Microplastics in composts, digestates, food waste, & agricultural soils

What is known?

Testimony to Vermont Senate Agriculture Committee

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Ongoing & near-term future microplastics research in my Nutrient Cycling & Ecological Design Lab at UVM

- Comprehensive literature review (draft ready to share in ~ 2 weeks)
  - ~150 papers reviewed by my team
  - Covers microplastics in composts, digestates, food waste, and agricultural soils
  - Makes recommendations for better linking science & policy
- Development of methods for measuring microplastics in complex organic matrices
- Quantification of microplastics in depackaged food waste, digestate, and composts
- Testing effects of microplastics on soil microbial functions

How do we measure microplastics?

Methods

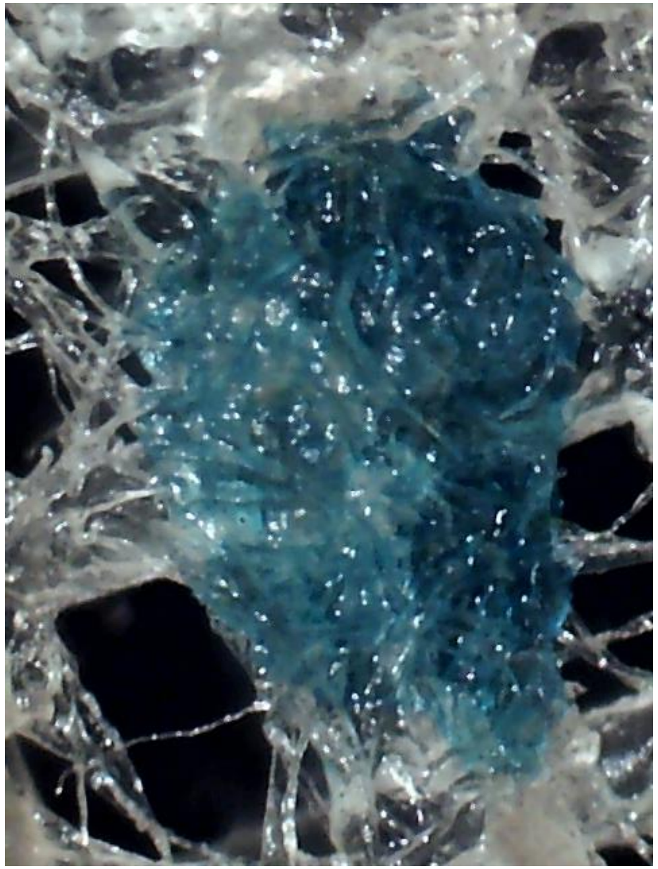
- Isolation:
  - Organic matter removal
- Identification:
  - Visual inspection (40X)
  - Dichotomous key
- Characterization:
  - Size distribution (0.5 – 1 mm, 1 – 5 mm, > 5 mm)
  - Shape (film, fiber, fragment)
  - Type (FTIR Spectroscopy)

Counting microplastics under the microscope (Photo: Luke Awtry for Seven Days)

How do we measure microplastics?

Challenges

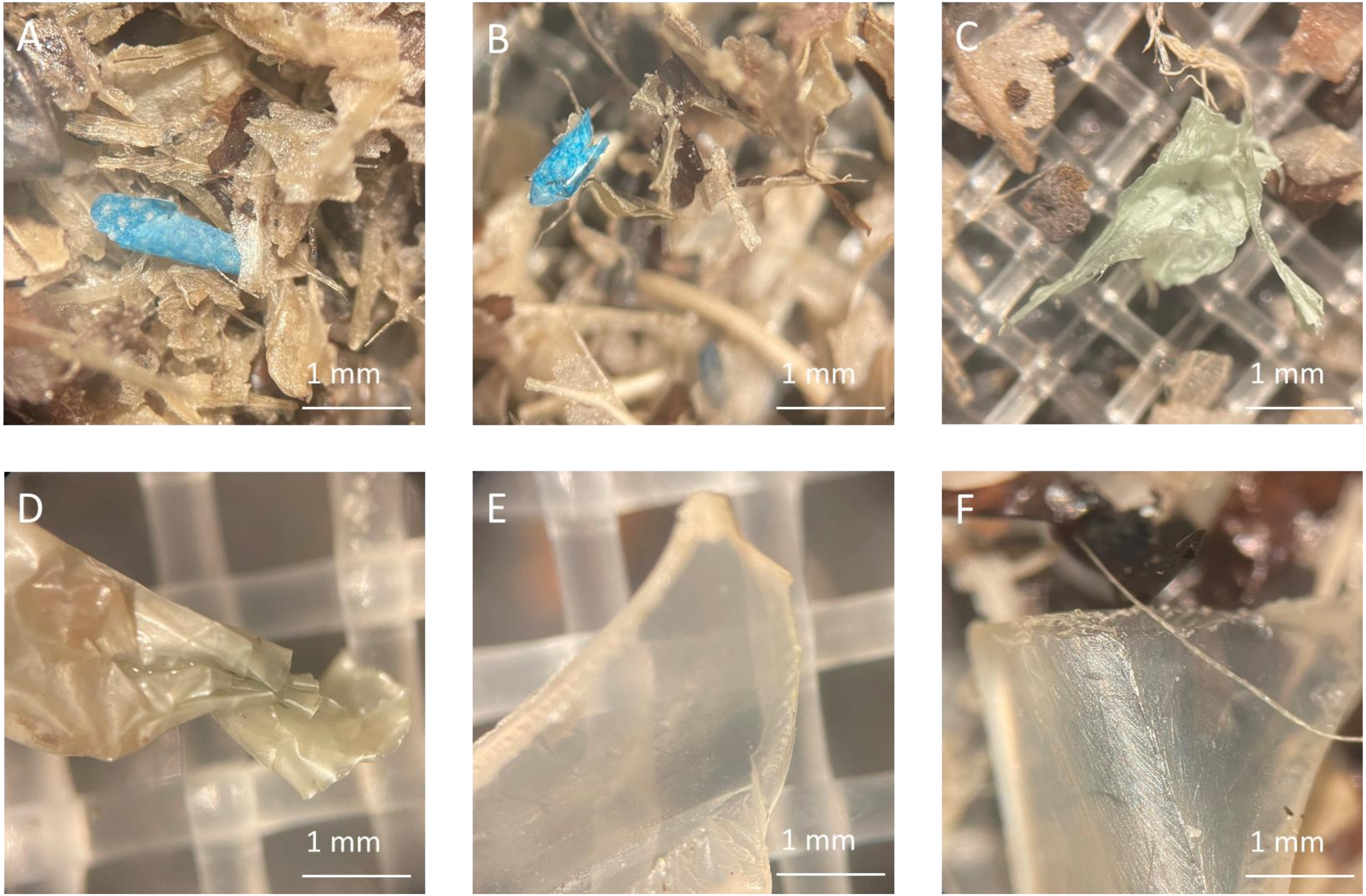
- Incomplete organic matter removal
- Melting
- Conversion of counts to mass, which will likely be more relevant for policy makers



Putative microplastic at 40X.

Sieve with residual material including non-plastic food fragments & microplastics (Photo: K. Porterfield)

Raw food waste presents more challenges than compost or digestate


A
1 mm
B
1 mm
C
1 mm
D
1 mm
E
1 mm
F
1 mm

Measurements of microplastics reported in the scientific literature for composts, digestates, and food waste

- 14 peer-reviewed papers providing original data on microplastics in organic residuals were identified and reviewed
- **Count values – typical ranges reported**
  - ~12 to ~82,800 particles per dry kg of green waste-derived compost
  - 20 to 30,000 particles per dry kg in composts made with food waste
  - 70 to 895 particles per dry kg digestate
  - ~40 to 1,400 particles per dry kg food waste
- **% by mass – typical ranges reported**
  - 0.00024% to ~0.1358% by dry weight in composts
  - 0.01% by dry weight (1-5 mm) to 0.12 ± 0.12% by wet weight (>6 mm) in digestate
  - ~0.025% in homogenized food waste to 5.6% w/w in source separated household biowaste (*higher value not directly measured – estimated by mass balance)

Measurements of microplastics reported in the scientific literature for composts, digestates, and food waste

- Fewer results for % by dry weight – most researchers are measuring abundance in terms of count of particles per dry kg of material

- Variability is likely driven by multiple factors, including feedstock, processing, and methods used to detect microplastics (e.g., size fractions included) – no standard methods exist

- Our preliminary data suggest that average microplastics counts for two depackaged food wastes & one digestate in VT fall within typical ranges listed on previous slide

Measurements of microplastics reported in the scientific literature for composts, digestates, and food waste

Example results from Germany

Schwinghammer et al. (2021)

"The German Fertilizer Ordinance states a weight limit of 0.4% of hard plastics and 0.1% of other plastics >1 mm. Our results show that both sludge and compost samples can comply with the regulation (Figure 3)"

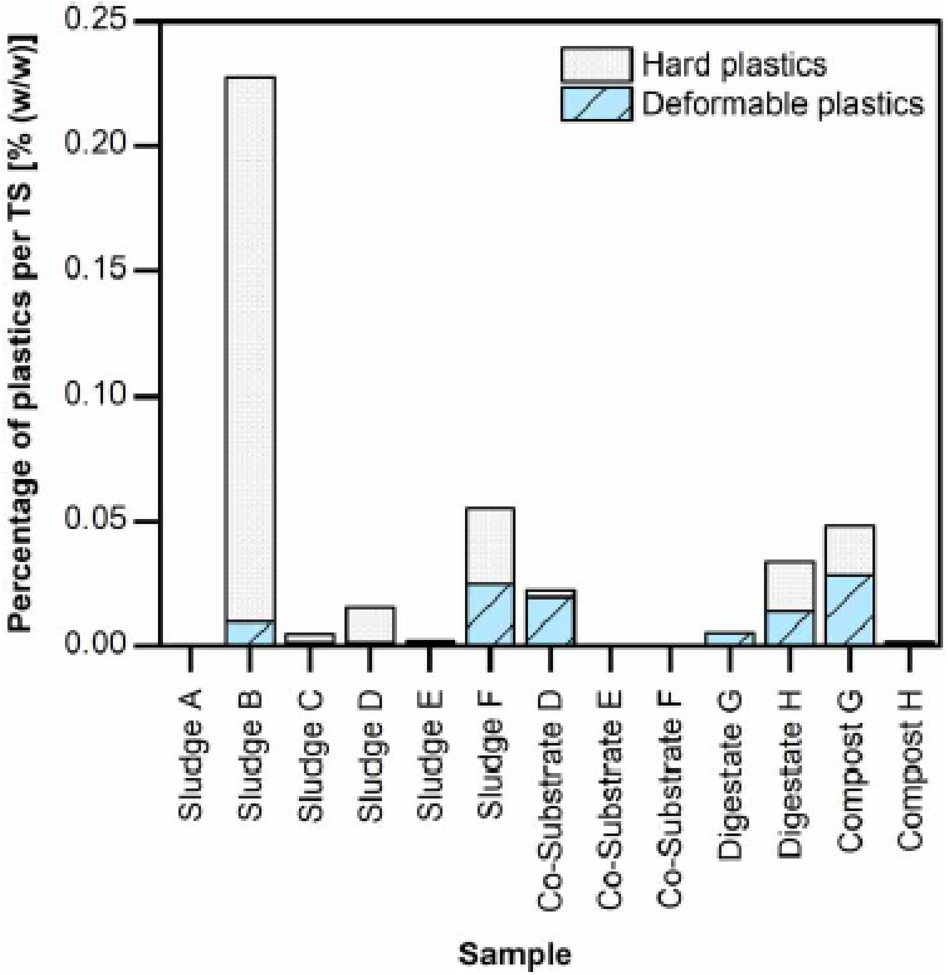


Figure 3 | Percentage of dry weight of hard and deformable MP per kg TS.

Microplastics in agricultural soils

- **Multiple potential pathways of introduction**
    - **Primary microplastics (engineered to be small)** - plastic-coated controlled-release fertilizers, treated seeds, and capsule suspension plant protection products (ECHA, 2020; Stubenrauch and Ekardt, 2020)
    - **Secondary microplastics (form from breakdown of macroplastics)**
        - Plastic mulching (Corradini et al., 2021)
        - Contaminated soil amendments (Corradini et al., 2021)
        - Irrigation water (Zhou et al., 2020)
        - Atmospheric deposition (J. Zhang et al., 2020)
        - Roads (Chen et al., 2020; Sommer et al., 2018)
        - Litter (de Souza Machado et al., 2018a)
    - **Not all of these sources will affect every site**
    - **Measurements reported in literature: 10's to 1000's of particles per dry kg of soil (overlaps with reported ranges for composts & digestates)**

Physical effects of microplastics in agricultural soils?
effects vary depending on polymer type and soils

- Microplastics have been found to **increase**:
    - soil aeration (de Souza Machado et al., 2019, 2018b; Lozano et al., 2021)
    - water repellence (Y. Qi et al., 2020; Steinmetz et al., 2016)
    - porosity (Huerta Lwanga et al., 2017; Y. Qi et al., 2020; Steinmetz et al., 2016)

- Microplastics have been found to **decrease**:
    - soil bulk density (de Souza Machado et al., 2018b; Mbachu et al., 2021; Y. Qi et al., 2020; Serrano-Ruiz et al., 2021)
    - aggregate sizes (Kim et al., 2021; Lozano et al., 2021)

Biological effects of microplastics in agricultural soils?

- **Soil microorganisms can be affected by microplastics** (Guo et al., 2020; W. Wang et al., 2020), with evidence of effects on:
  - Species dominance, diversity, and richness at microplastic doses in soils of 0.2–5% w/w (Fei et al., 2020; Ren et al., 2020; J. Wang et al., 2020; Y. Wang et al., 2021; Yi et al., 2021)
  - Overall microbial biomass at dosage of 1% w/w (Blöcker et al., 2020)

- Microplastics have been found to cause oxidative stress and abnormal gene expression at a dosing level of 0.25% w/w for **earthworms** (Cheng et al., 2020; B. Li et al., 2021), which can consume and transport microplastics (Zhang et al., 2018)

Biological effects of microplastics in agricultural soils?

- **Lower germination rates** in the presence of microplastics have been observed for rye grass and garden cress (Boots et al., 2019; Bosker et al., 2019; Pflugmacher et al., 2020)
- Microplastics have also been shown to **reduce root, shoot and/or total biomass growth at dosing rates of**:
    - 1–2% w/w for wheat (Pflugmacher et al., 2021; Qi et al., 2018)
    - 0.1–10% w/w for garden cress (Pflugmacher et al., 2020)
    - 1–2% w/w for Chinese cabbage (Yang et al., 2021)
    - 0.1–1% w/w for corn (Wang et al., 2020)
    - 0.1% w/w for rye grass (Boots et al., 2019)
    - 0.2–0.6% w/w for rice (Liu et al., 2021)
    - 2% w/w for spring onion (de Souza Machado et al., 2019)
    - 1% w/w for lime trees (Enyoh et al., 2020)

Biological effects of microplastics in agricultural soils?

- **However, in some instances negative effects were only observed for:**
  - Some polymer types but not others (Boots et al., 2019; de Souza Machado et al., 2019; Qi et al., 2018; F. Wang et al., 2020; M. Yang et al., 2021)
  - Certain sizes but not others (Z. Li et al., 2020; M. Yang et al., 2021)
  - Certain soil pH conditions (Liu et al., 2021)
- Inhibitory effects were **sometimes observed at lower but not higher microplastic dosing rates** (Liu et al., 2021; F. Wang et al., 2020)
- **To date, there is limited evidence that crops uptake plastics into their biomass** (Azeem et al., 2021; Huerta Lwanga et al., 2017)
  - However, some recent studies have reported finding microplastics in cultivated crops, including wheat (L. Li et al., 2020; Lian et al., 2020a, 2020b), radish (Tympa et al., 2021), garden cress (Bosker et al., 2019), corn (Sun et al., 2021), and cucumber (Z. Li et al., 2021)

Weaknesses in current soil microplastics research

- **Variability in results**

- **No easy way to determine the environmental relevance of existing ecotoxicity studies**
    - Microplastics in agricultural soils are being measured in counts of particles per dry kg, but ecotoxicity studies use dosing at various % by dry weight

- More research is needed to overcome the current **lack of information linking microbial community composition to function** (Hicks et al., 2021)

Microplastic effects remain uncertain – more research is needed

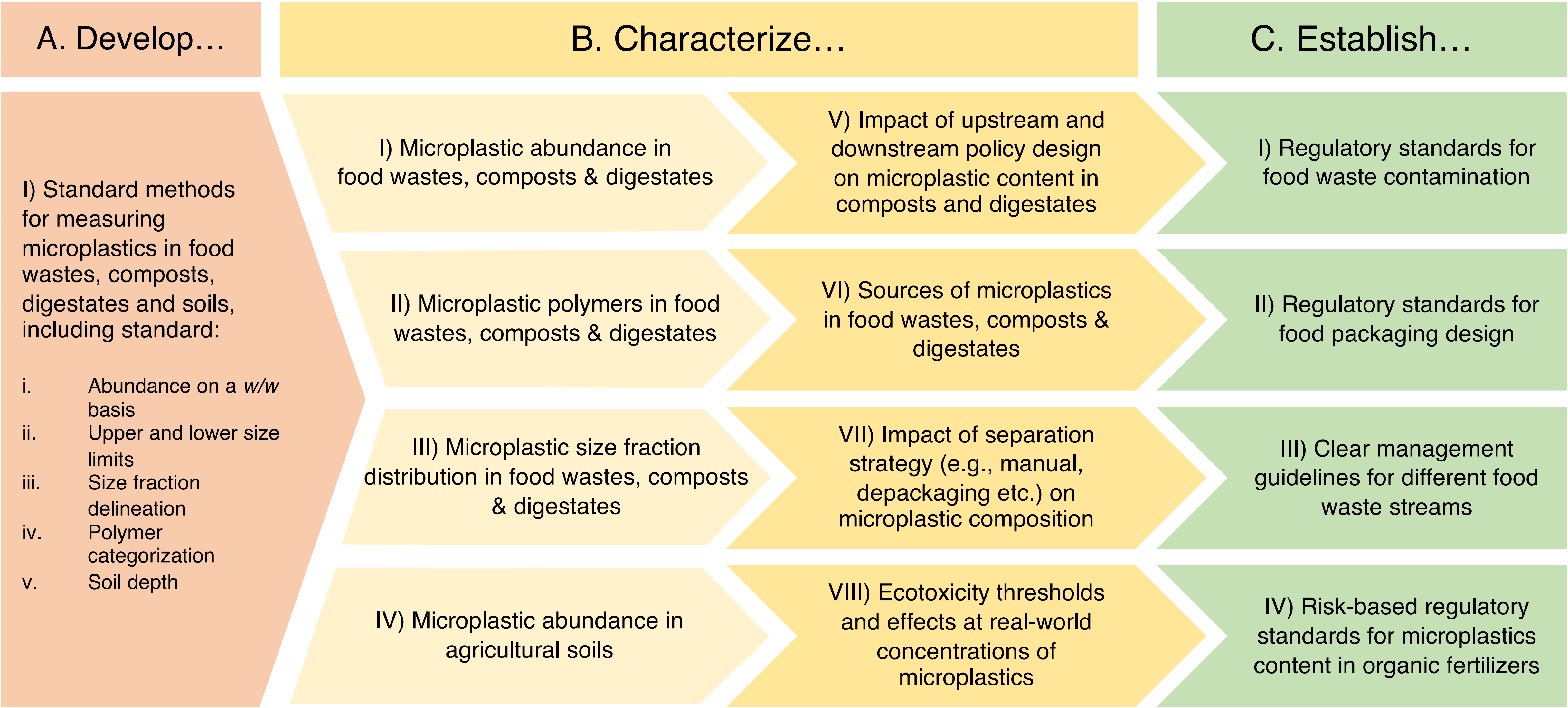
- EPA, 2021
  - **Much remains uncharacterized about the environmental fate of and exposure** to plastic particles in composts and digestates generated from food waste and used as soil amendments, making it challenging to evaluate risks to human health and the environment.
  - **The available literature does not provide substantial evidence of environmental or human health effects** that are occurring as a result of plastic contamination in finished compost and digestate products produced using food waste streams.
  - **It is also unclear how the risks associated with these products generated from food waste would compare to those of background levels** of plastic contamination and other sources of plastic contamination in the environment.

Gap between viewpoints of scientists & media

(Volker et al. 2020)

- Most scientific studies (67%) frame microplastics risk as hypothetical or uncertain, while 24% present them as established
- In contrast, most media articles reporting on microplastic impacts (94%) imply that risks of microplastics exist and harmful impacts are highly probable
- We need to rigorously evaluate the risks in Vermont, as well as the potential trade-offs of policy

design process to harmonize food waste microplastics science & policy



A. Develop…

I) Standard methods for measuring microplastics in food wastes, composts, digestates and soils, including standard:

i. Abundance on a *w/w* basis
ii. Upper and lower size limits
iii. Size fraction delineation
iv. Polymer categorization
v. Soil depth

B. Characterize…

I) Microplastic abundance in food wastes, composts & digestates

II) Microplastic polymers in food wastes, composts & digestates

III) Microplastic size fraction distribution in food wastes, composts & digestates

IV) Microplastic abundance in agricultural soils

V) Impact of upstream and downstream policy design on microplastic content in composts and digestates

VI) Sources of microplastics in food wastes, composts & digestates

VII) Impact of separation strategy (e.g., manual, depackaging etc.) on microplastic composition

VIII) Ecotoxicity thresholds and effects at real-world concentrations of microplastics

C. Establish…

I) Regulatory standards for food waste contamination

II) Regulatory standards for food packaging design

III) Clear management guidelines for different food waste streams

IV) Risk-based regulatory standards for microplastics content in organic fertilizers

Porterfield et al. (in prep)

Some thoughts on H.501

- This is very similar to the policy used in Germany
- The >1 mm aspect makes sense to me. Measuring microplastics less than 1 mm is much more challenging.
- The 0.5% by dry weight limit also seems reasonable.
  - Based on results reported in the literature, it seems most composts and digestates will test below this threshold.
  - One issue is that most researchers are quantifying microplastics on a count basis (particles per dry kg) versus a mass basis (% by dry weight), so we have more limited information on the latter.
- There is uncertainty about the environmental benefits/costs of this approach.
- My biggest question on this is the implementation/enforcement.
  - These measurements take time and currently no standard methods exist.
  - What will be the required frequency of testing? Who will do the testing?

Appendices

- Tables from review article in preparation

Porterfield, K.K., S. Hobson, D. Neher, M. Niles, and E.D. Roy. (in prep). Microplastics in Composts and Digestates Derived from Food Waste: A Review.

References listed in this presentation and the following tables are available upon request.

Microplastic abundance in composts and digestates on a count basis

Porterfield et al. (in prep)

Feedstock [d]	**Abundance (particles kg^{-1} dry)**	**Sizes (mm)**	**Polymer Types [d]**	**Location**	**Reference**
Compost					
Green waste	5733 ± 850 to 6433 ± 751	0.05–5	Mostly PP, also PE, nitrile rubber, PES	Lithuania	Sholokhova et al., 2021
Green waste	12 ± 8 to 46 ± 8	<1–>5	n/a	Germany	Braun et al., 2021
Green waste	1253 ± 561	0.03–2	PE, PP	Netherlands	van Schothorst et al., 2021
Green waste	82800 ± 17400	1–>300	PLA	Netherlands	Huerta-Lwanga et al., 2021
Household & green waste	20–24	1–>5	Mostly styrene-based polymers (PS etc.) & PE, also PES, PP, PET, PVC	Germany	Weithmann et al., 2018
Food waste	3783 ± 351 to 4066 ± 658	0.05–5	Mostly PE & PS, also PET, PP	Lithuania	Sholokhova et al., 2021
Household biowaste	32 ± 20	<1–>5	n/a	Germany	Braun et al., 2021
Rural domestic waste	2400 ± 358	0.05–5	Mostly PP, PE, also PES, PVC, PS, PE-PP, PU	China	Gui et al., 2021
OFMW digestate	39–102	1–5	Mostly PE & PVC, also PET, PS, PES, PUR	Germany	Schwinghammer et al., 2020
OFMW	2800 ± 616	0.03–2	PE, PP	Netherlands	van Schothorst et al., 2021
OFMW	10000–30000	<0.1–>30	Mostly PE, also PS, PP, PES, PVC, ACR	Spain	Edo et al., 2021
Unknown	5.2–42.8 (15.4) Mil [a]	<1	n/a	Austria	Meixner et al., 2020
Digestate					
OFMW	75–326 [c]	1–5	Mostly PES and PVC, also PP, PE, PET, PS, PA, EVA	Germany	Schwinghammer et al., 2020
Commercial biowaste	895	1–>5	n/a	Germany	Weithmann et al., 2018
Household biowaste	70–146	1–>5	Mostly styrene-based polymers (PS etc.), also PES, PE, PP, PET, PVC, PVDC, PA, PUR, latex- & cellulose-based polymers	Germany	Weithmann et al., 2018
Unknown	0.6–38.7 (7.1) Mil [a]	<1	n/a	Austria	Meixner et al., 2020

[a] dry/as-is not reconciled; [b] as-is; [c] estimated from graph; [d] Abbreviations: OFMW: organic fraction municipal waste; ACR: acrylic polymers; CE: cellophane; PA: polyamide; EVA: ethylene vinyl acetate; PE: polyethylene; PES: polyester; PET: polyethylene terephthalate; PLA: Polylactic acid; PP: polypropylene; PS: polystyrene; PU/PUR: polyurethane; PVC: polyvinyl chloride; PVDC: polyvinylidene chloride

Microplastic abundance in food wastes on a count basis

Porterfield et al. (in prep)

Feedstock [d]	**Abundance (particles kg^{-1} dry)**	**Sizes (mm)**	**Polymer Types** [d]	**Location**	**Reference**
Food Waste					
Grocery store	300000 [a]	n/a	n/a	US	Golwala et al., 2021
Pulped food waste	1400 ± 150 [a]	0.1–2	Mostly Mater-Bi®, also PP, PE, PS, CE	Italy	Ruggero et al., 2021
Homogenized food waste	40 [c]	1–5	Mostly PE, also PP, PS	Germany	Schwinghammer et al., 2020

[a] dry/as-is not reconciled; [b] as-is; [c] estimated from graph; [d] Abbreviations: OFMW: organic fraction municipal waste; ACR: acrylic polymers; CE: cellophane; PA: polyamide; EVA: ethylene vinyl acetate; PE: polyethylene; PES: polyester; PET: polyethylene terephthalate; PLA: Polylactic acid; PP: polypropylene; PS: polystyrene; PU/PUR: polyurethane; PVC: polyvinyl chloride; PVDC: polyvinylidene chloride

Microplastic abundance in composts, digestates, and food wastes on a mass basis

Feedstock [d]	**Abundance (% *w/w* dry)**	**Sizes (mm)**	**Polymer Types [d]**	**Location**	**Reference**
Compost					
Green waste	0.00024–0.0065	>0.5	n/a	Germany	Bläsing and Amelung, 2018
Green waste	0.0048 ± 0.0089 to 0.053 ± 0.05 [c]	<1 to >5	n/a	Germany	Braun et al., 2021
Biowaste	0.018	>0.5	n/a	Germany	Bläsing and Amelung, 2018
Household biowaste	0.1358 ± 0.0596	<1 to >5	n/a	Germany	Braun et al., 2021
Urban organic waste	0.001–0.0102 [a]	All	PET	Germany	Müller et al., 2020
OFMW digestate	0.005–0.05 [c]	1–5	Mostly PE and PVC, also PET, PS, PES, PUR	Germany	Schwinghammer et al., 2020
Digestate					
Kitchen & green waste	0.12 ± 0.12 [b]	>6	n/a	Switzerland	Kawecki et al., 2020
Organic waste	0.0209–0.0776 [a]	All	PET	Germany	Müller et al., 2020
OFMW	0.01– 0.0350 [c]	1–5	Mostly PES and PVC, also PP, PE, PET, PS, PA, EVA	Germany	Schwinghammer et al., 2020
Food Waste					
Kitchen & green waste	0.5 ± 0.46 [b]	>6	n/a	Switzerland	Kawecki et al., 2020
Homogenized food waste	0.025 [c]	1–5	Mostly PE, also PP and PS	Germany	Schwinghammer et al., 2020
Household biowaste	3.0–5.6	>2	n/a	Austria	do Carmo Precci Lopes et al., 2019
Household biowaste (mechanically sorted)	0.04–2.9	>2	n/a	Austria	do Carmo Precci Lopes et al., 2019

[a] dry/as-is not reconciled; [b] as-is; [c] estimated from graph; [d] Abbreviations: OFMW: organic fraction municipal waste; PA: polyamide; EVA: ethylene vinyl acetate; PE: polyethylene; PES: polyester; PET: polyethylene terephthalate; PP: polypropylene; PS: polystyrene; PUR: polyurethane; PVC: polyvinyl chloride

Porterfield et al. (in prep)

Summary of microplastic abundance in agricultural soils by mulching practice.

Porterfield et al. (in prep)

Plastic Mulch Practice	Agriculture Type	Mean Range (particles kg^{-1} dry)	Typical Order of Magnitude (particles kg^{-1} dry)	Sizes (mm)	Common Plastic Types Identified [a]	Soil Depth (cm)	Locations	References
Mulched	Mixed vegetable, Tomatoes, Beans, Cotton, Mixed crop lands, Watermelon, Unspecified	11–18760	100's–1000's	0.02–5, 0.05–10, <1–<5, 0.001–5, <0.1–5, 0.02–5, 0.02–<2, 0.03–2, 0.05–5	PE, PP, PS, PES, PPE, PP, PA, PVC, rayon, acrylic	0–10, 0–30, 0–40, 0-80	China, Spain, India, Greece	Beriot et al., 2021; Hu et al., 2021; Huang et al., 2021, 2020; Isari et al., 2021; Liu et al., 2018; Meng et al., 2020; van Schothorst et al., 2021; Vinoth Kumar M and Sheela A, 2021; J. Wang et al., 2021; Zhou et al., 2020
Non-mulched	Mixed crop, Pasture, Grasslands, Peanut, Wheat, Paddy, Woodland, Orchard, Unspecified	0.34–5490	100's	0.03–2, 1–600, 0.02–5, 0.05–5	Acrylates, PUR, PE, EVA, PP, PA, nitrile rubber, nylon, rayon, PS, PES, PVC	0–5, 0–10, 0–20, 0–30	China, Germany, Netherlands, Chile	Corradini et al., 2021; Q. Li et al., 2021; Piehl et al., 2018; van Schothorst et al., 2021; J. Wang et al., 2021; J. Yang et al., 2021; Zhou et al., 2020
Some mulched	Mixed crop, Farm / Grassland	4–1444	10's	<0.05–>1, 1–5, 0.02–5	PE, PP, PA, PS, EPC, nylon	0–6, 0–25, 0–30	China, Germany	Feng et al., 2021; Harms et al., 2021; Yu et al., 2021
Not Specified	Mixed vegetable, Mixed crop, Unspecified	560–3712	100's	0.02–5, 0.01–2, 0.05–5	PA, PP, PS, PE, PVC	0–5, 0–20, n/a	China, Mexico, Pakistan	Chen et al., 2020; Huerta Lwanga et al., 2017; Rafique et al., 2020