTrDA_1	663	619.042	11.66	178
PFTrDA_2	663	369.042	19.57	178
6:2diPAP_1	789.038	443.071	18.23	273
6:2diPAP_2	789.038	96.958	30.27	273
PFTeDA_1	713	668.97	11.87	186
PFTeDA_2	713	319.042	20.84	186
6:2/8:2diPAP_1	889.05	443.042	21.93	299
6:2/8:2diPAP_2	889.05	543.042	20.92	299
PFHxDA_1	813	769	13.13	219
PFHxDA_2	813	469.03	21.98	219
8:2diPAP_1	989.05	542.97	21.09	290
8:2diPAP_2	989.05	97.03	31.79	290
PFODA_1	913.05	869.083	14.69	226
PFODA_2	913.05	419.071	23.37	226
diSamPAP_1	1203.088	526	46.95	238

These parameters were exported directly from the instrument method derived after compound optimization for each PFAS.

Table S6. Concentrations of individual PFAS in each sample

Table S6a. PFAAs (ng g⁻¹ dry wt)

Sample ID	PFCAs								PFSAs		
	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFDA	PFUDA	PFDoA	PFBS	∑PFOS	PFNS
Mulch A	--	--	--	--	0.03	--	--	--	0.04	0.04	--
Mulch B	--	--	1.43	--	0.03	--	--	--	--	0.05	--
Mulch C	--	--	--	--	0.05	--	--	--	0.03	0.08	--
Food waste A	--	--	--	--	--	--	--	--	--	--	--
Food waste B	--	--	--	--	--	--	--	--	--	--	--
Food waste C	--	--	--	--	--	--	--	--	--	--	< LOQ
Food waste D	--	--	--	--	--	--	--	--	--	--	< LOQ
Food waste E	--	--	--	--	--	--	--	--	--	--	< LOQ
Food waste F	--	--	--	--	--	--	--	--	--	--	< LOQ
FCM leachate A	NR	131	1075	12.7	--	--	--	--	--	--	--
FCM leachate B	NR	126	1041	12.0	--	--	--	--	--	--	--
FCM leachate C	NR	129	1048	12.1	--	--	--	--	--	--	--
Collection 1- W1	--	1.61	--	--	--	--	--	--	--	0.03	--
Collection 1- W2	--	1.97	5.38	--	0.09	0.14	--	0.02	< LOD	0.06	--
Collection 1- W3	--	1.12	6.73	--	0.04	--	--	< LOD	0.05	0.05	--
Collection 1- W4	NR	2.22	16.7	0.19	0.08	--	--	0.01	0.04	0.04	--
Collection 1- W5	NR	2.91	22.1	0.23	0.20	--	--	0.02	0.05	0.06	--
Collection 2- W1	--	--	1.68	--	0.05	--	--	--	< LOD	0.03	--
Collection 2- W2	--	1.73	3.19	--	0.04	--	--	0.01	< LOD	0.04	--
Collection 2- W3	NR	2.26	7.34	--	0.06	--	--	0.02	0.03	0.05	--
Collection 2- W4	NR	--	13.1	0.36	0.08	--	< LOD	< LOD	0.02	0.05	--
Collection 2- W5	NR	3.59	28.1	< LOD	0.19	--	--	0.01	0.05	0.05	--
Collection 3- W1	--	--	< LOD	--	0.04	--	--	--	--	0.04	--
Collection 3- W2	NR	1.70	3.55	--	0.07	--	--	0.03	< LOD	0.05	--

Collection 3- W3	NR	2.28	9.09	--	0.09	--	--	0.01	0.06	0.05	--
Collection 3- W4	NR	2.07	13.9	< LOD	0.11	< LOD	--	0.02	0.06	0.04	--
Collection 3- W5	NR	2.73	22.7	0.29	0.24	--	--	0.01	0.04	0.06	--
Collection 4- W1	--	--	< LOD	--	0.07	--	--	--	< LOD	0.05	--
Collection 4- W2	--	--	3.09	--	0.07	< LOD	--	--	--	0.07	--
Collection 4- W3	NR	1.26	6.67	< LOD	0.11	< LOD	< LOD	0.02	--	0.15	--
Collection 4- W4	NR	2.09	9.54	--	0.13	< LOD	--	0.01	0.04	0.05	--
Collection 4- W5	NR	2.48	13.2	0.20	0.19	--	--	0.02	0.04	0.07	--
Collection 5- W1	--	--	2.20	--	0.06	--	--	--	< LOD	0.05	--
Collection 5- W2	--	--	1.82	--	0.04	--	--	--	0.05	0.03	--
Collection 5- W3	--	--	6.18	--	0.08	--	--	0.02	--	0.07	--
Collection 5- W4	NR	3.15	22.2	0.30	0.12	0.07	--	0.02	0.05	0.06	--
Collection 5- W5	NR	2.36	17.6	0.20	0.15	< LOD	< LOD	0.03	0.05	0.05	--
Collection 6- W1	--	--	--	--	0.04	--	< LOD	--	--	0.04	--
Collection 6- W2	NR	--	5.04	--	0.06	--	--	--	--	0.04	--
Collection 6- W3	--	--	3.50	--	0.08	--	--	--	< LOD	0.04	--
Collection 6- W4	NR	2.06	12.9	< LOD	0.12	< LOD	0.02	0.02	< LOD	0.07	--
Collection 6- W5	NR	3.08	10.2	--	0.10	--	< LOD	0.04	< LOD	0.06	--
Collection 7- W1	--	--	< LOD	--	0.05	--	--	--	< LOD	0.04	--
Collection 7- W2	--	--	2.37	--	0.07	--	--	< LOD	--	0.05	--
Collection 7- W3	NR	--	7.98	--	0.19	--	--	0.01	0.03	0.06	--
Collection 7- W4	NR	1.15	7.12	< LOD	0.08	--	--	0.01	< LOD	0.05	--
Collection 7- W5	NR	2.79	20.4	< LOD	0.10	--	0.02	0.03	0.05	0.07	--
Collection 8- W1	--	--	< LOD	--	0.06	--	--	< LOD	--	0.04	--
Collection 8- W2	--	--	1.63	--	0.06	--	--	0.01	--	0.05	--
Collection 8- W3	NR	--	3.51	--	0.08	--	--	0.01	< LOD	0.06	--
Collection 8- W4	NR	1.06	7.46	--	0.12	0.05	--	0.02	< LOD	0.05	--
Collection 8- W5	NR	1.72	15.1	0.20	0.11	0.05	0.01	0.02	0.04	0.06	--
Collection 9- W1	--	1.91	< LOD	--	0.08	--	--	--	--	0.06	--
Collection 9- W2	--	--	2.05	--	0.10	--	--	0.02	--	0.05	--

Collection 9- W3	--	1.23	3.19	--	0.07	0.03	--	0.01	--	0.04	--
Collection 9- W4	NR	1.25	6.39	< LOD	0.08	--	--	0.01	--	0.04	--
Collection 9- W5	NR	2.40	15.2	0.19	0.10	0.05	0.01	0.02	0.03	0.07	--
Collection 10- W1	--	--	--	--	0.05	--	--	--	--	0.04	--
Collection 10- W2	NR	--	1.97	--	0.08	--	--	0.02	0.03	0.06	--
Collection 10- W3	--	1.52	4.19	--	0.12	0.06	--	0.03	< LOD	0.07	--
Collection 10- W4	NR	1.67	7.37	< LOD	0.12	--	< LOD	0.02	< LOD	0.07	--
Collection 10- W5	NR	2.25	17.9	0.19	0.14	0.07	--	0.03	0.04	0.07	--
M1- A	NR	2.30	6.93	< LOD	0.16	0.09	ND	0.03	0.05	0.07	--
M1- B	NR	2.36	6.91	< LOD	0.15	0.08	0.02	0.03	0.05	0.07	--
M1- C	NR	2.82	12.0	< LOD	0.17	0.08	ND	0.04	0.07	0.11	--
M2- A	NR	9.54	11.9	< LOD	0.22	0.09	0.02	0.04	0.03	0.10	--
M2- B	NR	4.60	14.8	< LOD	0.18	0.14	0.03	0.03	0.04	0.10	--
M2- C	NR	3.89	8.95	< LOD	0.17	0.08	0.03	0.04	0.04	0.09	--
M3- A	NR	4.05	9.71	0.28	0.14	0.08	< LOD	0.04	0.01	0.09	--
M3- B	NR	9.18	25.2	0.43	0.14	0.07	< LOD	0.03	0.06	0.11	--
M3- C	NR	9.06	13.9	0.39	0.14	0.07	0.02	0.04	0.03	0.08	--
M6- A	NR	2.23	8.80	0.28	0.18	0.06	0.02	0.04	0.03	0.10	--
M6- B	NR	6.38	9.57	0.47	0.09	0.05	0.02	0.03	0.02	0.13	--
M6- C	NR	21.8	37.0	0.77	0.12	0.06	0.02	0.04	0.04	0.13	--
M12- A	NR	40.6	62.7	1.20	0.13	0.07	0.04	0.06	0.09	0.17	--
M12- B	NR	30.2	38.5	1.25	0.13	0.08	0.04	0.07	0.07	0.18	--
M12- C	NR	30.9	42.6	1.28	0.14	0.08	0.04	0.05	0.06	0.15	--

Table S6b. Other PFAS (ng g⁻¹ dry wt)

Sample ID	FTCA		FASA	FASAA	FTS		PAP			ΣPFAS
	6:2 FTCA	5:3 FTCA	FOSA	ΣEiFOSAA	8:2FTS	10:2FTS	6:2diPAP	6:2/8:2diPAP	8:2diPAP	
Mulch A	--	--	--	--	--	--	0.41	--	--	0.48
Mulch B	--	--	--	--	--	--	0.14	--	--	0.22
Mulch C	--	--	--	--	--	--	0.46	--	--	0.59
Food waste A	--	--	--	--	--	--	--	--	--	--
Food waste B	--	--	--	--	< LOQ	--	--	< LOQ	--	--
Food waste C	--	--	--	--	--	< LOQ	--	< LOQ	--	--
Food waste D	--	--	--	--	--	--	--	< LOQ	--	--
Food waste E	--	--	< LOQ	--	--	< LOQ	--	< LOQ	--	--
Food waste F	--	--	--	--	--	< LOQ	--	< LOQ	--	--
FCM leachate A	82.4	105	--	--	--	--	0.65	1.19	0.71	1408
FCM leachate B	80.5	101	--	--	--	--	0.79	0.93	0.32	1362
FCM leachate C	78.8	94.5	--	--	--	--	0.88	0.74	0.28	1364
Collection 1- W1	--	--	--	--	--	--	0.57	--	--	2.20
Collection 1- W2	--	--	--	0.03	--	--	0.78	0.20	0.07	8.76
Collection 1- W3	--	--	--	< LOQ	--	--	0.71	0.22	0.06	8.98
Collection 1- W4	--	1.46	--	0.16	--	--	0.51	0.08	0.03	21.5
Collection 1- W5	--	1.45	--	0.01	--	--	0.31	0.09	0.07	27.5
Collection 2- W1	--	--	--	--	--	--	0.53	< LOQ	0.03	2.31
Collection 2- W2	--	1.56	--	--	--	--	1.81	0.70	0.10	9.18
Collection 2- W3	--	2.92	--	< LOQ	--	--	0.96	0.12	0.04	13.8
Collection 2- W4	--	< LOD	--	0.07	--	--	2.19	2.58	0.90	19.3
Collection 2- W5	--	1.01	--	0.04	--	--	0.37	0.14	0.06	33.6
Collection 3- W1	--	--	--	--	--	--	0.72	0.21	0.13	1.14
Collection 3- W2	--	--	--	< LOQ	--	--	0.53	0.32	0.22	6.47
Collection 3- W3	--	< LOD	--	0.02	--	--	0.48	0.06	< LOQ	12.2
Collection 3- W4	--	0.94	--	0.04	--	--	0.55	0.14	0.04	17.9
Collection 3- W5	--	--	--	0.10	--	--	0.45	0.29	0.08	27.0

Collection 4- W1	--	--	--	--	--	--	0.70	0.24	0.08	1.14
Collection 4- W2	--	1.33	--	0.03	--	--	0.40	0.35	0.11	5.43
Collection 4- W3	--	1.34	--	0.03	--	--	0.59	0.20	0.08	10.5
Collection 4- W4	--	1.15	--	0.04	--	--	0.56	0.11	0.04	13.7
Collection 4- W5	--	< LOD	--	0.07	--	--	0.55	0.18	0.07	17.1
Collection 5- W1	--	--	--	--	--	--	0.87	0.31	0.09	3.59
Collection 5- W2	--	--	--	< LOQ	--	--	0.59	0.24	0.10	2.87
Collection 5- W3	--	2.61	--	--	--	--	1.03	0.41	0.31	10.7
Collection 5- W4	--	2.13	--	0.03	--	--	0.41	0.10	0.06	28.7
Collection 5- W5	--	2.33	--	0.08	--	--	0.37	0.15	0.03	23.4
Collection 6- W1	--	--	--	0.02	--	--	1.01	0.16	< LOQ	1.26
Collection 6- W2	--	2.24	--	< LOQ	--	--	0.83	0.37	0.09	8.66
Collection 6- W3	--	1.09	--	0.03	--	--	0.25	0.15	0.17	5.32
Collection 6- W4	--	2.81	--	0.03	--	--	0.55	0.23	0.09	18.9
Collection 6- W5	--	1.88	--	0.09	--	--	0.64	0.24	0.08	16.4
Collection 7- W1	--	--	--	--	--	--	2.12	0.14	0.05	2.39
Collection 7- W2	--	--	--	0.03	--	--	0.39	0.34	0.16	3.40
Collection 7- W3	--	2.10	--	0.03	--	--	0.55	0.24	0.07	11.3
Collection 7- W4	--	1.17	--	0.02	--	--	0.18	0.24	0.20	10.2
Collection 7- W5	--	1.94	--	0.06	--	--	0.20	0.14	0.05	25.8
Collection 8- W1	--	--	--	--	--	--	0.51	0.17	0.06	0.84
Collection 8- W2	--	--	--	--	--	--	0.34	0.24	0.12	2.45
Collection 8- W3	--	--	--	0.02	--	--	0.41	0.12	0.07	4.30
Collection 8- W4	--	0.91	--	0.03	--	--	0.18	0.11	0.09	10.1
Collection 8- W5	--	1.23	--	0.04	--	--	0.26	0.10	0.07	19.0
Collection 9- W1	--	--	--	--	--	--	0.69	0.17	--	2.91
Collection 9- W2	--	--	--	< LOQ	--	--	0.28	0.27	0.18	2.94
Collection 9- W3	--	--	--	< LOQ	--	--	0.41	0.13	0.04	5.16
Collection 9- W4	--	< LOD	--	0.02	--	--	0.18	0.42	0.21	8.61
Collection 9- W5	--	0.78	--	0.04	--	--	0.16	0.03	0.05	19.1

Collection 10- W1	--	--	--	< LOQ	--	--	0.60	--	0.04	0.74
Collection 10- W2	--	--	--	< LOQ	--	--	0.36	0.17	0.10	2.79
Collection 10- W3	--	< LOD	--	0.03	--	--	0.50	0.08	0.02	6.62
Collection 10- W4	--	1.03	--	0.04	--	--	0.35	< LOQ	0.03	10.7
Collection 10- W5	--	1.47	--	0.06	--	--	0.15	0.05	< LOQ	22.4
M1- A	--	0.77	--	0.05	--	--	0.19	0.20	0.07	10.7
M1- B	--	0.78	--	0.03	--	--	0.43	0.57	0.15	10.6
M1- C	--	0.94	--	0.06	--	--	0.18	0.13	0.05	16.5
M2- A	--	1.49	--	0.07	--	--	0.25	0.04	0.09	24.0
M2- B	--	0.93	--	0.05	--	--	0.15	0.21	0.15	21.1
M2- C	--	1.57	--	0.05	--	--	0.20	0.15	0.13	15.2
M3- A	--	2.02	--	0.06	--	--	0.17	0.05	0.10	16.8
M3- B	--	2.61	--	0.10	--	--	0.23	0.34	0.17	38.7
M3- C	--	1.77	--	0.06	--	--	0.83	0.30	0.07	26.8
M6- A	--	1.66	--	0.06	--	--	0.17	0.35	0.27	13.9
M6- B	--	1.95	--	0.05	--	--	0.11	0.06	0.11	19.3
M6- C	--	2.78	--	0.06	--	--	0.13	< LOQ	0.13	63.4
M12- A	--	ND	--	0.03	--	--	0.18	0.06	0.03	105.5
M12- B	--	ND	--	0.03	--	--	0.10	0.03	0.04	71.7
M12- C	--	1.12	--	0.03	--	--	0.13	0.05	0.06	75.7

Table S6c. Compost leachates (ng g⁻¹ dry wt).

Sample ID	PFBA	PFPeA	PFHxA	PFHpA	PFOA
Windrow 1-1	--	--	--	--	--
Windrow 1-2	--	--	5.92	--	< LOD
Windrow 1-3	--	--	7.25	--	--
Windrow 1-4	--	--	18.9	--	< LOD
Windrow 1-5	--	--	21.9	--	< LOD
Windrow 2-1	--	--	5.39	--	--
Windrow 2-2	--	--	4.00	--	--
Windrow 2-3	--	--	7.02	--	< LOD
Windrow 2-4	--	--	14.6	--	< LOD
Windrow 2-5	--	--	18.6	--	0.21
Windrow 3-1	--	--	< LOD	--	--
Windrow 3-2	--	--	4.61	--	0.11
Windrow 3-3	--	--	11.9	--	< LOD
Windrow 3-4	--	--	13.2	--	< LOD
Windrow 3-5	--	--	22.3	--	0.54
Windrow 4-1	--	--	< LOD	--	--
Windrow 4-2	--	--	2.85	--	--
Windrow 4-3	--	--	7.50	--	< LOD
Windrow 4-4	--	--	8.25	--	0.15
Windrow 4-5	--	--	12.5	--	0.20
Windrow 5-1	--	--	1.88	--	--
Windrow 5-2	--	--	2.17	--	--
Windrow 5-3	--	--	6.57	--	< LOD
Windrow 5-4	--	--	24.7	--	0.16
Windrow 5-5	--	--	16.4	--	< LOD
Windrow 6-1	--	--	--	--	--
Windrow 6-2	--	--	6.77	--	< LOD
Windrow 6-3	--	--	3.49	--	< LOD
Windrow 6-4	--	--	11.7	--	< LOD
Windrow 6-5	--	--	9.54	--	0.05
Windrow 7-1	--	--	--	--	--
Windrow 7-2	--	--	2.60	--	< LOD
Windrow 7-3	--	--	6.30	--	< LOD
Windrow 7-4	--	--	7.57	--	< LOD
Windrow 7-5	--	--	24.5	--	< LOD
Windrow 8-1	--	--	< LOD	--	< LOD
Windrow 8-2	--	--	2.41	--	< LOD
Windrow 8-3	--	--	4.39	--	< LOD
Windrow 8-4	--	--	6.80	--	< LOD
Windrow 8-5	--	--	18.6	--	0.07

Windrow 9-1	--	--	--	--	--
Windrow 9-2	--	--	3.05	--	--
Windrow 9-3	--	--	1.95	--	--
Windrow 9-4	--	--	7.50	--	< LOD
Windrow 9-5	--	--	16.8	--	< LOD
Windrow 10-1	--	--	--	--	--
Windrow 10-2	--	--	2.17	--	--
Windrow 10-3	--	--	4.52	--	< LOD
Windrow 10-4	--	--	6.85	--	0.09
Windrow 10-5	--	--	15.2	--	< LOD
Mature 1-A	--	2.14	6.83	--	0.09
Mature 1-B	--	3.03	7.08	--	0.09
Mature 1-C	NR	1.46	8.67	--	0.06
Mature 2-A	NR	4.94	10.3	< LOD	0.06
Mature 2-B	NR	3.04	11.7	< LOD	< LOD
Mature 2-C	NR	2.55	8.83	< LOD	< LOD
Mature 3-A	NR	2.68	6.72	0.29	0.02
Mature 3-B	NR	5.52	22.1	0.38	< LOD
Mature 3-C	NR	6.43	13.0	0.24	0.05
Mature 6-A	NR	2.18	8.75	< LOD	< LOD
Mature 6-B	NR	3.39	7.01	< LOD	< LOD
Mature 6-C	NR	10.5	25.6	0.46	--
Mature 12-A	NR	27.9	51.1	0.80	--
Mature 12-B	NR	11.3	31.3	0.85	--
Mature 12-C	NR	14.9	32.4	0.78	--

W1-W5 correspond to five intervals of increasing maturity sampled along the compost windrow. M1, M2, M3, M6, and M12 correspond to distinct mature compost stockpiles of increasing curing age. Letters A, B, C, etc. indicate replicates from one larger composite sample. Concentrations indicated with bold font were extrapolated above the highest level of the calibration curve for that PFAS. Greyed-out concentrations were not included in summary statistics (Table S7) or in figures because that PFAS was not present > LOQ in all replicates of that sample. PFBA concentrations could not be reported due to insufficient calibration curves and QC data; these unreported concentrations are indicated as “NR” (not reported).

Table S7. Summary statistics: averages and detection frequenciesTable S7a. PFAAs (ng g⁻¹ dry wt)

Sample ID	n	PFCA								PFSA		
		PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFDA	PFUDA	PFDoA	PFBS	∑PFOS	PFNS
Mulch	3	--	--	NA	--	0.04	--	--	--	NA	0.06	--
FW	6	--	--	--	--	--	--	--	--	--	--	NA
FCM leachate	3	NR	129	1050	12.3	--	--	--	--	--	--	--
W1	10	NR	1.76 (20)	1.94 (20)	--	0.06 (90)	--	--	--	--	0.04 (100)	--
W2	10	NR	1.80 (30)	3.01 (100)	--	0.07 (100)	0.14 (10)	--	0.02 (60)	0.04 (20)	0.05 (100)	--
W3	10	NR	1.61 (60)	5.84 (100)	--	0.09 (100)	0.04 (20)	--	0.02 (80)	0.04 (40)	0.06 (100)	--
W4	10	NR	1.86 (90)	11.7 (100)	0.28 (30)	0.10 (100)	0.06 (20)	0.02 (10)	0.02 (90)	0.04 (50)	0.05 (100)	--
W5	10	NR	2.63 (100)	18.3 (100)	0.21 (70)	0.15 (100)	0.06 (30)	0.01 (30)	0.02 (100)	0.04 (90)	0.06 (100)	--
M1	3	NR	2.50	8.61	NA	0.16	0.08	NA	0.03	0.05	0.08	--
M2	3	NR	6.01	11.9	NA	0.19	0.11	0.03	0.04	0.04	0.09	--
M3	3	NR	7.43	16.3	0.37	0.14	0.07	NA	0.04	0.03	0.09	--
M6	3	NR	10.1	18.5	0.51	0.13	0.05	0.02	0.04	0.03	0.12	--
M12	3	NR	33.9	47.9	1.24	0.13	0.08	0.04	0.06	0.07	0.17	--

Table S7b. Other PFAS and Σ PFAS (ng g⁻¹ dry wt)

Sample ID	FTCA		FASA	FASAA	PAP			Σ PFAS	±	stdev
	6:2 FTCA	5:3 FTCA	FOSA	Σ EtFOSAA	6:2diPAP	6:2/8:2diPAP	8:2diPAP			
Mulch	--	--	--	--	0.34	--	--	0.43	±	0.19
FW	--	--	NA	--	--	--	--	NA		
FCM leachate	80.6	100	--	--	0.95	0.44	0.77	1378	±	26.4
W1	--	--	--	0.02 (10)	0.83 (100)	0.20 (70)	0.07 (70)	1.85	±	0.97
W2	--	1.71 (30)	--	0.03 (30)	0.63 (100)	0.32 (100)	0.12 (100)	5.30	±	2.77
W3	--	2.01 (50)	--	0.03 (60)	0.59 (100)	0.17 (100)	0.10 (90)	8.88	±	3.32
W4	--	1.45 (80)	--	0.05 (100)	0.57 (100)	0.44 (90)	0.17 (100)	16.0	±	6.43
W5	--	1.51 (80)	--	0.06 (100)	0.35 (100)	0.14 (100)	0.06 (90)	23.1	±	5.45
M1	--	0.83	--	0.05	0.16	0.05	0.04	12.6	±	3.37
M2	--	1.33	--	0.06	0.16	NA	0.17	20.1	±	4.49
M3	--	2.14	--	0.07	0.44	0.29	0.11	27.4	±	11.0
M6	--	2.13	--	0.06	0.24	0.14	0.12	32.2	±	27.2
M12	--	NA	--	0.03	0.32	0.35	0.09	84.3	±	18.5

Table S7c. Compost leachates (ng g-1 dry wt)

Sample ID	n	PFBA	PFPeA	PFHxA	PFHpA	PFOA	∑PFAS	±	stdev
W1	10	--	--	3.63 (20)	--	--	3.63	±	1.74
W2	10	--	--	3.66 (100)	--	0.11 (10)	3.76	±	1.64
W3	10	--	--	6.09 (100)	--	--	6.09	±	2.75
W4	10	--	--	12.0 (100)	--	0.13 (30)	12.1	±	6.02
W5	10	--	--	17.6	--	0.22	17.8	±	4.62
M1	3	NA	2.21	7.53	NA	0.08	9.82	±	0.66
M2	3	NR	3.51	10.3	NA	0.06	13.9	±	2.10
M3	3	NR	4.88	13.9	0.30	0.04	19.1	±	9.16
M6	3	NR	5.37	13.8	NA	NA	19.2	±	14.7
M12	3	NR	18.0	38.2	0.81	NA	57.1	±	19.8

These values are the average concentrations (ng g-1 dry wt) of each analyte in each set of replicates depicted in manuscript Figures 2-4. For windrow compost, detection frequencies (% of 10 collections) are included in brackets below the average at each windrow interval (W1-W5). Within true replicates (samples taken concurrently), concentrations were only included in figures if that PFAS was measured > LOQ in all replicates. Windrow replicates (n=10), however, were collected on 10 different sampling trips over time, and so any concentrations measured > LOQ were included in Figure 3. W1-W5 correspond to five intervals of increasing maturity sampled along the compost windrow. M1, M2, M3, M6, and M12 correspond to distinct mature compost stockpiles of increasing curing age (in months). Letters A, B, C, etc. indicate replicates from one larger composite sample. NA= not applicable, if the compound was not measured > LOQ in all replicates.

Table S8. Results of significance testing among Σ_{40} PFAS in windrow composts and among Σ_{40} PFAS in mature composts.

Windrow compost age groups (W1-W5)		Mature compost age groups (M1-M5)	
Test	p-value	Test	p-value
Shapiro-Wilk	1.02E-03	Shapiro-Wilk	2.81E-03
Kruskal-Wallis	3.69E-08	Kruskal-Wallis	3.99E-02

Dunn post-hoc		Dunn post-hoc	
Comparison	p-value	Comparison	p-value
W1-W2	4.16E-01	M1-M2	9.41E-01
W1-W3	2.05E-02	M1-M3	5.80E-01
W2-W3	3.54E-01	M2-M3	1.00E+00
W1-W4	8.36E-05	M1-M6	1.00E+00
W2-W4	3.00E-02	M2-M6	9.27E-01
W3-W4	4.35E-01	M3-M6	1.00E+00
W1-W5	1.26E-07	M1-M12	1.90E-02
W2-W5	3.84E-04	M2-M12	4.97E-01
W3-W5	3.31E-02	M3-M12	1.00E+00
W4-W5	2.08E-01	M6-M12	5.43E-01

Table S9. EPA Regional Screening Levels (RSLs)

PFAS	Direct exposure (ng/g)		Protection of Groundwater SSLs (ng/g)
	Residential	Industrial	
PFBA	7800	120000	0.65
PFHxA	3200	41000	0.24
PFOA	19	250	0.091
PFNA	19	250	0.025
PFBS	1900	25000	0.19
PFHxS	130	1600	0.017
PFOS	13	160	0.031
GenX	23	350	N/A

These RSLs were updated on May 2023 (EPA, 2023a). We chose to use RSL values corresponding to a target hazard quotient (THQ) of 0.1, since the compost contains a mixture of targeted PFAS (EPA, 2023b).

FIGURES



Figure S1. Composite compost sampling scheme. Each mulch and compost sample was a composite of 12 scoops: two scoops each from the top, middle and bottom of the pile, on both sides of row. An example compost windrow sample is illustrated here. Each “X” represents one scoop. The top layer of material was moved aside before samples were scooped at an approximate depth of six inches below the surface of the pile.



Figure S2. Paper and other plant-fiber food contact materials (FCMs) separated from food waste feedstock arriving at the compost facility. Approximately 100 pieces of FCM were saved for PFAS analysis.

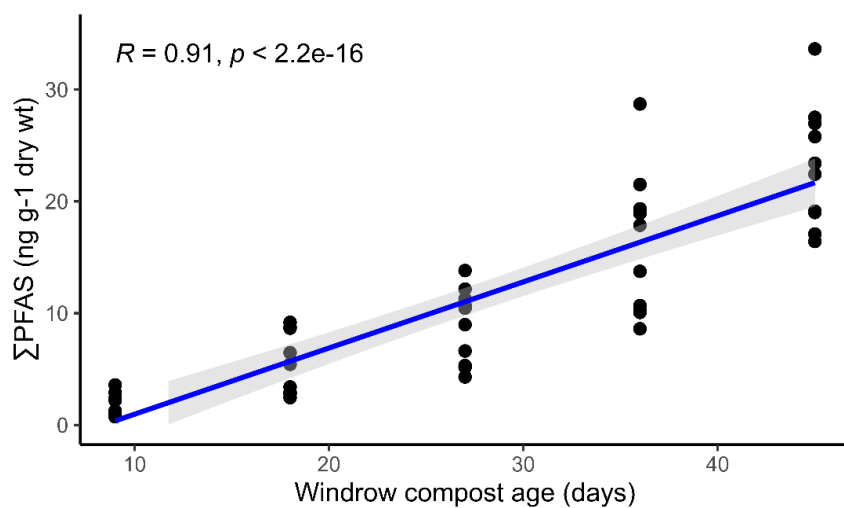


Figure S3. Spearman correlation ($p < 0.05$) of Σ_{40} PFAS with windrow compost age. Data points represent Σ_{40} PFAS in composts present in the windrow for approximately 9, 18, 27, 36, and 45 days, corresponding to compost samples W1, W2, W3, W4, and W5, respectively.

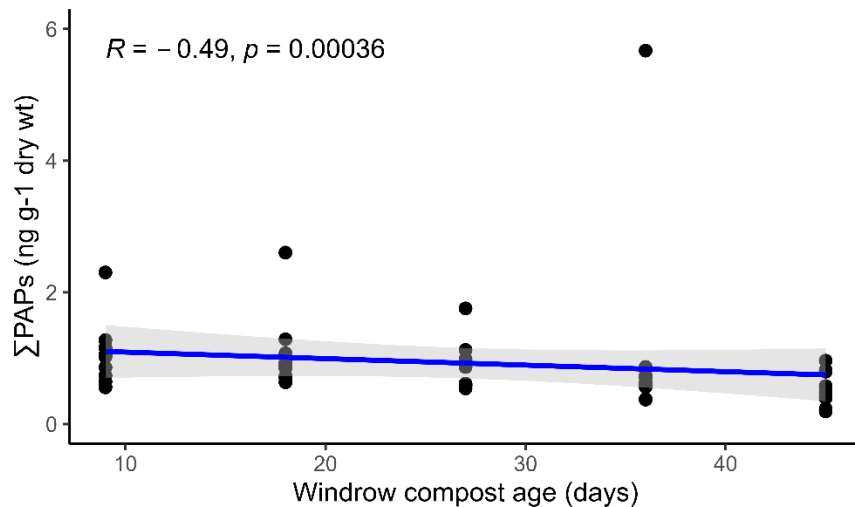


Figure S4. Spearman correlation ($p < 0.05$) of the sum of 6:2, 6:2/8:2, and 8:2 fluorotelomer phosphate diester ($\Sigma_3\text{diPAPs}$) with windrow compost age. Data points represent $\Sigma_3\text{diPAPs}$ in composts present in the windrow for approximately 9, 18, 27, 36, and 45 days, corresponding to compost samples W1, W2, W3, W4, and W5, respectively.

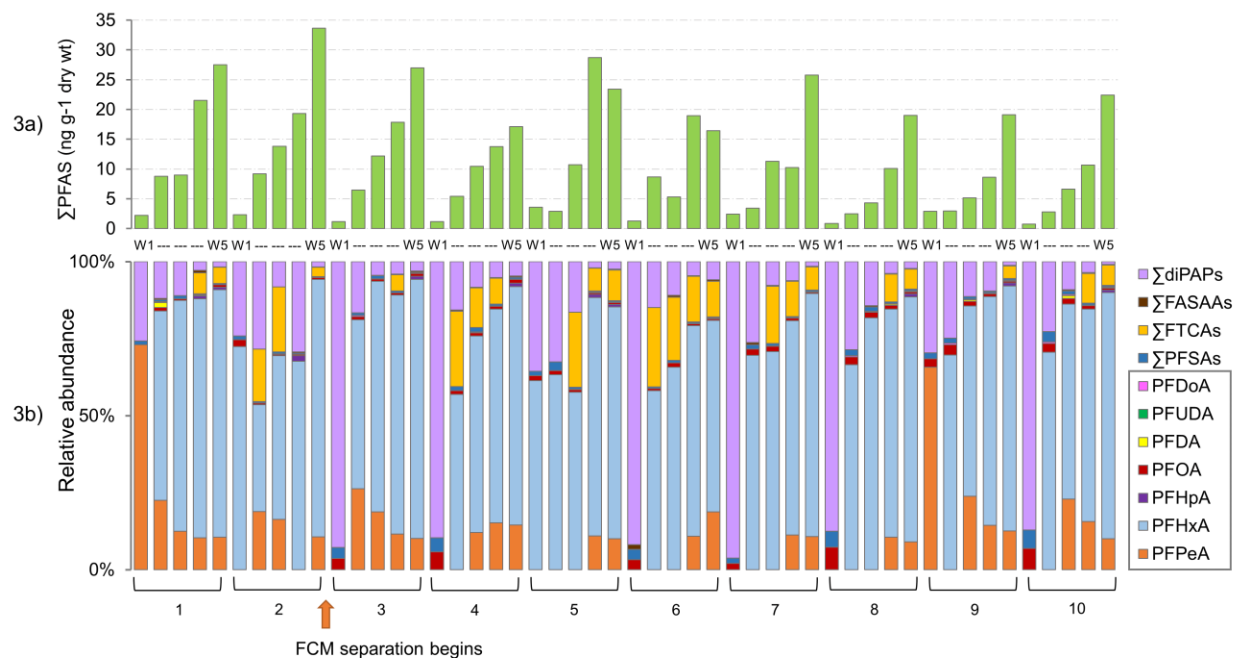


Figure S5. Bar charts illustrating $\Sigma_{40}\text{PFAS}$ (a) and relative abundance of individual PFCAs (boxed) and other PFAS subclasses (b) in each windrow compost sample. W1-W5 correspond to increasing compost maturity at the five sampling intervals along the windrow. Groups 1-10 indicate the 10 successive sampling trips during which windrow samples were collected. FCM separation began after the first two windrow compost collections.

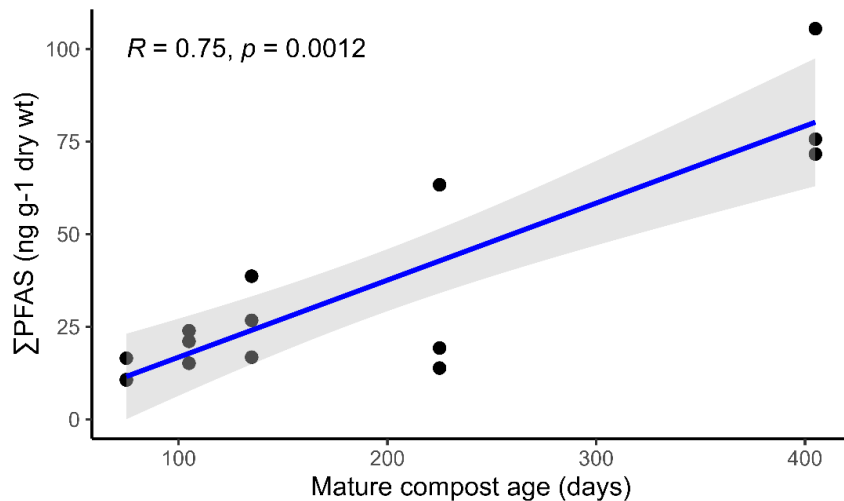


Figure S6. Spearman correlation ($p < 0.05$) of Σ_{40} PFAS with mature compost age. Data points represent Σ_{40} PFAS in individual compost samples from mature stockpiles M1, M2, M3, M6, and M12, which correspond to the curing ages of 1, 2, 3, 6, and 12 months, respectively, in addition to the 45 days spent within the compost windrow.

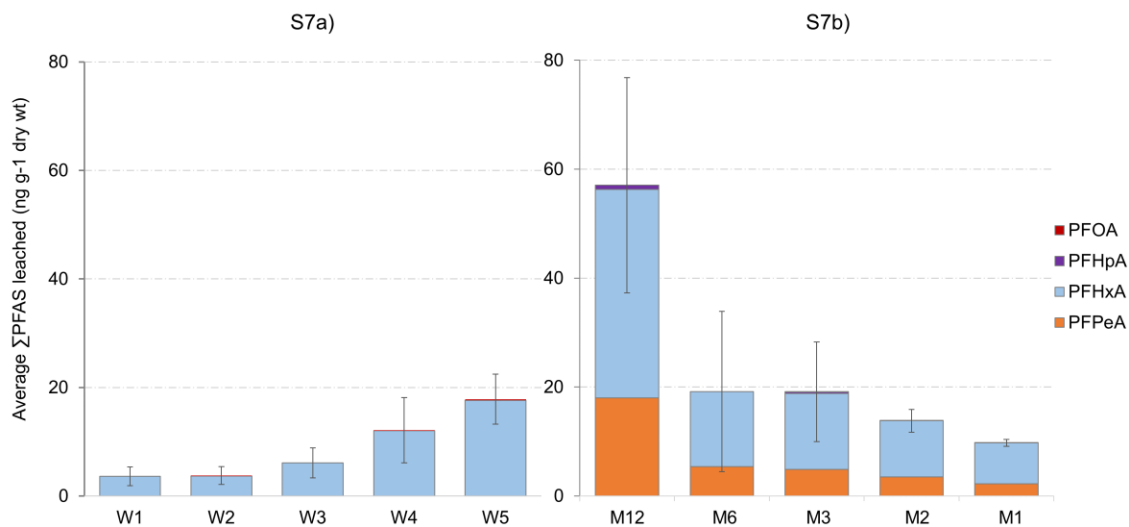


Figure S7. Bar charts summarizing average Σ_{40} PFAS measured in leachates from windrow (a) and mature (b) composts, each in chronological order. Error bars represent the standard deviation of Σ_{40} PFAS measured in leachates from windrow samples collected at each interval over 10 collections (a) or from mature compost replicates collected across each stockpile (b).

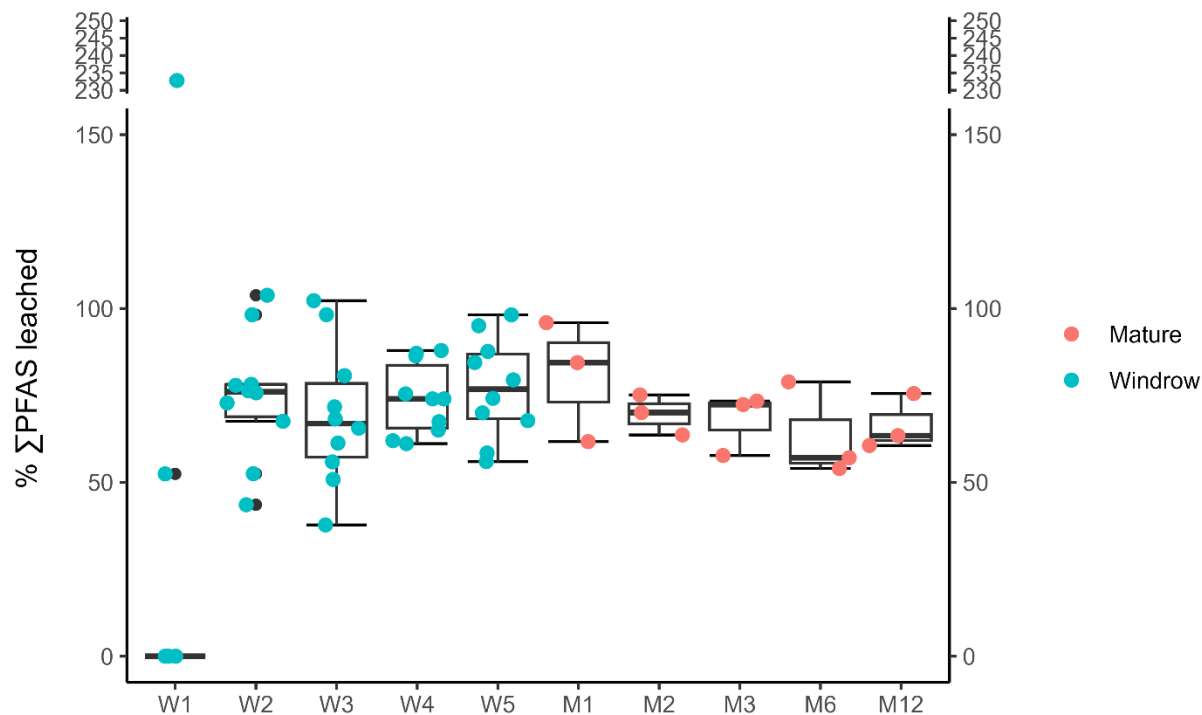


Figure S8. Boxplots illustrate the variation in percent (%) of solvent-extracted Σ_{40} PFAS that leached in composts grouped by increasing age. W1-W5 indicate composts that have been in the windrow for approximately 9, 18, 27, 36, and 45 days, respectively. M1, M2, M3, M6, and M12 indicate mature composts that have been curing for approximately 1, 2, 3, 6, and 12 months, respectively, in addition to the 45 days of windrow composting. For windrow composts, each jitter point represents Σ_{40} PFAS at that windrow transect in one of 10 collections. For mature composts, each jitter point represents Σ_{40} PFAS in a replicate of a mature compost stockpile (i.e. the jitter points for each curing age group represent the variation in Σ_{40} PFAS across the stockpile to which mature compost was added to over time). The axis break was achieved using ggbreak (Xu et al., 2021).

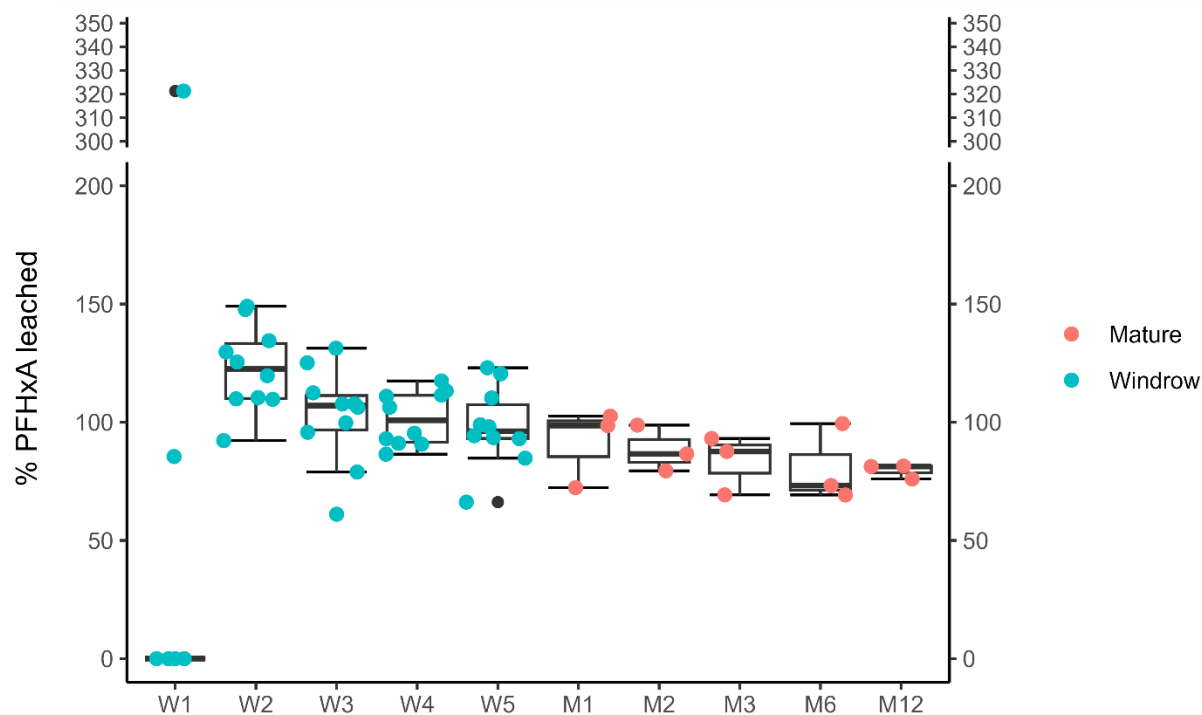


Figure S9. Boxplots illustrate the variation in percent (%) of solvent-extracted PFHxA that leached in composts grouped by increasing age. W1-W5 indicate composts that have been in the windrow for approximately 9, 18, 27, 36, and 45 days, respectively. M1, M2, M3, M6, and M12 indicate mature composts that have been curing for approximately 1, 2, 3, 6, and 12 months, respectively, in addition to the 45 days of windrow composting. For windrow composts, each jitter point represents Σ_{40} PFAS at that windrow transect in one of 10 collections. For mature composts, each jitter point represents Σ_{40} PFAS in a replicate of a mature compost stockpile (i.e. the jitter points for each curing age group represent the variation in Σ_{40} PFAS across the stockpile to which mature compost was added to over time). The axis break was achieved using ggbreak (Xu et al., 2021).

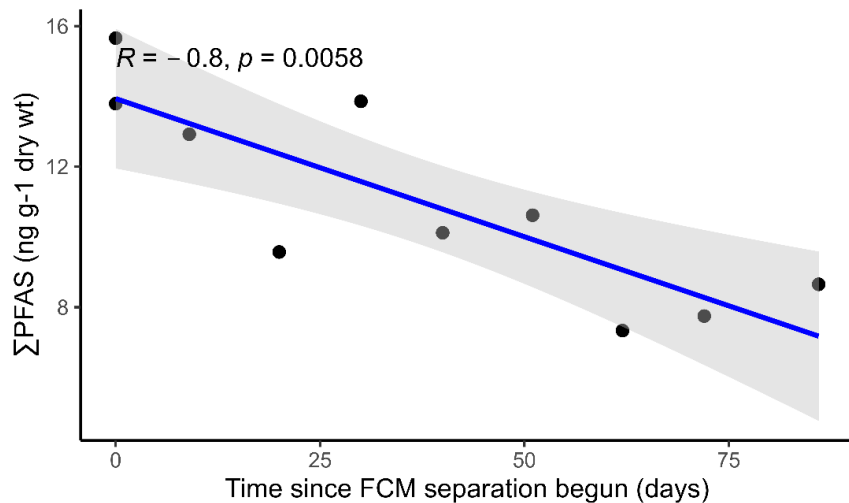


Figure S10. Spearman correlation ($p < 0.05$) of the average Σ_{40} PFAS in windrow composts versus the number of days passed since the practice of separating food contact materials (FCMs) from the compost feedstock was begun. Each data point represents the average Σ_{40} PFAS measured across all five windrow transects (W1-W5) within one of 10 collections. FCM separation began after two baseline windrow collections, which are positioned at zero days in this correlation analysis.

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