UNDERSTANDING PFAS CHALLENGES IN AGRICULTURE

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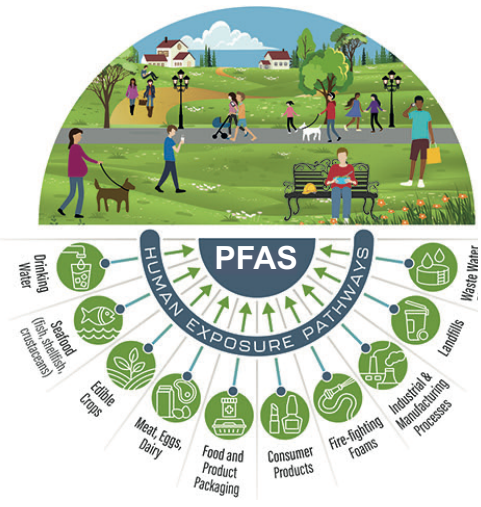
Understanding PFAS Challenges in Agriculture



- PFAS Basics: The what, where, and why of PFAS
- PFAS Basics to Understand Fate
- Fate with land application examples
- Plant uptake snapshots and mitigation strategies
- Key Take-Aways

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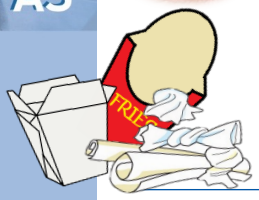
PFAS ARE PERVASIVE IN OUR PROCESSES AND PRODUCTS

Used in numerous products & processes due to their unique properties

PFAS BRAND NAMES

- Teflon
- Scotchguard
- Stainmaster
- Stainsafe
- Silverstone
- Polartec
- Texapore
- Gore-Tex



PFAS WORDS to AVOID

- "nonstick"
- "water-repellent"
- "weather-protective"
- "stain-resistent"
- "fluoro" or "perfluoro"

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Industries & Infrastructures	Products
• Municipal water and waste treatment	• Water, oil, and stain-resistant textile
• Industrial manufacturing of PFAS	• Floor coatings and cleaners
• Oil and gas operations	• Food wrappers
• Metal plating and coating	• Pharmaceuticals & Personal care products
• Aviation and transportation fire extinguishing	• Aqueous Film-Forming Foams (AFFFs)

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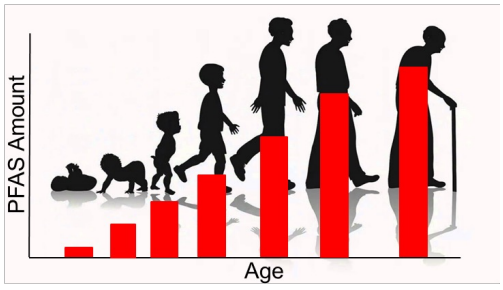
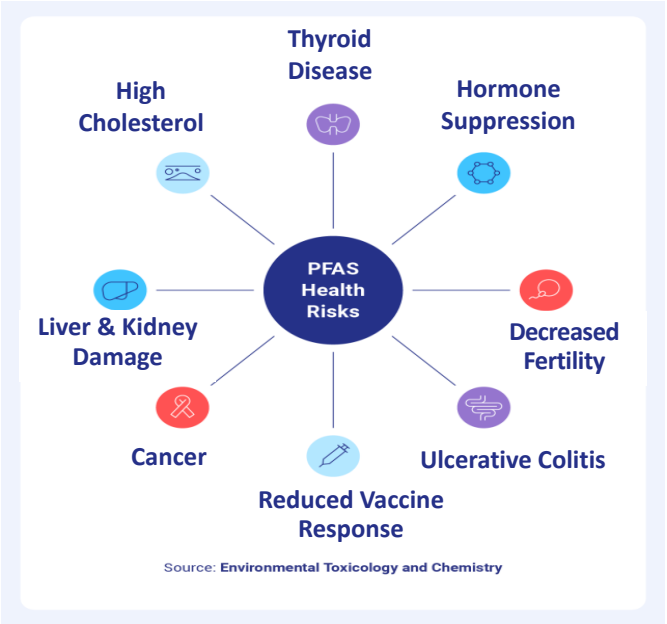
WHY THE GROWING CONCERN ABOUT PFAS?

- PFAS are **persistent**
- PFAS **bioccumulate** in humans , plants, and animals
- Some PFAS **biomagnify** up the trophic chain
- Exhibit toxicity





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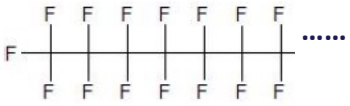
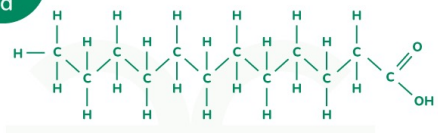
PFAS: PER- & POLYFLUOROALKYL SUBSTANCES – A LARGE SYNTHETIC DIVERSE CHEMICAL FAMILY

> *15,000* PFAS produced



Fatty Acid



- Fluorine-saturated chain of varying length
- Numerous subclasses
  - Each has a unique differentiating characteristic
  - Each with several different perfluoroalkyl chain lengths
- An individual PFAS like PFOS may be multiple molecules (isomers, same atoms but different arrangements)

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Is it a PFAS or not?

TIME

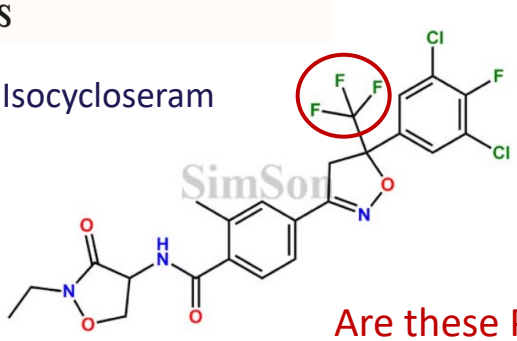
NOV 26, 2025 9:52 AM ET

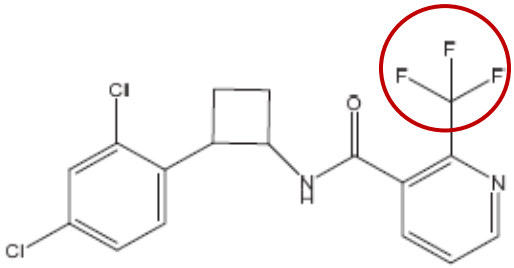
The EPA Is Embracing PFAS Pesticides. These Are The Health Risks

It is all about definition. Two main ones:

- *European Union - one perfluorocarbon*
- *EPA- two adjacent carbon atoms,*

Isocycloseram





Cyclobutrifluram

Are these PFAS?

Only by EU definition

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PER VERSUS POLYFLUOROALKYL SUBSTANCE

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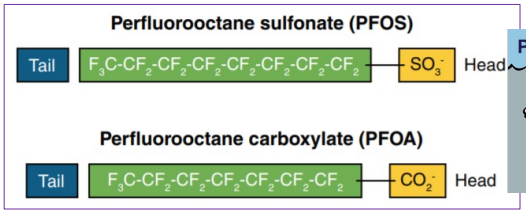
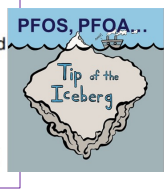
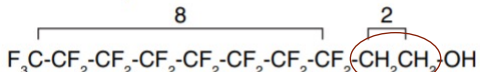
Per-





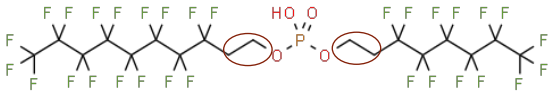
Poly-



8:2 FTOH (8:2 fluorotelomer alcohol)

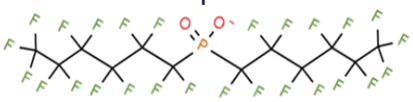
$CF_3CF_2CF_2CF_2CF_2CF_2CH_2CH_2SO_3^-$

6:2 Fluorotelomer sulfonate (6:2 FTS)



8:2 Fluorotelomer perfluoroalkyl phosphate diester (8:2 diPAP)

PFAS 'Replacements'



6:6 perfluorophosphinate (6:6 PFPi)

Perfluoroethylcyclohexane sulphonate (PFECHS)
erosion inhibitor in aircraft hydraulic fluids

IRTC PFAS Fact Sheet (Fig. 2.2); Buck et al., 2011, etc.

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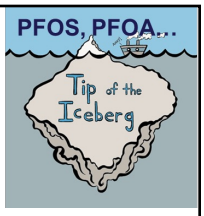
APRIL 10, 2024 U.S. EPA SETS PFAS MAXIMUM CONCENTATION LEVELS (MCLS) IN PPT (NG/L)

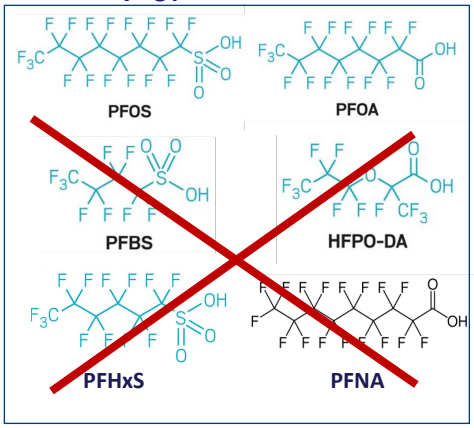


PFAS	MCLG	MCL (enforceable levels)
PFOA (C8)	Zero	4.0 ppt
PFOS (C8)	Zero	4.0 ppt
PFNA (C9)	10 ppt	10 ppt
PFHxS (C6)	10 ppt	10 ppt
PFBS (C4)	1000 ppt	1000 ppt
HFPO-DA (GenX Chemicals)	10 ppt	10 ppt
Mixtures of 2 or more PFNA, PFHxS, PFBS, and HFPO-DA	1.0 (unitless) Hazard Index Σ MCL/measured concentration	

MCLG = maximum contaminant level goals

EPA 1633A Method:
'40 PFAS' Targeted

Per-



Rescinded for now

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Units in the PFAS World

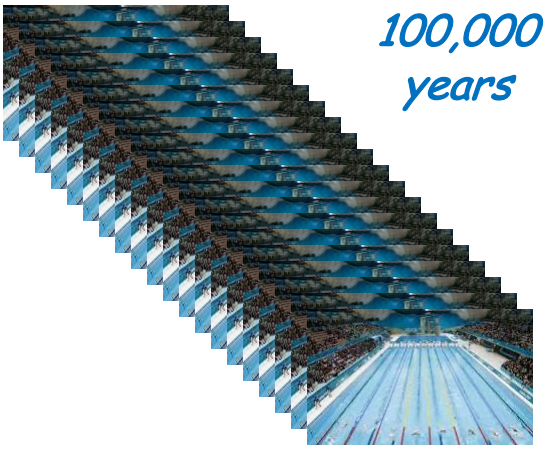
Water (ng/L)

Bioaccumulation, Sorption

X 1000

versus Blood, Biota, Soil,Biosolids ppb (ng/g)

3 sec in 100,000 years



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Now a Few PFAS Basics to Understand PFAS in the Agricultural Environment

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Short vs Long Chain vs Precursors/Intermediates

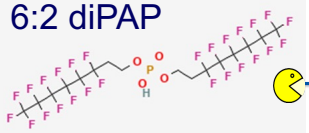
Perfluoroalkyl carboxylic acids (PFCAs, *like PFOA*) and perfluoroalkyl sulfonic acids (PFSAs, *like PFOS*) are together refer to as perfluoroalkyl acids (PFAAs) and are persistent in the environment

- Shorter chain PFAS
  - More mobile (rapidly leach through soil)
  - Less bioaccumulative
  - Higher transpiration into plants
- Longer chain like PFOS and PFOA
  - Not very mobile
  - More bioaccumulative
  - Biomagnify
  - Longer half-lives in humans

Precursors/Intermediates → PFAAs

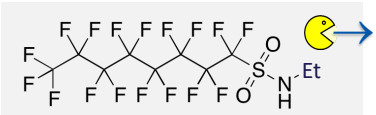
Fluorotelomer-based example

6:2 diPAP



→ → **Multiple PFCAs**

Electrochemically-derived (ECF) example



EtFOSA (C8)

→ → **C8 PFSA (PFOS)**

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THE CHALLENGE: MANAGING PFAS IN WASTEWATER AND BIOSOLIDS MANAGEMENT

Multiple PFAS sources – industry, AFFFs, landfills, domestic

Wastewater Influent → Sorption to Sludge → Effluent discharged to streams or used for irrigation

Conduit of our wastes

Treatment process with type and treatment stage

Biosolids → Land-applied as a soil amendment

PFAS enter our wastewater treatment plants and then exit via effluent or sludge (or air) unaffected or transformed to other PFAS

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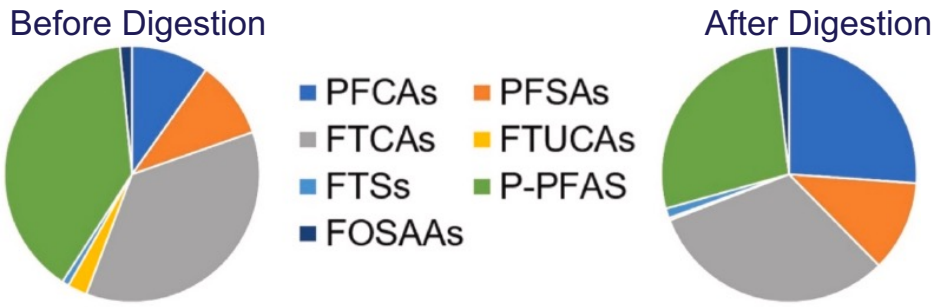
PFAS Transformation in Solids Processing: Example for Anaerobic Digestion (AD)



- Bulk of the PFAS are precursors (**green**) and intermediates (gray) and most not measured in the current USEPA 40 targets list in the USA
- Digestion to remove pathogens, etc. leads to PFAS conversion to PFAAs (**orange** and **blue**)
- Aerobic >> anaerobic transformation rates

Alukkal, Lee et al., 2024a,b
https://doi.org/10.1016/j.chemosphere.2024.143406
https://doi.org/10.1016/j.chemosphere.2024.143357

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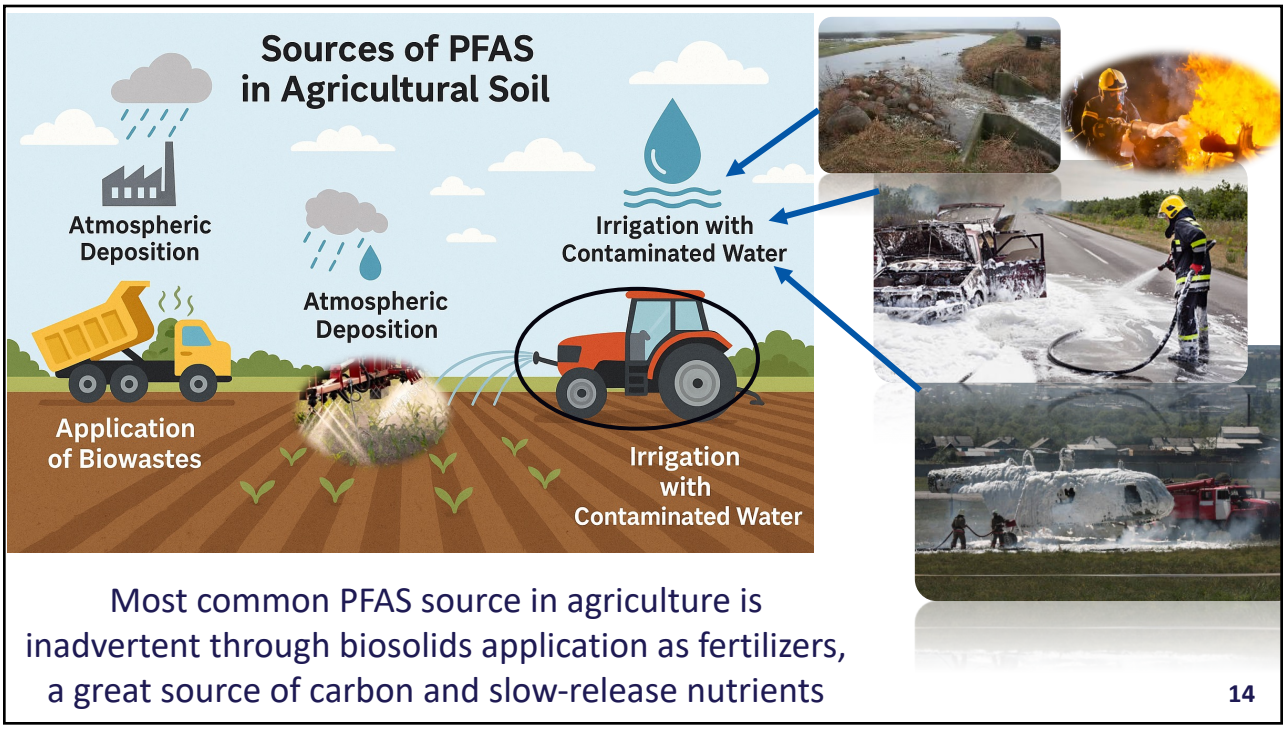

Most common PFAS source in agriculture is inadvertent through biosolids application as fertilizers, a great source of carbon and slow-release nutrients

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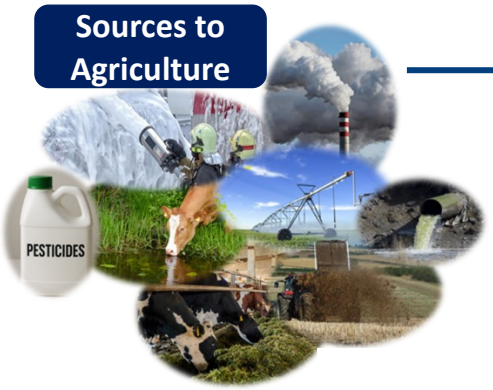
PFAS Fate after Discharge/Application to Land



PFAS Fate

Chemical Properties

Soil Properties

Air-water interface accumulation (PFAS)

Solid Phase adsorption

Biotransformation

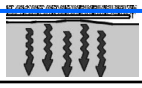
Plant Uptake

Leaching

Runoff

Tile-drain discharge

Let's look at some examples



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40-Y SURFACE DISPOSAL SCENARIO (WESTERN USA)

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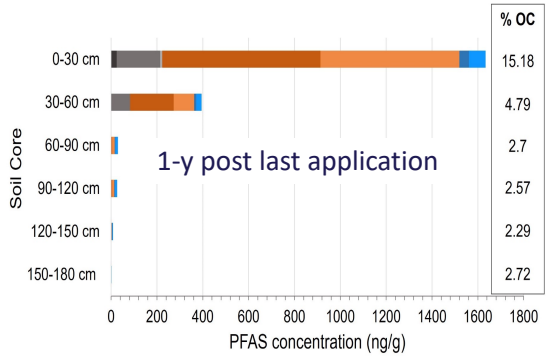
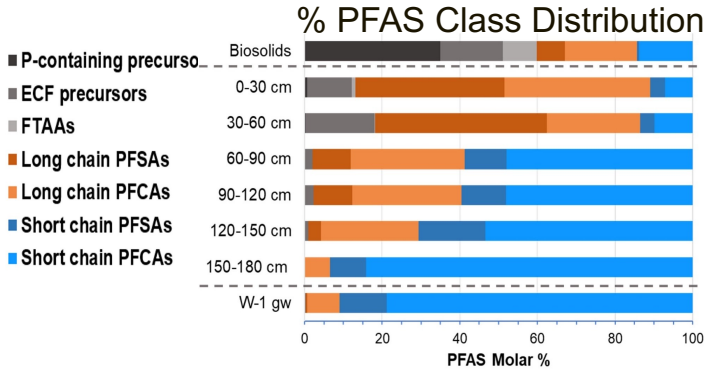
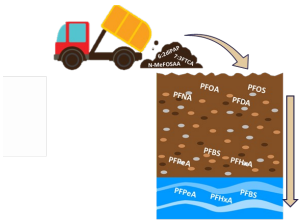




- Annual and high biosolids application rates led to PFAS and organic carbon (% OC) accumulation in soil over time
- Long-chain PFAS retained in the upper soil profile
- Most precursors degrade to PFAAs within 1 year
- Short-chain PFAAs dominate what is getting to groundwater



The Water Research Foundation

EPA United States Environmental Protection Agency

Alvarez, Lee et al. 2024 https://doi.org/10.1016/j.scitotenv.2024.176540

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38-Y AGRONOMIC BIOSOLIDS APPLICATION VA, USA STUDY SITE

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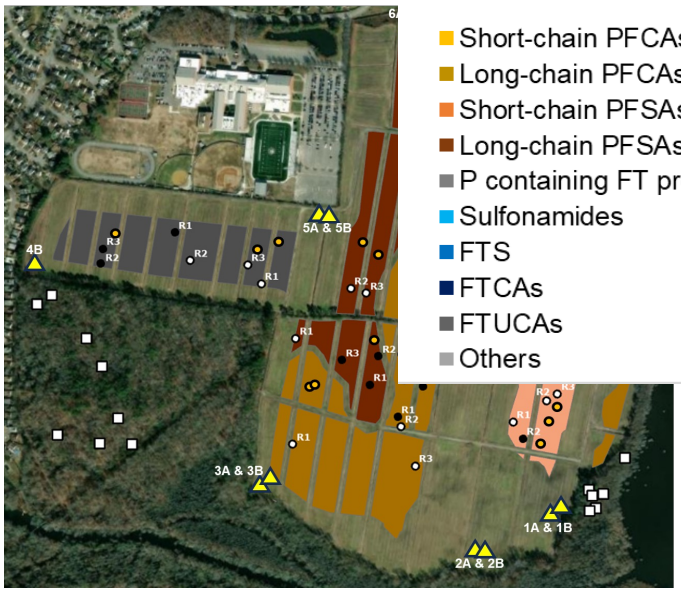
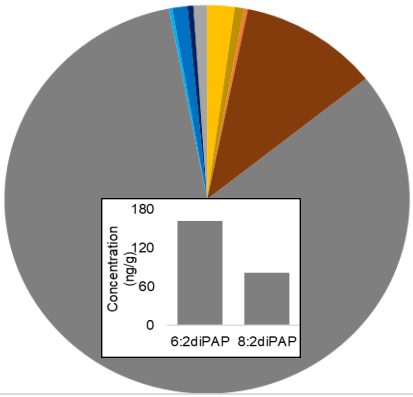


- Short-chain PFCAs
- Long-chain PFCAs
- Short-chain PFSAs
- Long-chain PFSAs
- P containing FT precursors
- Sulfonamides
- FTS
- FTCAs
- FTUCAs
- Others



- 3 soil types – low to high permeability
- Class B biosolids application 1986 – 2014
- Mostly Corn/soybean rotations – animal feed
- Switch to Class A in 2023 (after a 9-y pause)
- PFAS in 2023 biosolids mostly diPAPs

EPA United States Environmental Protection Agency

HRSD

Peter, Lee et al. 2025,
https://doi.org/10.1016/j.jenvman.2025.128137

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38-Y AGRONOMIC BIOSOLIDS APPLICATION, HRSD VA STUDY SITE

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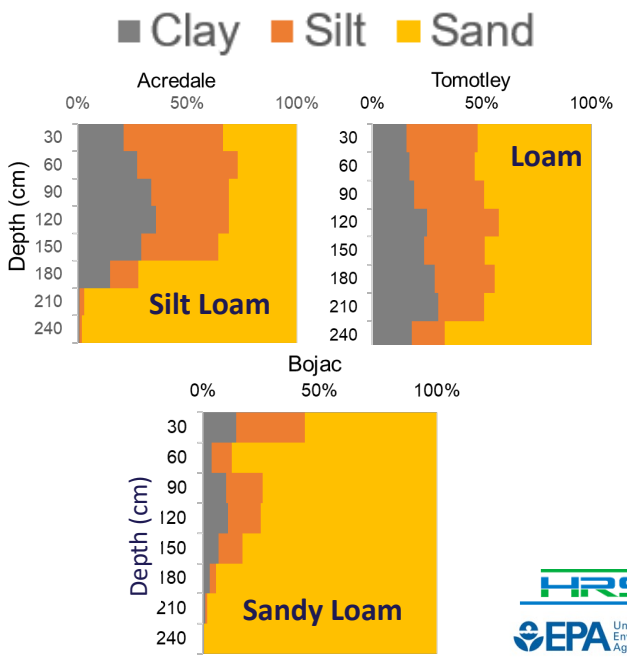

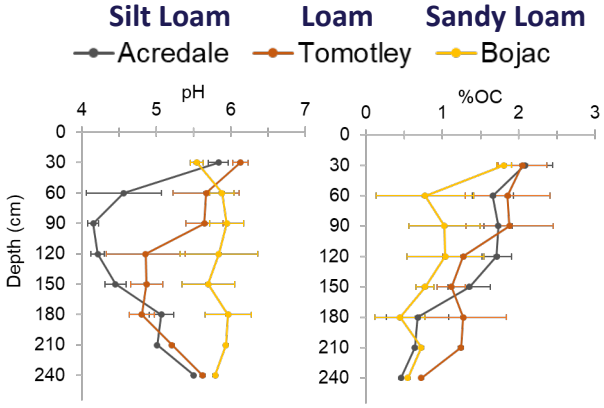

HRSD

EPA United States Environmental Protection Agency

Peter, Lee et al. 2025,
https://doi.org/10.1016/j.jenvman.2025.128137

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38-Y AGRONOMIC BIOSOLIDS APPLICATION, HRSD VA STUDY SITE DISTRIBUTION WITH DEPTH

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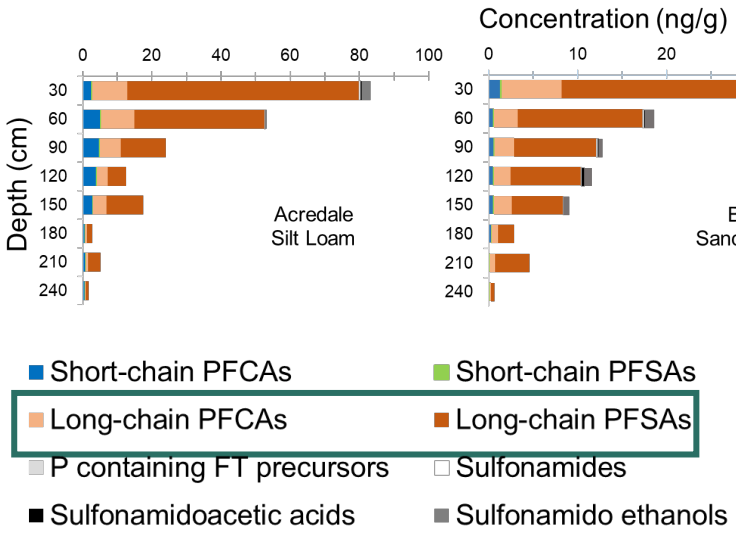

- Long-chain PFAS (**oranges**) persist, particularly in the upper soil horizon
- Textural driven processes evident
- Post-2023 application no different than Acredale reference site *(not shown)*

Peter, Lee et al. 2025,
https://doi.org/10.1016/j.jenvman.2025.128137

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OTHER PFAS SOURCES EXEMPLIFIED FOR THE VA, USA STUDY SITE

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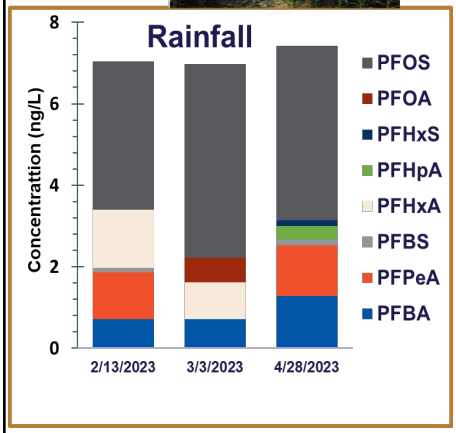
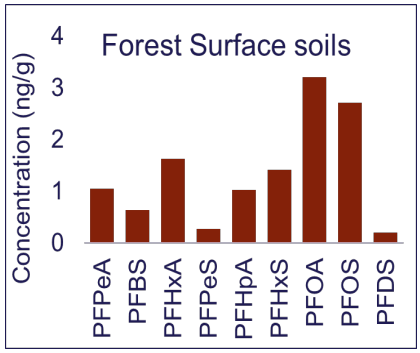
- Rainwater had PFAS signature
- Military base, airport within 5-mi radius
- Multiple PFAS source receiving Lake borders





- Forest soil with no history of biosolids application similar to PFAS signature in rainwater

Peter, Lee et al. 2025a
https://doi.org/10.1016/j.jenvman.2025.128137

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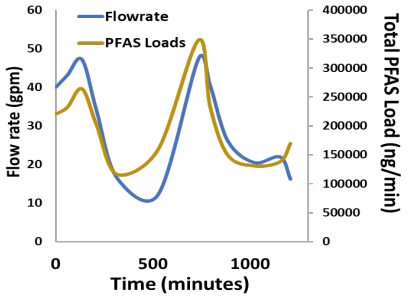
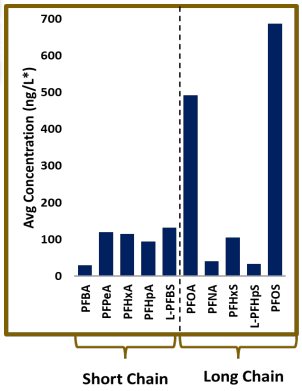
POTENTIAL IMPACT OF RUNOFF FROM PFAS-CONTAMINATED LAND





With high PFAS retention in surface soils, runoff into streams, wetlands, and farm ponds may be a significant PFAS exposure pathway to fish, wildlife, and grazing cattle, and subsequently, humans.

Peter, 2025, PhD Dissertation

Examples:

- 200-1400 ppb PFOS in fish in farm ponds surrounded by farms with legacy biosolids application (pre-2002)
- 150-200 ppt in milk from free grazing dairy cattle; an AFFF-contaminated stream is their drinking water source

Confidential, unpublished data

USDA FSA, USGS 104B

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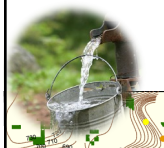
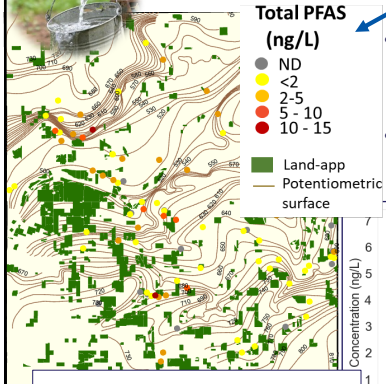
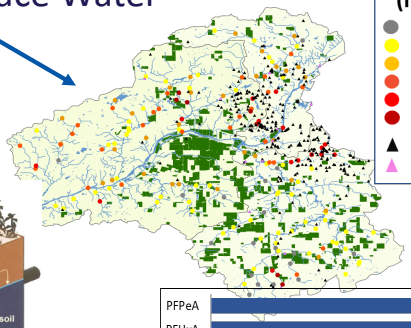
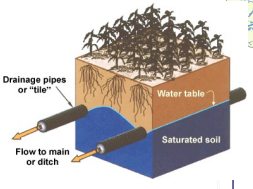
Indiana: Greater Tippecanoe County: PFAS in Rural Water Supplies & Surface Water

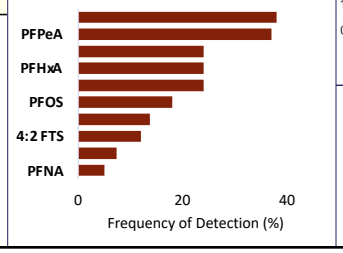


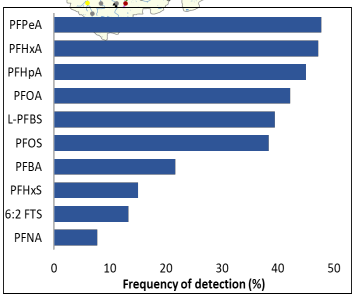


- Major sources: agricultural, industrial and WTTP discharges
- Most agriculture fields are tile-drained









- PFAS detected in 88% of surface water samples.
- 20 PFAS detected in surface water with highest for PFBS @ 85 ng/L

Peter, Lee, 2024 https://doi.org/10.1021/acs.est.4c09490

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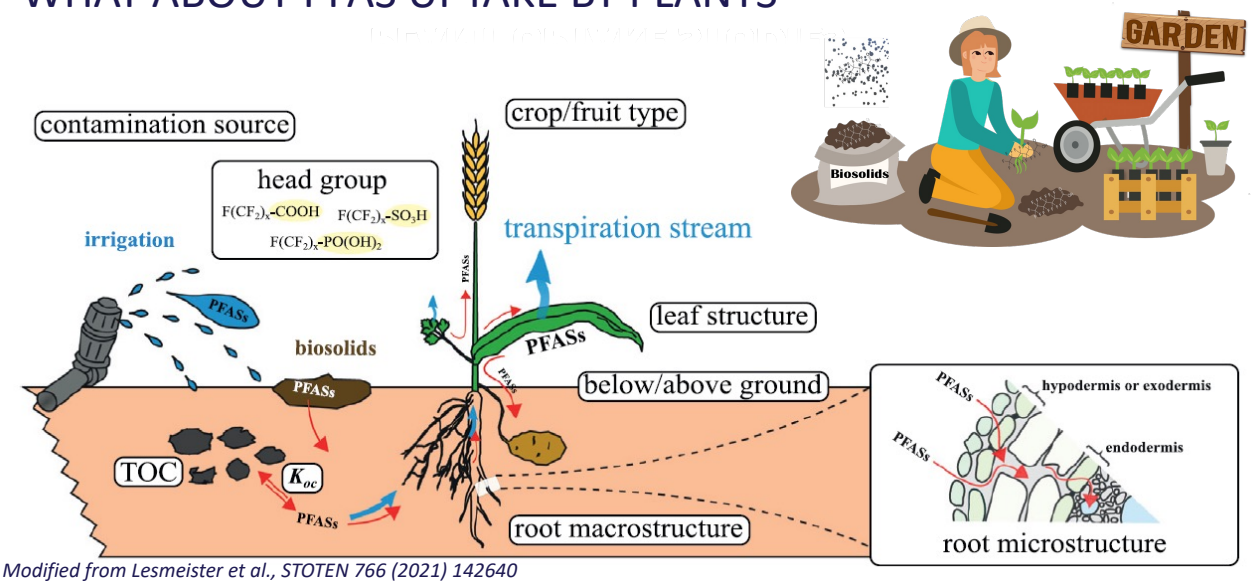
WHAT ABOUT PFAS UPTAKE BY PLANTS



Modified from Lesmeister et al., STOTEN 766 (2021) 142640

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PFAA Plant Uptake Summary (∑PFAS or just *Some* PFAS)

- **PFAS properties, soil properties, plant types, and climate influence uptake magnitude**
- No significant phytotoxic effects at concentrations found in agricultural landscapes or in biosolids
- PFAS may sorb to roots and root vegetables
- Some PFAS may be taken up into plants through transpiration (xylem)
- Potential for some PFAS transfer to phloem
- Plant root protein and lipid content can influence uptake

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Schilling-Costello, M. C and L.S. Lee. 2020, Sources, Fate and Plant-Uptake in Agricultural Systems of Per- and Polyfluoroalkyl Substances, *Current Pollution Reports*

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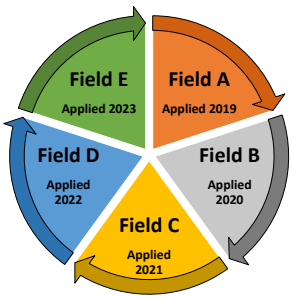
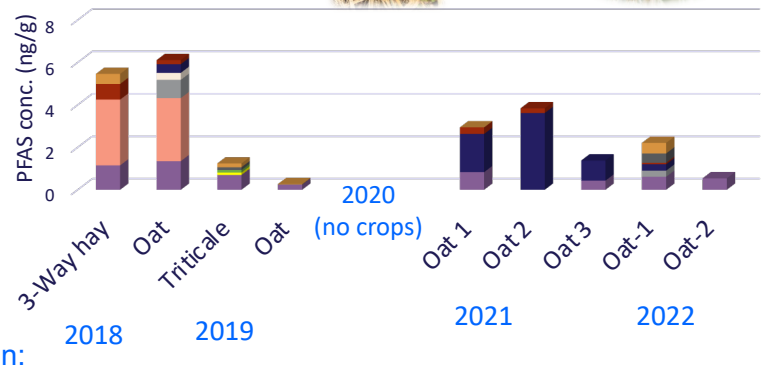
FEED CROP UPTAKE EXAMPLE: WEST COAST BIOSOLIDS-APPLIED SITE





Last Biosolids Application:

Manuscript in preparation

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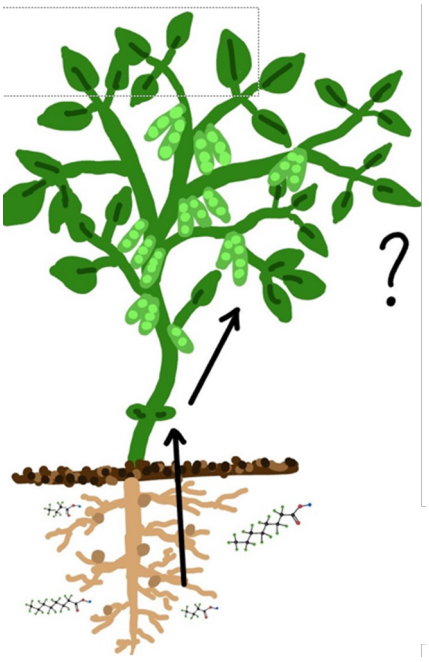
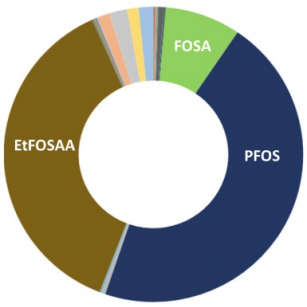
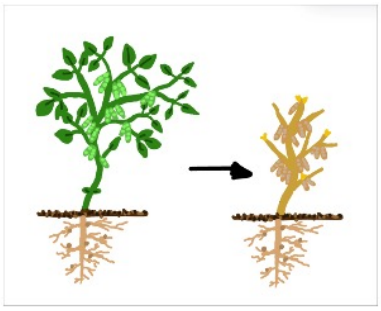
CROP UPTAKE HIGHLIGHTS: SOYBEANS

- Soils from years of **paper mill biosolids**-applied fields
- Soils had ∑PFAS ~2800 ppb, most are PFOS + ETFOSAA
- All pots were amended with Milorganite Biosolids at a rate of 1% for PFCA precursor addition
- 6 different soybean varieties grown through senescence
- No PFOS or ETFOSA in the bean
- Only primarily PFBA, PFPeA & PFHxA
- Higher % protein, higher uptake







USDA-NRCS CRP Lands
Linda S Lee, PI

EPA United States Environmental Protection Agency

USDA Agricultural Research Service

Lazo, Lee, Ma, Cark et al., Manuscript in process

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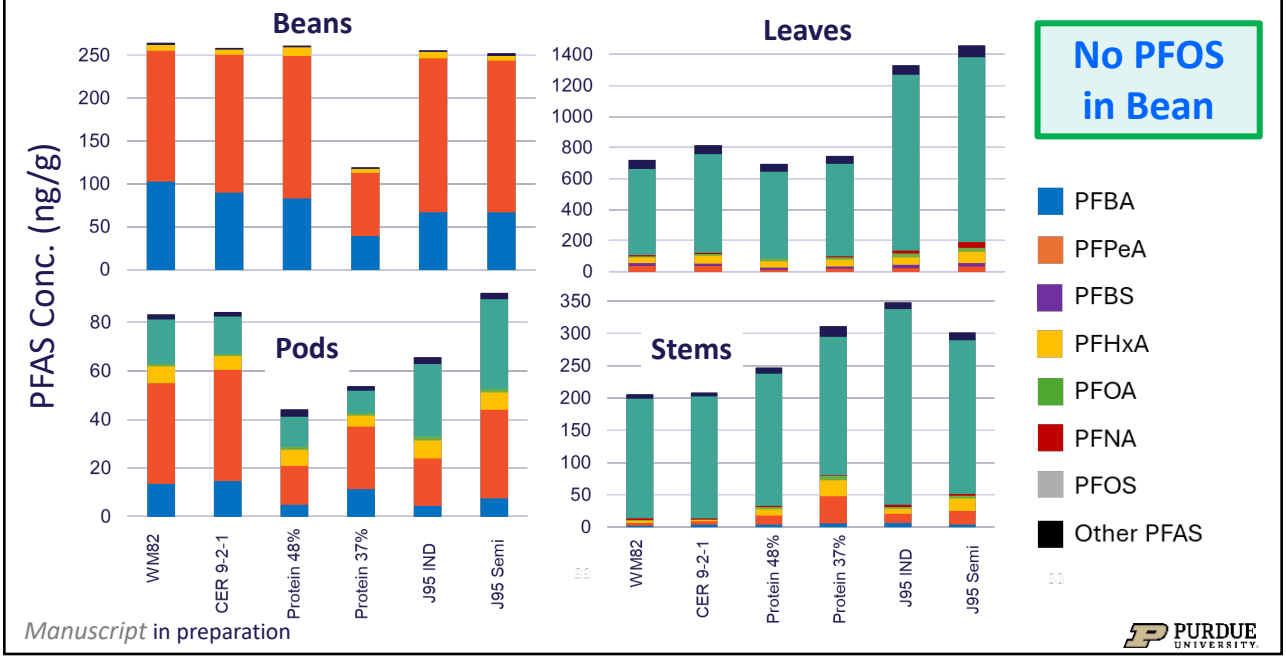
UPTAKE - SOYBEAN PLANTS: LEAVES > STEMS > BEANS > PODS



Manuscript in preparation

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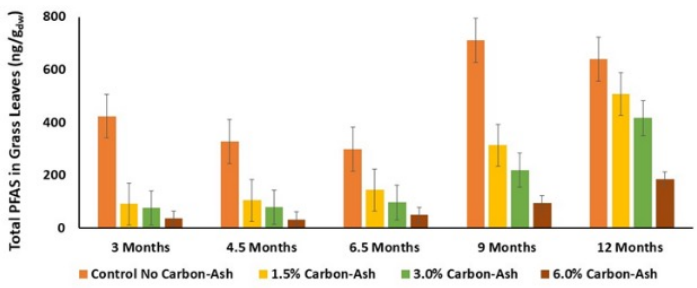
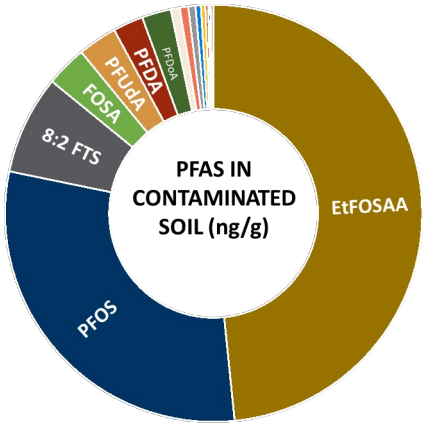
Grass Greenhouse Studies: Uptake and Mitigation

- Contaminated agricultural soil from Maine - ∑PFAS = 840 ng/g with most being PFOS and PFOS precursors (Me- & EtFOSAAs, FOSA)
- Biochar (**wood chips ash**) mixed at 3 rates (1.5%, 3% and 6%); n= 5
- Grass mix (40% Tall Fescue, 30% Orchard grass, 20% Festulolium and 10% Timothy) – typical feed grasses for cattle
- Soil seeded in March 2024
- Pots watered as needed weekly
- 4 Grass leaves harvest: *3, 4.5*, 6 and 7.5 months….





USDA Conservation innovation grants
USDA Agricultural Research Service

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Grass Greenhouse Studies: Uptake and Mitigation

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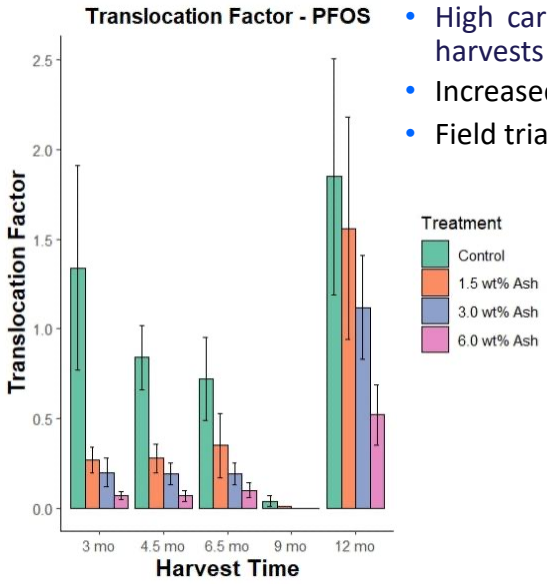
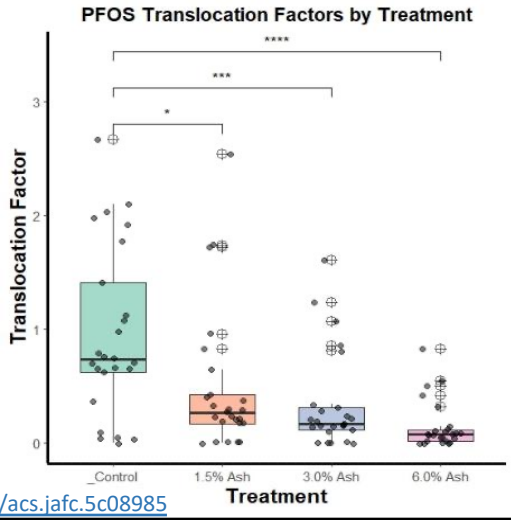


- High carbon wood ash reduced uptake for all harvests over one year
- Increased variability with time
- Field trials in process



Openiyi, Lee, Carpenter et al., J. of Agricul. & Food Chem., https://doi.org/10.1021/acs.jafc.5c08985

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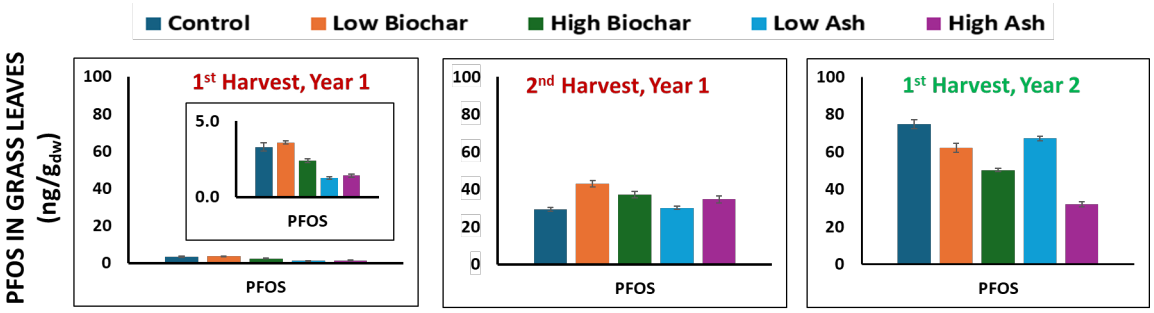
Initial Field Study Results (PFOS)



- 2 times higher PFOS detected in control plots from Year 2 First Harvest compared to Year 1 2nd Harvest
- Mitigation effect of wood ash is more pronounced in the second year for PFOS
- **57%** reduction in PFOS detected in grass leaves from wood ash (high application rate) plots relative to control plots

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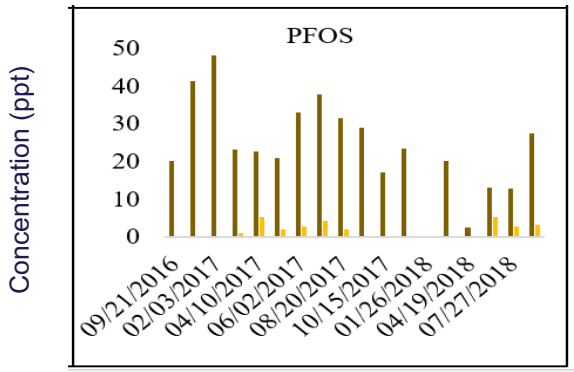
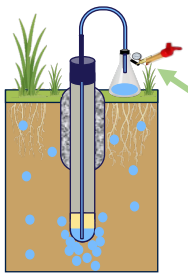
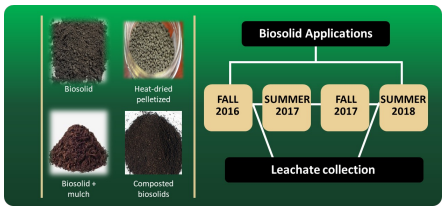
LAND RECLAMATION SITE (5X AG RATE): BIOSOLIDS: MULCH BLENDING EXAMPLE FOR REDUCING PFAS LEACHATE CONCENTRATIONS

Leaching captured 15-cm below the surface







Biosolids only
Biosolids-mulch blend

Biggest impact observed for PFOS

Peter et al., 2024 J. Environ. Qual. DOI: 10.1002/jeq2.20576

United States Environmental Protection Agency

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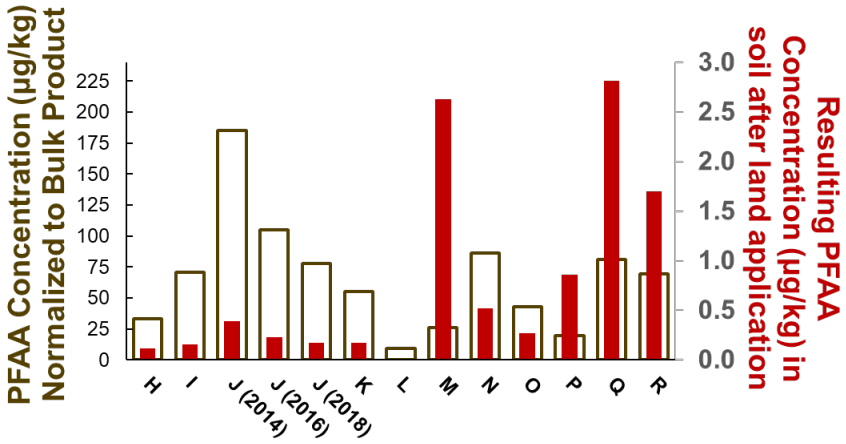
Putting PFAS in Biosolids in Perspective *(Example)*



White bars: PFAAs in biosolids being applied at N recommendations

Red bars: PFAA concentrations in soil after mixing into the growing media where roots reside

- Soil amendments/fertilizers are often applied based on N requirements
- Products low in N could lead to higher PFAS loads with a single application

Lazcano-Kim, Choi, Mashtare, and Lee, 2020, EST. https://doi.org/10.1021/acs.est.9b07281

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PLANT UPTAKE AND ANIMAL BIOACCUMULATION EXAMPLE

- **Low PFAS concentrations bioaccumulate in plants, then biomagnify in livestock (milk and meat)** - particularly long chain like PFOS
- PFAS in the feed
  - PFAS uptake is greatest into leaves and stalk
  - Therefore, PFAS accumulate in grasses (hay)
  - PFAS uptake is small into fruit (e.g., tomatoes), seeds (e.g., soybeans, corn kernels and cob)
- Also, PFAS bioaccumulate from drinking water

Only Maine has guidance; currently
- 3.4 ppb in meat
- 211 ppt in milk
- Expect 5x reduction in milk guidance

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Key Take-Aways

- PFAS migration from soil to gr… …ted by short-chain PFAS
- Long-chain PFAS pe… …soil profile means they are subject to lon… …nd runoff into water bodies impacti… …n exposure routes
- Fields under… …d, but discharge in… …nated PFAS-contaminate…
- Our biggest P… …iosolids applications pri… …bioaccumulative.
- Reduce PFAS uptak… …waiting future other mitigation strategies cur…

Power at the Cash Register

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Finding PFAS Testing Support

- USDA Dairy Indemnity Payment Program
- Conservation evaluation and monitoring activity – PFAS testing water or soil
- Extension agencies/Land grant institutions
- S.747 – Relief for Farmers Hit with PFAS Act 118th Congress (authorizing USDA grants for testing, remediation, health monitoring, farm transition/relocation, and equipment upgrades, BUTit didn't become law HOWEVER it serves as a model for future legislation)

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Questions?

Acknowledgments

Lee Lab

EPA Disclaimer: Data and views shared have not been formally reviewed by EPA and are solely the views of the researchers and not the agency.

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