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PFAS: Forever Chemicals in Soils

There is no need to discuss their presence anymore; they are ubiquitous, they are „forever chemicals". More than anything else, the issue of their remediation has to be addressed. Per- and polyfluoroalkyl substances (PFAS) in soil are persistent environmental contaminants with potential far-reaching impact. These synthetic compounds, found in various industrial and consumer products, exhibit remarkable stability and resistance to degradation. Their widespread presence in soil, even in remote locations, poses concerns for both environmental and human health. Investigating PFAS in soil is crucial to comprehend their distribution, persistence, and associated risks. Only then we can discuss strategies to rid the environment of them.

Figure 1: Illustrative image of soil

PFAS in soil

Pilot studies have predominantly focused on the presence and movement of PFAS in the atmosphere, surface water, and groundwater. Yet, there are growing indications that soils play a crucial role as a substantial reservoir and enduring source of PFAS, both locally and on a broader scale.

The prevalence of PFAS in soil is evident across nearly all tested locations, even in remote areas distant from potential PFAS sources. This substantial soil reservoir poses a persistent threat, serving as a long-term contaminant source for surface water, groundwater, the atmosphere, and biota. Notably, concentrations of PFAS in soil at contaminated sites often surpass typical groundwater levels by orders of magnitude, reaching up to parts-per-million levels. A significant concern arises regarding the long-term migration of PFAS to surface water, groundwater, and the atmosphere.

PFAS can influence soil properties and structures, with reported effects including a decline in soil respiration and water stable aggregates, alongside an increase in soil pH. Furthermore, PFAS alter bacterial communities, boosting the abundance of certain bacteria while reducing overall bacterial diversity even at very low concentrations. The impact of PFAS extends beyond the soil's microbial community, contaminating groundwater and accumulating in plants. Therefore, a comprehensive understanding of PFAS fate and transport in soil is crucial for effective environmental management.

Sources of PFAS in soil

- Firefighting foams: Professional Aqueous Film Forming Foams (AFFF), commonly used in firefighting exercises, contain PFAS compounds. Accidental releases and training exercises contribute to soil contamination.
- Industrial discharges: Certain industrial activities producing PFAS-containing products may release these substances into the environment. Industrial discharges and improper waste disposal can result in PFAS entering the soil.
- Landfills and waste sites: Landfills and waste disposal sites that receive PFAS-containing materials can lead to leaching of these substances into soil. Improper disposal practices contribute to soil contamination.
- Wastewater treatment plants: Effluents from wastewater treatment plants, which may receive industrial or domestic wastewater containing PFAS, can introduce these compounds into the soil when used for irrigation or discharged into water bodies.
- Atmospheric deposition: PFAS can settle onto soils through precipitation or air deposition. This source is particularly relevant for areas near industries using or emitting PFAS.
- Consumer products: Some consumer products, such as water-resistant textiles, non-stick cookware, and food packaging, may contain PFAS. Over time, these products can release PFAS into the environment, contributing to soil contamination.
- Runoff from contaminated areas: Rainwater runoff from areas with historical PFAS use or contamination can transport these substances into nearby soils.

The Case Study: Analysis of PFAS in selected soil samples in 2023

The monitoring study of the occurrence of PFAS in soils was conducted in 2023. The study involved the analysis of 209 soil samples.
The analysis focused on 20 PFAS substances, which are currently legislatively required to be monitored in drinking waters (*). The analysis was conducted using the standard method (Table 1) with quantification limits (LOQ) ranging from 0.5 to 2.5 µg/kg DW (Table 1).
Approximately 70% of tested samples were negative (below LOQ) for all the analytes (Figure 2).
In positive samples, as anticipated, the most frequently detected substances were two compounds: PFOS and PFOA. It is worth noticing that predominantly long-chain PFAS (PFDA, PFNA, PFNS, etc.) can be detected in soils. Additionally, alongside the mentioned substances, compounds 6:2 FTS and FOSA are present in soils quite often.

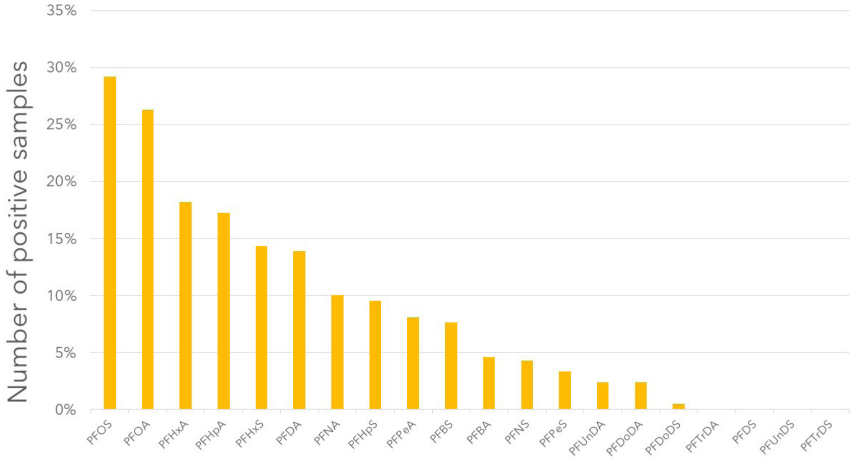

Figure 2: Number of positive samples for PFAS coumpounds in tested soils

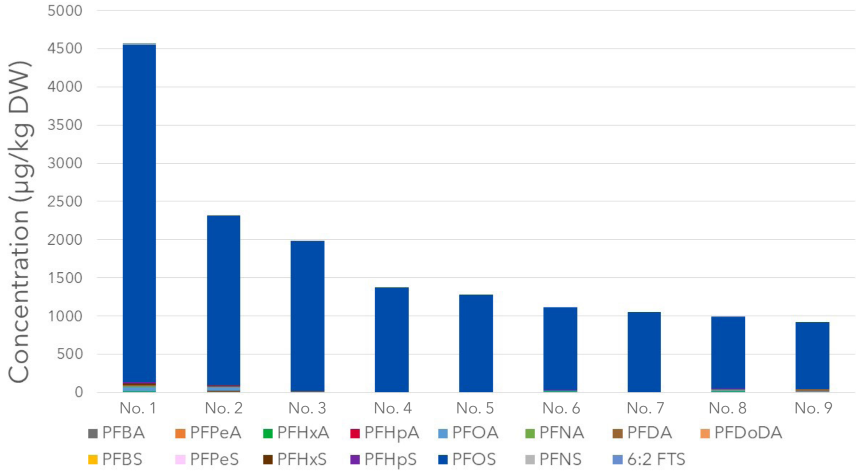

Figure 3: Concentration levels of PFAS in selected soil samples (µg/kg DW)

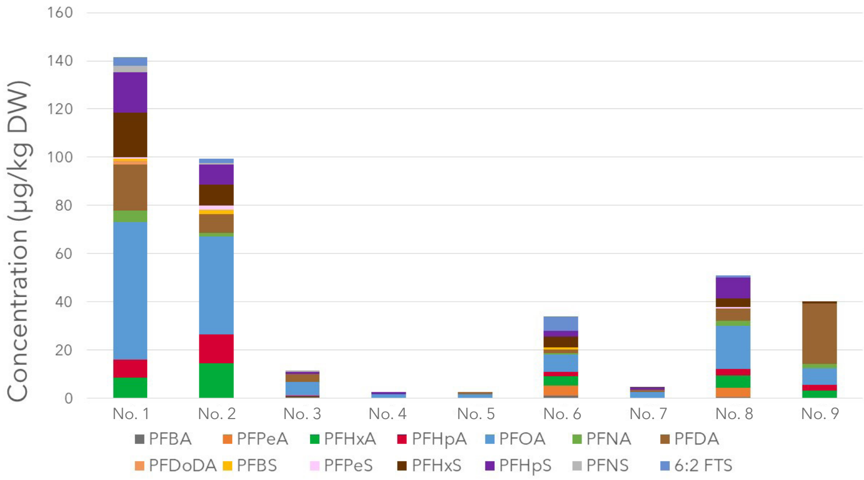

Figure 4: Concentration levels of PFAS in selected soil samples (µg/kg DW), without PFOS

Occurrence of PFAS in soil samples

The profiles of detected individual PFAS in contaminated samples are presented in Figures 3 and 4.
It is evident, and expectable, that PFOS was detected at the highest concentration levels (Figure 3) significantly surpassing other analytes. The profile of other PFAS (without PFOS) and their concentration levels are shown in Figure 4.

In practice, it is clear that the representation of PFAS in soils can vary, primarily depending on the sampled location.

Literature cited:

- Y. Wang, U. Munir, Q. Huang. Occurrence of per- and polyfluoroalkyl substances (PFAS) in soil: Sources, fate, and remediation. 2023. https://doi.org/10.1016/jseh.2023.100004
- M. L. Brusseau, R. H. Anderson, B. Guo. PFAS Concentrations in Soils: Background Levels versus Contaminated Sites. 2020. doi: 10.1016/j.scitotenv.2020.140017

Related EnviroMails / Europe:

- EnviroMail 01 / Europe: PFAS Testing in Waters: The Scope of Analyses and Current State of Legislation (May 2023)
- EnviroMail 02 / Europe: Sampling Recommendations for PFAS to Maximize Data Quality (May 2023)

Table 1. The list of PFAS target analytes and report limits as validated for SOIL samples.

Groups	Analytes	Abbreviation	Standard (µg/kg DW)	Low-limits (µg/kg DW)
Perfluoroalkyl-carboxylic acids	Perfluorobutanoic acid	PFBA*	0.5	0.05
	Perfluoro-3-methoxypropanoic acid	PFMPA	2.5	n.a.
	Perfluoropentanoic acid	PFPeA*	0.5	0.2
	Perfluoro-4-methoxybutanoic acid	PFMBA	2.5	n.a.
	Perfluorohexanoic acid	PFHxA*	0.5	0.2
	2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoic acid	HFPO-DA	2.5	n.a.
	Perfluoroheptanoic acid	PFHpA*	0.5	0.2
	4,8-dioxa-3H-perfluorononanoic acid	DONA	0.5	n.a.
	7H-perfluoroheptanoic acid	HPFHpA	0.5	0.2
	Perfluorooctanoic acid	PFOA*	0.5	0.05
	Perfluoro-3,7-dimethyloctanoic acid	P37DMOA	0.5	0.2
	Perfluorononanoic acid	PFNA*	0.5	0.05
	Perfluorodecanoic acid	PFDA*	0.5	0.05
	2H,2H,3H,3H-perfluoroundecanoic acid	H4PFUnDA	5	n.a.
	Perfluoroundecanoic acid	PFUnDA*	0.5	0.05
	Perfluorododecanoic acid	PFDoDA*	0.5	0.05
	Perfluorotridecanoic acid	PFTrDA*	0.5	0.05
	Perfluorotetradecanoic acid	PFTeDA	0.5	0.05
	Perfluorohexadecanoic acid	PFHxDA	5	1
	Perfluorooctadecanoic acid	PFOcDA	5	5
Perfluoroalkyl-sulfonic acids	Perfluoropropane sulfonic acid	PFPrS	2.5	n.a.
	Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	2.5	n.a.
	Perfluorobutane sulfonic acid	PFBS*	0.5	0.1
	Perfluoropentane sulfonic acid	PFPeS*	0.5	0.05
	Perfluorohexane sulfonic acid	PFHxS*	0.5	0.1
	Perfluoroheptane sulfonic acid	PFHpS*	0.5	0.1
	Perfluorooctane sulfonic acid	PFOS*	0.5	0.05
	Perfluoro-4-ethylcyclohexanesulfonic acid	PFECHS	0.5	n.a.
	Perfluorononane sulfonic acid	PFNS*	0.5	0.05
	Perfluorodecane sulfonic acid	PFDS*	0.5	0.05
	Perfluoroundecane sulfonic acid	PFUnDS*	2.5	n.a.
	Perfluorododecane sulfonic acid	PFDoDS*	0.5	0.05
	Perfluorooctane sulfonic acid	PFTrDS*	2.5	n.a.
Perfluorinated telomer sulfonates	4:2 Fluorotelomer sulfonic acid	4:2 FTS	0.5	0.05
	6:2 Fluorotelomer sulfonic acid	6:2 FTS	0.5	0.05
	8:2 Fluorotelomer sulfonic acid	8:2 FTS	0.5	0.1
	10:2 Fluorotelomer sulfonic acid	10:2 FTS	0.5	0.2
Perfluorinated sulfonamides	Perfluorooctane sulfonamide	FOSA	0.5	0.05
	N-Methyl perfluorooctane sulfonamide	MeFOSA	0.5	0.05
	N-Ethyl perfluorooctane sulfonamide	EtFOSA	0.5	0.05
Perfluorinated sulfonamidoethanols	N-Methyl perfluorooctane sulfonamidoethanol	MeFOSE	0.5	0.2
	N-Ethyl perfluorooctane sulfonamidoethanol	EtFOSE	0.5	0.2
Perfluorooctane-sulfoamidoacetic acids	Perfluorooctane sulfonamidoacetic acid	FOSAA	0.5	0.5
	N-Methyl perfluorooctane sulfonamidoacetic acid	MeFOSAA	0.5	0.5
	N-Ethyl perfluorooctane sulfonamidoacetic acid	EtFOSAA	0.5	0.5
Fluorotelomer carboxylic acids	2H,2H,3H,3H-perfluorohexanoic acid	3:3 FTCA	2.5	n.a.
	2H,2H-perfluorooctanoic acid	6:2 FTCA	5	n.a.
	2H,2H,3H,3H-perfluorooctanoic acid	5:3 FTCA	5	n.a.
	2H-perfluoro-2-octenoic acid	6:2 FTUCA	5	n.a.
	2H,2H,3H,3H-perfluorodecanoic acid	7:3 FTCA	5	n.a.
	2H,2H-perfluorodecanoic acid	8:2 FTCA	5	n.a.
	2H-perfluoro-2-decenoic acid	8:2 FTUCA	0.5	n.a.
Chlorinated perfluoroalkyl sulfonic acids	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS	0.5	n.a.
	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	0.5	n.a.

n.a. = Not Analyzed:
* *Analytes included in the sum of 20 PFAS in drinking water according to DIRECTIVE (EU) 2020/2184 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2020 on the quality of water intended for human consumption.*