Title:	Performance and Adoptability of Biodegradable Plastic Mulch for Sustainable Specialty Crop Production

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Non-Technical 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.

Accomplishments

Major goals of the project

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.
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).
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.
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.

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

What was accomplished under these goals?

Plastic mulch films that specialty crop growers use to reduce weeds and conserve water and soil, are stockpiled or burned subsequent to use because of poor biodegradability conventional plastic mulch materials and limited recycling options, releasing harmful residues into the environment. Concerns of growers, suppliers and county Extension agents about existing biodegradable mulches (BDMs) have limited their widespread use based on perceived barriers: lack of knowledge, high cost, and unpredictable breakdown. To overcome these hurdles, we are implementing a 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.
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 begun. Researchers and Extension specialists collected data, produced mulch samples for laboratory analysis, built economic data that will help growers determine the feasibility of using biodegradable mulches on their farms, and disseminated information. Students collected and analyzed data and will be prepared to address future agricultural production issues using transdisciplinary research.

A. Evaluate the impacts of long-term use of BDMs on 1) the soil ecosystem and 2) a specialty crop production system along with its associated growers and consumers.
Significant coordination among the team members and advisors was essential in designing the experimental field trial, which is central to the entire project. The 5-year trial involves site locations in Knoxville, TN and Mount Vernon, WA and is guided by the protocol included in "Other Products." The plot design incorporated numerous experiments to assess 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 accommodates environmental monitoring equipment, soil leachate collection, mulch sampling, a buried mulch study, and collection of economic data related to BDM use.
The Yr 1 field trial was initiated May 2015. The WG members prepared plots, laid mulches, and planted and maintained pumpkin plants, and collected and recorded disease, insect, weed, and mulch performance data. In-field observations suggest that there will be many significant differences when the treatment and site comparisons are made (draft publication in fall 2015).
The Soil Ecology WG team members developed research protocols (See "Other Products") and recorded environmental factors at field test sites using soil temperature and moisture sensors, lysimeters, and weather stations.
For studies of soil quality, microbial community, carbon storage and leaching, and mulch particle leaching, the team conducted baseline soil sampling in May 2015. Data will be compared to post-harvest data to assess changes in soil health and soil quality. Progress included testing methods to identify microorganisms responsible for biodegradation.
Preliminary tests of degradation-via-composting verified methods and showed that all mulches tested (in mesh bags, buried in compost) were completely degraded after 4 months. Consequently, the research protocol requires mulch pieces be removed every two weeks.
B. Identify BDM degradation mechanisms.
The Plastics Analysis WG (PA WG) performed physicochemical testing on the test BDMs per the Plastics Analysis Protocol described in "Other Products." BDM samples were sent to Michigan State University's School of Packaging to perform simulated weathering in July, 2015. To determine the inherent biodegradability of BDMs measured by ASTM D5338 (composting) and 5988 (ambient soil conditions), the apparatus was assembled. PA and Soil Ecology WG members developed a white paper for collaborative experiments to deepen the understanding of the biodegradation process.
C. Compare diverse scales of operation, climate regions, and methodology for evaluating the soil degradation of BDMs to improve performance regulations.
See Goals A and B.
D. Identify bridges and barriers to BDM adoption by growers and intermediaries; and educate growers, intermediaries, consumers, and the general public on BDMs.
Research 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 and involved several AC members.
Efforts to educate our various audiences in Yr1 are discussed in "Dissemination."
E. Assess the economic feasibility of agricultural products grown with BDM technologies through the entire supply chain to

consumers.
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 (1) worked with the Field Activities WG members to identify the data needed to estimate BDM mulch use costs; (2) collected farm labor data relevant to BDMs at the TN test site and at production farms; (3) drafted consumer survey to assess the willingness to pay for agricultural products grown with BDMs; (4) developed a model of supply chain and markets involved in biodegradable plastic mulches; and (3) drafted an Excel spreadsheet version of a mulch calculator for use and disposal in agriculture.
F. Interact with a community of stakeholders to increase interest in sustainable deployment of BDMs throughout the U.S. and worldwide.
Significant interactions with our stakeholders occurred through their representatives on the AC (see "Target Audience."). Field tours and presentations are detailed in "Dissemination."
At a BDM field demonstration, the "exit survey" showed the event changed participants' knowledge and awareness of BDMs positively and significantly, but the possibility that participants would adopt BDMs on their farms was not changed significantly. The Project Evaluation WG will compare these results to results from later field demonstrations that will involve project-based information about BDM performance.
G. Educate and train project team on skills needed to work on transdisciplinary research problems.
"Transdisciplinary" research integrates across disciplines and significantly involves stakeholders. Twelve AC members and 24 team members including 4 students participated in a training session that focused on overcoming transdisciplinary research barriers by building mutual understanding of disciplinary skill, theory, and language; expecting and accepting opportunities for collaboration; building institutional rewards for collaboration; and minimizing the transaction costs of collaborating. Other training occurred through:

- AC members participated in conference calls, reviewed draft publications, and visited trial plots
- WG members worked on activities outside their research area (e.g., social scientists and bioengineers participated in horticulture and soil science data collection).
- WG leaders collaborated on a publication that integrates various disciplinary perspectives and knowledge of BDM use and acceptance

What opportunities for training and professional development has the project provided?

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 Accomplishments, Goal G section, above.

How have the results been disseminated to communities of interest?

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://biodegradablemulch.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.

What do you plan to do during the next reporting period to accomplish the goals?

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.

Participants

Actual FTE's for this Reporting Period

Role	Non-Students or faculty	Students with Staffing Roles			Computed Total by Role
		Undergraduate	Graduate	Post-Doctorate	
Scientist	4.4	0.5	2.2	0.1	7.2
Professional	0.4	0	0	0	0.4
Technical	3.3	0.9	0	0	4.2
Administrative	0	0	0	0	0
Other	0	0	0	0	0
Computed Total	8.1	1.4	2.2	0.1	11.8

Student Count by Classification of Instructional Programs (CIP) Code

Undergraduate	Graduate	Post-Doctorate	CIP Code
5	3	1	01.12 Soil Sciences.
2	1	1	01.11 Plant Sciences.
	2		01.01 Agricultural Business and Management.
	2		45.06 Economics.
		1	45.13 Sociology and Anthropology.
1			52.02 Business Administration, Management and Operations.

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 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

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2015	YES

Citation

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

Type	Status	Year Published	NIFA Support Acknowledged
Websites	Published	2015	YES

Citation

http://biodegradablemulch.org

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Published	2015	YES

Citation

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.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Accepted	2015	YES

Citation

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.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Accepted	2015	YES

Citation

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.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Under Review	2015	YES

Citation

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.

Type	Status	Year Published	NIFA Support Acknowledged
Journal Articles	Awaiting Publication	2015	YES

Citation

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

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2015	YES

Citation

"Biodegradable Mulch Products." http://biodegradablemulch.org. University of Tennessee Institute of Agriculture (UTIA). July 2015. Online. https://ag.tennessee.edu/biodegradablemulch/Pages/factsheets.aspx

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2015	YES

Citation

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

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2015	YES

Citation

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.

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2015	YES

Citation

Flury, M., Bary, A., DeBruyn, J., Schaefer, S., Sintim, H., and Bandopadyay, 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

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2015	YES

Citation

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

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2015	YES

Citation

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

Type	Status	Year Published	NIFA Support Acknowledged
Other	Published	2015	YES

Citation

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/

Type	Status	Year Published	NIFA Support Acknowledged
Other	Other	2015	YES

Citation

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

Other Products

Product Type

Other

Description

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.

Product Type

Other

Description

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.

Product Type

Other

Description

Eight field days, field site tours, and presentations engaged a total of 195 members of our target audience. Specific details are outlined in the Accomplishments Section.

Product Type

Other

Description

Five student tours of the field sites and invited classroom lectures introduced the research objectives and methodologies to 143 students. Specific details are outlined in the Accomplishments Section.

Product Type

Other

Description

One MS student in Agricultural Economics (engaged in project research one semester; Advisor: Velandia; Student Matthew Johnson).

Product Type

Evaluation Instruments

Description

“Meeting Assessment Survey” for implementation at Advisory Committee Annual Meeting. March 2015.

Product Type

Evaluation Instruments

Description

“Change in Knowledge & Practice” survey for persons engaged in project informational/educational/training events. May 2015.

Product Type

Models

Description

Model of biodegradable plastic mulch supply chain and markets (producer to consumer). Identifies all inputs and outputs and their relation.

Product Type

Data and Research Material

Description

Dataset: Environmental data (air temperature, soil temperature, precipitation, solar radiation, wind speed and direction, soil moisture, drainage rates)

Product Type

Data and Research Material

Description

Dataset: Soil quality data for spring soil quality assessments.

Product Type

Audio or Video

Description

Videos of soil quality assessment, composting, and mulch burial. Footage will be used in Yr2 Extension/Outreach products.

Product Type

Audio or Video

Description

Videos addressing project objectives and potential impact. Footage will be used in student training.

Product Type

Audio or Video

Description

Video addressing transdisciplinary research. Footage will be used in student training.

Product Type

Protocols

Description

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 lay-out, 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.

Product Type

Protocols

Description

Developed research protocol for measuring mulch degradation in the soil.

Product Type

Protocols

Description

Plastics Analysis Protocol. Protocol for conducting 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). The protocol also includes methodology for the preparation of the BDMs, including their cleaning and the cutting of samples for testing.

Product Type

Protocols

Description

Developed a protocol for determination of authorship for scientific and Extension publications and presentations.

Changes/Problems

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 a no-cost extension if the team does not secure year 3-5 funding.