



Performance and Adoptability of
Biodegradable Mulch

biodegradablemulch.org

ANNUAL REPORT 2015

Summary

Mulching with plastic materials is standard practice for specialty crop growers throughout the U.S. to reduce weeds and conserve water and soil, among many benefits. Unfortunately, most plastic mulch after use is stockpiled or burned illegally due to poor biodegradability of conventional plastic mulch materials, and limited recycling options, releasing harmful residues into the environment. Biodegradable plastic mulches (BDMs) have been developed to address the environmental deficiencies. However, concerns by growers and key intermediaries (e.g., suppliers and county extension agents) have limited the widespread use of BDMs based on perceived barriers: lack of knowledge, high cost, and unpredictable breakdown. To overcome these hurdles, we will implement an integrated and transdisciplinary science- and application-based research design to improve crop production, reduce post-harvest and environmental costs, and increase economic vitality for growers and consumers by using BDMs. Specifically, we will address multiple objectives: 1) evaluate the impacts of long-term BDM deployment (diverse scales of operation and climates) and environmentally-friendly disposal options (tilling into the soil vs. retrieving followed by composting) on soil quality, microbial communities, pests, diseases, and crop production; 2) assess the economic feasibility of BDM utilization (cost and benefits) for growers and consumers; and 3) engage with relevant stakeholders to increase interest in sustainable deployment and disposal of BDMs leading to increased adoption and economic and environmental benefits for growers and consumers.

Target Audience

Target audiences reached during the first year of the project (Yr1) included specialty crop growers and intermediaries, including extension specialists and agents; agricultural plastic film and mulch manufacturers; agricultural plastics recyclers; scientists in several different disciplines; and undergraduate and graduate students. Three key efforts to reach target audiences in Yr1 of the project focused on developing extension publications and handouts, the project website, and the project's 21-member Advisory Committee (AC). The public website provides basic information resources, e.g., descriptions of how soil impacts are analyzed and a glossary of



The target audience is varied and information products are tailored for the different audiences.

terms important to understand when considering use of biodegradable mulches, and will be a gateway to scientific outputs of the project. The project AC includes specialty crop growers and representatives of grower organizations; Extension specialists; experts in food safety, polymer science, mulch manufacturing, composting, materials standards, government policy, sociology, agricultural economics, soil microbiology, climate science, various horticultural specialties, and transdisciplinary research. Engaging the AC is paramount for our transdisciplinary project and was accomplished through team-wide meetings to review project research protocols and outreach plans, informal consultations with members via email and telephone, and participation of AC members in project Working Group (WG) meetings and conference calls. Members of the scientific community—particularly horticultural scientists and agricultural plastics researchers and industry representatives—were reached through two presentations at scientific conferences. Additional presentations have been accepted for scientific conferences occurring in fall 2015. Post-doctoral, graduate and undergraduate students were engaged in research, and students were targeted also through invited classroom lectures and other outreach and educational activities. Field-days and field tours engaged numerous specialty crop growers.

Products

1. Website

Project website: <http://biodegradablenmulch.org>

2. Journal Articles (includes proceedings of a conference, if conference is recurring)

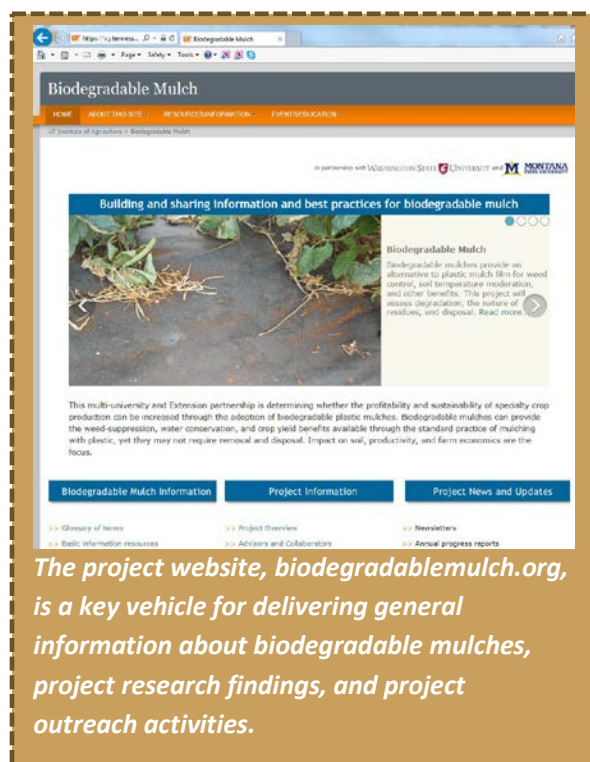
2.1 Published:

Miles, Carol. Biodegradable mulch film for organic production systems, American Society of Horticultural Science (ASHS) Annual Conference, New Orleans, LA, 5 Aug 2015.

Miles, C. 2015. Performance and adoptability of biodegradable plastic mulch for sustainable specialty crop production, The Second Agricultural Plastics Recycling Conference (APRC 2015) Proceedings. San Diego, CA, 21 Aug 2015.

2.2 Accepted:

Sintim, H.Y., Bandopadhyay, S., Ghimere, S., Flury, M., Bary, A.I., Schaeffer, S., DeBruyn, J.M., Miles, C., Inglis, D.: Soil quality, moisture, and temperature evaluation under different biodegradable mulches. American Society of Agronomy (ASA)-Crop Science Society of America (CSSA)-Soil Science Society of America (SSSA)-Annual Meeting, Minneapolis, MN, 15-18 Nov 2015.



Schaeffer, S. et al.: Assessing soil quality as affected by different mulches. American Geophysical Union (AGU)-Annual Meeting, San Francisco, CA, 14-18 Dec 2015.

2.3 Under review:

Jiang, J. T.L. Marsh, and P. Tozer. 2015. "Policy Induced Price Volatility Transmission: Linking the U.S. Crude Oil, Corn and Plastics Markets," *Energy Economics*. Under revision.

2.4 Awaiting publication:

Dharmalingam, S., D. Hayes, L. Wadsworth, R. Dunlap. 2015, Analysis of the time course of degradation for fully biobased nonwoven agricultural mulches in compost-enriched soil, *Textile Research Journal*, in press. doi: 10.1177/0040517515612358

3. Other publications

"Biodegradable Mulch Products." <http://biodegradablemulch.org>. University of Tennessee Institute of Agriculture (UTIA). July 2015. Online.

<https://ag.tennessee.edu/biodegradablemulch/Pages/factsheets.aspx>

Inglis, D., Miles, C., and Wszelaki, A. "Why Grow Pumpkins in a Biodegradable Mulch Field Study?" *Performance and Adoptability of Biodegradable Mulch* Report # FA-2015-01. June 2015. Online.

<https://ag.tennessee.edu/biodegradablemulch/Pages/factsheets.aspx>

Miles, C. and Scheenstra, E. "Biodegradable Mulch Film for Organic Production Systems." Washington State University (WSU) Mount Vernon Northwestern Washington Research and Education Center (NWREC) Report 102. May 2015.

Flury, M., Bary, A., DeBruyn, J., Schaefer, S., Sintim, H., and Bandopadhyay, S. "What Is Soil Quality and How Is It Measured?" *Performance and Adoptability of Biodegradable Mulch* Report # SE-2015-01. August 2015. Online.

<https://ag.tennessee.edu/biodegradablemulch/Pages/factsheets.aspx>

Andrews, N., DeVetter, L., and Miles, C. "Biodegradable mulch update – new NOP rule." *Oregon Small Farm News* X(3): 9 -12. Summer 2015. Online. <http://smallfarms.oregonstate.edu/newsletter>

"Biodegradable Mulch for Vegetable Production." WSU Extension. Online. June 2015. <http://ext100.wsu.edu/impact/biodegradable-mulch-for-vegetable-production/>



Team members have delivered several professional conference presentations and have manuscripts in review for publication in scientific journals, including those above.

McDaniels, P. "UT Institute of Agriculture Leads Multi-State Bioplastics Mulch Investigation." UTIA News & Announcements. February 2015. Online. <http://growingtennessee.com/features/2015/02/ut-institute-agriculture-leads-multi-state-bioplastic-mulch-investigation/>

Sanchez, Elsa. "Project addresses barriers to using biodegradable plastic mulches." Penn State Extension Vegetable, Small Fruit, and Mushroom Production News. April 2015. Online. <http://extension.psu.edu/plants/vegetable-fruit/news/2015/biodegradable-plastic-mulches>

4. Other products

Events:

First Annual Meeting of the Biodegradable Plastic Mulches SCRI CAP AC and project team, March 2015. Knoxville, TN. This meeting was an extended engagement of the project audiences for input and feedback; transdisciplinary training opportunity; and opportunity to develop project research protocols.

Monthly (or more frequent) conference calls of individual working groups, with AC members participating as available. These many conference calls ensure engagement of representatives of our target audiences and coordination of research across project sites and teams.

Team members have led numerous tours of the field test sites and given presentations to students and others. These products are reflected in the following table.

Date	Description	No. of Participants	Participant type
Tours of Field Sites and Presentations to Stakeholders			
28 Aug 15	General discussion on biodegradable plastic mulch with manufacturers and visit the research plots. UT East Tennessee Research and Education Center (ETREC), Knoxville, TN	1	Mulch manufacturer rep
10 Aug-15	General discussion on biodegradable plastic mulch with manufacturers and visit the research plots. WSU NWREC, Mount Vernon, WA	3	Mulch manufacturer reps
7 Aug 15	Polythene plastic mulch vs. biodegradable plastic mulch. Seattle Goodwill Industry tour, WSU NWREC, Mount Vernon, WA	30	Tour
6 Aug 15	General discussion on biodegradable plastic mulch with manufacturer and visit the research plots. WSU NWREC, Mount Vernon, WA	1	Mulch manufacturer
10 Jul 15	Biodegradable plastic mulch use for pumpkin production in Northwest Washington and mulch biodegradation. Skagitonians to Preserve Farmland summer farm tour, WSU NWREC, Mount Vernon, WA	25	Farmer tour

9 Jul 15	Miles, C. et al. Biodegradable plastic mulch use for pumpkin production in Northwest Washington and mulch biodegradation. WSU NWREC Field Day, WSU NWREC, Mount Vernon, WA.	90	Field Day (farmers and intermediaries)
31 Mar 15	Miles, C. Biodegradable mulch in vegetable production. Presentation at Clallam County (WA) small farm seminar.	15	Commercial growers and home gardeners
13 Nov 14	Douglas G. Hayes [invited speaker], Bioplastics: sorting through the waste to find the truth, Advanced Oleochemical Technology Division (AOTD) of the Malaysian Palm Oil Board (MPOB), Putrajaya, Malaysia,	30	Scientists and researchers
STUDENT EXPOSURE to Biodegradable Mulches, Project Objectives, and Transdisciplinary Research			
25 Aug 15	D. Hayes et al. Biodegradable mulch-related projects for Biosystems Engineering capstone design project for undergraduate seniors	3	Presentation
14 Jul 15	Miles, C. et al. An overview of biodegradable plastic mulches in vegetable production and mulch biodegradation. Evergreen State College undergraduate field visit class: Practice of organic farming, WSU NWREC, Mount Vernon, WA	35	Student tour
19 May 15	Biodegradable plastic mulch use for pumpkin production in Northwest Washington and mulch biodegradation. Graduate student statewide tour, WSU NWREC, Mount Vernon, WA.	45	Student tour
30 April 15	Tozer, P. New agricultural technologies and their effects on products and markets. Presentation to Washington State University Agricultural Economics class.	30	Presentation
17 Oct 14	Inglis, D., Miles, C., and Marsh, T. Achieving transdisciplinary success: Biodegradable mulches for specialty crops produced under protective covers. Presentation to Washington State University Ag & Food Systems graduate class.	30	Presentation

Outputs:

- One MS student in Agricultural Economics (engaged in project research one semester; Advisor: Velandia; Student Matthew Johnson).
- “Meeting Assessment Survey” for implementation at Advisory Committee Annual Meeting. March 2015.
- “Change in Knowledge & Practice” survey for persons engaged in project informational/educational/training events. May 2015.

- Model of biodegradable plastic mulch supply chain and markets (producer to consumer).
- Dataset: Physicochemical analysis of biodegradable mulches during storage
- Data and Research Material: Environmental data (air temperature, soil temperature, precipitation, solar radiation, wind speed and direction, soil moisture, drainage rates)
- Data and Research Material: Soil quality data for spring soil quality assessments.
- Videos of soil quality assessment, composting, and mulch burial. Footage will be used in Yr2 Extension/Outreach products.
- Videos addressing project objectives and potential impact. Footage will be used in student training.
- Video addressing transdisciplinary research. Footage will be used in student training.
- Protocol: Field Plot Protocol. Developed, thoroughly vetted, and systematically updated throughout the course of the experiment, the experimental field plot protocol addresses all aspects of trial layout, data collection, cultural practices, and trial management. It covers the seeding, transplanting, growing, harvesting, storage, winter cover cropping, and sampling. This protocol ensures comparability of data at the two research sites, as well as coordination of activities across research objectives.
- Protocol: Developed research protocol for measuring mulch degradation in the soil.
- Protocol: Developed plastics analysis protocols. (with AC members' review)
- Protocol: Developed a protocol for determination of authorship for publication and presentations.

Accomplishments

Mulching with plastic materials is standard practice for specialty crop growers throughout the U.S. to reduce weeds and conserve water and soil, among many benefits. Currently the market for agricultural films is 4.4 million kg, of which 40% is used as mulch. Growth of 7.6% (compound annual growth rate) is projected by 2019. Unfortunately, after use most plastic mulch is stockpiled or burned because of poor biodegradability of conventional plastic mulch materials, and limited recycling options, releasing harmful residues into the environment. Biodegradable plastic mulches (BDMs) have been developed to address these environmental deficiencies.

However, concerns by growers and key intermediaries (e.g., suppliers and county Extension agents) have limited the widespread use of BDMs based on perceived barriers: lack of knowledge, high cost, and unpredictable breakdown. To overcome these hurdles, we are implementing an integrated and transdisciplinary science- and application-based research design to improve crop production, reduce post-harvest and environmental costs, and increase economic vitality for growers and consumers by using BDMs. Specifically, we are 1) evaluating the impacts of long-term BDM deployment (diverse scales of operation and climates) and environmentally friendly disposal options (tilling into the soil vs.



retrieving followed by composting) on soil quality, soil microbial communities, pests, diseases, and crop production; 2) assessing the economic feasibility of BDM utilization (cost and benefits) for growers and consumers; and 3) engaging with relevant stakeholders to increase interest in sustainable deployment and disposal of BDMs leading to increased adoption and economic and environmental benefits for growers and consumers.

The project is on schedule to produce reliable data and information to better inform specialty crop growers, the policy/regulatory community, and consumers about biodegradable mulches. The first year of a multi-year field trial was conducted, with agricultural productivity and soil quality data collected. This first year's field trial produced mulch samples for laboratory analysis and helped to generate economics data collection tools that will be used to help growers determine the feasibility of using biodegradable mulches on their farms. Students being trained through this project assisted with deployment of the experimental design, data collection and analysis and will be prepared to address future agricultural production issues using transdisciplinary research. Team research scientists and Extension specialists receive guidance from the 21-member Advisory Committee, which assures that project research has scientific validity and practical application for specialty crop growers.

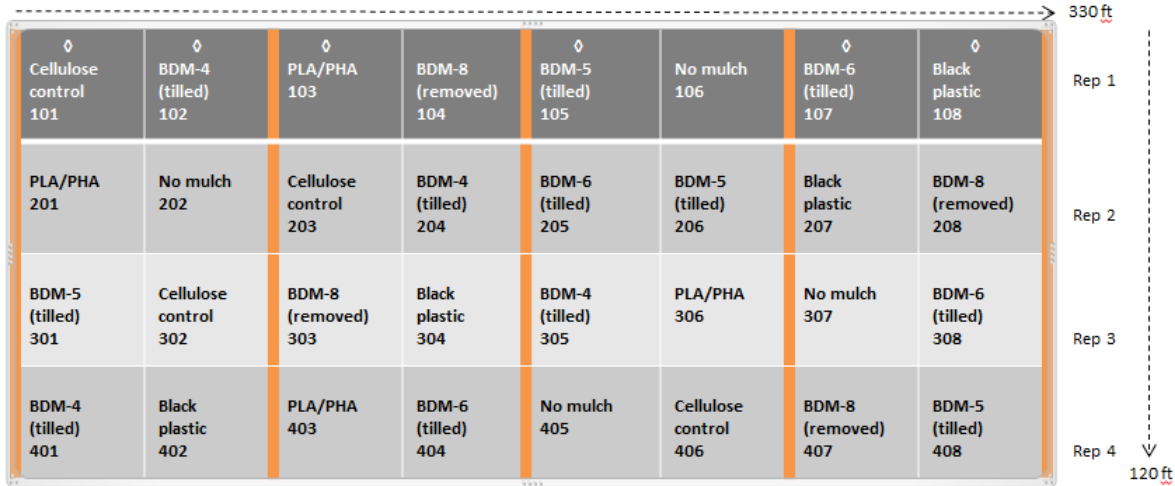
Goal A. Evaluate the impacts of long-term use of BDMs on 1) the soil ecosystem (i.e., soil quality, microbial communities, and long-term storage of carbon); and 2) on a specialty crop production system along with its associated growers and consumers.

Significant coordination among the Field Activities WG and with other team members and advisors was essential in designing the experimental field trial, which is central to the entire project. The trial involves two site locations (Knoxville, TN and Mount Vernon, WA) that are characterized by different soils, geographies and climates. The trial will be carried out over five growing seasons. The plot design incorporates several different experiments, including effects of mulch treatments on: pumpkin yield and quality; pumpkin diseases, insects and weeds; mulch weathering; and soil chemical and physical quality parameters when mulches are tilled-into the soil or removed for composting after the growing season. The trial design further accommodates environmental monitoring equipment, lysimeters to collect soil leachate, mulch sampling, a buried mulch study, and collection of economic data related to mulch laying and stockpiling. The field plot map that follows is a representation of the rows designated for some of the specific research purposes.



SCRI BDM Field Trial: Addendum for TN spray equipment

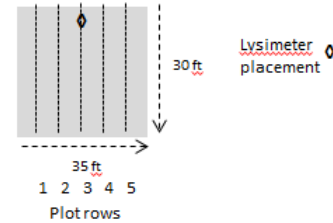
Experimental field plot design for long-term biodegradable mulch experiment, Knoxville, TN : randomized complete block design; 30 x 35 ft plots of 5 rows; outer rows 1 and 5 (for borders); inner rows 2 and 4 (randomly assigned to buried mesh bag and mulch accumulation studies); center row 3 (for fruit quality, weed, yield, soil quality data; rows 2, 3, 4 for pest and disease surveys. Note: In WA only, \diamond = lysimeter, placed 2 m from end of row 3 in selected Rep 1 plots.



Treatment descriptions:

1. 106, 202, 307, 405. Bare ground (no mulch); no treatment control; soil tilled
2. 108, 207, 304, 402. Non-biobased, conventional "polyethylene plastic" (1 mil thick black film; Clearwater Supply, Inc.); non-biodegradable negative control; retrieved from the field
3. 101, 203, 302, 406. Fully biobased "cellulosic" paper BDM (Sunshine Paper Co.); positive BDM control; tilled into the soil
4. 102, 204, 305, 401. Partially biobased "BDM-4", BioAgri, (BioBag, Palm Harbor, FL); commercial BDM product; tilled into the soil
5. 105, 206, 301, 408. Partially biobased "BDM-5" (Custom Bioplastics, Burlington, WA); commercial BDM prototype; tilled into the soil
6. 107, 205, 308, 404. Partially biobased "BDM-6", (BASF, Ludwigshafen, Germany); commercial BDM prototype; tilled into the soil
7. 103, 201, 306, 403. Fully biobased "PLA/PHA" film (NatureWorks and Metabolix), experimental nonwoven BDM; tilled into the soil
8. 104, 208, 303, 407. Partially biobased "BDM-8" (BioAgri), retrieved from the field

Note: Except for Trt #2 and #8, mulches are tilled into the soil at the end of each growing season



Considerable coordination also occurred among Field Activities WG members and between other WGs in the implementation of the 2015 trial across the two locations. To ensure good communication, a detailed written protocol on all aspects of trial lay-out, data collection, cultural practices, and trial management was assembled, thoroughly vetted, and systematically updated throughout the course of the experiment. It covers the seeding, transplanting, growing, harvesting, storage, winter cover cropping, and sampling. Conversations and communications occurred with Extension/Outreach WG (videography for outreach products), Soil Ecology WG (installation of monitoring equipment, soil and mulch sampling schedule), Plastics Analysis WG (cleaning methods and in-situ mulch sampling), and Supply Chain and LCA WG (economic data for crop budgets and LCA).

In Yr1, the Field Activities WG secured a 5-year supply of mulches to be used in trials for the subsequent years at both sites (Knoxville, TN, and Mount Vernon, WA), to insure that comparisons can be made using mulches manufactured from the same feedstocks. These 'future' mulches are being stored indoors in laboratories at both sites under similar climate and light controlled conditions, with the temperature and relative humidity being monitored on a monthly basis, to ensure uniformity and maintain quality over the life of the project. The Plastics Analysis WG will test the stored mulches during the winter months of each year for changes in physicochemical properties. The Field Activities WG also secured the same seed lot of pumpkin cultivar Cinnamon Girl for a similar reason.

The Yr 1 field trial was initiated May 2015 (the summer growing season), which is near the end of the first year of project activity. The WG members have prepared plots, laid mulches, and planted and maintained pumpkin plants. Throughout the growing season the team also collected and recorded disease, insect, weed, and mulch performance data, and assisted the other WGs with multiple tasks. Data entry and analysis will begin fall 2015, but in-field observations suggest that there will be many significant differences when the treatment and site comparisons are made. The Field Activities WG publication plan targets the draft of a publication of Yr1 trial results in fall 2015.

To evaluate the impacts of BDMs on the soil ecosystem, the Soil Ecology WG team members developed research protocols to ensure agreed upon research methods for field sampling, data collection and sample storage methods. To record environmental factors at the Washington and Tennessee field test site, the team installed instrumentation: soil temperature and moisture sensors, lysimeters, and weather stations. Site-specific calibrations were performed for soil moisture sensors. Instrumentation was installed in such a way that it can be removed for field operations, such as tillage and planting. This required some modification of standard instrument designs, particularly for the permanently installed lysimeters, which had to be placed well below tillage depth. Environmental data are collected and logged automatically in hourly intervals. Data are uploaded to a server via a Cellular network and are accessible to the entire project team in real-time. Data for the first growing season have been successfully monitored and recorded, and the instruments have been deployed for the fall and winter season.



For in-situ studies of soil quality, microbial community, carbon storage and leaching, and mulch particle leaching, the team conducted pre-season/baseline soil sampling at both field locations in May 2015. All sampling and tests will be repeated after the pumpkin harvest in September 2015, and data from the two time periods will be compared, with similar comparisons planned for Yr2, Yr3, and Yr4 to assess changes in soil health and soil quality. In addition to sample collection, progress included testing methods to identify microorganisms responsible for biodegradation. The in-situ soil quality assessment was documented for an Extension publication and video.

A second objective of the Soil Ecology research is to quantify the degradation of weathered BDMs after incorporation into the soil. Toward this objective, the team tested several mesh bags—the bags in which post-use BDMs will be placed for subsequent quantification of mulch degradation—for contact angles to evaluate hydrophobicity. Based on these tests, the Soil Ecology WG selected Nylon as the material for the mesh bags, and a mesh size of 250 micrometer was chosen to let microorganisms freely pass, but still keep smaller mulch pieces inside the mesh bags. Mesh bags were manufactured from large Nylon sheets, with polystyrene threads used for the sewing. After harvest in August/September 2015, mulch pieces will be sampled from the field and then cut and placed into the mesh bags. Each mulch piece will

be recorded photographically and analyzed for size and surface area with digital image processing. Mesh bags will be deployed to the field again in October 2015. Mesh bags were placed at 10-cm depth into the soil and will be removed every 6 months to track mulch degradation over time.

Progress toward quantifying degradation of BDMs during composting comprised a preliminary test conducted primarily to verify methods and analysis of that preliminary data. We placed test mulch pieces into mesh bags and buried the pieces in compost. All mulches tested were completely degraded after 4 months of composting. Based on the preliminary tests, we will conduct a time series of composting, with mulch pieces removed every two weeks to see how long it will take for complete decomposition of mulches in a compost pile. Mesh bags and mulch pieces for the first composting study have been prepared, and the composting study with the experimental mulches will start in late October 2015. The compost pile will be typical of a small farm's compost.

Goal B. Identify BDM degradation mechanisms (e.g., changes at the macroscopic and molecular levels) and interrelationships among the life stages of BDMs: their origin (fossil fuel-derived vs. biobased), service life (role of weathering), and potentially sustainable end-of-life outcomes (ambient soil degradation vs. retrieval followed by composting).

With assistance of AC, the Plastics Analysis WG developed a protocol for the conduction of physicochemical analyses of BDMs, designed to provide useful information without infringing on proprietary information related to the BDM products, such as their chemical composition. The protocol includes mechanical strength testing (e.g., weight, thickness, tensile strength, and elongation) and chemical testing (colorimetry, FTIR spectroscopy, gel permeation chromatography, elemental analysis (carbon content), and thermogravimetric analysis (to determine the % moisture and adsorbed soil). For the PLA+PHA experimental BDM, NMR and DSC will be included in the chemical analysis. The protocol also includes methodology for the preparation of the BDMs, including their cleaning and the cutting of samples for testing.



The Plastics Analysis WG performed physicochemical testing on the BDMs as received from the manufacturer, per the protocol described above, in March. These tests will be performed yearly, to ensure the absence of BDM degradation during their storage. BDM samples were sent to Michigan State University's School of Packaging to perform simulated weathering, or weatherometry in July, 2015. The weatherometry-treated samples are currently undergoing testing. We collaborated with the Field Activities and Soil Ecology WGs to develop the protocol of field activities occurring at the time for harvesting of pumpkins (projected to occur in September), which includes the retrieval of BDMs from the field sites, the shipping to the Project Director Douglas Hayes' lab, the analysis of soil

microorganisms by co-PI Jennifer DeBruyn's lab, followed by the return to the Hayes lab for cleaning and physicochemical analyses.

To determine the inherent biodegradability of BDMs measured by ASTM D5338 (composting) and 5988 (ambient soil conditions), the apparatus was assembled. Initial tests will take place in December, 2015. Ms. Nurul Farhana Omar, a PhD student, will lead the testing. Obtaining a deeper understanding of the biodegradation process, a white paper has been generated for collaborative experiments that will involve the Co-PIs Jennifer DeBruyn and Sean Schaeffer's laboratories, and serve as part of Ms. Omar's PhD dissertation. Initial experiments will commence in late 2015, examining firstly the effect of soil temperature. The same three laboratories also collaborated on writing a draft for a Biosystems Engineering Senior (undergraduate) capstone design project that focused upon improved machinery design for the plowing-in of BDMs and/or the machine-laying of BDMs. The design description was not selected by any of the student groups, although one group expressed interest.

Goal C. Compare diverse scales of operation (field vs. laboratory studies), climate regions, and methodology for evaluating the soil degradation of BDMs to improve performance regulations.

The data for these comparisons are being built through activities and accomplishments associated with the first two objectives. In the next year of the project, data analysis will begin to address this objective.

Goal D. Identify steps along the supply chain for BDMs to better understand the bridges and barriers to BDM adoption by growers and intermediaries (e.g., extension agents, agricultural input suppliers, and crop consultants,) as related to economic relevance and regulation; and educate growers, intermediaries, consumers, and the general public on BDMs and biobased mulches and plastics, especially as related to sustainable and organic agriculture.

Research to better understand bridges and barriers to BDM adoption is scheduled (as per the proposal) to begin in Yr2 of the project. Preliminary discussions about the type of producers to engage in the survey research, the criteria for selecting farm case studies, and the goals of the focus groups occurred primarily during the Spring 2015 project meeting. Several AC members are participating in these discussions.

Efforts to educate our various audiences in Yr1 of the project included our public website, a field-day presentation in Washington State attended by 30 specialty crop growers, several trial plot tours, various presentations and classroom lectures about the project's research methods and objectives, and a number of university, Extension, and grower organization news articles explaining the project's aims. The field-day, presentations, and tours are captured in the table in the Products/Events sections. News articles are included as "other publications" in the Publications section of this report.

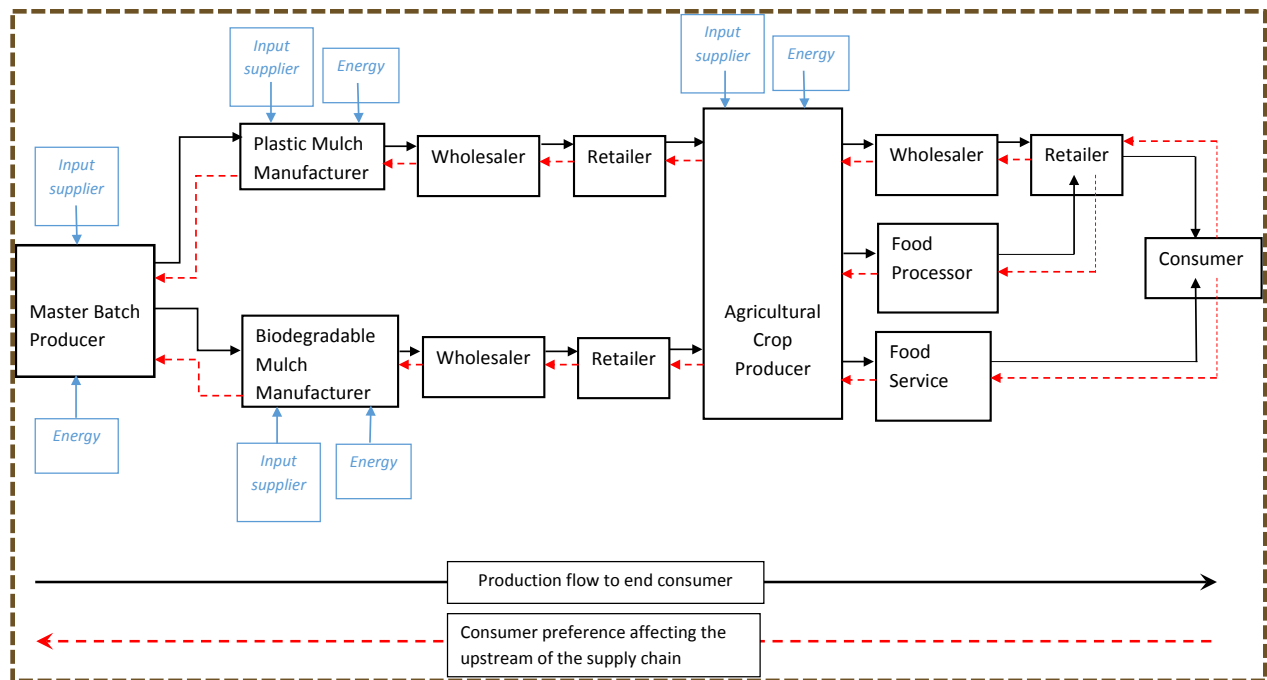


Goal E. Assess the economic feasibility of agricultural products grown with BDM technologies through the entire supply chain to consumers, and identify potential BDM-associated disease and pest problems.

Considerable information collection and preparatory work was underway or completed in Year 1. To guide the consumer survey, enterprise budgets, and data collection for the LCA, literature reviews were completed to address the: (1) LCAs relevant to biodegradable mulch; (2) markets and prices for biodegradable plastics and materials; and (3) willingness to pay relevant to consumers’ preference for environmentally favorable technologies and products.

Supply Chain and LCA WG members worked with the Field Activities WG members to finalize data collection protocols from field activities that will be used in crop enterprise budgets and identify the data needed to estimate BDM mulch use costs. Collection of farm labor data relevant to mulch films (traditional plastic and biodegradable) occurred during the summer field season at the TN test site and at production farms.

LCA team members: (1) drafted consumer survey to assess the willingness to pay for agricultural products grown with BDMs; (2) developed a flowchart of supply chain and markets involved in biodegradable plastic mulches (shown below); and (3) drafted an Excel spreadsheet version of a mulch calculator for use and disposal in agriculture. Next the survey will be pre-tested and fielded, supply chain and markets model further developed, and mulch calculator completed.



Because disease and pest issues affect economic feasibility, project research focuses on these issues also. The data to identify potential BDM-associated disease and pest problems are being built through the field trial discussed in Project Objective A. At the end of Yr1, the field season was still ongoing; thus data are not yet available.

Goal F. Interact with a community of stakeholders (consumers, growers, intermediaries, regulators, composters, and scientists) to increase interest in sustainable deployment of BDMs throughout the U.S. and worldwide.

In initiating the project, the primary interactions with our stakeholders occurred through their representatives on the AC, the makeup of which is detailed in the “Target Audience” section.

At one field demonstration given by a team member about BDMs (see additional description at Goal D, above), the “exit survey” produced by the Project Evaluation WG showed that, after the event, the participants’ change in both knowledge and awareness of BDMs was positive and statistically significant, but the possibility that participants would adopt BDMs on their farms was not changed significantly. The Project Evaluation WG will compare these early results with results from later field demonstrations which will be associated with project-based information about BDM performance that will reduce growers’ uncertainty. Additional field tours and presentations to growers, intermediaries, and other stakeholders are outlined in the table of presentation and tours in the “Products: Events” section.

Engagement of stakeholders also occurred through the public website where the team is building both basic information sources that are accessible to growers and consumers and scientific publications relating to BDMs and produced by team members.

Goal G. Educate and train undergraduate and graduate students, postdoctoral research assistants, and principal investigators on skills needed to work on transdisciplinary research problems.

Transdisciplinary research integrates research across disciplines and significantly involves stakeholders in the design and implementation of the project. Thus, integration and engagement are keys to project success. To ensure success, at the March 2015 meeting the team participated in a transdisciplinary research training session led by sociologist and project advisor Douglas Jackson Smith. Two separate sessions (0.5 and 2.0 hours) engaged 12 AC members and 24 team members including 4 students. The training focused on overcoming transdisciplinary research barriers by building mutual understanding of disciplinary skill, theory, and language; building respect; expecting and accepting opportunities for collaboration; building institutional rewards for collaboration; and minimizing the transaction costs of collaborating, and building social ties through informal activities. Discussion and training exercises focused on these points.



Building upon this training, the team in Yr1 did the following:

- Team members engaged in planning and update conference calls of Working Groups outside their primary affiliation
- AC members identified the WGs with which they be more actively involved and have since participated in planning/update video conferences and conference calls, reviewed draft publications, visited the trial plots, and written news articles about the project
- Working Group members worked on activities outside their research area (e.g., social scientists and bioengineers participated in horticulture and soil science data collection; horticulturists are involved in identifying farms for technology adoption case studies).
- Team leaders from across all working groups collaborated on a publication that integrates various disciplinary perspectives and knowledge of BDM use and acceptance
- Challenged each WG (research focus area) to develop at least one Extension/Outreach product in Yr1 – Yr2.



Opportunities for Training and Professional Development

Nine undergraduate students have assisted with research activities in Yr1, learning field and laboratory research methods and assisting with the annual meeting and field days. The project also has five PhD students and four Masters of Science students conducting research and developing outreach products to meet project objectives. Additionally, two Post-Doctoral assistants joined the project in August 2015.

All project PIs and 12 AC members participated in the March 2015 meeting that involved two opportunities for professional development. As noted previously, this project's research and outreach objectives are being met through transdisciplinary activities. Inter-WG sessions occurred between all WGs at the meeting so that members could become familiar with all WG objectives, be introduced to each WG's research plans and methods, coordinated activities and outputs, and discern opportunities and needs for ongoing dialogue. Also, as the March 2015 meeting, all PIs and the participating AC members engaged in a training in Transdisciplinary Research. Details of this professional development are outlined in the "Accomplishment, Goal G" section, above.

Dissemination of Results

Dissemination of results is incorporated into two of our project objectives (Goal D and F). Efforts to disseminate results included two publications in conference proceedings (and the associated presentations) and two manuscripts submitted for publication in professional journals (one is awaiting

publication and the other under review). Three Extension-type publications addressing various aspects of the project research also were produced and are available on the project and WSU Extension websites. Other efforts to disseminate results and engage our communities of interest included our public website <http://biodegradablenmulch.org> , a field-day presentation in Washington State attended by 30 specialty crop growers, several trial plot tours, various presentations and classroom lectures about the project's research methods and objectives, and a number of university, Extension, and grower organization news articles explaining the project's aims. The field-day, presentations, and tours are captured in the table below. News articles are included as "other publications" in the "Publications" section of this report.

Next Reporting Period

Analyses are underway of all the Yr1 environmental, horticultural, soil, and BDM performance data, and Yr1 horticultural results will be submitted for publication in Yr2. Laboratory analysis of soils and field-applied BDMs also are underway. Because long-term changes in productivity and soil are a project focus, multiple years of field trials are planned. The second field trial will begin in May 2016. In Yr2, the surveys to assess growers' perceptions of adoption barriers and consumers' awareness and interest will be conducted. The first set of farm case studies (with associated field demonstrations) will occur at locations in TN and WA. LCA will continue in Yr2, as will producer cost and benefits assessment. Several Extension publications are in progress or planned for Yr2, and a number of scientific presentations have been submitted to or are planned for conferences. Resources and information will be added to the project website.

Changes

There are no significant changes in the research schedule, goals, or research compliance protocols in Yr1. The only delay in expenditure resulted from delays in identifying one post-doctoral research associate and one PhD student at Washington State University and one Masters student at the University of Tennessee. These personnel have now been hired, and the delays will not have significant impact on rate of expenditure because the scheduled activities proceeded with the assistance of research associates and undergraduate students.

In the first few months of the project, the team accepted a kind offer from Metabolix, Inc., to prepare a PLA+PHA film to serve as the "experimental BDM." (This is in lieu of the team preparing a Meltblown nonwoven material as proposed). Co-PI Larry Wadsworth coordinated the preparation of the BDM with assistance from Techmer, NatureWorks, and Metabolix in procuring the feedstocks and carbon black dye and in the preparation of the BDM film.

The project is funded through August 2016 (two-years), with opportunity to reapply for funding for an additional three years (through August 2019). Data from the second field season will be produced through September 2016 and will require no-cost extension if the team does not secure year 3-5 funding.