THE UNIVERSITY OF MAINE

The Agroecology Lab

Uptake Takeaways: A Review of Uptake Drivers of Per- and Polyfluoroalkyl Substances (PFAS) in Crops

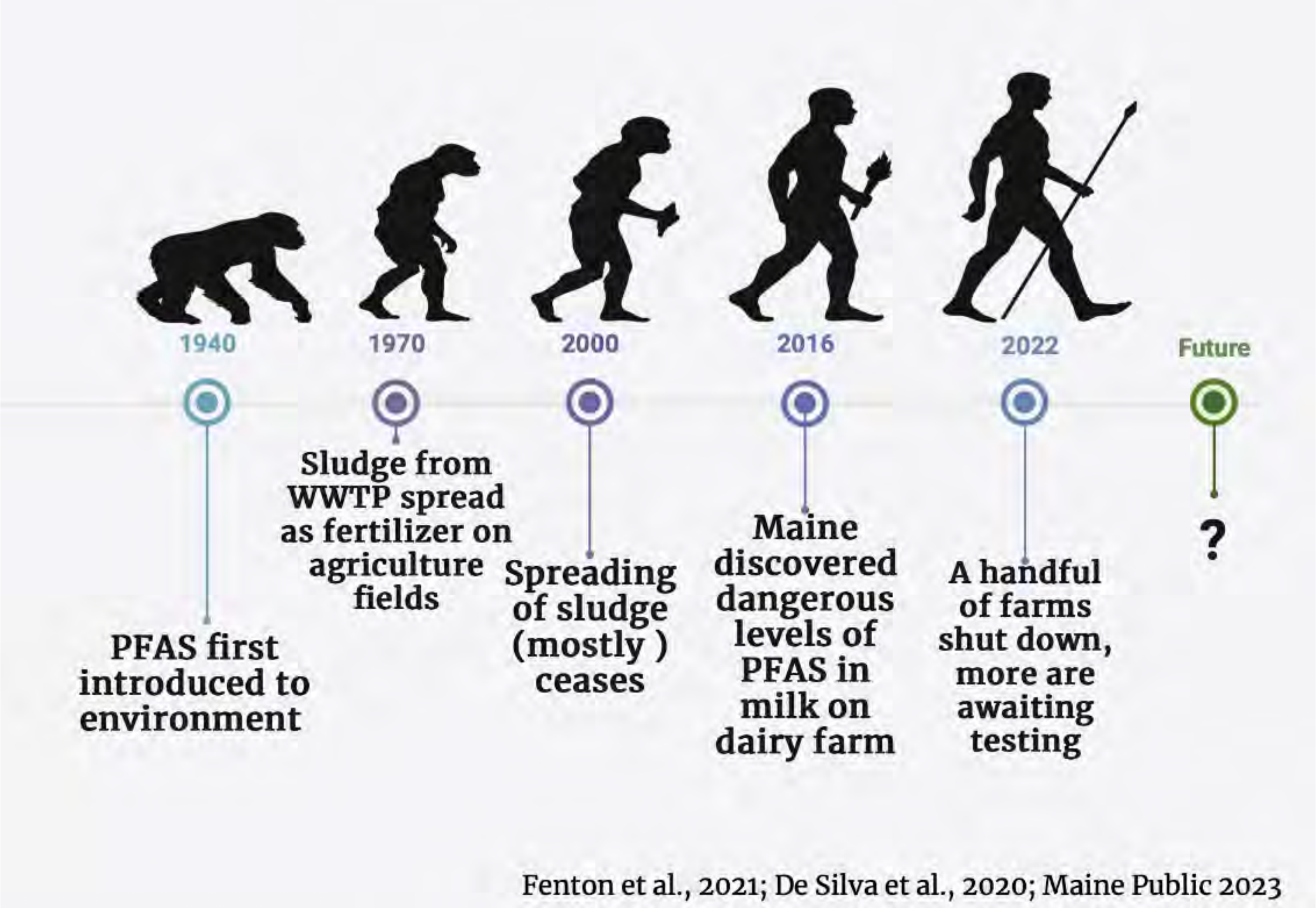
Alex Scearce[1], Dr. Rachel Schattman[1]

Dr. Jean MacRae[2], Dr. Caleb Goossen[3], Dr. Ellen Mallory[4], Dr. Yongjiang Zhang[1]

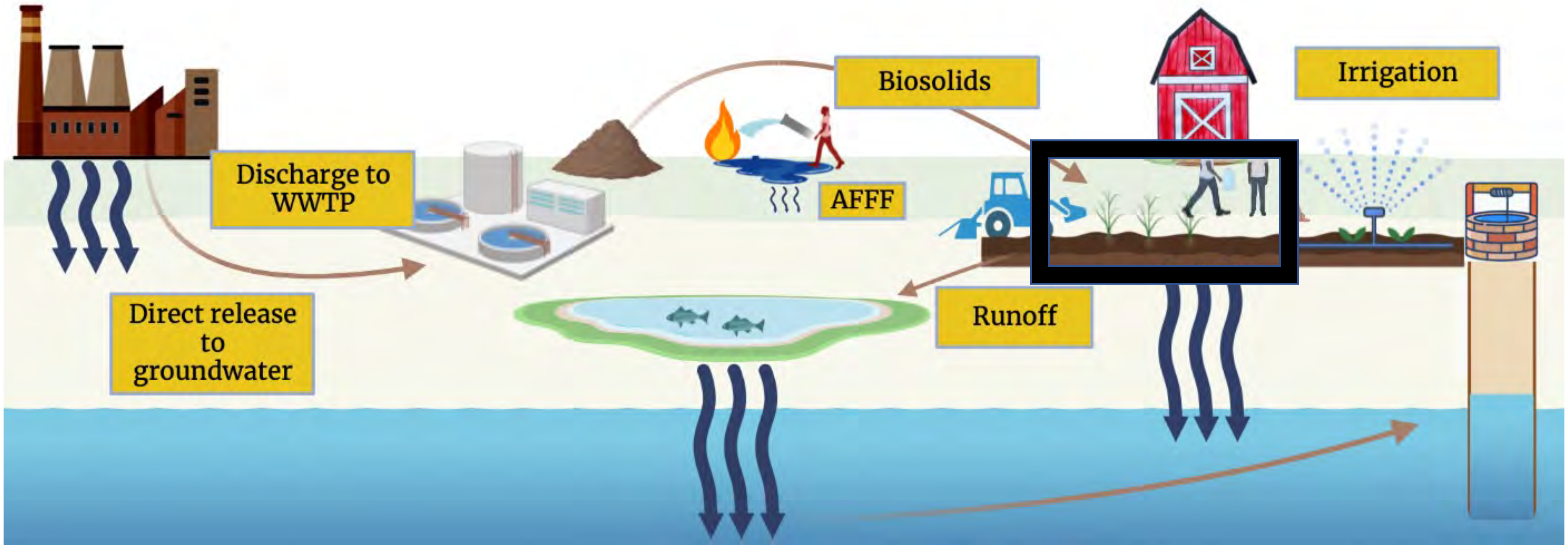
[1]University of Maine, Plant Soil and Environmental Sciences; [2]University of Maine, Civil and Environmental Engineering; [3]Maine Organic Farmers and Gardeners Association; [4]Maine Agriculture Extension Agency

PFAS(t) facts

- Group of 9000+ organic contaminants
- Uses: Firefighting foams, pesticides, non-stick materials, carpet, dental floss, etc.
- Human Health impacts: Cancer, organ damage, autoimmune suppression

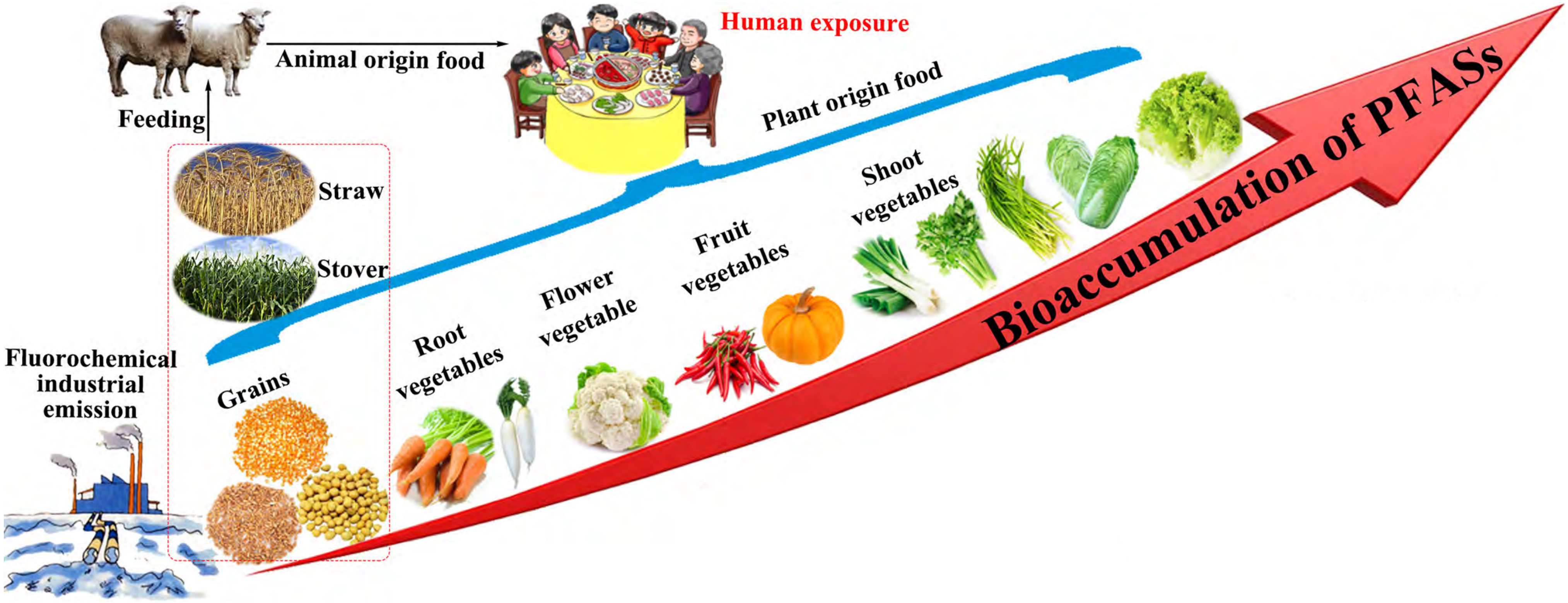


PFAS movement throughout the environment



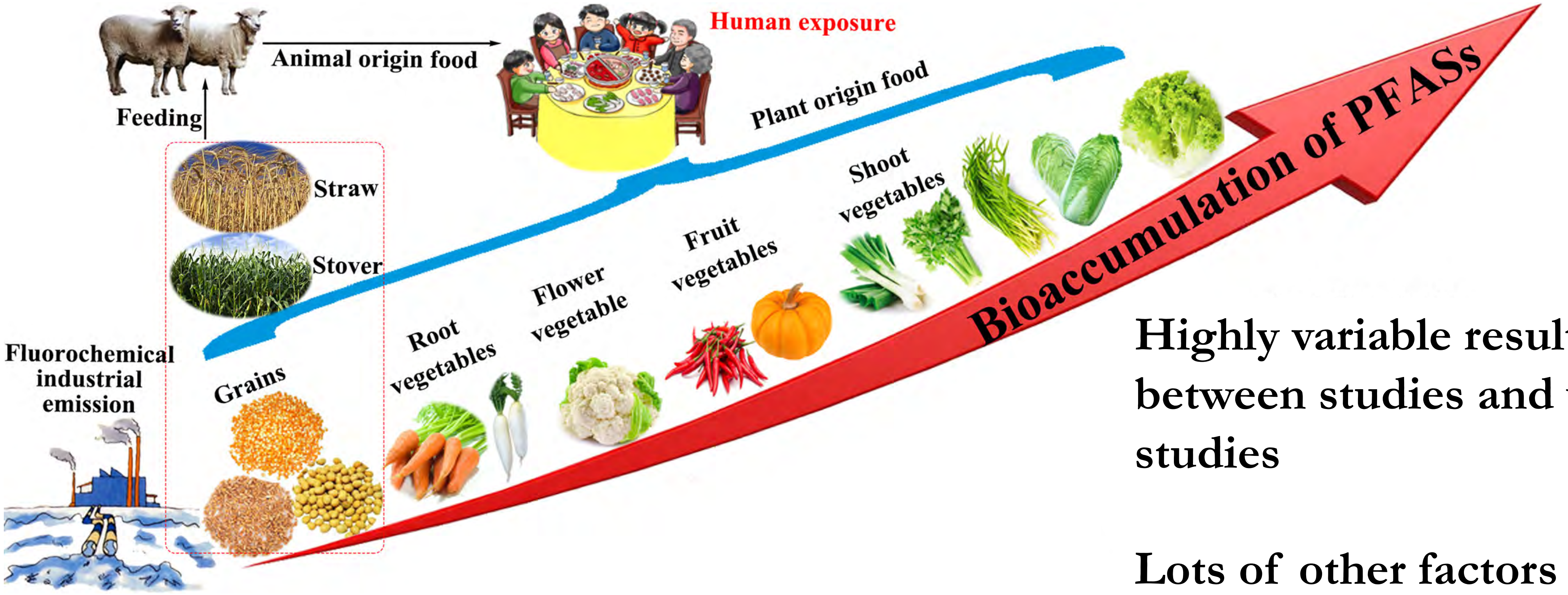
Sunderland et al., 2019; 3M 2000

What we see in some studies



Liu et al., 2019

What we see in some studies

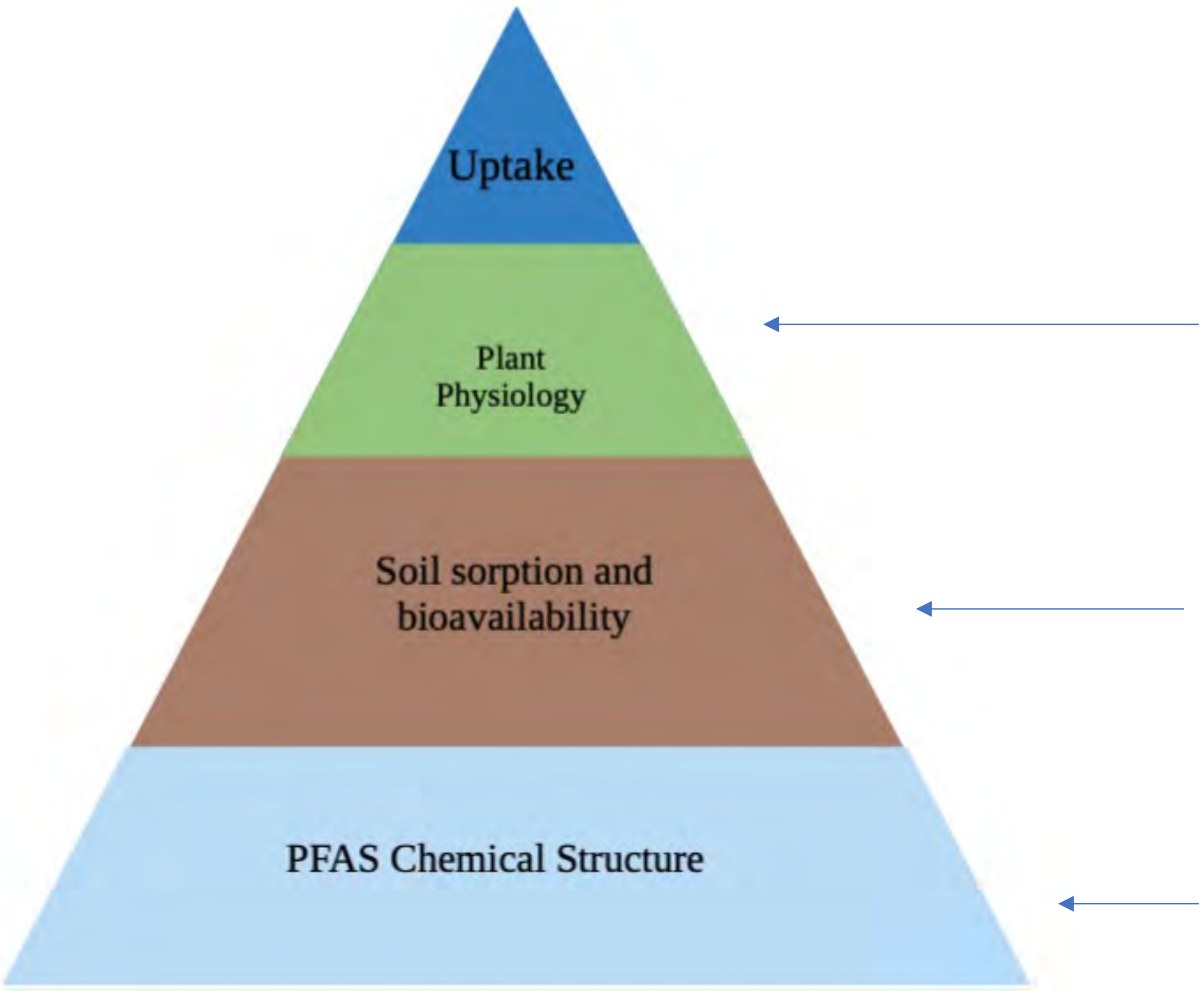


Highly variable results between studies and within studies

Lots of other factors at play

Liu et al., 2019

Reality



Root features, transport processes, transpiration force

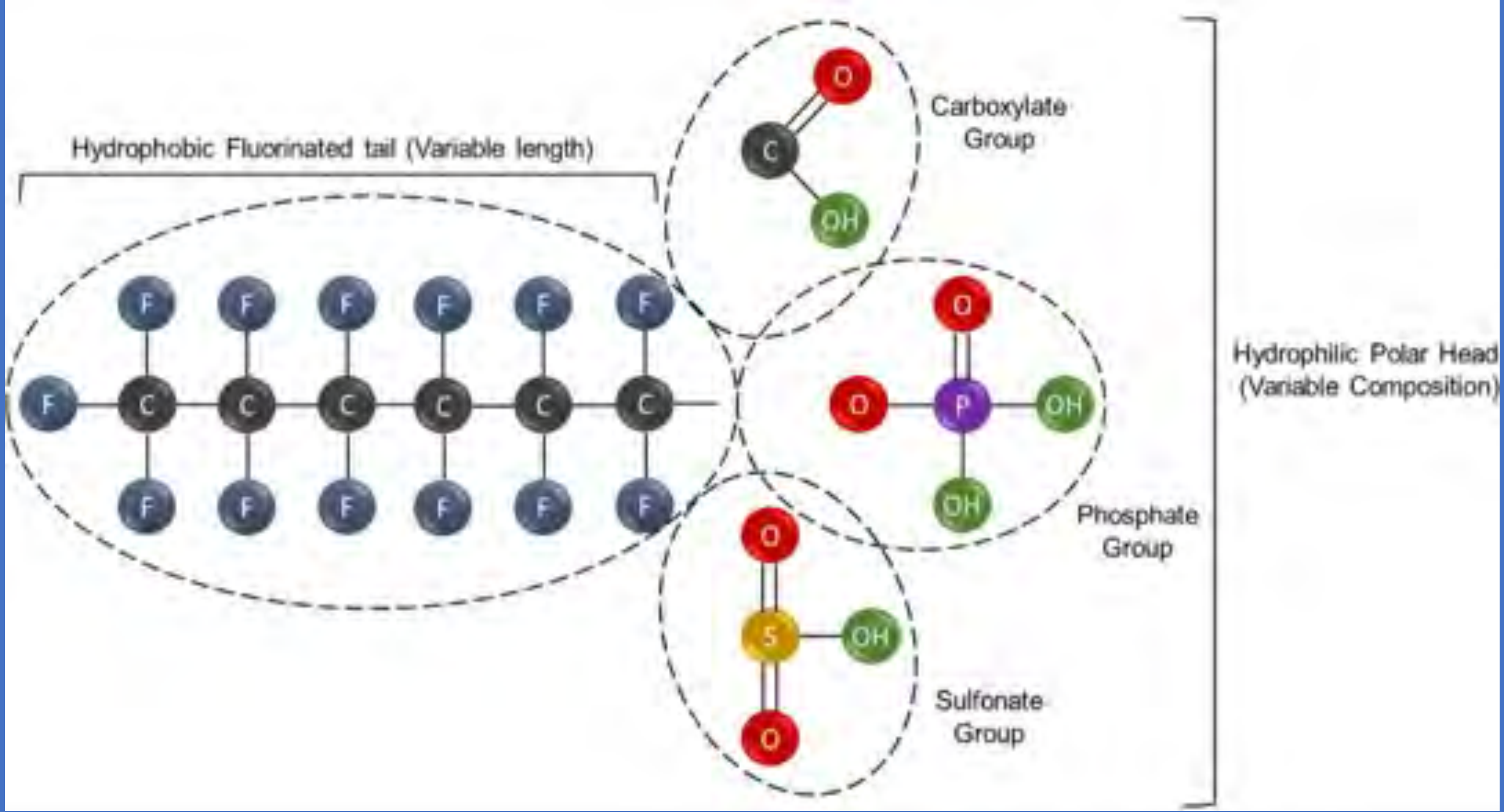
Electrostatic and hydrophobic interactions

Chain length and end group

Lesmeister et al., 2021; Mei et al., 2015; Costello and Lee 2020; Campos-Pereira et al., 2023

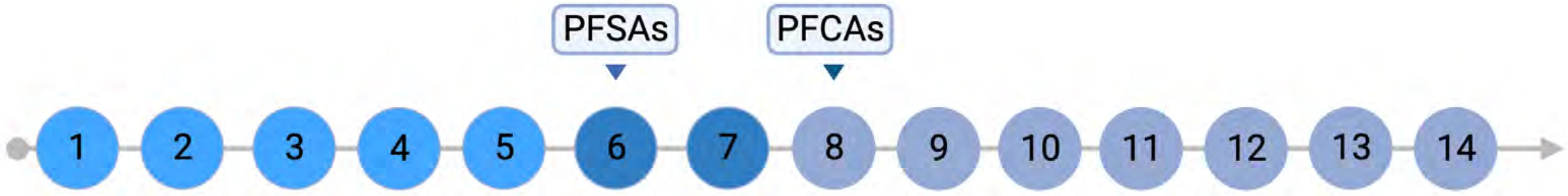
Chemical drivers: PFAS Structure

- Most are negatively charged (anionic)
- Water-fearing tail
  - Carbon-Fluoride chain
- Water-loving head
- End group
  - Sulfonate: PFSA
  - Carboxylic Acid: PFCA



Panieri et al., 2022

Chemical factors: Chain length



Short Chain (SC) PFAS

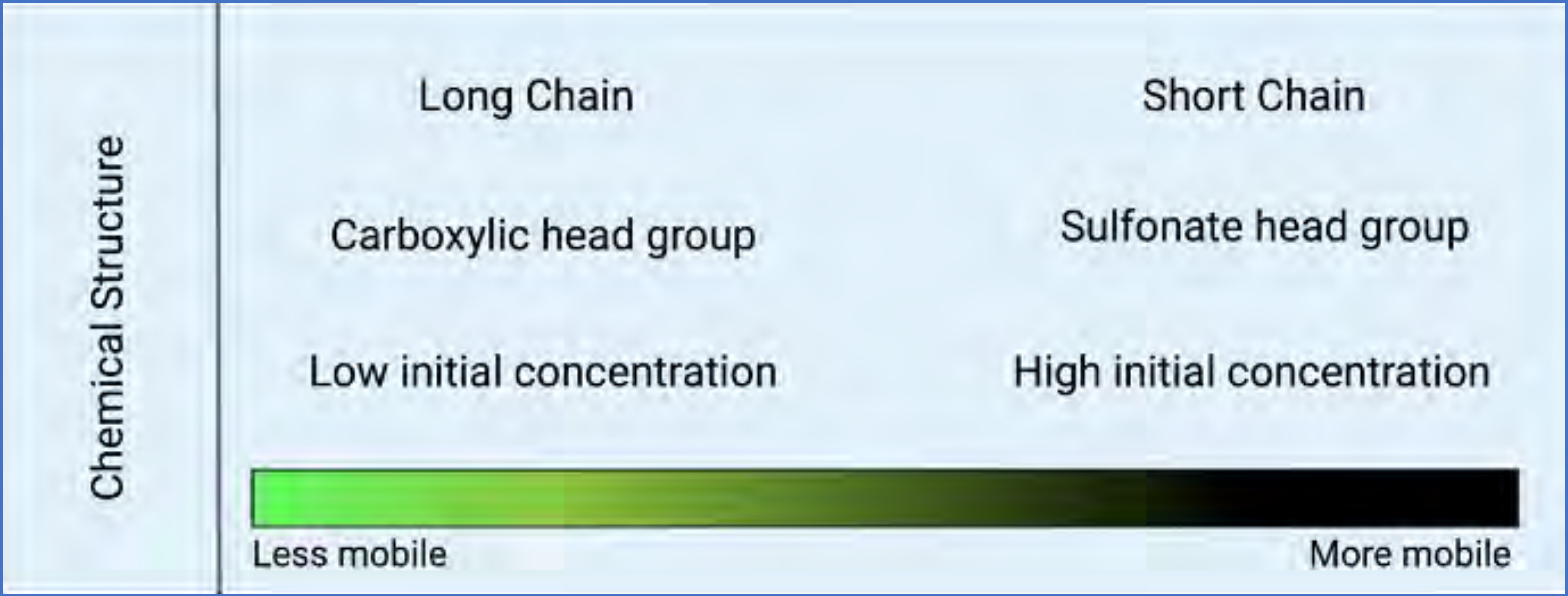
- Less persistent half life
- Less regulated
- High concentrations at soil depths

Long Chain (LC) PFAS

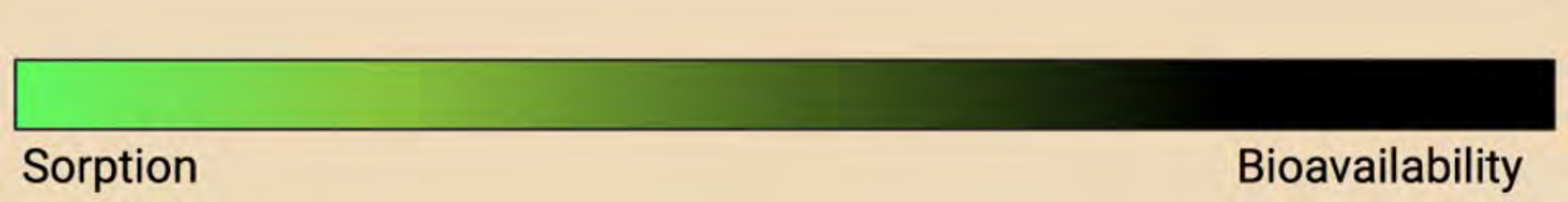
- Adverse health impacts
- More commonly found in sludge
- More regulations on horizon
- Higher concentrations at soil surface

American Waterworks Association 2022; Ateia et al., 2019; Brusseau et al. 2020; Buck et al., 2011

Chemical drivers: PFAS Structure



Soil Drivers of PFAS Uptake in Plants



Sorption: PFAS bound to soil

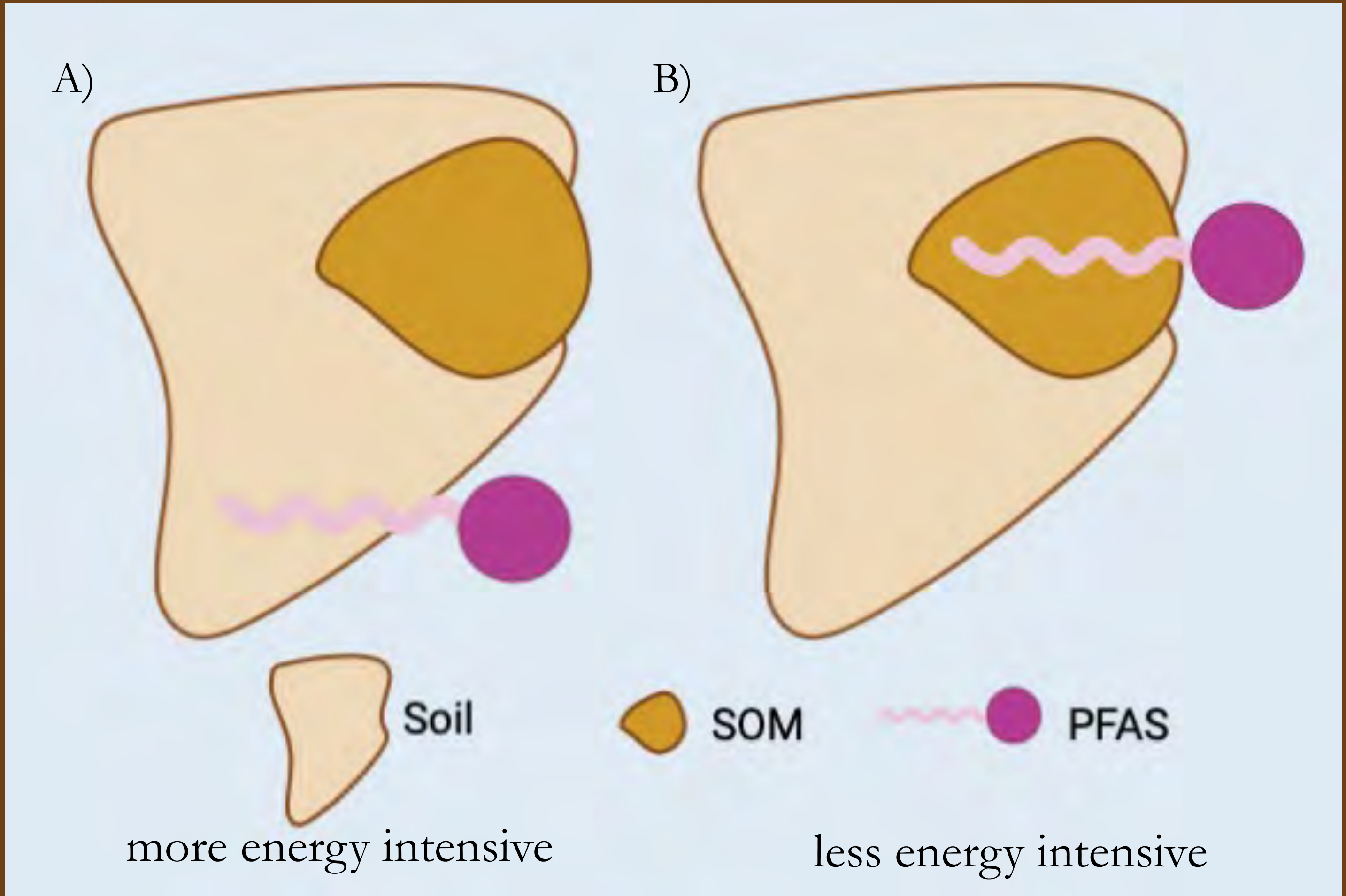
Bioavailability: PFAS readily available to be taken up by plant

Hydrophobic Interactions: A tail of efficiency

Hydrophobic rings of SOM and hydrophobic tail of PFAS bind

SOM ↑ ↑ sorption

Driver of LC sorption
LC = more hydrophobic
SC = less hydrophobic



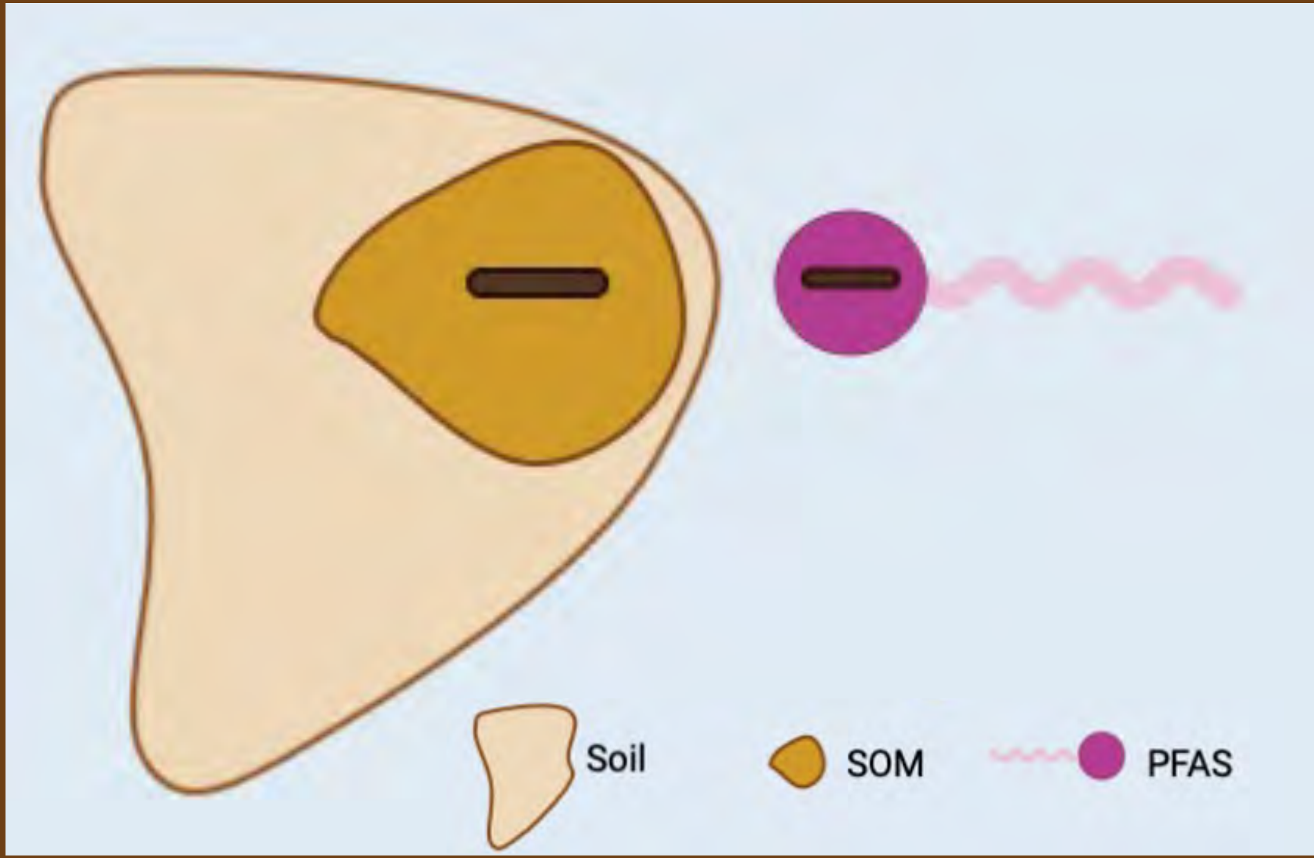
Bolan et al., 2021;Mei et al., 2021; Campos-Periera 2018

Soil Drivers: Electrostatic Interactions

Repulsion between negatively charged SOM and anionic PFAS:

SOM ⇦ ⇨ PFAS = ⇩ sorption

pH conditions: High



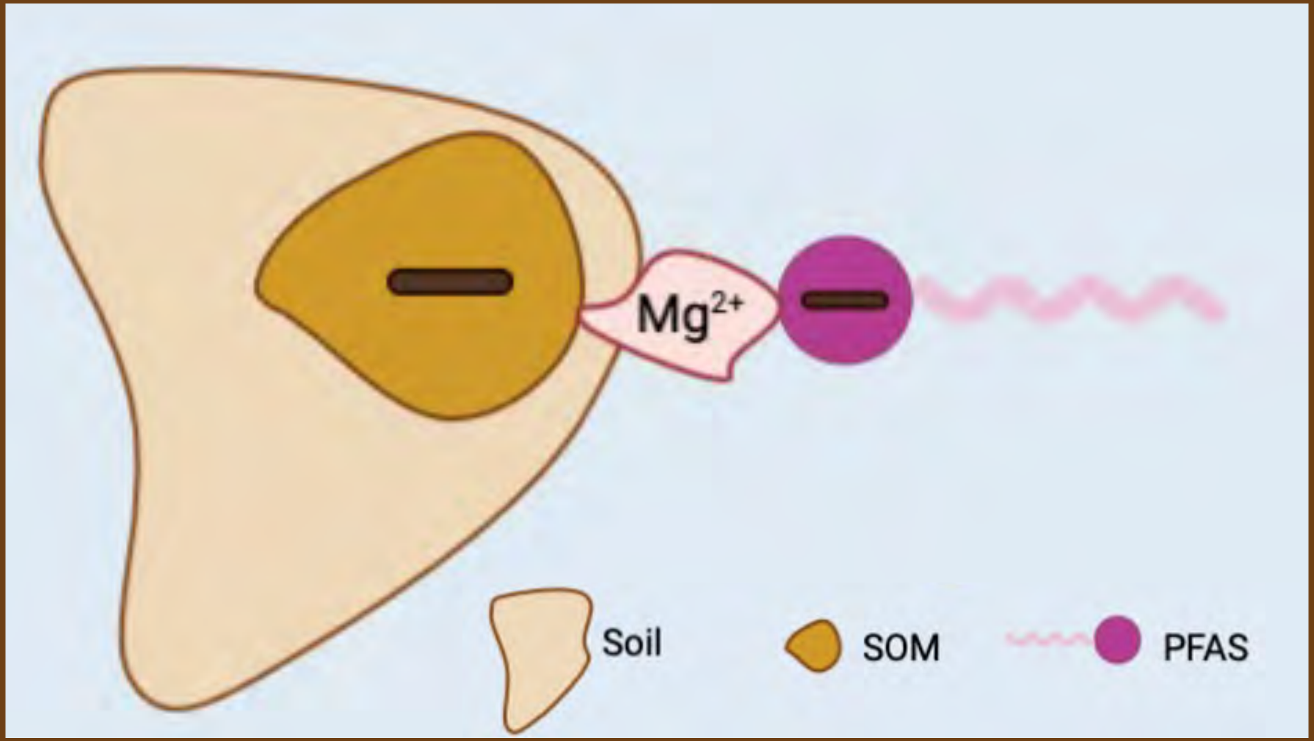
Mei et al., 2021

Soil Drivers: Electrostatic Interactions

Repulsion between SOM and PFAS can be overcome by cation bridging

SOM → ↑ ← PFAS = ↑ sorption

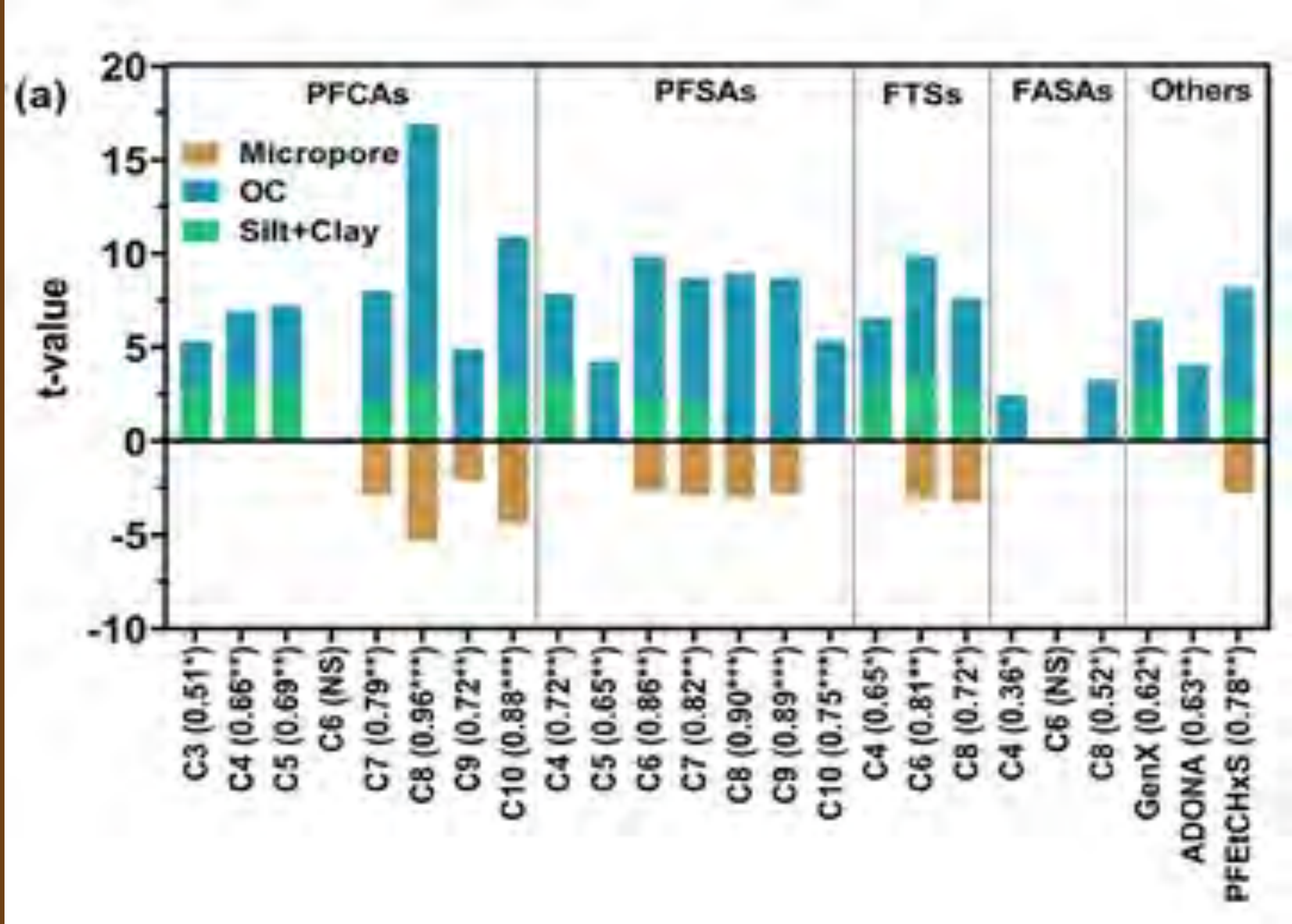
Mg^{2+}, Ca^{2+}



Mei et al., 2021

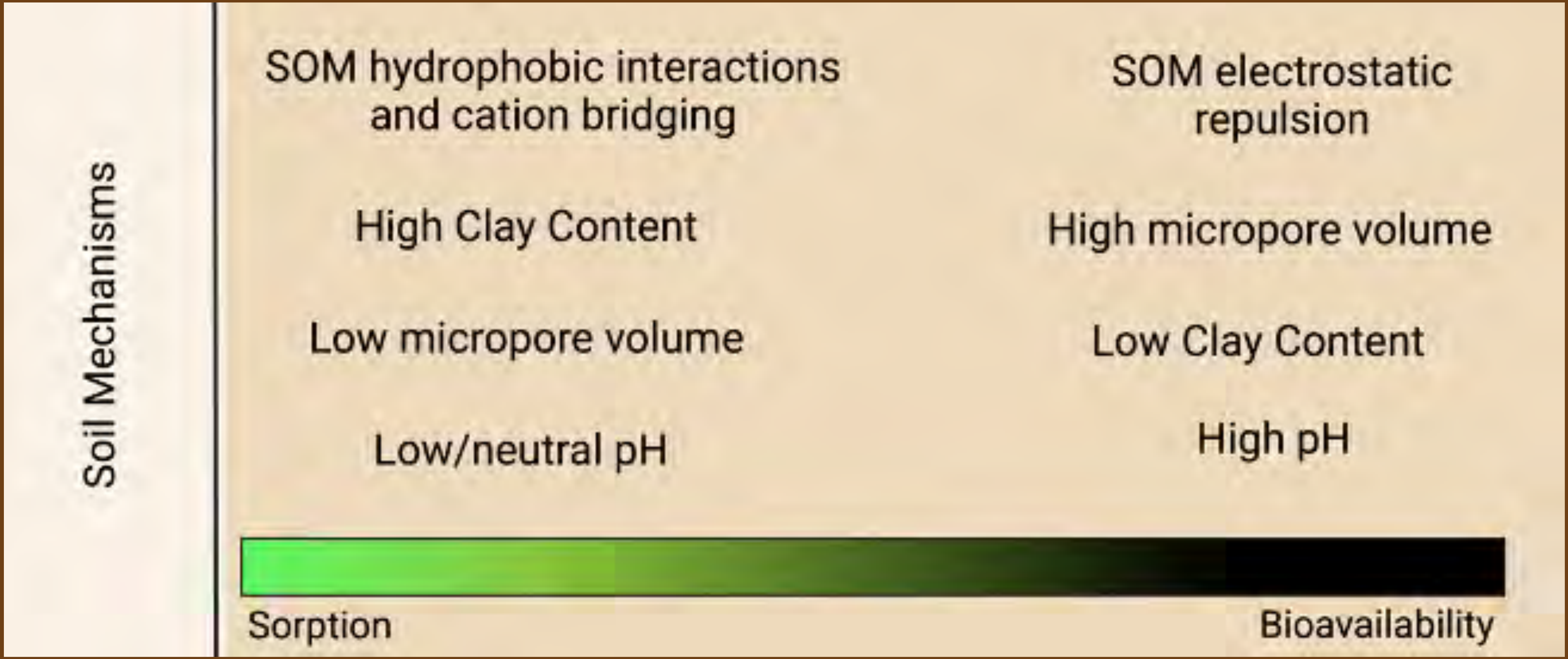
Additional Soil Drivers

Together, OC, silt + clay content, and soil micropore volume described sorption (represented by K_d value) of anionic PFAS

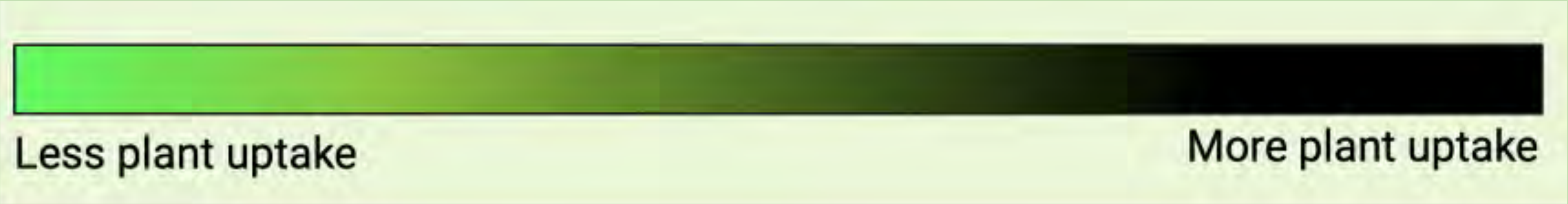


Nguyen et al., 2020; Mei et al., 2021

Soil Drivers of PFAS Uptake in Plants

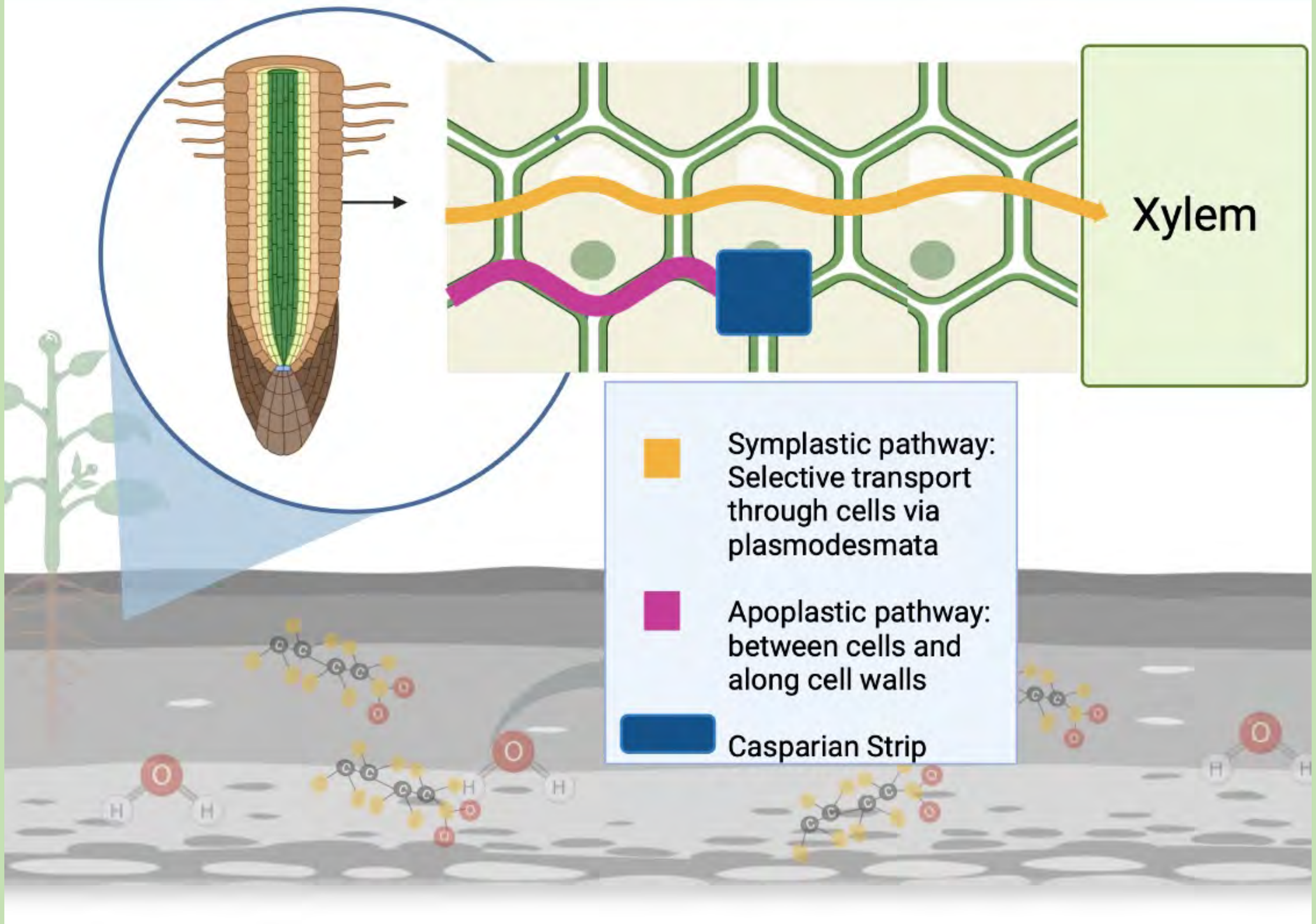


Physiological Drivers of PFAS Uptake in Plants



Physiological Drivers: Root Barriers

- Roots are the primary route for PFAS uptake
- Casparian strip is a barrier to apoplastic transport
  - Forces PFAS through symplast
  - Symplast filters LC PFAS
  - Casparian strip is absent in young roots



Lesmeister et al., 2018; Mei et al., 2021; Costello and Lee 2020

Physiological Drivers: Leaves

BAF values:

Leaf vegetables > root vegetables > flower vegetables > shoot vegetables

Why?

- Leaf blade area impacts pressure-flow model
- Transpiration in leafy greens
- Airborne transmission

% Mass of PFAS in tomatoes

	Roots	Stem	Twig	Leaf	Fruit
PFBA	3%	4%	10%	43%	40%
PFPeA	5%	8%	7%	20%	60%
PFHxA	12%	8%	9%	42%	30%
PFHpA	12%	8%	9%	67%	4%
PFOA	29%	7%	9%	53%	1%
PFNA	56%	5%	7%	32%	0%
PFDA	72%	5%	5%	17%	0%
PFUnA	88%	4%	4%	5%	0%
PFDoA	90%	5%	3%	2%	0%
PFTrA	96%	2%	1%	1%	0%
PFTeA	98%	1%	0%	1%	0%
PFBS	21%	4%	9%	65%	1%
PFHxS	38%	5%	7%	49%	0%
Br-PFOS	68%	6%	5%	21%	0%
L-PFOS	71%	5%	4%	19%	0%

Felizeter et al., 2014; Xu et al., 2022; Liu et al., 2019; Blaine et al., 2012; Lesmeister et al., 2021

Physiological Drivers: Aboveground Translocation

- PFAS in fruit < PFAS in stem for LC PFAS
  - Indicative of extra barrier between stem and fruit:
    - Cambium
    - Active transport through phloem

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PFHpA	12%	8%	9%	67%	4%
PFOA	29%	7%	9%	53%	1%
PFNA	56%	5%	7%	32%	0%
PFDA	72%	5%	5%	17%	0%
PFUnA	88%	4%	4%	5%	0%
PFDoA	90%	5%	3%	2%	0%
PFTrA	96%	2%	1%	1%	0%
PFTeA	98%	1%	0%	1%	0%
PFBS	21%	4%	9%	65%	1%
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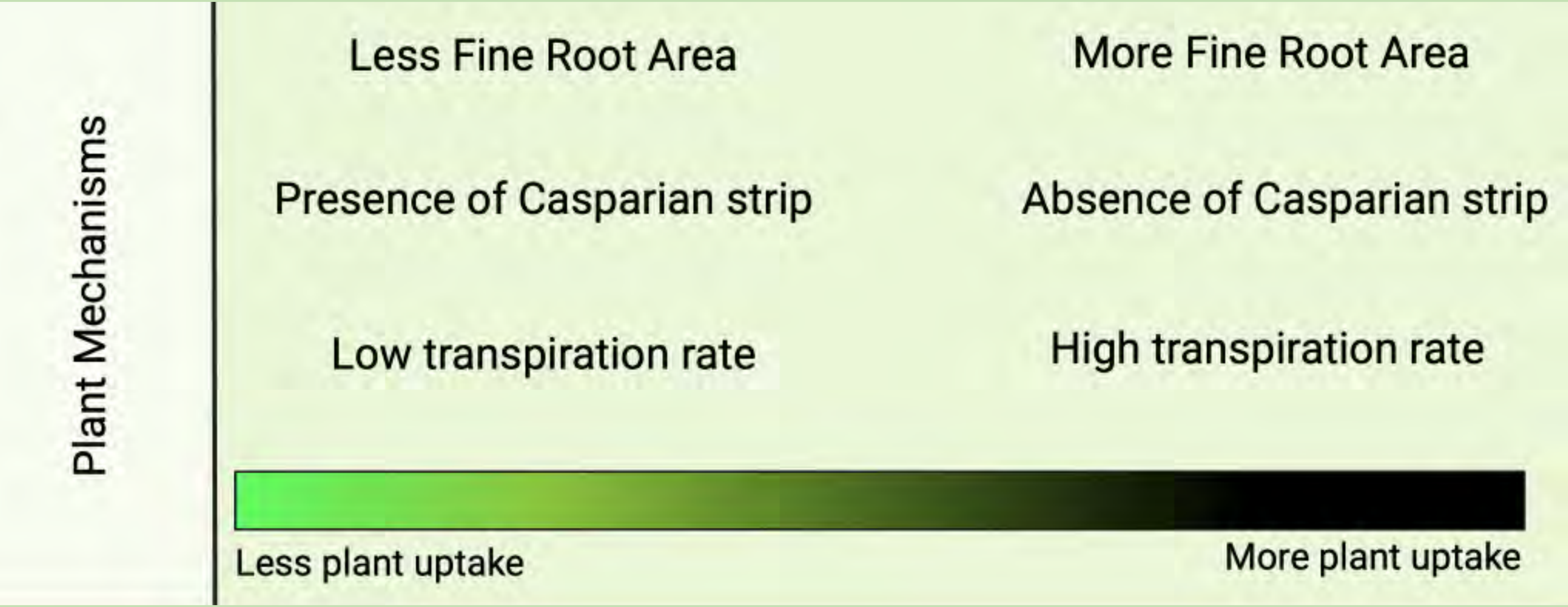
Felizeter et al., 2014; Strasburg et al., 2008; Lesmeister et al., 2018

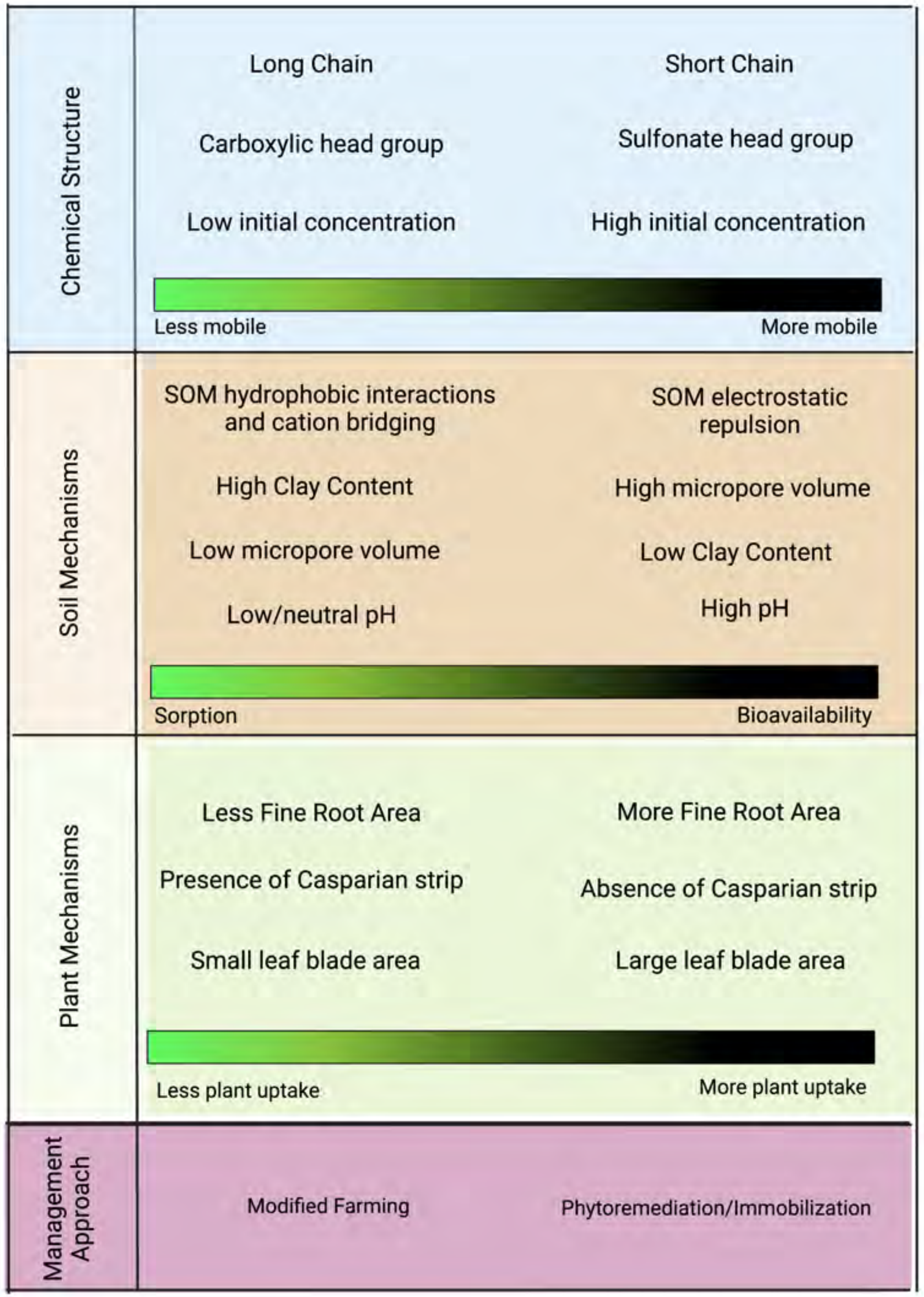
Physiological Drivers of PFAS Uptake in Plants



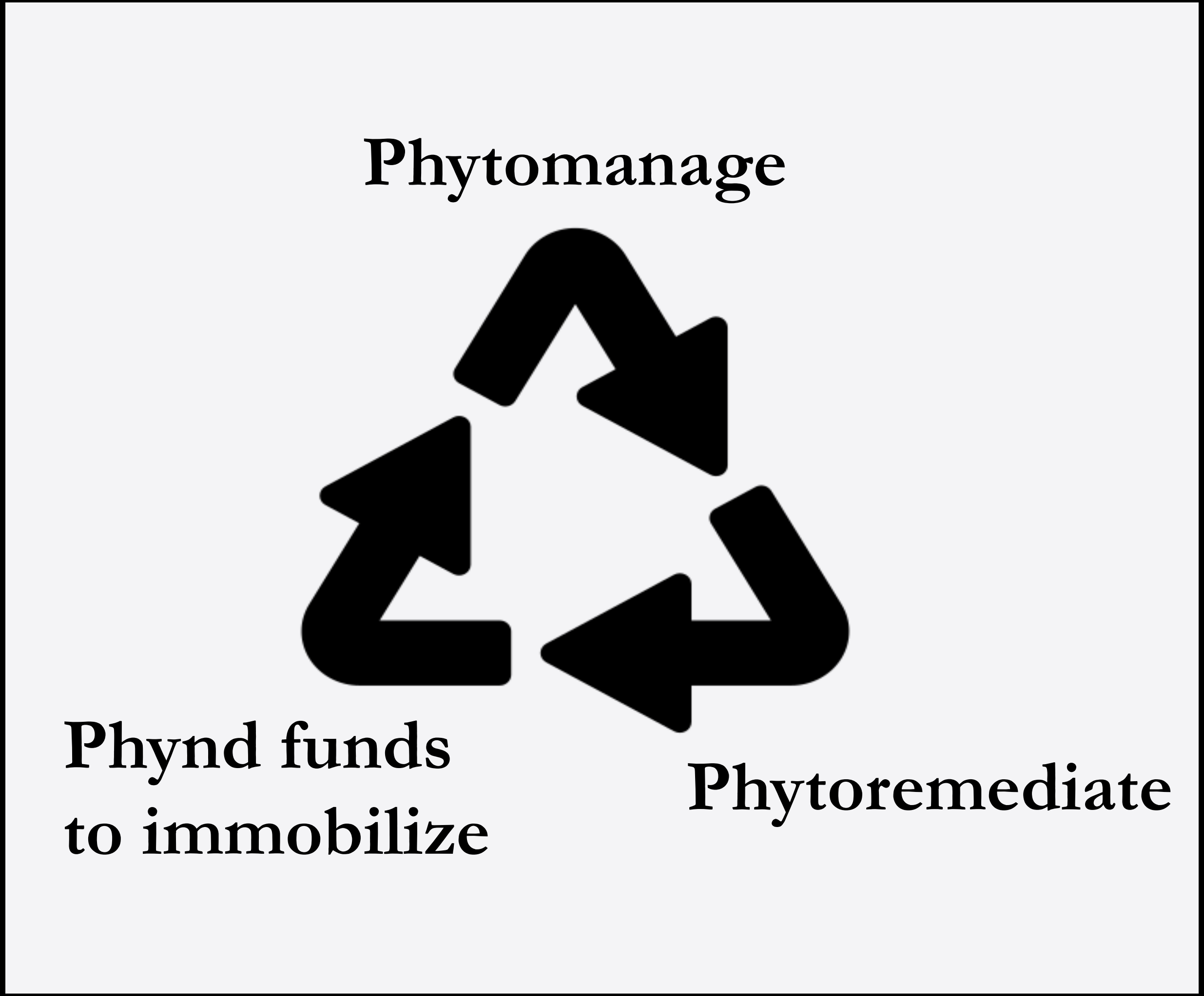
Knowledge Gaps

- How do these factors interact?

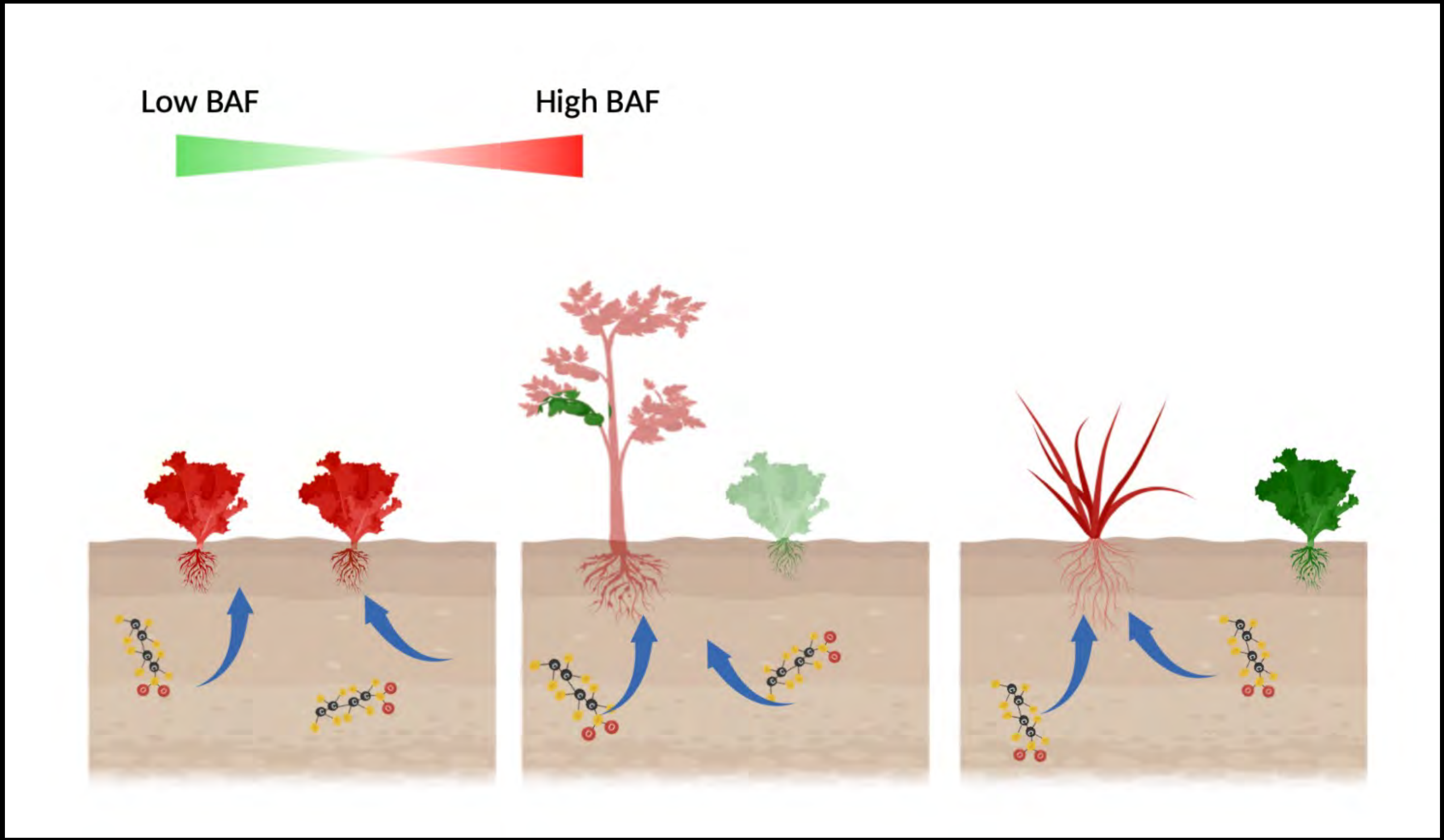
Research that:
- Elucidates mechanisms
  - Which are drivers?
  - Which are mediators?
- Builds datasets
- Creates models



Considering Environment, Cost and Viability



Our Research: How can these interactions be manipulated to decrease PFAS uptake in vulnerable crops?



Special thanks to…

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The Agroecology Lab

Jean MaCrae
Caleb Goossen
Yongjiang Zhang
Ellen Mallory

Alex Scearce
alexandra.scearce@maine.edu