EVALUATING POTENTIAL BIODEGRADABLE MULCHES FOR HIGH TUNNEL AND FIELD VEGETABLE PRODUCTION
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Abstract:
An interdisciplinary team of agricultural, horticultural, materials, and social scientists is evaluating potentially biodegradable mulches (BDM) in high tunnel and open field tomato production. Mulches include an experimental spun-bonded BDM produced from polylactic acid (PLA) fibers, two commercially-available BDM products (BioAgri and Biotelo), and conventional black polyethylene mulch film (PE). Field experiments were initiated in 2010 and are underway in western WA, eastern TN, and central TX, and include cellulose and non-mulch treatments as reference controls. The team is evaluating the degradability and biodegradability of BDMs, and the effects of BDMs on crop production and soil quality. The rate and extent of degradation and biodegradation are being measured through changes in BDM visual, physical, chemical, and mechanical properties as well as through changes in soil physical, chemical and biological properties. BDM sample evaluations include thickness, weight, pore size, flexibility, tensile strength, and elongation. Crop assessments include weekly plant disease incidence and severity ratings, the extent and diversity of weed populations, crop yield, and the marketability and quality of harvested tomato fruit. Soil analyses feature a suite of soil quality indicators which target nutrient cycling, biodiversity, and microbial activity. Following final harvest, BDMs will be incorporated into the soil and periodically analyzed for byproducts of hydrolysis. Results are being made available to the public via our project website http://vegetables.wsu.edu/plasticulture.html, and also by press releases, seminars, workshops, field days, and publications in peer-reviewed journals.

Introduction
High tunnels have been shown to produce earlier, higher yielding and higher quality crops, including berries (Kadir et al., 2006; Heidenreich et al., 2009), leafy greens (Zhao et al., 2007), melons (Jett, 2007) and tomatoes (Wszelaki and Rogers, unpublished data; O’Connell, 2008; Luthria et al., 2006). Tomato is the primary crop grown in high tunnels throughout the United States (Carey et al., 2009). Most high tunnel systems utilize plastic mulch for weed control and soil moisture conservation (Lamont, 2005; Hill et al., 1982; Takakura and Fang, 2001). A biodegradable plastic mulch could reduce the overall environmental impact of these production systems if the mulch is completely biodegradable and does not negatively impact soil, water and human health (Shogren, 2000; Hochmuth, 2001; Narayan, 2010a). Under aerobic soil conditions, biodegradability is defined as the biological conversion of carbon substrates to CO₂ (Narayan, 2010b). This project is measuring the efficacy, degradability, biodegradability, and potential residues of presumed biodegradable mulches in laboratories at Pullman, Washington and Knoxville, Tennessee, and in the field soil of high tunnel and open field tomato experimental plots in three diverse environments, ie., Mount Vernon, Washington; Knoxville, Tennessee; and, Lubbock, Texas.

This project is primarily funded through an SCRI SREP grant (Project No.2009-51181-05897) and includes a team of agricultural, horticultural, materials, and social scientists at five universities in three
states, plus a committee of grower and industry stakeholders, and scientific advisors. Field sites have been established and high tunnels have been constructed at the three sites to provide environmental contrasts for BDM performance and degradability. Mount Vernon has a marine climate with relatively cool summer temperatures and moderate monthly precipitation; soil type in the region tends to be loamy sand with good organic matter content. Knoxville has a humid subtropical climate with mild winters and warm humid summers; soil type tends to be heavy clay with low organic matter content. Lubbock is in the High Plains region and has high summer temperatures, low humidity and rainfall, and high winds; soils tend to be sandy loam with less than 1% organic matter.

The field study at all three locations includes four presumed biodegradable mulches (BDMs), black polyethylene (PE) mulch film, and a bare ground treatment. All treatments are applied in high tunnel and open field plots and replicated four times, and are planted with a tomato crop. The BDM trial treatments both within and outside of high tunnels are being monitored and evaluated for: (i) impact on key soil quality physical, chemical, and biological indicators; (ii) influence on plant foliage disease, root disease and insect pest incidence and severity; (iii) relative ability to meet mulch performance standards including weed suppression, soil moisture conservation and durability throughout the crop growing season; (iv) the presence/absence of mulch by-products in the soil environment, and potential effects on soil ecology, (v) changes in the physical, chemical, and mechanical properties of the mulch material after field exposure, and (vi) biodegradability in soil and composting environments. Crop yield, marketability, and fruit quality are important to producers in deciding whether to transition to BDMs and high tunnels. Thus, tomato fruit quality is being measured for US No. 1 graded tomatoes in all treatments at harvest and following two weeks of storage, and includes juiciness, soluble solids, titratable acidity, lycopene, ascorbic acid content, and storability/shelf-life.

Materials and Methods

Experimental design
As of this writing, a field study has been established at three locations (Mount Vernon, Knoxville, and Lubbock) with high tunnel and open field plots and six treatments: (i) an experimental spun-bonded nonwoven composed of 100% PLA polymer (obtained from NatureWorks, Blair, Nebraska); (ii) BioAgri (Palm Harbor, Florida); (iii) BioTelo (Dubois Agrinovation, Waterford, Ontario, Canada); (iv) standard black plastic PE mulch 1.0 mil embossed (Pliant Corp, Schaumburg, Illinois); (v) cellulose mulch, completely biodegradable standard (WeedGuard Plus, SunShine Paper Company, Aurora, Colorado); and (vi) bare ground / non-mulch control. All mulch treatments were applied by hand in plots measuring 3 feet wide (mulched bed width) and 14 feet long, and were planted with tomato cv. Celebrity. The experimental design was a randomized complete block with four replications. Drip tape has been applied under the mulch and plots have been irrigated as needed based on Watermark (Spectrum Technologies, Inc., Plainfield, Illinois) soils moisture sensor readings. Granular organic fertilizer was broadcast over the bed centers at the rate 85 lbs N per acre, and incorporated prior to planting. Plants received organic fertilizer injected through the drip irrigation system weekly (following tomato fertigation guidelines, University of Florida). Environmental data are being recorded by a Hobo Weather Station (Onset Computer, Bourne, Maine) at 15 minute intervals every day. Tomato plants are staked by a Florida weave training system, and pruned to 1-2 main stems. Extensive environmental monitoring (air and soil temperature, humidity, soil moisture, and leaf wetness) is also being done, but is not reported in this paper.
**Soil quality assessment**

Soil samples (0-15 cm) were collected prior to mulch application in Year 1 (2010) and will also be collected in Years 2 and 3 of this project; the Year 1 pre-mulch soil sample serves as the baseline for all subsequent samples. Soil samples will be collected after BDM treatments have degraded for approximately 6 months (i.e., from final harvest to planting the following year). To investigate the effects of mulch treatments on soil quality, an assessment of key physical, chemical, and biological soil quality indicators is being conducted. For the purposes of this study, soil quality is defined by the “capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (Doran et al., 1994). The key soil quality indicators provide information relating to critical soil functions such as nutrient cycling (electrical conductivity, pH, total organic C, total N, microbial biomass C and N, beta-glucosidase activity, and potentially mineralizable N), physical stability (bulk density, water stable aggregates), and biodiversity (microbial biomass C) and microbial activity (beta-glucosidase activity). Results from these analyses are anticipated to be assessed through the Soil Management & Assessment Framework Model (SMAF) (Andrews et al., 2004) to help interpret soil indicator data and compute relative soil quality indices; doing so will help compare changes over time due to crop and mulch management. Additional analyses performed but not entered into SMAF include: phospholipid fatty acid profiling to characterize the soil microbial community structure, available water content, cation-exchange capacity, and another enzyme assay (beta-D-glucosaminidase) which is involved in N and C cycling in soil and has been well correlated with N mineralization indices.

**Plant and root health, and insect assessment**

Crop plants in each high tunnel and open field plot are being monitored weekly at all field sites for incidence and severity of foliar and root diseases as well as insect attraction to the BDM treatments. All plant disease symptoms are being observed weekly, and the ratings converted to area under disease progress curves (AUDPC) values in order to make comparisons of potential disease epidemics. Upon discovery of an insect population, monitoring is occurring at least twice weekly to document the species, extent and severity of damage, differential attraction to the different BDM treatments, and to determine if measures are needed for control. At the end of the growing season, harvested tomato fruits and plants are being rated for the incidence and severity of fruit, crown, and root diseases, as well as for root mass and weight. Health assessments on roots carefully extracted from soil will be based on general plant pathology diagnostic and culture-based techniques, and when appropriate, will utilize plant imaging technology (Assess 2.0; APS, Minneapolis, MN). Root health assessments are particularly important to document whether or not there is an impact of the BDM trial treatments on plant health and growth.

**Weed activity assessment**

To monitor weed populations in each treatment, an area of one meter squared has been marked in the center of each plot. Following mulch laying, weeds have been counted in the data collection area every two weeks. Six weeks following mulch laying, the weeds were collected, sorted into species, counted and weighed (fresh weight). As the mulch samples are removed for degradation/biodegradation analysis (see above), weeds will also be collected and counted within the exposed bed area. Weed sampling is not being performed in the non-mulch plots as they are being maintained weed-free. After sampling the mulches and removing the weeds, the exposed bed area is being covered with black plastic to prevent subsequent weed growth. The primary purpose of mulch is to suppress weed growth, and BDM durability throughout the growing season and BDM ability to block light to prevent weed germination is of key importance to crop growers.


**Crop yield and fruit quality assessments**

Crop yields are being recorded throughout the production season at all three locations. Tomato fruit are being harvested twice a week at the red-ripe stage, total yield is recorded, and then fruit is sorted into unmarketable and marketable categories and weighed. Marketable fruit is being sorted based on USDA grading factors for fresh tomato, weighed, counted, and average fruit weight is being calculated. Unmarketable fruit is being categorized by its predominant disorder or disease (i.e., cat facing, cracking, late blight, etc.). Fruit quality is being measured for fruit in the third cluster for all treatments: five tomatoes collected from this cluster per plot will be washed, and homogenized in a blender, and each sample will be tested for juiciness (fresh weight divided by dry weight), soluble solids (°Brix), titratable acidity, lycopene, and ascorbic acid contents (%citric acid). Lycopene content will be measured by spectrophotometry (Rodriguez-Concepcion & Gruissem, 1999), and ascorbic acid will be measured by titration using the method defined by the AOAC (1990).

**Mulch treatment degradation and biodegradation assessment**

Mulch samples are being collected from all locations at the time mulch is received from the manufacturer/supplier (Time 0), before mulch laying (Time 1), field samples during the growing season (Time 2), and field samples collected after the growing season is complete (Time 3). Samples are being evaluated to monitor primary physical/structural characteristics by measuring thickness, weight, pore size, flexibility, tensile strength, and elongation, and to determine if changes in physical and mechanical properties have occurred (Table 1). Additional samples will be exposed to simulated accelerated weathering to predict longevity. Evidence of chemical degradation is being assessed using Gel Permeation Chromatography, which measures the change in the average molecular weight.

**Table 1. Test methods and test equipment used to measure BDM properties.**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Test Method</th>
<th>Test equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>ASTM D5729-97 Test method for thickness of textile materials (10 specimens)</td>
<td>Digital Micrometer M121 (Testing Machines Inc.) (test range: 0.01mm ~ 20mm)</td>
</tr>
<tr>
<td>Weight</td>
<td>ASTM D3776-07 Test method for mass per unit area (weight) of fabric (5 specimens)</td>
<td>Balance (Denver Instrument BC BC 100) (test range: 0.001g ~ 210g)</td>
</tr>
<tr>
<td>Stiffness</td>
<td>IST 90.2 (01) Standard test method for stiffness of nonwoven fabrics using the Gurley Tester (5 specimens for each fabric direction)</td>
<td>Bending Resistance Tester (Gurley Precision Instrument) (test range: 2.78mg ~ 335328mg)</td>
</tr>
<tr>
<td>Tensile properties</td>
<td>ASTM D5035-06 Test method for breaking strength and elongation of textile fabrics (Strip method) (5 specimens for machine direction and 8 specimens for cross direction)</td>
<td>Instron 5565A (Instron Corporation) (test range: 0.4N ~ 5000N)</td>
</tr>
<tr>
<td>Porosity</td>
<td>No standard test method applies. (Ten specimens were tested following the equipment instruction manual)</td>
<td>Capillary Flow Porometer CFP-1200AEX (Porous Materials, Inc.) (test range: 0.013µm ~ 500µm)</td>
</tr>
<tr>
<td>Weathering resistance</td>
<td>ASTM G155-05a Standard practice for operating xenon arc light apparatus for exposure of non-metallic materials</td>
<td>Atlas Ci 3000+ Xezon Weatherometer</td>
</tr>
</tbody>
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In the field, mulch treatments are being visually assessed each week during the tomato growing season to measure environmental degradation. First, the number of rips, tears and holes are being counted for a
5-foot section in the center of each plot and the severity of each is being noted. Second, a Horfall-Barrett rating is being used to assign a percentage of degradation for each plot. To determine in situ decomposition rates of the various BDM treatments after crop harvest, in each BDM plot soil plus BDM pieces (cut into sizes to simulate tillage) are being buried 10 cm deep (to simulate tillage depth) in nylon mesh (50 µm) bags following final harvest. One bag per plot will be collected each month for 6 months to determine hydrolysis byproducts. At the final sampling time, one additional bag from each plot will be collected and analyzed to determine the mass of lost material. Additionally, promising BDM treatment entries will be evaluated for their capacity to undergo complete biodegradation under anaerobic and composting conditions according to ASTM D5338 (2003) and D5988-03. The first test examines biodegradability under laboratory testing conditions, while the second employs testing under soil conditions. The test results will also be evaluated using the specifications of ASTM D6400 to determine if the materials can be labeled “compostable.” This work is anticipated to take place in Years 2 and 3 of the project in collaboration with Dr. Ramani Narayan at Michigan State University.

**Conclusions**

As of Spring 2010, this project has now been developed, coordinated, and implemented at three locations across the U.S. Currently, Time 0 and Time 1 BDM trial entry samples have been collected from Washington, Tennessee and Texas, and laboratory analyses are complete. Time 2 samples are in the process of being collected and evaluated. Baseline soil samples have been collected and analyzed from all sites. Crop disease, pest, environmental, and yield data are being collected at all three locations and are being analyzed, and preliminary results are being considered. Year 1 soil assessment results will prove essential in estimating overall field variability and for assessing qualitative differences between locations across years. This project provides a unique opportunity for scientists to work across disciplinary boundaries, and to develop broad-based approaches for investigating potentially degradable and biodegradable materials which have good potential for practical utilization in horticultural systems. As Year 1 of the study concludes, and stakeholder and advisory committee input and feedback is obtained, modifications and improvements in our methodology for assessing degradation and biodegradation, is expected.

**Literature Cited**


Wszelaki, A., and M. Rogers (unpublished data 2009) found that tunnel grown tomatoes had a lower incidence of early blight, higher soluble solids content and higher lycopene values than field grown fruit.