Comparison of Weathering at Two Diverse Geographic Locations and Simulated Weathering on the Physicochemical Properties of Biodegradable Plastic Mulches

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Introduction

- Plastic mulches are an integral component of specialty crop production
  - Prevention of weeds
  - Reduction of water evaporation loss
  - Control of soil temperature
  - → increased crop yield and quality → benefits to both farmers and consumers
- Yet, conventional (polyethylene (PE) mulches are problematic:
  - Labor-intensive retrieval and disposal
  - Minimal recycling options available
  - Poorly biodegradable → debris, micro- and nano-plastic formation → potential harm to organisms and the environment
- Biodegradable plastic mulches (BDMs) were developed to address the deficiencies:
  - BDM can be tilled into the soil → reduced labor costs
  - Widespread use limited by higher cost, unpredictable breakdown and variable performance during deployment, and variable biodegradability after being incorporated into the soil
  - Long-term impacts of continual deployment and soil incorporation of BDMs are unknown (overall objective addressed by our SCRI project)

Objectives and Significance

- Deterioration of BDMs via environmental factors ("weathering") can affect:
  - BDM performance for weed prevention
  - Potential adhesion of plastics on fruit
  - The rate and extent of biodegradation
- Weathering conditions can vary greatly across geographical regions and climates, and between years; extreme events can also impact (e.g., storms)
- The impact of weathering on biodegradability is an important factor for ASTM WK29802, a standard under development for biodegradation of plastics in soil.
- Can simulated weathering ("weatherometry") be used to standardize weathering conditions for plastic mulches?
- Objectives:
  1. Compare the impact of weathering across two diverse geographic locations (Mount Vernon, WA, and Knoxville, TN; Table 1) with simulated weathering on changes in physicochemical properties and biodegradability of BDMs and control mulch treatments (Table 2)
  2. More deeply understand underlying mechanisms of BDM deterioration
  3. Determine which physicochemical properties are the most important for monitoring deterioration

Table 1. Environmental conditions during the field trials for pie pumpkin grown using plastic mulches at Knoxville, TN, and Mount Vernon, WA (USA) in 2015.[1]

Environmental parameters	Knoxville	Mount Vernon
Mulch Deployment Dates	28 May-17 Sept	26 May-18 Sept
Ave. daily air tem. (°C)	24.9	17.4
Ave. daily max. air temp. (°C)	30.3	23.7
Ave. daily min. air temp. (°C)	19.6	11.1
Degree Days (°C)	1934	1494
Total solar radiation (MJ/m²)	2033	2455
Relative humidity (%)	81.6	75.9
Ave. wind speed (m/s)	2.31	1.74
Total rainfall (mm)	354	89.8
Soil Temperature (10 cm depth), °C	25-27	20-23

Table 2. Treatments in BDM field experiment at Knoxville, TN and Mount Vernon, WA in 2015. (PLA = polylactic acid, PHA = polyhydroxylkanoate, PBAT = polybutylene adipate terephthalate)

Mulch Product	Manufacturer	Key product ingredient(s)
Polyethylene (PE) [Negative Control]	Filmtech, Allentown, PA	Polyethylene
WeedGuardPlus (WGP) [Positive Control]	Sunshine Paper Co., Aurora, CO	Cellulose
PLA+PHA	Experimental Film	Ingeo®PLA+Mirel™ amorphous PHA
BioAgri	BioBag Americas, Inc. Dunedin, FL	Polyesters blends w/ or w/o starch
Organix	Organix Solutions, Maple Grove, MN	BASF®Ecovio® (PLA + PBAT)
Naturecycle	Custom Bioplastics, Burlington, WA	Starch-polyester blend

Methods

- Field weathered mulches thoroughly and carefully cleaned prior to analyses (via soft-bristle brushes)
- Weathering treatments
  1. Field Weathering in TN and WA (Table 1)
  2. Simulated Weathering, 21 d, ASTM G155a (Michigan State University)
  3. Indoor storage (1 yr, TN and WA)
- Mechanical strength testing: Weight, thickness, maximum peak load and %elongation at maximum tensile strength
- Colorimetry (L, a, b, ΔE)
- Surface properties (contact angles)
- Chemical: FTIR-ATR, NMR (for PLA+PHA), gel permeation chromatography (GPC; for MW), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), stable carbon isotope analysis
- Biodegradability (ASTM D5988)
- Statistical analysis (in progress)

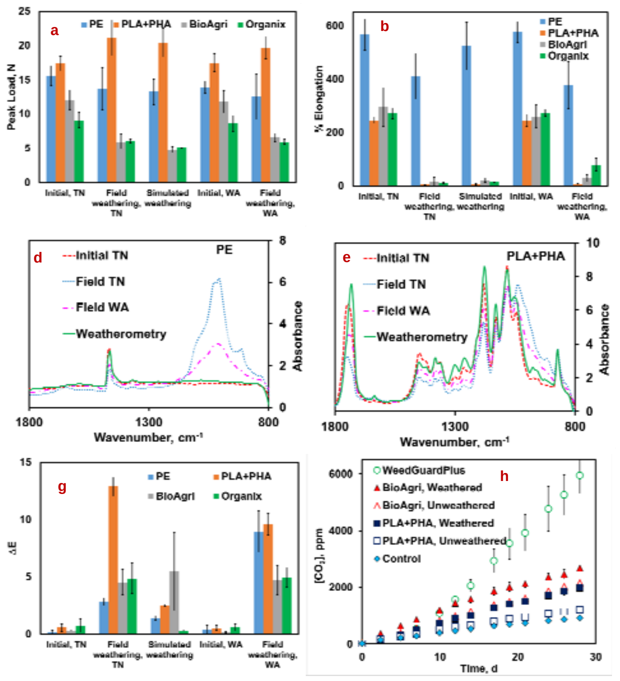

Figure 1. Effect of TN and WA Field Weathering on physicochemical properties of plastic mulches: (a) peak load and (b) elongation at maximum tensile stress; (c) weight-averaged molecular weight (Mw), (d-f) FTIR-ATR spectra, (g) ΔE (colorimetry), and (h) biodegradability (TN field weathered; control = mulch-free soil)

Results and Discussion

- Indoor storage produced minor changes in physicochemical properties (data not shown)
- Trends for Naturecycle generally followed those of BioAgri (data not shown)
- WGP underwent major deterioration (macroscopic disintegration in TN)
- Only minor changes in chemical composition observed, including a minor increase in % of inorganics (carbon isotope analysis; NMR; TGA)
- In 2015, TN had a warmer and moister climate; no major difference in solar radiation (Table 1)
- Field and simulated weathering led to a major loss of tensile strength (except for PLA+PHA) and % elongation, the latter indicating embrittlement (Fig 1 ab)
- The increase of tensile strength for PLA+PHA is perhaps due to formation of cross-links (Fig 1b)
- For PLA+PHA and BioAgri, depolymerization was greatest for simulated weathering (30-34%), followed by TN and WA field weathering (19-27% and 19-21%, respectively; Fig 1c).
- For Organix, only TN field weathering lowered M_w to a major extent (22.2%; Fig 1c)
- PE underwent a major FTIR spectral change due to TN (and WA) field, but not simulated, weathering → (hydroxides and peroxides; Fig 1e
- *Field* (but not simulated) *weathering* of PLA+PHA and BioAgri produced major changes consistent with hydrolysis; *simulated weathering* produced different spectral changes→Nourrish Type II photodegradation (Fig 1 e+f)
- Whitening of color occurred during field weathering, but not during simulated weathering (Fig 1g)
- Weathering enhanced the biodegradation rate for PLA+PHA and BioAgri (Fig 1h)

Conclusions

- Weathering in TN, WA produced different effects on physicochemical properties.
  - %Elongation and molecular weight decrease was greatest for TN → higher temperatures promoted embrittlement and depolymerization
  - ΔE being higher in WA may reflect the slightly higher exposure to solar radiation in WA.
- Field and simulated weathering possessed different mechanisms of degradation
- Weathering enhances biodegradation.

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