

Uptake takeaways: Lessons on PFAS in crops from a paired greenhouse and field study



The Agroecology Lab

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BACKGROUND

The practice of spreading *biosolids*, also called sludge, as a method of fertilizing agricultural fields began in the 1970's. The State of Maine banned this practice in April 2022 in the State of Maine in response to the widespread presence of per- and polyfluoroalkyl substances (PFAS), often referred to as “forever chemicals,” found in these soil amendments. PFAS have strong carbon-fluorine bonds, making them difficult to break down in the environment. Detection of PFAS in agricultural fields poses concerns about the health of consumers and farm workers encountering soils and crops growing in these environments. The repercussions of sludge spreading disproportionately affect farmers, who are confronted with uncertainty surrounding what can and cannot be safely grown in PFAS-contaminated fields.

To assess the risks of growing crops in PFAS-contaminated areas, we sought to study the transfer of PFAS from soil to plants for specific crops. The transfer was quantified as a *transfer factor (TF)*, which is a ratio of the content of PFAS in the plant relative to the content of PFAS in the soil. TFs vary greatly based on soil properties, chemical characteristics of individual PFAS compounds, crop type and the amount of contamination.

Research is continuing to explore cropping practices that can support farm viability and human health simultaneously. Our studies explored the practice of intercropping, manipulating plant neighbor pairs, to explore the effects on PFAS uptake in crops.

RESEARCH OBJECTIVES

The following research questions were addressed through this study:

- (1) How does PFAS uptake differ in edible portions of lettuce, tall fescue and tomato crops?
- (2) Does intercropping facilitate or mitigate plant uptake of PFAS?
- (3) Are PFAS evenly distributed throughout a field where biosolids were historically applied?
- (4) Did greenhouse and field settings show similar results?

FINDINGS

- (1) Tall fescue showed the greatest transfer of PFAS in both environments. Lettuce was often in the middle of the ranking order, and tomato fruit often had the least transfer, except for high levels of short-chained PFBA in greenhouse tomatoes.
- (2) Generally, uptake was increased under intercropping scenarios, suggesting that companion planting is not a reliable method for decreasing crop uptake.
- (3) PFAS were distributed randomly across the field, with the most drastic example (NEtFOSAA) ranging from 170 ng/g to 547 ng/g, a 3.2-fold difference just within a 25 feet distance. This shows that contaminated fields can have highly variable PFAS concentrations even within a single field.
- (4) Soil to plant transfer of PFAS was significantly higher in the greenhouse than the field. This highlights that transfer can vary as a function of environmental conditions (e.g., potting media, plant spacing, growth environment), and inferences about TFs from greenhouse studies may be limited.

METHODS

We considered three crops: a leafy green (lettuce), a forage grass (tall fescue), and a fruit vegetable (tomato), which were grown to their typical harvest maturities, respectively. To discern the distribution of PFAS within a plant, we sampled each plant part separately. Additionally, we explored whether the cropping strategy (monocropped or intercropped) could alter the uptake of PFAS. Crops were paired in monocropped and intercropped lettuce/tomato and lettuce/tall fescue treatments.

In the greenhouse, crops were grown in containers with spiked potting mix containing four PFAS compounds (PFBA, PFBS, PFOA and PFOS). In the field, crops were grown on an agricultural site with a history of biosolid applications from 1993-1999.

RESULTS

How does PFAS uptake differ in edible portions of lettuce, tall fescue and tomato crops?

Tomato has been considered a potential lower PFAS-risk food with low long-chain PFAS transfer factors reported by two studies.^{1,2} Our results corroborate this finding, as tomato fruits showed little to no uptake of long-chain PFAS, and the majority of uptake consisting of short-chained PFBA (*Table 1*). This is said with caution, as toxicological profiles of short- and long-chain PFAS are still being studied.

Our findings corroborate previous findings showing that forage grasses can take up greater amounts of PFAS, but overall uptake may be limited by the low biomass of this forage crop. We add additional caution for those growing forage crops as PFAS are reported to bioaccumulate in livestock.

Does intercropping facilitate or mitigate plant uptake of PFAS?

Generally, greenhouse and field studies found that intercropping *increased* the uptake into one or both plants involved, if any effect was observed at all. However, one exception in the greenhouse study showed that intercropping lettuce and tomato

decreased uptake of short-chained PFBA into tomato while increasing it in lettuce.

Cheap and effective PFAS management strategies are not yet widely accessible. There is still not enough known about the facilitative and/or competitive relationships of different crop types. This study allows us to rule out intercropping of lettuce/tomato and lettuce/tall fescue as a management strategy to mitigate PFAS presence in edible portions of the crop. Intercropping is not an effective mitigation approach at this time, but more species pairings need to be explored.

Are PFAS evenly distributed throughout a field?

No, PFAS were randomly distributed across the field. The highest PFAS concentration of a single compound was 3.2 times greater than the lowest (*Figure 1*). This highlights the importance of collocated soil and crop samples to best measure transfer. Further, when fields are being sampled for PFAS, samples should encompass the entire field, either by individual samples or an aggregated representative sample.

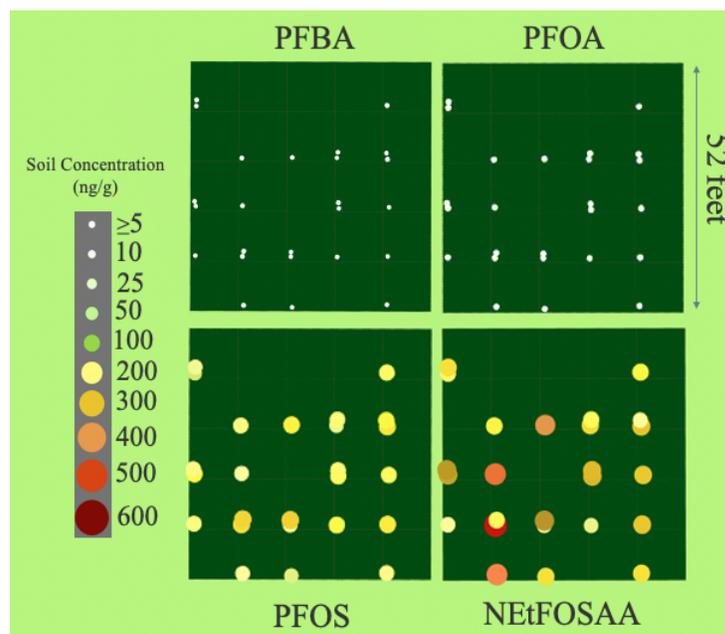


Figure 1: Field concentrations at Hunter Farm in Unity, Maine. Concentration ranges are indicated by bubble size and color ranging from 0 ng/g to 547 ng/g across a 0.001-acre field.

¹Blaine et al., (2014). Perfluoroalkyl acid distribution in various plant compartments of edible crops grown in biosolids-amended soils.

²Felizeter et al., (2012). Uptake of perfluorinated alkyl acids in by hydroponically grown lettuce (*Lactuca sativa*).

Did greenhouse and field settings show similar results?

Species	Plant part	Environment	PFBA	PFOA	PFOS
	Leaf	Greenhouse	4.54 ± 2.55	0.04 ± 0.02	0.01 ± 0.02
		Field	2.61 ± 1.48	0.01 ± 0.03	0.01 ± 0.01
	Leaf	Greenhouse	8.47 ± 3.61	0.18 ± 0.14	0.03 ± 0.05
		Field	2.37 ± 0.15	0.08 ± 0.06	0.04 ± 0.01
	Fruit	Greenhouse	15.88 ± 13.78	0.00 ± 0.01	0.00 ± 0.00
		Field	0.21 ± 0.29	0.00 ± 0.00	0.00 ± 0.00

Table 1: Mean and standard deviation of the transfer factors (plant concentration/soil concentration) for each part of the crop in greenhouse (top) and field (bottom) environments. Dark blue indicates significant differences between greenhouse and field results.

No, PFBA, PFOA and PFOS compounds were significantly higher in the greenhouse plant tissue than the field.

Greenhouse studies allow for controlled experiments to explore factors that may influence PFAS uptake. Some of these studies, including ours, use spiked PFAS cocktails to introduce PFAS to the greenhouse environment.³ While we are unsure the degree to which the spiking, potting mix, plant spacing, and pot containment influenced greenhouse plant uptake,

the greenhouse study showed higher transfer of PFAS into the plant. Despite many studies reporting transfer factors of greenhouse crops, our results suggest that greenhouse studies may not accurately reflect field conditions, therefore policymakers should be cautious when setting regulatory soil screening thresholds based on greenhouse experiments. It is important to further explore the roles of soil sorption and soil type on PFAS uptake as these have been determined to influence bioavailability.⁴

³Zhang et al., (2021). Plant uptake and soil fractionation of five ether-PFAS in plant-soil systems

⁴Scarce et al., (2024). Linking drivers of plant per- and polyfluoroalkyl substances (PFAS) uptake to agricultural land management strategies.

ACKNOWLEDGEMENTS

Funding for this research

This work was supported by American Farmland Trust, Maine Farmland Trust, Maine Organic Farmers and Gardeners Association, and USDA-NIFA Hatch Project number ME0-022332 through the Maine Agricultural & Forest Experiment Station.

Thank you

Thank you to the Hunter Family for bravely reenvisioning their land to support PFAS research. Thank you to our other collaborators: Sandesh Thapa, Dr. Ling Li, Dr. Yongjiang Zhang, Dr. Jean MacRae, Maine Agricultural and Forest and Experimental Station, Maine Organic Farmers and Gardeners Association, and Maine Farmland Trust. Factsheet design by Mario Guevara.

Suggested Citation

Scarce, AE., Holt, KP., Goossen, CP., & Schattman, RE. (2024). Assessing Plant Uptake of PFAS in a Paired Field and Greenhouse Experiment [Fact sheet]. University of Maine Agroecology Lab. Orono, Maine.

Our mission

The Agroecology Lab at the University of Maine is led by Dr. Rachel E. Schattman. Its overarching goal is to engage in research that leads to agricultural resilience in a changing climate while simultaneously protecting natural resources. In pursuit of this goal, we work with specialty crop producers and agricultural advisors to identify and address production challenges, specifically through the lens of climate change adaptation.