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Short-term exposure to soils and sludge induce changes to plastic morphology induce changes to and ^{13}C stable isotopic composition

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Introduction

Plastic waste and microplastics are accumulating in terrestrial systems where they can potentially interfere with the natural processing of soil organic carbon and other nutrient cycling processes. We evaluated the decomposition of low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polyethylene terephthalate (PETE) using controlled soil and sludge microcosm experiments.

Objectives

Our principal objective is to understand how plastics decompose in differing soil environments at the molecular and microscale and identify if underlying native microbial communities drive their mineralization.

Environmental Significance

The fate and mineralization of soil plastics will be related to the natural variability of the soil microenvironments they are found in, their association and/or integration within soil aggregates, and more broadly related to the soil microbiome. Feedbacks to whole ecosystem level processes and fundamental connection between microplastics, soil organic matter content, and the larger carbon cycle, vis-à-vis potential implications related to soil carbon storage, sequestration, and greenhouse gas emissions have been surmised.

Approach

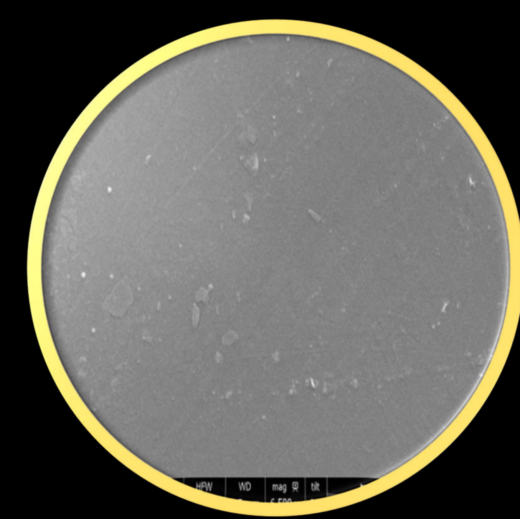
Disks (~3.4 mm Dia.) were punched from consumer stock materials and placed in microcosms containing either a sludge, a fresh soil, or an aged soil and mechanically agitated at 20 °C for 30 days. Retrieved plastics were analyzed using a combination of scanning electron microscopy (SEM) and Isotope Ratio Mass Spectrometry (IRMS).

Sample Preparation

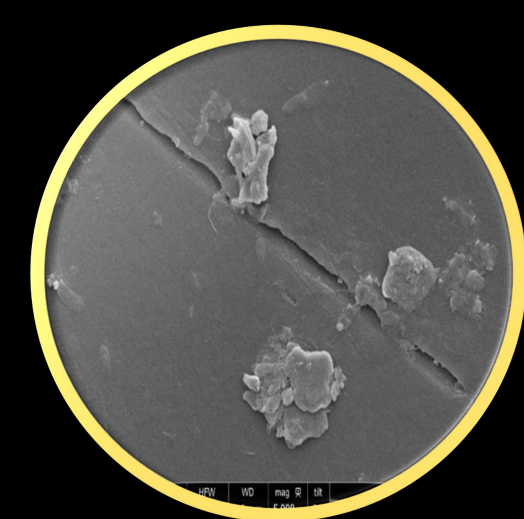
Morphology imaging or ^{13}C IRMS analysis: samples were removed of soil organic matter with 30% H2O2, a mild oxidizer (12 hrs.).

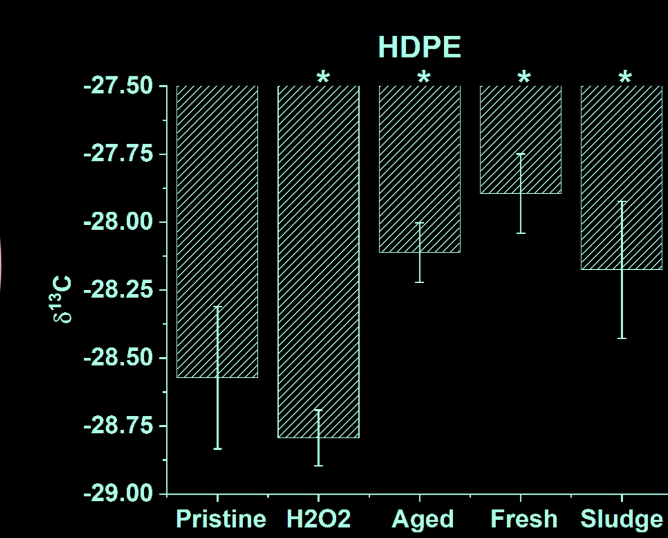
Biofilm and microbial attachment imaging: samples were chemically fixed using 2.5% glutaraldehyde in phosphate buffer solution (pH 7, 2 hrs.); serially dehydrated using 70%, 90%, 100% ethanol (20 min. each); and treated with 100% hexamethyldisilazane (20 min.) as a final drying agent.

Pristine PET Surface (shown); HDPE and L/LDPE were similar in appearance.

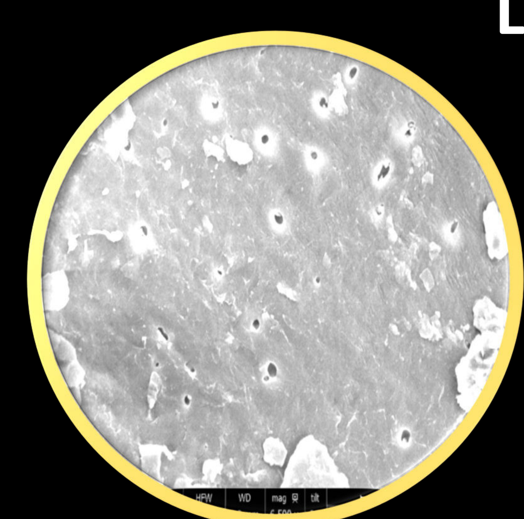


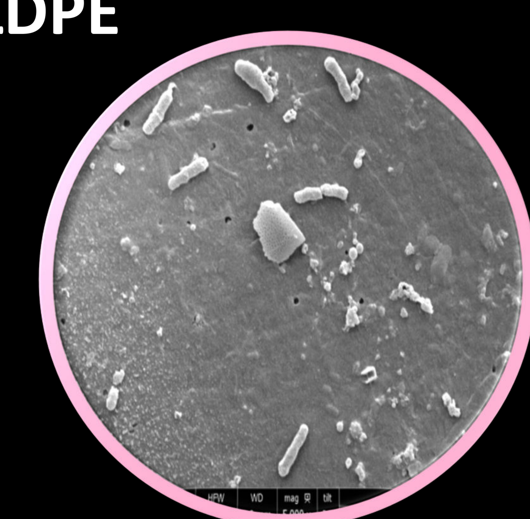
HDPE

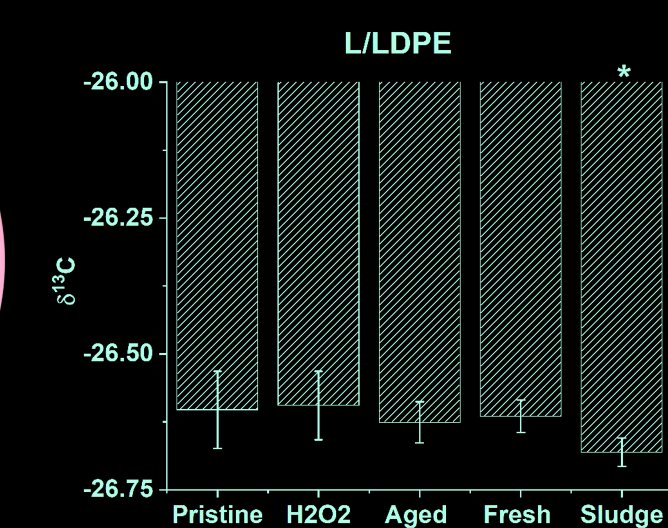




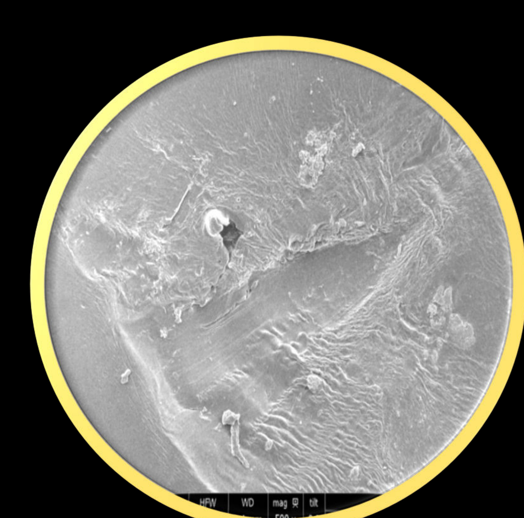
L/LDPE

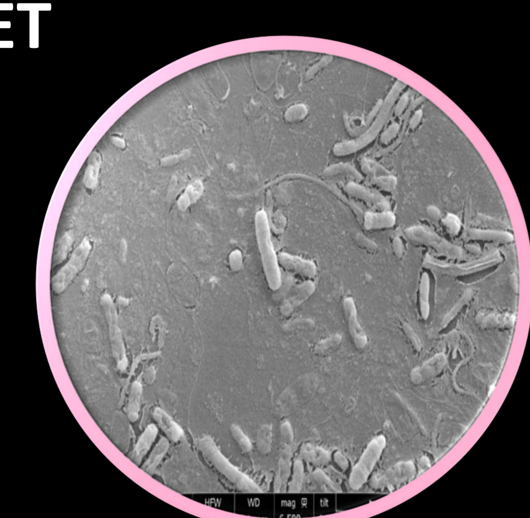


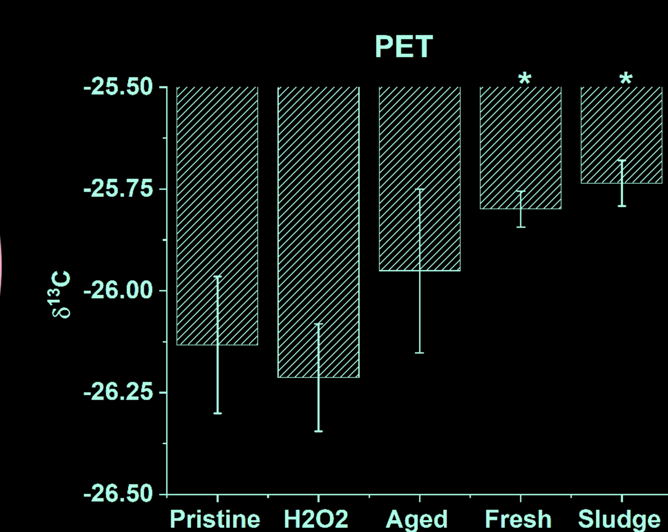




PET







SEM images at 5 μm scale

Plastic Morphology

We observed morphological changes to all plastics; these were related to the physical and chemical properties of the polymer itself:

- Crystallinity
- Roughness
- Hydrophobicity
- Rigidity
- Brittleness
- Elongation

Biofilm & Microbial Attachment

We observed attachment of biofilm and microorganisms on all surfaces:

- PET and HDPE surfaces were favored compared to L/LDPE
- Related to the hydrophilic nature of the plastics – PET > L/LDPE > HDPE
- Related to surface roughness – L/LDPE > HDPE > PET
- Fungal and/or microbial hyphae were observed on PET surfaces

^{13}C-Isotopic Composition

$\delta^{13}C$ values are a ratio of $^{13}C/^{12}C$ and measured using an Isotope Ratio Mass Spectrometer. Mean values for pristine plastics (n = 10), pristine plastics treated with 30% H2O2 (n = 6), and plastics exposed to fresh soil, aged soil, or digested sludge (n = 3, each) are shown. Significantly different sample measurements compared to the pristine plastic are denoted with asterisks.

In general:

- Positive isotopic enrichments were observed for HDPE and PET
- Variability in values observed across soils and sludge, possibly indicating different geochemical variables
- L/LDPE had negligible isotopic changes

Conclusions and Future Steps

Our results show:

- Plastics are physically altered and colonized by microbial communities in soil environments within a short 32-day period.
- Significant changes in stable isotopic values were observed for HDPE and PET, but these cannot be assigned to any one degradation pathway.
- Degradation may be related to plastics' chemical/physical properties.

This research is preliminary and ongoing:

- We did not characterize geochemical parameters (pH or organic matter content); these are important factors in soil.
- Isotopic changes were not attributed to specific degradation pathways; these will be explored in upcoming work.
- Future efforts will incorporate liquid or gas chromatography isotope mass ratio spectrometry to help identify plastic degradation processes, 16S rRNA sequencing and PLFA characterization of the soil microbiome.

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