Development of Next Generation of Biodegradable Mulch Nonwovens to Replace Plastic Films

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Plastic mulches have been used on crops since early 1960’s for weed control, disease protection, and optimization of soil temperature but drawbacks are:

- Cost of PE mulch is increasing
- PE can not be tilled into soil and must be removed by hand from the field
- Disposal of PE mulch is an environmental problem
Estimated that ~50% of plastics are burned on farm (often illegally) which releases toxic pollutants such as heavy metals, dioxins and particles into air.

More and more landfills are refusing to accept plastic mulch.

Photodegradable plastics are unpredictable and do not degrade completely.

Biodegradable starch-based plastics are expensive and degrade unpredictably.
Our goal is to make meltblown and spunbond PLA fabrics more susceptible to biodegradation in the field which still have the required strength for use in mulching by

1) Applying treatments used in growing crops

2) Working with PLA producer to develop resin compositions more susceptible to degradation
Properties of PLA Polymer

- PLA is made from lactic acid, a fermentation byproduct derived from corn, wheat, rice, or sugar beets
- When polymerized, the lactic acid forms an aliphatic polyester
- Unlike other fibers from vegetable sources like cellulosics which have to be solvent spun, PLA is melt spun
Figure 1. PLA polymer repeat unit
Properties of PLA Polymer

- The lactide dimer occurs in three forms:
  - L form, which rotates polarized light in a clockwise direction;
  - D form, which rotates polarized light in a counter-clockwise direction; and
  - Meso form, which is optically inactive
Control over the content and arrangement of the three stereoisomers allows the polymerization of PLA in which the melt temperature can be controlled between about 120°C and 175°C.

The low melting temperature polymers are essentially completely amorphous.

The more amorphous polymer should be more assessable to enzymes and microbes in the soil and those which are added as treatments for easier biodegradation at ambient soil conditions.
Hakkarainen et al. (2000) incubated 1.8 mil thick samples of PLA film at 86°F in a mixed culture of microorganisms extracted from compost. After 5 weeks of incubation, it degraded to a fine powder, whereas the untreated control remained intact. Although this study used only the L form, it illustrates that application of a broad range of readily available microorganisms from compost can accelerate breakdown.
Biodegradation of PLA Polymer – Cont.

- Many of these microorganisms already exist in fertile agricultural soils

- To our knowledge, a 100% PLA fabric mulch has not been tested in the field with different soils and treatments normally applied in growing crops

- Degradation is rapid when PLA is composted at 140°F, but stability below 140°F when the fabric is in contact with soil organic matter remains to be determined
Experimental

- Different treatments were applied onto soils with different pH values and compositions containing 75 gsm meltblown PLA specimens to accelerate degradation of the fabric.

- The tests were carried out in a greenhouse in trays containing 2 liters of soil with the fabric specimens placed approximately 1.5 inches beneath the soil.

- Trays with soil and buried mulch were initially watered with tap water to saturation/run-off and trays were kept moist with addition of 500 ml water every other day.
The three treatments consisted of 1) tap water only, 2) lime (2 tons/acre or 27.2 g/tray) and 3) Black Kow composted cow manure (20 tons/acre or 585 g/tray).

After 20 weeks exposure from December 15, 2008 through April 29, 2009, the specimens were removed and carefully washed over a screen and air dried.

Performed physical testing and representative specimens were analyzed for fiber breakage and morphological changes by SEM and for decrease in molecular weight by GPC analyses.
Tray of Organic Farm Soil with Lime Treatment of MB PLA Fabric
MB PLA Fabric after 20 Weeks Exposure in High Tunnel Soil and Tap Water Only
MB PLA from High Tunnel Soil (pH 6.4) on left vs Organic Farm Soil (pH 5.5) on right – Note greater apparent degradation of specimens in higher pH soil on left
All of the specimens showed signs of degradation such as cracks and tears and notable discoloration.

The specimens from the High Tunnel pH 6.4 soil were too fragile to be subjected to tensile strength testing.
Table 1a. Effects of treatments after 20 weeks exposure on physical properties of MB PLA fabric.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Specimen No.</th>
<th>Weight (g/m²)</th>
<th>Thickness (mm)</th>
<th>Peak Force (N)</th>
<th>Peak Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-received Control</td>
<td>3 Control Swatches</td>
<td>73.0</td>
<td>0.512</td>
<td>17.37</td>
<td>8.77</td>
</tr>
<tr>
<td>Tap Water Only= C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H=High Tunnel Conv Soil pH of 6.4</td>
<td>HC1, HC2, HC3</td>
<td>90.4</td>
<td>0.538</td>
<td>Too Weak to test (TW)</td>
<td></td>
</tr>
<tr>
<td>D=Soil from Organic Farm pH of 5.5</td>
<td>DC1, DC2, DC3</td>
<td>73.2</td>
<td>0.458</td>
<td>1.92</td>
<td>1.17</td>
</tr>
</tbody>
</table>
Table 1b. Effects of treatments after 20 weeks exposure on physical properties of MB PLA fabric.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Specimen No.</th>
<th>Weight (g/m²)</th>
<th>Thickness (mm)</th>
<th>Peak Force (N)</th>
<th>Peak Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-received Control</td>
<td>3 Control Swatches</td>
<td>73.0</td>
<td>0.512</td>
<td>17.37</td>
<td>8.77</td>
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<tr>
<td>Lime Treatment=L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H=High Tunnel Soil with pH 6.4</td>
<td>HL1, HL2, HL3</td>
<td>82.0</td>
<td>0.532</td>
<td>Too Weak to test (TW)</td>
<td></td>
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<tr>
<td>D=Soil from Farm with pH of 5.5</td>
<td>DL1, DL2, DL3</td>
<td>73.6</td>
<td>0.470</td>
<td>1.09</td>
<td>1.24</td>
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<tr>
<td>B= Black Kow Compost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H=High Tunnel Soil with pH 6.4</td>
<td>HB1, HB2, HB3</td>
<td>68.5</td>
<td>0.508</td>
<td>TW</td>
<td></td>
</tr>
<tr>
<td>D=Soil from Farm with pH of 5.5</td>
<td>DB1, DB2, DB3</td>
<td>81.6</td>
<td>0.520</td>
<td>1.91</td>
<td>1.37</td>
</tr>
</tbody>
</table>
2 a) MB PLA Control at 100X

2 b) MB PLA Control at 500X

2 c) MB PLA Control at 1000X
3 a) MB Specimen HC at 100X (20 Weeks)

3 b) MB Specimen HC at 500X (20 Weeks)
4a) SEM of HL at 100X (20 Weeks)

4b) SEM of HL at 500X (20 Weeks)

4c) SEM of HL at 2000X (20 weeks)
5a) SEM of HB at 2000X (20 Weeks)
## DSC Crystallinity of Control and Soil Exposed MB PLA

<table>
<thead>
<tr>
<th>Condition</th>
<th>% Crystallinity</th>
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</thead>
<tbody>
<tr>
<td>MB PLA Control</td>
<td>27.3</td>
</tr>
<tr>
<td>Tap Water &amp; pH 6.4 soil (HC)</td>
<td>26.3</td>
</tr>
<tr>
<td>Tap Water &amp; pH 5.5 Soil (DC)</td>
<td>10.4</td>
</tr>
<tr>
<td>Lime &amp; pH 6.4 Soil (HL)</td>
<td>16.0</td>
</tr>
<tr>
<td>Lime &amp; pH 5.5 Soil (DL)</td>
<td>17.0</td>
</tr>
<tr>
<td>Compost &amp; pH 6.4 Soil (HB)</td>
<td>22.1</td>
</tr>
<tr>
<td>Compost &amp; pH 5.5 Soil (DB)</td>
<td>13.5</td>
</tr>
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</table>
GPC Analysis of Control MB PLA and Compost Exposed PLA

<table>
<thead>
<tr>
<th></th>
<th>Average Molecular Weight</th>
<th>Polydispersity</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB PLA Control</td>
<td>89,522</td>
<td>1.4272</td>
</tr>
<tr>
<td>MB PLA Exposed to “Black Kow” compost in High Tunnel soil (pH 6.4) for 20 weeks</td>
<td>82,905</td>
<td>1.5408</td>
</tr>
</tbody>
</table>
Conclusions

- All of the specimens showed signs of degradation such as cracks and tears and notable discoloration and the specimens exposed in the high tunnel soil with a pH of 6.4 were too fragile to be subjected to tensile strength testing.

- The soil-exposed specimens that were intact enough to be tested had only 1/16 to 1/9 the strength of the non-exposed PLA MB specimens.

- SEMs showed many broken filaments in the soil exposed specimens but not in the as-received MB PLA fabric.
Conclusions - Continued

- From DSC analysis, most of the soil exposed specimens showed a notable decrease in crystallinity indicating that over 20 weeks degradation of both the crystalline and amorphous regions occurred.

- GPC analyses for molecular weight and polydispersity of the compost treated sample showed less change than would have been expected compared to the decrease in tensile strength.

- In future studies, the PLA fabric will be exposed in soil for up to 40 weeks.
The soil will be examined for any PLA fragments and analyzed before, during and after the study to determine any effects of the degraded PLA on the composition of the soil and its properties.

Also MB and SB made from PLA compositions engineered to degrade under crop growing conditions will be evaluated.
ACKNOWLEDGEMENTS

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