

Sustainable Mulch **MANAGEMENT** *Plastic Mulches in Horticulture Production*

Fall 2026
Volume 5, Issue 3



Improved End-Of-Life of Plastic Mulches

smallfruits.wsu.edu/plastic-mulches/



In This Issue...

Project Director's Note	1
End-of-Life Management of Plastic Mulch in Strawberry Production Survey Now Open: We Want to Hear From You.....	2
USDA SCRI Findings from a Commercial Field Trial of BDM in California	3
Public Views on Biodegradable Plastic Mulch Fragments in Farm Fields	6
How Micro-Fourier-Transform-Infrared-Spectroscopy Reveals the Hidden Story of Mulch Degradation	8
Engineering Soil-Biodegradable Mulch Films for Fumigated Cropping Systems.....	10
From Production to End-of-Life: What Makes Soil-Biodegradable Mulch Films More Sustainable?.....	12
Assessment of the Incorporation of Plastic Mulch into Fiberboard.....	15
Pyrolysis as a Potential Recycling Technology for Spent Plastic Mulch	17
Cynthia Sigira.....	19
Kevin Morris.....	20
Recent Publications	21

Cover photo TIF film applied to a field.
Credit: Hang Liu.



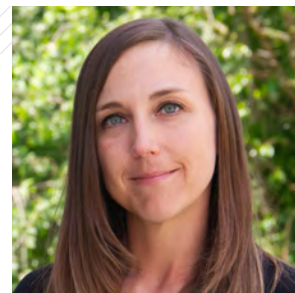
This material is based upon work that is supported by USDA SCRI award 2022-51181-38325. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and should not be construed to represent any official USDA or U.S. Government determination or policy.

WSU Extension programs and employment are available to all without discrimination. Evidence of noncompliance may be reported through your local WSU Extension Office.

Mention of trade names does not indicate endorsement or promotion.

Project Director's Note

**Lisa Wasko DeVetter, Project Director,
Professor, Washington State University**



This issue of *Mulch Matters* presents continued advancement of research and outreach activities conducted by our project team that address the performance, perception, and end-of-life management of plastic mulch. The articles represent an impressive level of coordinated efforts across horticulture, soil science, engineering, economics, and social science, and together span work on soil-biodegradable plastic mulches as well as emerging and established recycling approaches for polyethylene (PE) mulch.

Findings from the on-farm strawberry mulch trial in Monterey, California indicate that BDM mulches performed comparably to PE mulch in terms of yield under large commercial conditions. Continued attention is needed, however, regarding the potential food safety risks associated with fruit contacting soil surfaces, as well as the risks of residual BDM fragments in the soil being harvested with rotational crops (e.g. in the crown of lettuce baby leaf greens) and entering the food stream. As with any mulch evaluation, results from different regions with distinct soils and climates broaden our understanding of the factors that support or limit successful use of this technology.

Public perception research conducted by members of our team in western Washington show that most shoppers were initially unaware of plastic use in specialty crop production or the availability of mulch alternatives. Interviewed participants viewed soil-biodegradable mulch and the fragments shown during photo elicitation more positively once informed about biodegradability, and many recommended clear communication to support consumer acceptance of biodegradable alternatives. These insights may help growers address concerns related to field aesthetics and consumer expectations, particularly for soil-biodegradable mulches that deteriorate and degrade throughout the crop cycle.

Advances in analytical methods are also highlighted. Micro FTIR spectroscopy has been demonstrated to be a reliable way to confirm the identity of recovered plastic particles and distinguish mulch residues from natural soil materials. This work supports long term evaluations of mulch degradation in complex soil environments and informs product development.

Additional articles examine engineering mulch films for fumigated systems, sustainability assessments from production to end-of-life, incorporation of mulch into fiberboard, pyrolysis as a recycling pathway, and challenges associated with contaminated mulch streams. Updates on graduate student research, recent publications, and upcoming events are also included.

Collectively, these contributions demonstrate the breadth of our team's work and provide new information to support evidence based decision making for specialty crop production.



Lisa Wasko DeVetter, editor
Carol Miles, editor
Nataliya Shcherbatyuk, assistant editor
Andrew Mack, designer

lisa.devetter@wsu.edu, 360-848-6124
milesc@wsu.edu
n.shcherbatyuk@wsu.edu

End-of-Life Management of Plastic Mulch in Strawberry Production Survey Now Open: We Want to Hear From You

Nataliya Shcherbatyuk, Washington State University



Plastic mulch plays an important role in many specialty crop production systems, especially within high value crops like strawberries. While polyethylene (PE) mulch offers numerous agronomic benefits, such as improved weed management, soil moisture retention, and crop quality, its end of life management remains a challenge for growers, land managers, and the broader agricultural community.

To better understand these challenges and support more sustainable solutions, the End of Life Management of Plastic Mulch in Strawberry Production project team has launched a new public survey. The survey is designed to gather real world insights from growers and industry professionals, as well as assess general knowledge about mulch use, disposal, recycling, and awareness of our project's resources.

The survey is now available through our project website, and we warmly invite you to participate: [End-of-Life Management of Plastic Mulch in Strawberry Production — Project Survey](#)

WHY WE'RE CONDUCTING THIS SURVEY

Managing PE mulch at the end of the season can be labor-intensive, costly, complicated by contamination with soil and plant debris, and further constrained by the lack of recycling operations that accept this material. At the same time, soil-biodegradable plastic mulch (BDM) is gaining interest as a potential alternative, but questions remain about performance, cost, certification within organic systems, and long term soil impacts.

In addition to understanding farm practices, we also aim to assess general knowledge and perceptions related to plastic mulch use, environmental impacts, and available management options. This includes awareness of PE mulch, BDM, recycling pathways, and the educational materials produced by our project.

Your input will help us tailor future research, outreach, and Extension programming to real world needs.

WHAT THE SURVEY COVERS

The survey includes 10 sections and is open to growers, farm managers, Extension educators, researchers, and industry partners. Topics include:

- Crop types and farm characteristics
- Knowledge and awareness of PE mulch, BDM, and recycling options
- Current mulch use and end of life practices
- Challenges with removal, disposal, and recycling
- Concerns related to adopting BDM
- Awareness and use of project resources
- Changes in knowledge, attitudes, and practices
- A brief knowledge assessment section
- Future needs for equipment, guidelines, and research
- Open ended comments and experiences

This structure helps us understand not only what practices are currently in place, but also where knowledge gaps exist and what support stakeholders need most.

WHY YOUR INPUT MATTERS

Your experiences and observations are essential to shaping the future of sustainable mulch management. By participating, you help us:

- Understand the practical realities of mulch use across diverse operations
- Identify barriers that limit recycling and sustainable disposal
- Highlight knowledge gaps and misconceptions within the community
- Evaluate the impact of our project's outreach efforts
- Guide future research, field trials, and educational materials
- Inform discussions with industry partners and policymakers

Your voice ensures that the solutions we develop are practical, relevant, and grounded in real world conditions.

SURVEY PARTICIPANTS

We welcome participation from anyone who:

- Works with strawberries or other specialty crops
- Uses PE mulch, BDM, or both
- Has experience with mulch removal, disposal, or recycling
- Has interest in sustainable mulch management

Responses are anonymous, and participation is voluntary, taking approximately 10–12 minutes to complete.

JOIN US IN MOVING MULCH MANAGEMENT FORWARD

Sustainable mulch management is a shared challenge that touches on horticulture, agronomy, economics, recycling and waste management, environmental stewardship, and day to day farm logistics. Understanding how mulch is used and managed, and general perceptions of plastic mulch, is essential for developing effective, science based solutions.

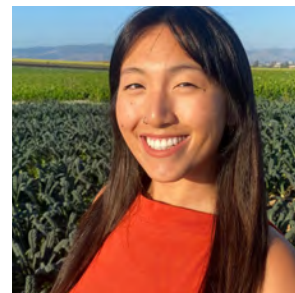
We encourage you to share your experiences and insights. Your input will help shape future research and support the development of practical tools and resources for the specialty crop industry.

TAKE THE SURVEY

The survey is now available through our project website: [End-of-Life Management of Plastic Mulch in Strawberry Production — Project Survey](#)

USDA SCRI Findings from a Commercial Field Trial of BDM in California

Alena Anousinh, California Marine Sanctuary Foundation/Monterey Bay National Marine Sanctuary



If you're a regular reader of the Mulch Matters newsletter, you are likely aware that soil-biodegradable plastic mulches (BDM) are not a new technology. Growers in the U.S. Eastern Coast and Europe have utilized BDM as an alternative to polyethylene (PE) for the past few decades. However, BDM adoption remains minimal in California, despite the region being responsible for producing about 90% of the nation's strawberries, and the strawberry crop is grown exclusively with plastic mulch (Yeh et al., 2023). In 2016, WSU conducted a survey of strawberry growers in California, the Pacific Northwest, and the mid-Atlantic, and found that most strawberry growers use PE mulch, and the most common method of its disposal was landfilling (Goldberger et al., 2019). Some landfills in California have completely banned PE mulch due to the volume of waste it contributes, and tipping fees at other locations are rising. In Santa Maria, for example, tipping fees jumped from \$158 to \$250 between 2025 and 2026. While BDM has a higher initial purchase price compared to PE mulch, BDM generates savings on labor and disposal by eliminating the need for plastic removal and landfill fees (Velandia et al., 2018). With mounting pressures from rising costs and environmental concerns over PE pollution in agricultural soils, it is crucial to explore viable commercial alternatives that can assist growers in overcoming these challenges while sustaining their operational profitability.

As part of our USDA Specialty Crop Research Initiative project, we established two BDM trials on an 80-acre commercial conventional strawberry ranch in Monterey, CA from 2023-2025. The trials were a collaboration between Washington State University, the California Marine Sanctuary Foundation, Monterey Bay National Marine Sanctuary, and the commercial grower.

The first trial was implemented in the Fall of 2023, with BDM applied over 20 crop beds (beds were 48-in. wide with two staggered strawberry rows per bed at 16-inch in-row plant spacing), and each bed was 50 ft long. Notably, the BDMs were not tucked into the soil at the end of the bed, and the bed length was shorter than the grower's standard 200 ft. Consequently, the strong winds from multiple atmospheric rivers combined with the shortened beds and untucked ends, caused the mulch to lift from the beds. We applied these lessons learned in our second trial in Fall 2024, that was implemented using the grower standard 200-ft beds with the mulch tucked in at the end of each bed. The trial consisted of four BDMs that varied in color (green and black) and thickness (0.9 and 1.1 mil; 1 mil = 25.4 microns), with one Taffeta PE mulch made with recycled content. The control mulch was considered a green PE-based film manufactured by SolarShrink; this was used in place of green totally impermeable film (TIF) that is more standard for the region (Table 1). BDMs and Taffeta mulch were donated by PolyExpert, Quebec, Canada. This article presents preliminary results from our second-year field trial.

METHODS

The trial was designed without replicates due to its large size, which included 18 beds, with each mulch treatment plot spanning across three beds. Mulch application occurred on 4 November 2024 and the BDMs were tilled into the soil 30 October 2025. Temperature and soil moisture were recorded at 15-minute intervals (TEROS 12 sensors; METER Group, Pullman, WA). For intensive data collection, permanent 1-meter plots were set up in the middle bed of each treatment to record canopy measurements and monthly percent soil exposure (PSE). PSE provided a visual measurement of mulch deterioration where 0% PSE indicates that the mulch is completely intact without any exposed soil and 100% PSE indicates complete mulch breakdown with the soil fully exposed.

Plots used for yield assessments each contained 20 plants and were staggered across all the treatment beds, either at the beginning, middle, or end of each bed. Following the grower's practice, we hand harvested and sorted all fruit twice-weekly into marketable and non-marketable categories using USDA U.S. no. 1 strawberry grading guidelines [United States Department of Agriculture (USDA), 2006]. Means are presented, as statistical comparisons cannot be conducted without replication.

Table 1. Mulch treatments in a 2024-2025 field trial on a commercial strawberry farm in Monterey, CA.

Mulch Type	Color/Brand	Feedstock	Thk.
Soil-biodegradable plastic mulch (BDM)	Black BioGuard00	Novamont Mater-Bi	0.9 mil
Soil-biodegradable plastic mulch (BDM)	Black BioGuard05	BASF ecovio®	0.9 mil
Soil-biodegradable plastic mulch (BDM)	Green BioGuard00	Novamont Mater-Bi	1.1 mil
Soil-biodegradable plastic mulch (BDM)	Green BioGuard05	BASF ecovio®	1.1 mil
Polyethylene (PE) mulch with recycled content	Black Taffeta	Polyethylene, post-consumer recycled resin	1.0 mil
Polyethylene (PE) control mulch	Green Solar Shrink	Polyethylene	0.9 mil

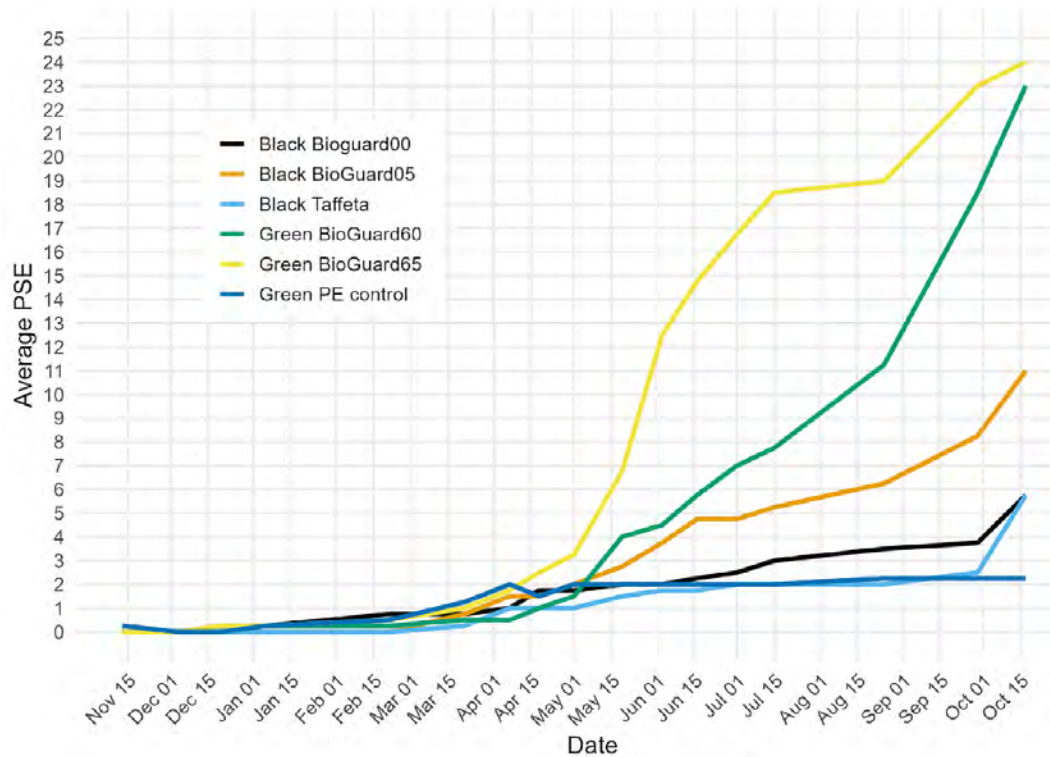


Figure 1. Average percent soil exposure (PSE) of soil-biodegradable plastic mulch (BDM) and non-biodegradable polyethylene (PE) mulch treatments in Monterey, CA from November 2024 to October 2025.

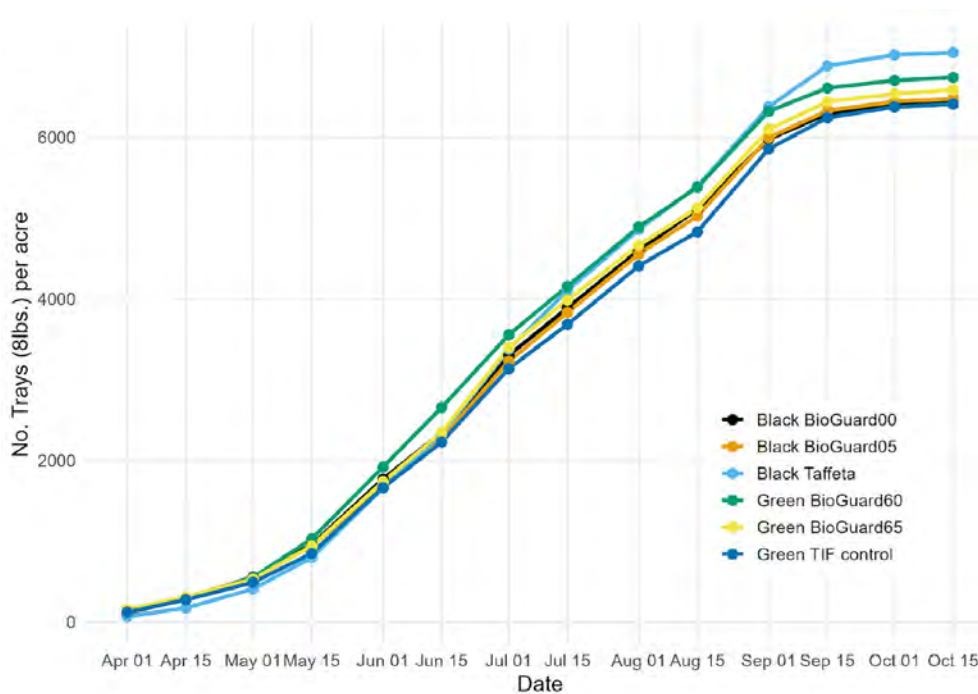


Figure 2. Cumulative 8-lb trays per acre of marketable strawberries harvested from soil-biodegradable plastic mulch (BDM) and non-biodegradable polyethylene (PE) mulch treatments in Monterey, California from April to October 2025.

RESULTS

PERCENT SOIL EXPOSURE.

All mulch treatments had PSE < 5% until 1 May 2025 (178 days after mulch application), then BDM treatments began to deteriorate (Fig. 1). All the BDM treatments had <25% PSE by the end of the trial, meaning that a quarter or less of the bed area had exposed soil. The green BDM treatments had the highest PSE (24%), potentially due to the absence of carbon black pigment in the mulch formula, which serves as a UV stabilizer (DeVetter et al., 2021). Green PE mulch had the lowest PSE (2%) by the end of the trial. Maintaining a low PSE is a critical consideration for growers due to fruit quality defects associated with strawberry crops coming into contact with the soil (USDA, 2006).

YIELD.

Marketable strawberry yield was extrapolated to 8 lb. trays per acre, the standard yield measurement in our region. Based on our analysis, marketable fruit yield remained similar across all treatments (Fig. 2). These results align with previous BDM trials that have demonstrated comparable strawberry crop yields between PE mulch and BDM (DeVetter et al., 2017; Gull et al., 2026, In preparation).

FIELD SCENARIOS COMPATIBLE WITH BDM USE

While our commercial trial findings align with university studies and demonstrate comparable strawberry yields between BDM and PE mulch, several factors should be considered for future commercial expansion. Currently available BDMs are not EPA approved tarps for soil fumigation and consequently do not qualify for buffer zone reduction credits when used during bed fumigation. Nonetheless, BDM remains a viable mulch option for conventional fields that utilize pre-plant flat fumigation and EPA-approved totally- or virtually impermeable tarps (TIF or VIFs, respectively) for soilborne pest and disease management, particularly in the context of reducing fumigant emissions and pursuing buffer zone reduction credits.

In co-rotation agricultural systems, growers have speculated that BDM could pose a food safety concern. BDM fragments could be accidentally mixed with crops that are harvested close to the soil surface and packaged on-site (e.g., lettuce, spinach, leafy greens). This concern could be alleviated by growing crops that are harvested above the soil surface (e.g., Brussel sprouts, artichokes). However, the vegetable grower who followed the BDM soil-incorporation from our trial and planted a leafy greens rotation crop did not express any concerns regarding residual BDM fragments.

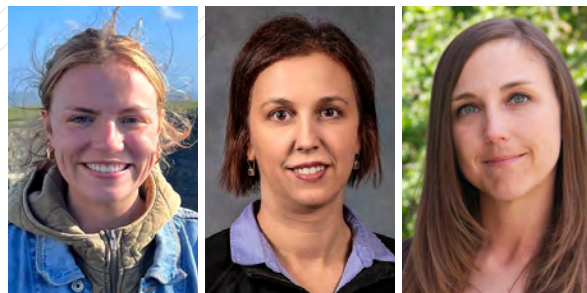
Additionally, under the USDA National Organic Program rules and regulations, there are currently no BDMs approved for certified organic growers in the US. Although BDMs are included in the list of allowed substances in certified organic systems, no commercially available BDM fulfills the required standard of 100% biobased content. Future regulatory evaluations, including the 2027 and 2029 Sunset Reviews, should be monitored closely for potential National Organic Standards Board revisions.

REFERENCES

- DeVetter, L.W., Zhang, H., Ghimire, S., Watkinson, S., Miles, C.A. 2017. Plastic biodegradable mulches reduce weeds and promote crop growth in day-neutral strawberry in western Washington. HortScience, 52(12), 1700-1706. <https://journals.ashs.org/view/journals/hortsci/52/12/article-p1700.xml>
- DeVetter, L., Shrestha, S., Hayes, D. (2021). What is a Soil-Biodegradable Plastic mulch Composed Of? Washington State University Small Fruit Horticulture Research & Extension Program. <https://s3.wp.wsu.edu/uploads/sites/2181/2021/07/What-is-in-a-BDM.pdf#:~:text=UV%20Stabilizers%20Prevents%20polymer%20break%20down%20by,or%20may%20not%20be%20nat%2D%20urally%20derived.>
- Goldberger, J. R., DeVetter, L. W., Dentzman, K. E. (2019). Polyethylene and Biodegradable Plastic Mulches for Strawberry Production in the United States: Experiences and Opinions of Growers in Three Regions. HortTechnology 29(5), 619–628. <https://doi.org/10.21273/horttech04393-19>
- Gull, N., Inci, D., Wortman, S., Weiss, B., Griffin-LaHue, D., Wasko DeVetter, L. 2026. Soil biodegradable plastic mulches provide comparable horticultural performance to polyethylene (PE) mulch in diverse strawberry production systems. HortScience. *In preparation*.
- United States Department of Agriculture. (2006). United States Standards for Grades of Strawberries. https://www.ams.usda.gov/sites/default/files/media/Strawberry_Standard%5B1%5D.pdf
- Velandia, M., Smith, A., Wszelaki, A., Galinatio, S., Marsh, T. (2018). The Economics of Adopting Biodegradable Plastic Mulch Films. <https://ageconsearch.umn.edu/record/302940/?v=pdf>
- Yeh, D.A., Kramer, J., Calvin, L., Weber, C. (2023). The changing landscape of U.S. strawberry and blueberry markets: Production, trade, and challenges from 2000 to 2020 (Report No. EIB-257). U.S. Department of Agriculture, Economic Research Service. <https://doi.org/10.32747/2023.8134359.ers>

Public Views on Biodegradable Plastic Mulch Fragments in Farm Fields

Aidan Williams, Jessica R. Goldberger, and Lisa Wasko DeVetter, Washington State University



Growers often cite public concerns about unsightly plastic scraps as one reason for their reluctance to adopt soil-biodegradable plastic mulch (BDM). But what does the public really think? An exploratory study was conducted to address this knowledge gap and assess public attitudes towards soil-biodegradable and non-biodegradable plastic mulches as well as their knowledge of mulching practices.

Non-biodegradable polyethylene (PE) mulch has been widely used in commercial agriculture since the 1950s because of its consistent effectiveness, ease of application, and affordability (Somanathan et al., 2022). Despite sustainability concerns regarding plastic use in agriculture, PE mulch is permitted in organic production under the condition that it is entirely removed from the field at the end of the growing season (USDA NOP, 7 CFR 205.601, 2024). In practice, however, com-

plete removal is almost impossible to achieve, and limited recycling facilities, combined with undesirable disposal methods such as landfilling, stockpiling, or burning, contribute to plastic pollution in agricultural soils and their surrounding ecosystems (Goldberger et al., 2019; Li et al., 2022).

BDM was created as an environmentally friendly alternative to PE mulch. Although BDM provides similar agronomic benefits to PE mulch (Tofanelli and Wortman, 2020), growers are hesitant to adopt it (Dentzman and Goldberger, 2020). Research suggests that growers' reluctance to adopt BDM is in part due to aesthetic and social concerns that BDM fragments left in the soil to degrade will be viewed as plastic waste or garbage, and therefore a reflection of "bad-farming" practices (Dentzman and Goldberger, 2019). Failure to meet social

standards, such as cleanliness, can lead to external judgments that portray farmers as unorganized or unskilled, which may affect their social standing and access to resources (Sutherland and Burton, 2011).

In parallel, willingness to pay studies show that consumers are more likely to purchase products that align with their personal values, such as environmental sustainability and support for local farmers (Thilmany et al., 2006 and 2008). Building on this foundation, the present study explored consumer perceptions of BDM fragments remaining in farm fields after harvest. The research compared direct-market (farmers market) and indirect-market (discount grocery store) shoppers in Bellingham, WA, USA, by addressing three main questions: (1) What do shoppers know about current mulching practices?

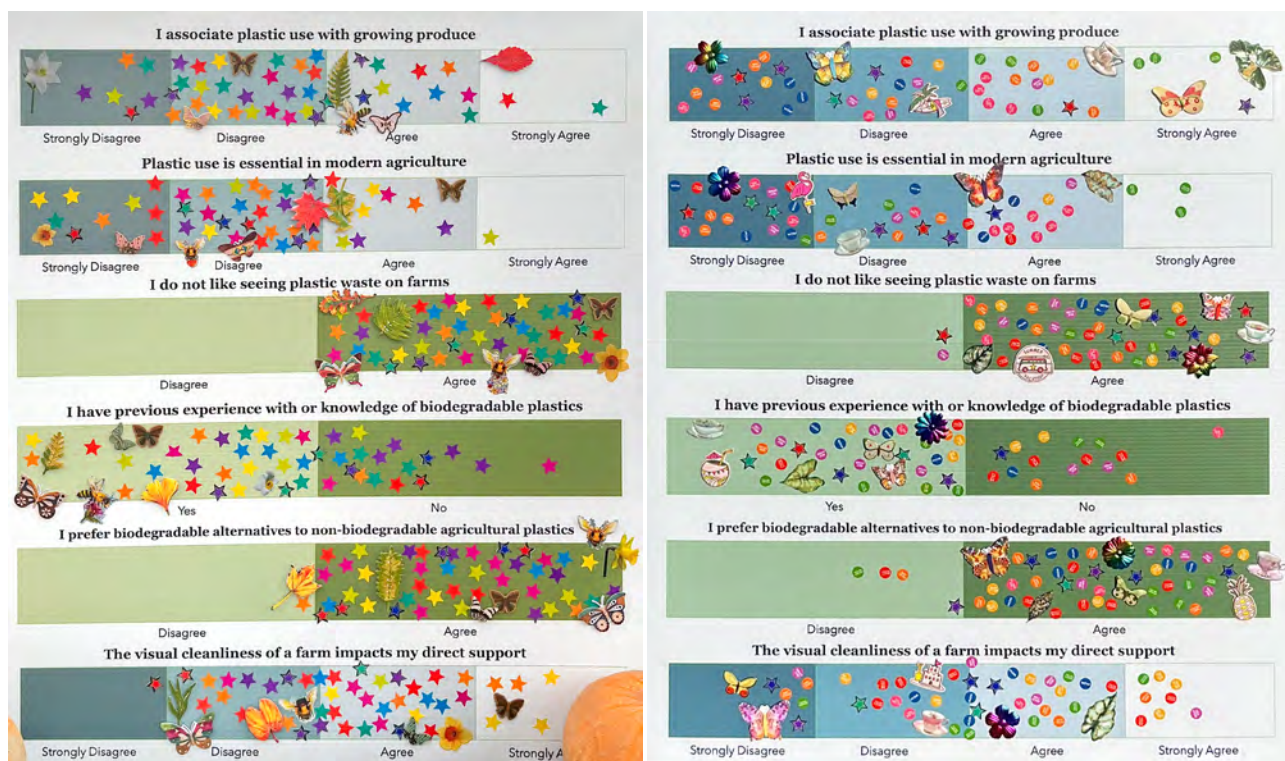


Figure 1. Direct- (left) and indirect-market (right) shopper rapid market assessment poster boards deployed at a farmers market and discount grocery store in 2024-2025. Each sticker represents an individual shopper's response to the prompt on the poster board.

(2) What are their perspectives on BDM fragments in agricultural fields? and (3) Do they prefer biodegradable options over non-biodegradable plastics in agriculture?

Using rapid market assessments (RMAs) and semi-structured interviews, data were collected from 102 shoppers (51 at each sampling location) and 14 interview participants (8 direct-market and 6 indirect-market shoppers). Figure 1 shows responses to the RMA poster boards displayed at a farmers market (left) and a discount grocery store (right). Participants indicated their answers by placing a sticker in the corresponding response box.

PUBLIC KNOWLEDGE OF MULCHING

Most RMA participants did not associate plastic use with growing produce nor believe that plastic is essential in modern agriculture (61% and 70%, respectively). However, most interview participants were aware that non-biodegradable PE mulch is used in agriculture. Interviewees were largely unaware of BDM but tended to prefer it once informed that it biodegrades naturally in soil through microbial activity. After learning about its biodegradability, most interviewees viewed BDM fragments positively, even when shown photos of on-farm biodegradable plastic scraps that resembled conventional plastic.

PUBLIC PERSPECTIVES ON BDMS IN FIELDS

While RMA results show clean, orderly field visuals were generally preferred, interviewees expressed a greater willingness to purchase produce grown with BDM rather than PE mulch, overcoming aesthetic preferences. Interviewees also revealed a common suggestion: labeling. Five out of the 14 interviewees proposed that farmers using BDM display signage at field edges to clarify that visible plastic fragments are biodegradable. This finding supports the idea that clear communication and transparency can strengthen public trust and help growers avoid negative assumptions about their practices.

PUBLIC PREFERENCE

Shoppers participating in interviews expressed a willingness to potentially pay a premium for produce grown with BDM, highlighting that education, through product labeling, outreach, or signage, is key to public acceptance.

CONCLUSIONS

Overall, this research shows that the general public in the study location is unaware of plastic use in agriculture yet supportive of biodegradable alternatives once informed. Increased education and transparency surrounding BDM use can strengthen public acceptance and align values with sustainable farming practices, despite aesthetic preferences. Future research should address this study's limitations by expanding the sample population size, as well as including multiple regions with diverse demographics to improve representativeness and generalizability.

This work was recently published and the full article is available at:

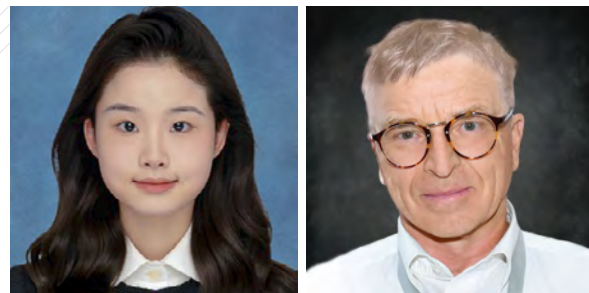
Williams, A. R., Goldberger, J. R., DeVetter, L. W. (2026). Public perceptions of agricultural plastic: Comparing shopper views of polyethylene and biodegradable mulch in Washington State. Renewable Agriculture and Food Systems. 41: e22. doi:10.1017/S1742170526100477

REFERENCE

- Dentzman, K. E., and Goldberger, J. R. (2020). Organic standards, farmers' perceptions, and the contested case of biodegradable plastic mulch in the United States. Journal of Rural Studies 73, 203–213. <https://doi.org/10.1016/j.jrurstud.2019.11.002>
- Dentzman, K. and Goldberger, J.R., (2019). Plastic scraps: biodegradable mulch films and the aesthetics of 'good farming' in US specialty crop production. Agriculture and Human Values 37(1), 83-96. <https://doi.org/10.1007/s10460-019-09970-x>
- Goldberger, J. R., DeVetter, L. W., Dentzman, K. E. (2019). Polyethylene and biodegradable plastic mulches for strawberry production in the United States: Experiences and opinions of growers in three regions. HortTechnology 29(5), 619-628. <https://doi.org/10.21273/horttech04393-19>
- Li, S., Ding, F., Flury, M., Wang, Z., Xu, L., Li, S., Jones, D. L., Wang, J. (2022). Macro- and microplastic accumulation in soil after 32 years of plastic film mulching. Environmental Pollution 300, 118945. <https://doi.org/10.1016/j.envpol.2022.118945>
- Somanathan, H., Sathasivam, R., Sivaram, S., Mariappan Kumaresan, S., Muthuraman, M. S., Park, S. U. (2022). An update on polyethylene and biodegradable plastic mulch films and their impact on the environment. Chemosphere 307, 135839. <https://doi.org/10.1016/j.chemosphere.2022.135839>
- Sutherland, L.-A. and Burton, R. J. F. (2011). Good farmers, good neighbours? The role of cultural capital in social capital development in a Scottish farming community. Sociologia Ruralis 51, 238-255. <https://doi.org/10.1111/j.1467-9523.2011.00536.x>
- Thilmany, D., Bond, J., Bond, C. (2006). Direct marketing of fresh produce: Understanding consumer interest in product and process-based attributes. American Agricultural Economics Association Annual Meeting Paper, Long Beach, California. <https://doi.org/10.22004/ag.econ.21217>
- Thilmany, D., Bond, C., Bond, J. (2008). Going local: Exploring consumer behavior and motivations for direct food purchases. American Journal of Agricultural Economics 90(5),1303-1309. <https://www.jstor.org/stable/20492389>
- Tofanelli, M. B., and Wortman, S. E. (2020). Benchmarking the agronomic performance of biodegradable mulches against polyethylene mulch film: A meta-analysis. Agronomy 10(10),1618. <https://doi.org/10.3390/agronomy10101618>
- United States Department of Agriculture (USDA). (2024). National Organic Program (NOP), § 205.601(b)(2)(i–iii). <https://www.ecfr.gov/current/title-7/subtitle-B/chapter-I/subchapter-M/part-205#205.601>

How Micro-Fourier-Transform-Infrared-Spectroscopy Reveals the Hidden Story of Mulch Degradation

Xueyu Zhou and Markus Flury, Washington State University



MEASURING MULCH DEGRADATION MATTERS

Soil-biodegradable plastic mulches (BDMs) offer farmers an environmentally friendly alternative to conventional polyethylene (PE) mulch because they can be tilled into the soil after use instead of being removed and sent to landfills. However, an important question remains: how do we know when a soil-biodegradable mulch has truly degraded?

Several traditional methods, such as measuring mulch weight loss or observing breakdown of large fragments, provide useful information but often cannot distinguish between physical damage and actual chemical decomposition. A mulch film may fragment into smaller pieces while much of the original plastic polymer remains intact. To better understand how soil-biodegradable mulches break down, researchers need tools that can look beyond what is visible to the naked eye.

MULCH DEGRADATION FROM SOIL TO MICRO-FOURIER-TRANSFORM-INFRARED SPECTRA

Studying soil-biodegradable mulch degradation begins with a challenge: recovering tiny plastic residues from complex soil samples. To isolate these plastic particles, we first used a Fenton reaction, a chemical treatment that removes natural organic matter from the soil while leaving plastic particles largely intact. The treated samples are then subjected to density separation, in which a high-density zinc chloride solution allows lightweight plastic particles to float while heavier soil minerals settle to the bottom. The recovered plastic particles were collected on a 1.2 μm filter and examined under a microscope to identify materials that appeared to be plastic (Figure 1).

To confirm the identity of these suspected plastic particles, we used micro-Fourier Transform Infrared Spectroscopy (micro-FTIR, Figure 2). This technique identifies materials by measuring how they absorb infrared light. Because every polymer has a unique infrared 'fingerprint', micro-FTIR can distinguish biodegradable mulch residues from conventional polyethylene plastics and natural organic matter.

Each suspected particle was analyzed individually, and its infrared spectrum was compared with reference libraries to determine its composition. Plastic particles were classified only when their spectra matched known polymer signatures. By combining microscopy with chemical analysis, micro-FTIR provides a much more reliable method for identifying plastic residues than visual observation alone.

FOLLOWING PLASTIC'S CHEMICAL FINGERPRINT

Micro-FTIR analysis confirmed that the particles recovered from the soil were not all the same. By comparing the infrared "fingerprints" of individual particles with reference libraries, we were able to distinguish conventional PE mulch residues, soil-biodegradable mulch particles, and non-plastic materials.

One interesting finding came from comparing the two extraction methods. PE particles were detected after the water extraction step but were not found in the subsequent zinc chloride extraction. This suggests that the lighter PE particles had already been successfully recovered during the first extraction, demonstrating that the separation procedure effectively isolated different types of plastic particles.

Perhaps the most important finding is that soil-biodegradable plastic particles (< 2 mm) could still be identified in agricultural soils approximately five years after the mulch films were incorporated into the field. This highlights the value of micro-FTIR as a tool for tracking the long-term fate of both conventional and biodegradable plastic mulches.

IMPROVING HOW WE EVALUATE BIODEGRADABLE MULCHES

As soil-biodegradable mulch products become more widely used, understanding what remains in the soil after field use is becoming increasingly important. Our study demonstrates that micro-FTIR provides a reliable way to confirm the identity of recovered plastic particles, allowing researchers to distinguish true plastic residues from natural soil materials that may look similar under a conventional microscope.

However, identifying the plastic particles is only part of the story. To better understand whether soil-biodegradable plastics are continuing to decompose or simply persisting in the soil, we need to combine micro-FTIR with additional analytical techniques. Fatty Acid Methyl Ester (FAME) analysis will help us investigate chemical signatures associated with BDM degradation, while Nuclear Magnetic Resonance (NMR) spectroscopy will provide information about the molecular structures of degradation products.

Together, these complementary approaches will provide a more complete picture of what happens to BDM after incorporation into soil. The knowledge gained from this research will help improve methods for evaluating soil-biodegradable plastics and support the development of mulch products that perform effectively in the field while minimizing long-term environmental impacts.

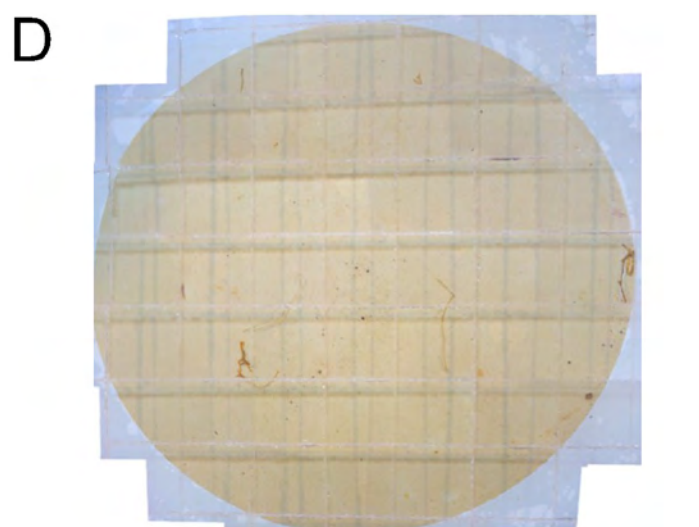
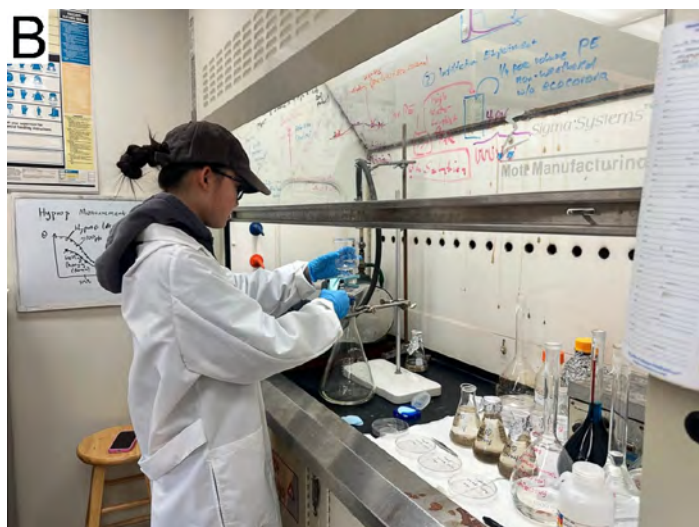


Figure 1. Photographs documenting the microplastic extraction process from soil. (A) Soil and reagent mixtures prepared by Fenton digestion and density separation prior to filtration. (B) Filtration and separation of suspended particles. (C) Stereo microscope used to inspect and select suspected plastic particles for micro-FTIR identification. (D) Image of a filter paper containing extracted microplastics.

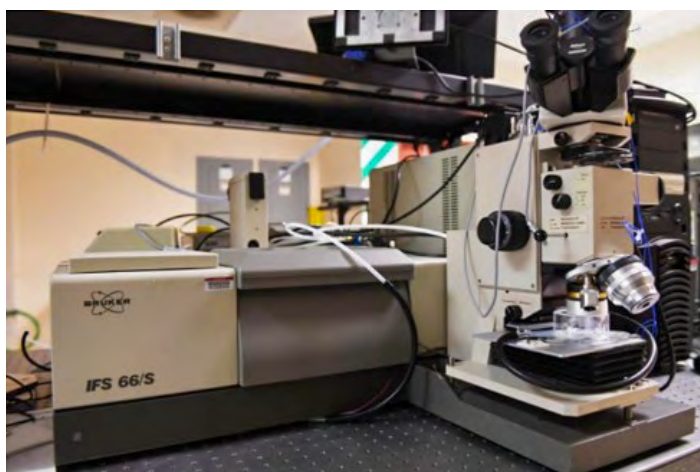


Figure 2. Micro-Fourier-Transform Infrared microscope at the Pacific Northwest National Laboratory (PNNL; Richland, WA) used to identify plastic particles recovered from agricultural soils. The instrument combines infrared spectroscopy with microscopy to determine the chemical composition of suspected biodegradable and conventional plastic residues. Photo credit PNNL.

Engineering Soil-Biodegradable Mulch Films for Fumigated Cropping Systems

Hang Liu, Washington State University



Figure 1. Fumigated beds covered with totally impermeable film (TIF), prior to planting raspberries in Washington. Photo by Lisa DeVetter

Plastic mulch is widely used in specialty crop production for weed suppression, conserving soil moisture, and regulating soil temperature. For crops that benefit from soil fumigation, impermeable plastic films (i.e., tarps) serve the important function of keeping fumigants in the soil to prevent them from escaping into the atmosphere, where they pose risks to human health, reduce air quality, and affect surrounding ecosystems. Plastic mulches with enhanced gas-barrier properties are commonly used for this purpose (Figure 1). However, these mulches are made of petroleum-based, non-biodegradable polymers, creating disposal challenges after the growing season. Our team at Washington State University is developing soil-biodegradable mulch (BDM) that can provide similar fumigant retention while reducing plastic waste.

SOIL FUMIGATION: WHY IT MATTERS

Soil fumigation is an important soilborne pathogen and pest management practice for many high-value crops, including strawberries, tomatoes, peppers, ornamentals, and nursery crops. Soil fumigants are pesticides applied in liquid or solid form prior to planting. After application, they volatilize into gases that diffuse through the soil within minutes to hours [U.S. Environmental Protection Agency (U.S. EPA), 2013]. Common fumigants include 1,3-dichloropropene, chloropicrin, and metam sodium that converts to methyl isothiocyanate in the soil. These fumigants suppress a wide range of soilborne pathogens and pests that are difficult to manage by other methods, including nematodes, fungi, oomycetes, bacteria, arthropods (e.g., insects), and weeds that can damage roots, cause disease, reduce plant growth, and lower crop yields (U.S. EPA,

2026). Because a single fumigation treatment can suppress several types of pathogens and pests at once, soil fumigation remains a key tool in specialty crop production.

PLASTIC MULCHES FOR SOIL FUMIGATION: BENEFITS AND CHALLENGES

To reduce fumigant emissions, plastic mulches or “tarps” with high gas-barrier properties are used to restrict the movement of fumigants into the atmosphere. These mulches also help limit exposure of fumigants to sunlight, which can accelerate the breakdown of some fumigants. Barrier films, such as virtually impermeable films (VIF) and totally impermeable films (TIF), are commonly used in fumigated production systems. These films typically have a multilayer structure, with outer layers that provide moisture resistance and mechanical strength and inner layers that serve as gas barriers. One common

VIF structure consists of two polyethylene (PE) layers with a nylon or ethylene-vinyl alcohol (EVOH) layer in between. In some TIF films, multiple EVOH layers are sandwiched between PE layers to further improve barrier performance (Fennimore and Ajwa, 2011). As these films are made from nonbiodegradable plastics, they must be removed from the field before the next crop is planted. Collecting, transporting, and recycling used mulch can be difficult and costly, and there may be concerns regarding their potential pesticide contamination for recycling purposes.

BDM may be a potential alternative as it can be incorporated into the soil at the end of its use, rather than being removed from the field. Commercial BDMs are made from biodegradable polymers, such as poly(butylene adipate-co-terephthalate) (PHA), polylactic acid (PLA), thermos-plastic starch (TPS), and other biodegradable polyesters. However, most currently available BDMs are not designed for fumigated production systems. Compared with VIF and TIF, fumigants generally diffuse through BDM more readily, reducing fumigant retention and potentially lowering treatment efficacy. Improving the barrier properties of BDMs is therefore a critical step toward using them to replace conventional plastics in fumigated agriculture.

ENGINEERING THE NEXT GENERATION OF BIODEGRADABLE MULCH FILMS

One approach to improving the use of BDM for fumigation is to create a multilayer design, in which different biodegradable materials are combined into a single film, with each layer serving a specific function. One example is a three-layer film that places a biodegradable gas-barrier layer between two biodegradable structural layers. The outer layers provide the strength and flexibility needed for mulch application and field performance, while the middle layer slows the movement of fumigants through the film. Our team is investigating the incorporation of a biodegradable EVOH layer into commercial BDMs, such as BioGuard, to improve gas-barrier properties for potential use in fumigated cropping systems. To prevent moisture from penetrating through the BDM and reducing the barrier performance of EVOH, bio-based and biodegradable coatings, such as beeswax, are being applied to the film surface to help maintain gas-barrier properties under wet field conditions. Various processing parameters related to constructing the multilayer film and coating are being investigated. Other researchers who focus on food packaging are also investigating biodegradable polymer blends and adding fillers to improve the gas-barrier properties of biodegradable films. Although most of the research is on food packaging applications, the findings may also help guide the development of BDMs for fumigated cropping systems.

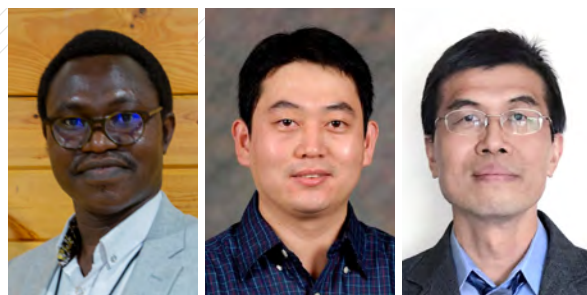
Several factors must be balanced during mulch development for fumigation. An effective BDM film should: retain fumigants throughout the treatment period, which can be several days to a few weeks, depending on the fumigant and field conditions (Ashworth and Yates, 2019); withstand field conditions during crop production; resist moisture; be compatible with commercial manufacturing methods; and biodegrade in the soil after use without leaving persistent plastic residues. Although BDM films specifically designed for fumigated production systems are not yet commercially available, recent advances in polymer science and multilayer film technology, such as the one that our team is working on, have improved their potential for these applications.

REFERENCE

- Ashworth, D. J. and Yates, S. R. 2019. Effect of application rate on chloropicrin half-life and simulated emissions across a range of soil conditions. Science of the Total Environment 675, 2657–2665. <https://doi.org/10.1016/j.scitotenv.2019.05.203>
- Fennimore, S.A. and Ajwa, H.A., 2011. Totally impermeable film retains fumigants, allowing lower application rates in strawberry. California Agriculture 65(4), 211–215. <https://escholarship.org/uc/item/8768v588>
- U.S. Environmental Protection Agency (EPA) 2013. Safety information for handlers participating in a field fumigant application for 1,3-dichloropropene/chloropicrin combination products. Washington, DC: U.S. Environmental Protection Agency. Available at: <https://www.epa.gov/sites/default/files/2013-11/documents/soil-fumigants-safety-info.pdf> [Accessed 18 July 2026].
- U.S. Environmental Protection Agency (EPA), 2026. What are soil fumigants? Available at: <https://www.epa.gov/soil-fumigants/what-are-soil-fumigants> [Accessed 18 July 2026].

From Production to End-of-Life: What Makes Soil-Biodegradable Mulch Films More Sustainable?

Oluwatunmise Dada and Ting Chi, Washington State University;
Liang Yu, Kentucky State University



As plastic mulch use continues to increase in agriculture, growers face an important question: Should I use biodegradable mulch film (BDM) or conventional polyethylene (PE) mulch? The answer depends on more than product cost and return on yield. It also depends on the environmental cost of managing the plastic mulch after the growing season. This end-of-life question is especially relevant because BDM and PE mulch can provide similar crop-yield benefits in several production systems, including strawberry (DeVetter et al., 2017; Wang et al., 2022), pumpkin (Ghimire et al., 2018), raspberry (Zhang et al., 2019), tomato (Cowan et al., 2014), melon (Iapichino et al., 2014), and cucumber (Wortman et al., 2016), among others. With similar crop performance, it becomes important to consider the sustainability of plastic mulch through the final stages of its life cycle. To better understand sustainability considerations, we evaluated the environmental impacts of two market-representative BDM formulations, poly(butylene adipate-co-terephthalate)/poly(lactic acid) (PBAT/PLA) and poly(butylene adipate-co-terephthalate)/thermoplastic starch (PBAT/TPS) in strawberry production, and compared them to PE mulch. We considered the full life cycle of the plastic mulches, from

production to field use and end-of-life management, using a method called life cycle assessment (LCA). After the growing cycle, we evaluated three scenarios for BDMs: incorporation and degradation in the soil as the intended end-of-life route, and collection of BDM remnants from the field and disposal through composting or anaerobic digestion. For PE mulch, we considered landfilling as a realistic end-of-life pathway for plastic mulch following its use in the field (Goldberger et al., 2019).

WHY MULCH FILM END-OF-LIFE MANAGEMENT MATTERS

Our results show that PE mulch had lower environmental impacts during manufacturing (Fig. 1a), but this advantage was lost after PE mulch use at the end-of-life stage (Fig. 1b). In our study, PE mulch landfilling had the highest end-of-life burden, mainly because of ecotoxicity and eutrophication impacts linked to landfill disposal (Fig. 1b). Although landfilling is still a common disposal method for PE mulch waste, landfill emissions from leachate can contaminate soil, groundwater, and surface water, while particulates and toxic gases can pollute the air (Dada et al., 2025).

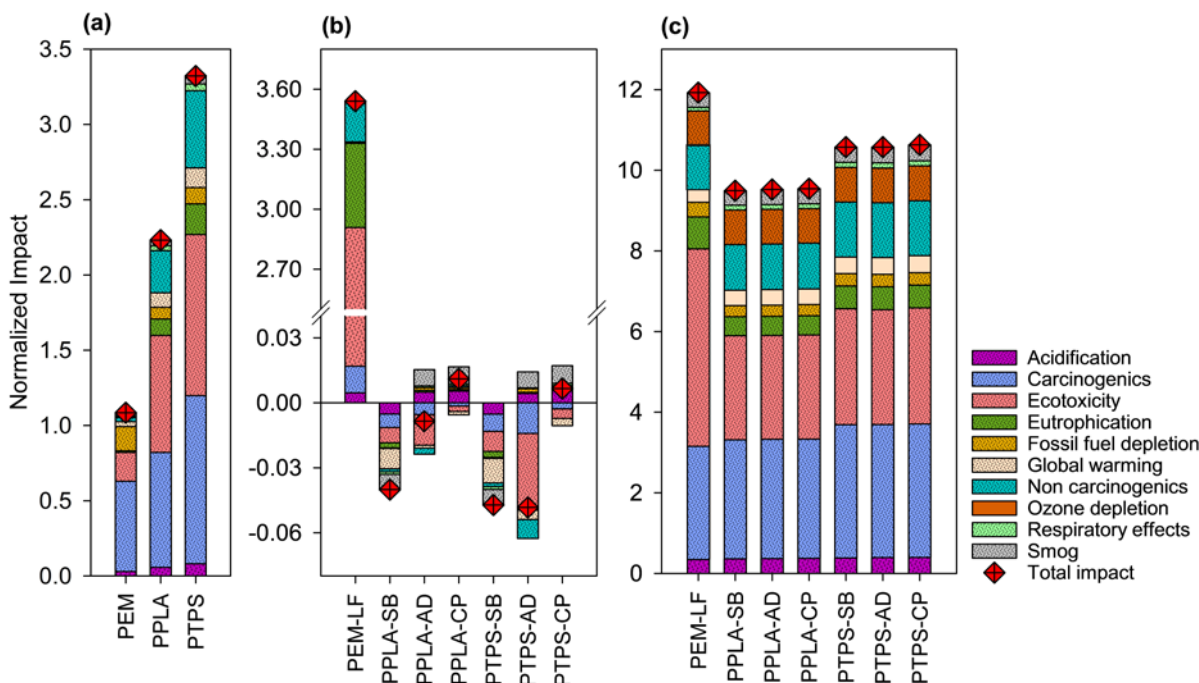


Figure 1. Panel (a) shows mulch film manufacturing impacts. PE mulch has the lowest total manufacturing impact, followed by PPLA and PTPS. Panel (b) shows end-of-life impacts, with the landfilling of PE mulch having a much higher total impact than all biodegradable mulch scenarios. Soil biodegradation and anaerobic digestion of the recoverable biodegradable mulch fraction produce net environmental credits. Composting scenarios are less favorable than soil biodegradation or anaerobic digestion but still far lower than PE landfilling. Panel (c) shows total cradle-to-grave impacts, including manufacturing, strawberry field use, and end-of-life management, with landfilling of PE mulch having the highest total impact. The figure shows that although polyethylene mulch has lower manufacturing impacts, its landfilling burden results in the highest overall life-cycle impact. When planted mulches were equalized in areal weight at 19.15, 22.63, and 26.57 g/m², the total impacts of both BDMs and PE mulch increased, but the relative environmental impact reductions achieved by BDMs compared with PE mulch became progressively larger with increasing areal weight due to lower EoL impacts.

In contrast, both BDMs performed better at the end-of-life stage (Fig. 1c). When BDM remains in the soil and degrades, growers can avoid some of the fuel use, labor, and environmental burdens associated with collecting and transporting plastic waste (Dada et al., 2025). Soil biodegradation also provides potential soil amendment benefits because the carbon components of BDM are converted into useful biomass, which benefits the soil (Xiong et al., 2024).

Combining anaerobic digestion with soil biodegradation was also promising, especially for starch-based BDM, although not as promising as allowing all BDM to biodegrade in the soil. In this pathway, the collected BDM can be treated in an anaerobic digester, where part of the mulch is converted into biogas (Habarakada Liyanage et al., 2025), while the BDM waste left in the field retains the benefits of soil biodegradation. This biogas can be used for energy recovery, helping offset some of the energy demand of the process.

Composting the collected BDM was less favorable than soil biodegradation combined with anaerobic digestion, mainly because composting requires heavy equipment, water, and energy (Chazirakis et al., 2022) but does not provide the same energy credit as anaerobic digestion. Even so, composting collected BDM still performed better than landfilling PE mulch.

THE HIDDEN ENVIRONMENTAL BURDEN OF BDM PRODUCTION

One important finding from our study is that BDM does not have a low environmental impact simply because it contains biodegradable feedstocks. We found that BDMs have higher manufacturing impact than PE mulch due to contributions from the fossil component of the polymers that are blended to make the BDM (Fig. 1a). For the BDMs evaluated in our study, PBAT accounted for about 70% of the formulation, and TPS or PLA accounted for about 30%. PBAT is often produced from fossil-derived petrochemical intermediates, including 1,4-butanediol, adipic acid, and terephthalic acid. Producing these intermediates and combining them into PBAT requires additional materials and energy and generates emissions, which adds to the BDM manufacturing environmental impact. In contrast, PE mulch is made almost entirely from polyethylene derived from ethylene, which is sourced from crude oil or natural gas. In our study, fossil fuel depletion was the only manufacturing category in which PE performed worse than the BDMs, which is due to PE being almost entirely derived from fossil resources.

For BDM, PBAT accounted for over 90% of the manufacturing-related environmental impacts in PBAT/PLA BDM, including global warming potential. For PBAT/TPS BDM, the share of manufacturing environmental impacts was between 68% and 96%. In our study, when PBAT was reduced to 30%, PBAT/PLA BDM had environmental impacts close to PE mulch. This reveals an opportunity to improve BDM manufacturing sustainability by increasing the percent of bio-based feedstocks and by reducing the environmental burden of fossil-based polyester components.

OVERALL ENVIRONMENTAL BENEFITS AND PRACTICAL TAKEAWAYS

Although PE mulch had a lower environmental impact in the manufacturing stage because of the higher impact from the fossil-based component of the evaluated BDMs (Fig. 1a), when the full life cycle was considered from production to end-of-life, BDMs had 7.5–18.2% lower overall environmental

impacts than landfilled PE mulch (Fig. 1c). The greatest benefits for BDM sustainability were found when they were incorporated into the field for soil biodegradation, followed by soil biodegradation combined with anaerobic digestion of collected BDM fragments, especially for starch-based BDM (Fig. 1c). The benefits of using BDM and PE mulch in strawberry production were found to be similar. These results show that BDM can provide environmental advantages, but their overall benefits depend on their feedstocks and end-of-service management. Sensitivity analysis shows that BDMs provide the greatest environmental benefits when the film contains less fossil-derived polyester, field biodegradation is faster and more complete, and plastic mulch waste can be treated close to the farm (this also reduces transport costs). Further, the sustainability of BDM with anaerobic digestion is improved when energy is recovered from the digestion process.

Overall, our study shows that BDMs can have lower environmental impacts than PE mulch, especially when paired with appropriate end-of-life strategies, particularly soil biodegradation, which is the intended end-of-life for BDM. Growers should consider end-of-life management in addition to purchase price and crop performance when making decisions regarding which plastic mulch to use.

This work was recently published and the full article is available at:

Dada, O.I., Wang, J., Liyanage, T.U.H., Dahal, K., Liu, H., Chi, T., Yu, L., Chen, S. 2026. Life cycle assessment of biodegradable mulch films in strawberry production under alternative end-of-life scenarios. Journal of Environmental Management 417, 130888. <https://doi.org/10.1016/j.jenvman.2026.130888>.

REFERENCES

- Cowan, J.S., Miles, C.A., Andrews, P.K., Inglis, D.A. (2014). Biodegradable mulch performed comparably to polyethylene in high tunnel tomato (*Solanum lycopersicum* L.) production. Journal of the Science of Food and Agriculture 94, 1854–1864. <https://doi.org/10.1002/jsfa.6504>
- Dada, O.I., Habarakada Liyanage, T.U., Chi, T., Yu, L., DeVetter, L.W., Chen, S. (2025). Towards sustainable agroecosystems: A life cycle assessment review of soil-biodegradable and traditional plastic mulch films. Environmental Science and Ecotechnology 24, 100541. <https://doi.org/10.1016/j.es.2025.100541>
- DeVetter, L.W., Zhang, H., Ghimire, S., Watkinson, S., Miles, C.A. (2017). Plastic biodegradable mulches reduce weeds and promote crop growth in day-neutral strawberry in Western Washington. HortScience 52, 1700–1706. <https://doi.org/10.21273/hortsci12422-17>
- Chazirakis, P., Giannis, A., Gidakos, E. (2022). Modeling the Life Cycle Inventory of a Centralized Composting Facility in Greece. Applied Sciences 12(4). <https://doi.org/10.3390/app12042047>
- Ghimire, S., Wszelaki, A.L., Moore, J.C., Inglis, D.A., Miles, C. (2018). The use of biodegradable mulches in pie pumpkin crop production in two diverse climates. HortScience 53, 288–294. <https://doi.org/10.21273/hortsci12630-17>

- Goldberger, J.R., DeVetter, L.W., Dentzman, K.E. (2019). Polyethylene and biodegradable plastic mulches for strawberry production in the United States: experiences and opinions of growers in three regions. HortTechnology 29 (5), 619-628. <http://doi.org/10.21273/horttech04393-19>
- Habarakada Liyanage, T.U., Dada, O., Abeyasinghe, S., Liu, H., Yu, L., Chen, S. (2025). Digestibility and fate of biodegradable plastic mulch films in thermophilic anaerobic digestion. Chemosphere 379, 144411. <https://doi.org/10.1016/j.chemosphere.2025.144411>
- Iapichino, G., Mustazza, G., Sabatino, L., D'Anna, F. (2014). Polyethylene and biodegradable starch-based mulching films positively affect winter melon production in Sicily. Acta Horticultura 225–231. <https://doi.org/10.17660/ActaHortic.2014.1015.25>
- Wang, X., Shrestha, S., Tymon, L., Zhang, H., Miles, C., DeVetter, L. (2022). Soil-biodegradable mulch is an alternative to non-biodegradable plastic mulches in a strawberry-lettuce double-cropping system. Frontiers in Sustainable Food Systems 6. <https://doi.org/10.3389/fsufs.2022.942645>
- Wortman, S.E., Kadoma, I., Crandall, M.D. (2016). Biodegradable plastic and fabric mulch performance in field and high tunnel cucumber production. HortTechnology 26, 148–155. <https://doi.org/10.21273/horttech.26.2.148>
- Xiong, L., Li, Z., Shah, F., Wang, P., Yuan, Q., Wu, W. (2024). Biodegradable mulch film enhances the environmental sustainability compared with traditional polyethylene film from multidimensional perspectives. Chemical Engineering Journal 492, 152219. <https://doi.org/10.1016/j.cej.2024.152219>
- Zhang, H., Miles, C., Ghimire, S., Benedict, C., Zasada, I., DeVetter, L. (2019). Polyethylene and biodegradable plastic mulches improve growth, yield, and weed management in florican red raspberry. Scientia Horticulturae 250, 371–379. <https://doi.org/10.1016/j.scienta.2019.02.067>

Assessment of the Incorporation of Plastic Mulch into Fiberboard

Riley Grieve and Karl Englund, Washington State University



Fiberboard is a versatile material that has a wide range of production methods and applications. While the majority of fiberboard is made from wood fibers, a large variety of agricultural products can also be processed into fiberboard panels. The properties of fiberboard panels can span a large variety of uses, and are found in many applications, like door skins, cabinetry and molding, to name a few. The global medium density fiberboard (MDF) panel production and market size are expected to reach 80 million cubic meters and \$70 billion dollars, respectively, by 2027 (Walsh, 2026). With this substantial growth in the fiberboard industry since its inception in 1965, many studies have explored the production, properties, and applications of MDF, including studies on wood species, fiber characteristics, and hot press conditions, to only name a few (Benthien et al., 2017; Gul et al., 2017; Hong et al., 2017; Park et al., 2001; Xing et al., 2006). Despite all the current applications of MDF, its water resistance is minimal and restricts its use for exterior applications or for areas that require more durable performance (García-Garrido et al., 2025). By nature, wood-based materials will sorb water from the environment, which causes durability and structural issues (Irribarra et al., 2022). Increasing the water resistance of MDF would allow it to be used in exterior applications such as cladding and trim, as well as in high moisture/humidity interior applications in kitchens and bathrooms (Irribarra et al., 2022; García-Garrido et al., 2025).

While processing recycled plastic into MDF can be a challenge, creating a value-added MDF product that can be used in high moisture applications is the overarching goal of our study. In our attempts to incorporate plastic into the MDF manufacturing process, we have found that we can increase its water resistance as we increase its plastic content. The strength of the MDF panels is negatively affected as a higher percentage of plastic is added, but with extra study, adjustments, and analysis, we hope to minimize that effect.



Figure 1. Final surface preparation of a medium density fiberboard (MDF) panel before hot pressing.

MEDIUM DENSITY FIBERBOARD (MDF) PRODUCTION

The wood composite industry has been recycling waste for decades, using waste wood chips and planar shavings from sawmills as the primary feedstock for MDF production (Setunge et al., 2009). While using recyclates isn't new to MDF production, incorporating waste plastic mulch is a new field. Before the waste plastic mulch can be incorporated along with wood chips into MDF, the plastic mulch that was removed from agricultural fields needs to be broken down from its "as is" or shipped state for easier processing. In our previous study, we found agglomeration, or densification, was a reliable method for breaking apart the waste plastic mulch into a workable state. Once agglomerated, waste plastic mulch becomes dense and pellet-like, and we mixed it with wood chips in five ratios (by dry weight): 10%, 20%, 30%, 40%, and 50%. Each formulation was steamed to

soften the wood chips then run through an attrition mill to fiberize the mixture. The fiber formulations were then dried, mixed with an adhesive resin, placed in a rectangular mold (Fig. 1), and hot pressed. The hot pressed MDF panels were cut to shape and stored in humidity and temperature-controlled rooms until samples were cut for testing. The strength of the panels was measured through flexural and internal bonding tests that determine maximum weight the panels can withstand while bending and being pulled apart perpendicular to the surface, respectively. Water sorption tests (water absorbed into and adsorbed onto the panels) were also performed on the panels to measure their water resistance.

RESULTS AND NEXT STEPS

The results from this study were overall very successful in demonstrating how waste plastic mulch can be incorporated into MDF panels. Panels with up to 40% (by dry weight) of waste plastic mulch were successfully pressed

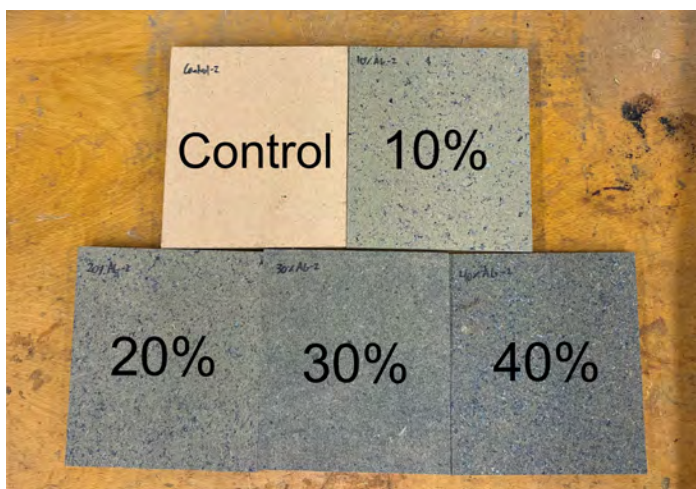


Figure 2. Samples of successful agglomerated medium density fiberboard (MDF) panels, from top left to bottom left: 0% (control), 10%, 20%, 30%, and 40% plastic mulch content.

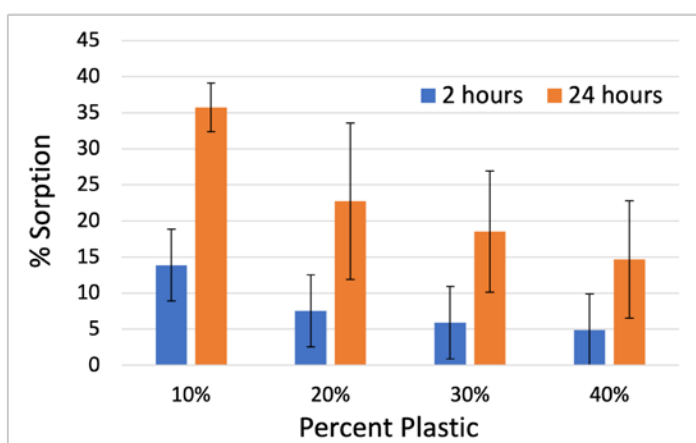


Figure 3. Water sorption (%) of agglomerated medium density fiberboard (MDF) panels after 2 and 24 hours of submersion in water. Values on the y axes represent the quantity of polyethylene waste plastic incorporated into the fiberboard matrix.

(Fig. 2), and its strength was comparable with the control panels (MDF without plastic). As the waste plastic mulch content was increased, less water sorption and swelling occurred (Fig. 3). Overall, this study shows that waste plastic mulch can be incorporated into MDF panels that are comparable in strength to the control panel and with superior water resistance and stability.

Further studies and data are needed to confirm our results and expand the analysis of the MDF panels with added plastic mulch. Of particular interest is the relationship between panel strength and increased percentages of added plastic. Our most immediate next steps are to focus on clarifying and comparing panel properties with application standards, and we are planning some advanced testing. As the majority of MDF is used to assemble products like doors, windows, cabinets, and other household milled composite pieces, we will perform double lap shear tests with assembly resins to evaluate how the added waste plastic mulch in the MDF panels influences the assembly resin. Our group is both excited and intrigued at the implications of this study and looks forward to further exploring the benefits and opportunities of this largely unused recycling pathway for waste plastic mulch.

REFERENCES

- Benthien, J. T., Heldner, S., Ohlmeyer, M. (2017). Investigation of the interrelations between defibration conditions, fiber size and medium-density fiberboard (MDF) properties. European Journal of Wood and Wood Products 75(2), 215-232. <https://doi.org/10.1007/s00107-016-1094-2>
- García-Garrido, J., Martínez-Filgueira, D., Barrio, A., Eceiza, A., Saralegi, A., Tejado-Etayo, Á. (2025). Enhancing water resistance of medium density fibreboards via periodate oxidation of thermomechanical fibres. European Journal of Wood and Wood Products 83(5), 171. <https://doi.org/10.1007/s00107-025-02325-w>
- Gul, W., Khan, A., Shakoor, A. (2017). Impact of Hot Pressing Pressure on Medium Density Fiberboard (MDF) Performance. AAPPS Bulletin. Association of Asia Pacific Physical Societies. <https://hal.science/hal-01612472>
- Hong, M. K., Lubis, M. A. R., Park, B. D. (2017). Effect of Panel Density and Resin Content on Properties of Medium Density Fiberboard. Journal of the Korean Wood Science and Technology 45(4), 444-455. <https://doi.org/10.5658/wood.2017.45.4.444>
- Iribarra, L. M., Kamke, F. A., Leavengood, S. (2022). Comparison of Water Resistance for Modified Medium-Density Fiberboard. Forest Products Journal 72(4), 235-240. <https://doi.org/10.13073/fpj-d-22-00047>
- Park, B. D., Kim, Y., Riedl, B. (2001). Effect of Wood-Fiber Characteristics on Medium Density Fiberboard (MDF) Performance. Journal of the Korean Wood Science and Technology 29(3), 27-35.
- Setunge, S., Wong, K. K., Jollands, M. (2009). Economic and Environmental Benefits of Using Hardwood Sawmill Waste as a Raw Material for Particleboard Production. Water, Air, & Soil Pollution: Focus 9(5), 485-494. <https://doi.org/10.1007/s11267-009-9224-z>
- Walsh, T. (2026). Mdf Industry Statistics. Worldmetrics, Construction Infrastructure Report. <https://worldmetrics.org/mdf-industry-statistics/>
- Xing, C., Deng, J., Zhang, S. Y., Riedl, B., Cloutier, A. (2006). Properties of MDF from black spruce tops as affected by thermomechanical refining conditions. European Journal of Wood and Wood Products 64(6), 507-512. <https://doi.org/10.1007/s00107-006-0129-5>

Pyrolysis as a Potential Recycling Technology for Spent Plastic Mulch

Cynthia B. Sigira and Hui Li, North Carolina State University



Plastic mulch has become a vital material in modern agriculture given its ability to increase crop yield while conserving water resources and suppressing weeds. However, at the end of its service life, plastic mulch can pose significant risks, such as deteriorating soil health, while conventional disposal methods can have detrimental health and environmental impacts (Sarpong et al., 2024). Different recycling technologies—including mechanical, thermal, chemical, and biological—offer potential solutions to address these challenges. Pyrolysis, a thermochemical recycling technique, is one of the promising technologies that can help recover value from spent plastic mulch.

INTRODUCTION TO PYROLYSIS

Pyrolysis is the thermal decomposition of carbon-based materials in the absence of oxygen, usually at high temperatures, with the aim of producing value-added byproducts (Chang, 2023). During pyrolysis, long polymer

chains undergo thermal cracking, producing condensable gases (collected as liquid oil), non-condensable gases, and solid residues (including char and ash). The relative product distribution depends on the feedstock properties and operating conditions, including temperature, heating rate, residence time, and pyrolysis reactor configuration (Chang, 2023). Pyrolysis has received considerable attention because it can handle contaminated polyethylene (PE) mulch that is often unsuitable for other recycling technologies (Sarpong et al., 2024). The resulting liquid oil contains hydrocarbons that can be upgraded into transportation fuels or chemical feedstocks, which can potentially support plastic circular economy initiatives (Dai et al., 2022)

THE ROLE OF MULCH CONTAMINATION

One of the greatest challenges associated with recycling PE mulch is its heterogeneous nature. Heterogeneity can originate from other

carbon compounds and additives incorporated during mulch manufacturing (Radhakrishnan et al., 2025). Contamination comes from field use through the accumulation of soil particles, plant debris, fertilizers, and other agricultural residues (Sarpong et al., 2024). This heterogeneity introduces compounds beyond the desired hydrocarbon composition, and several studies have shown that their presence alters the physicochemical properties of feedstocks, thereby directly influencing pyrolysis performance (Sorino et al., 2025). In a preliminary study, we characterized feedstock of PE mulch collected in Oxnard, California (CA) and our results are consistent with these studies.

Proximate analysis provides the physicochemical composition in terms of moisture content (MC), volatile matter (VM), fixed carbon (FC), and ash. VM represents the fraction that can vaporize and form condensable products, while ash contains non-combustible materials remaining after thermal decomposition. A high VM corresponds to higher liquid oil production, and the converse is true for a high ash content (Chang, 2023). Our preliminary findings show that despite never being used, virgin PE mulch had a considerably high ash content (10 wt.%) (Fig. 1), unlike pure PE from past studies (0.2–0.9 wt.%) (Chang, 2023). This difference can be attributed to the presence of non-carbon additives introduced during mulch manufacturing.

The amount of external contamination (mainly soil) on the used PE mulch was ~22% and ~26% for dry-washed (Dry Wash) and untreated mulch post-collection (As Is), respectively. Correspondingly, ash content increased dramatically to approximately 33–35 wt.% (Fig. 2), accompanied by a noticeable reduction in VM compared with virgin PE mulch. Soil had an ash content of 94.72 wt.%, suggesting it may have played a major role in the increase in ash content of the used PE mulch that was deployed in the field. Because VM serves as the primary

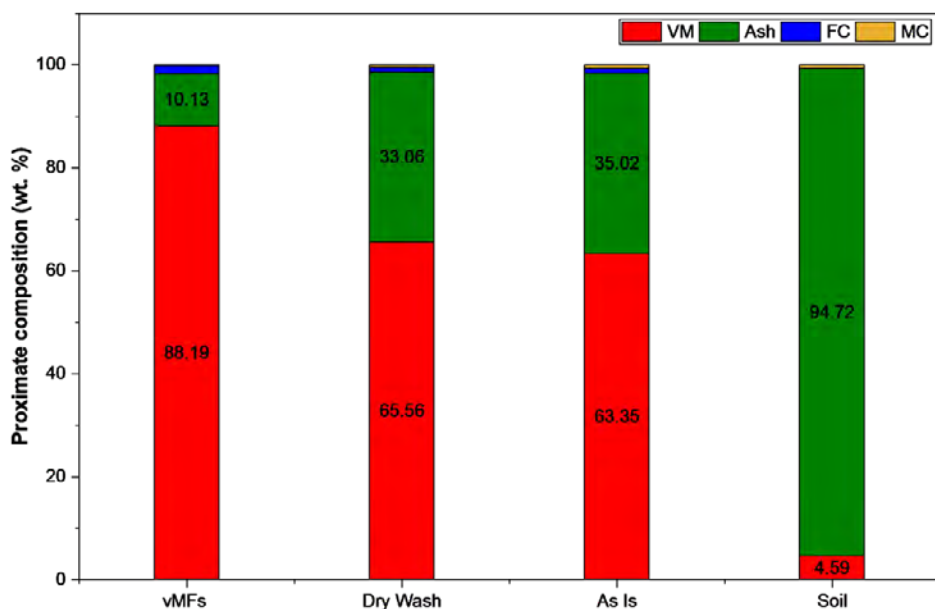


Figure 1. Proximate composition of three materials—virgin polyethylene mulch (vPEM), spent polyethylene mulch (sPEM; shown as Dry Wash and As Is), and agricultural soil from Oxnard, California (CA). Bars show the percentage of four measured components: volatile matter (VM), ash, fixed carbon (FC), and moisture content (MC). This comparison illustrates how these properties differ between unused mulch, field used mulch, and local soil.

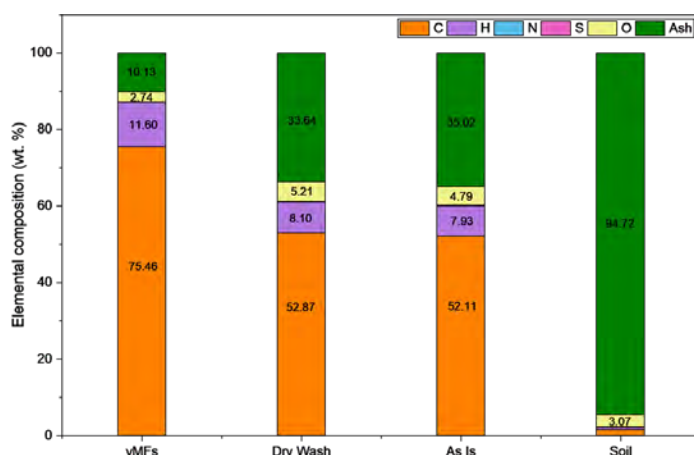


Figure 2. Elemental composition of three materials, virgin polyethylene mulch (vPEM), spent polyethylene mulch (sPEM; shown as Dry Wash and As Is), and agricultural soil from Oxnard, California (CA). Bars represent the percentage of five measured elements: Carbon (C), Hydrogen (H), Nitrogen (N), Sulfur (S), and Oxygen (O). This comparison highlights how elemental profiles differ between unused mulch, field used mulch, and local soil.

precursor for condensable vapors, these changes are anticipated to reduce the maximum attainable liquid oil yield while increasing solid residue production.

Elemental composition, which provides feedstock composition in terms of carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O), is equally important for evaluating pyrolysis feedstocks. C and H are the principal contributors to hydrocarbon production, whereas O generally promotes the formation of oxygenated compounds (Chang, 2023). N and S are usually negligible but can be integrated into products such as oil. Due to the inherent heterogeneous nature of virgin PE mulch, the C and H contents were considerably lower (C: ~75 wt.% and H: ~12 wt.%) than those normally reported in the literature (C: ~86 wt.% and H: ~14 wt.%) (Chang, 2023). In addition to the heterogeneity of PE mulch, external contaminants such as soil, pesticides, and fertilizers containing heteroatoms and non-carbon-based compounds dilute the hydrocarbon-rich polymer fraction and alter the apparent elemental composition of used PE mulch. This can be seen in our preliminary findings, as shown in Fig. 2. Understanding these compositional factors and changes is essential for accurately predicting and optimizing pyrolysis performance.

WHAT LIES AHEAD

We are currently working on an optimization study to maximize plastic oil yield by varying two major factors that influence product distribution: temperature and feedstock residence time during pyrolysis. The optimization experiments are still in their early stages, and this will remain the main focus in the coming months. We will carry out laboratory-scale pyrolysis experiments at moderate temperatures (450 °C to 600 °C) and moderate feedstock residence times (30 min to 90 min). The byproducts, obtained under optimal conditions, will then be comprehensively characterized using appropriate analytical techniques. We look forward to sharing these results soon.

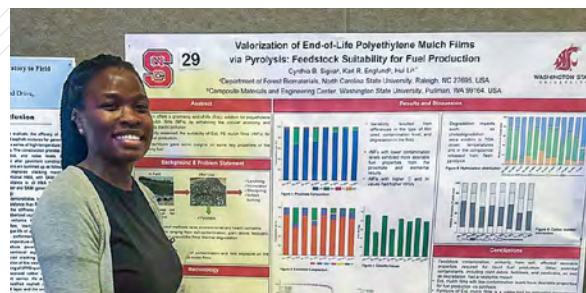
REFERENCES

- Chang, S. H. (2023). Plastic waste as pyrolysis feedstock for plastic oil production: A review. Science of the Total Environment 877. <https://doi.org/10.1016/j.scitotenv.2023.162719>
- Dai, L., Zhou, N., Lv, Y., Cheng, Y., Wang, Y., Liu, Y., Cobb, K., Chen, P., Lei, H., Ruan, R. (2022). Pyrolysis technology for plastic waste recycling: A state-of-the-art review. Progress in Energy and Combustion Science 93, 101021. <https://doi.org/10.1016/j.pecs.2022.101021>
- Radhakrishnan, H., Mohammed, A. A. B. A., Coffman, I., Bai, X. (2025). Influence of functional additives, fillers, and pigments on thermal and catalytic pyrolysis of polyethylene for waste plastic upcycling. Green Chemistry 27(20), 5861–5882. <https://doi.org/10.1039/D5GC00688K>
- Sarpong, K. A., Adesina, F. A., DeVetter, L. W., Zhang, K., DeWhitt, K., Englund, K. R., Miles, C., Sarpong, K. A., Adesina, F. A., DeVetter, L. W., Zhang, K., DeWhitt, K., Englund, K. R., Miles, C. (2024). Recycling agricultural plastic mulch limitations and opportunities in the United States. Circular Agricultural Systems 2024 1:E005 4(1). <https://doi.org/10.48130/cas-0024-0003>
- Sorino, D., de Vizia, P., Baldelli, M., Bartolucci, L., Cordiner, S., Falsetti, A., Lombardi, F., Mulone, V. (2025). Pyrolysis of mixed contaminated plastic waste: Assessing the influence of polymers composition, temperature and residence time. Waste Management 201, 114793. <https://doi.org/10.1016/j.wasman.2025.114793>

Cynthia Sigira GRADUATE STUDENT SPOTLIGHT

Cynthia Sigira is a PhD student at North Carolina State University, specializing in Forest Biomaterials with a minor in Chemical and Biomolecular Engineering. She conducts her research under the guidance of Dr. Hui Li (North Carolina State University), with Dr. Karl Englund (Washington State University) serving as her co advisor. Her work centers on evaluating pyrolysis as a recycling pathway for end-of-life for plastic mulch films. Pyrolysis is a thermochemical process that uses high temperatures to break down materials into liquid, gaseous, and solid products. Cynthia's research specifically examines how contamination influences the properties and pyrolysis behavior of polyethylene (PE) mulch films, and how process conditions can be optimized to improve the recovery of valuable products.

A recent milestone in her academic journey was the publication of her 2025 study in Waste Management, which investigated how soil contamination affects feedstock characteristics and pyrolysis outcomes for PE mulch films. She has shared this work at multiple poster sessions, including a graduate symposium at NC State University and a micro and nano plastics workshop in Mobile, Alabama. Cynthia and Jianying Wang, a PhD student at Washington State University, were also recipients of the USDA SCRI Graduate Student Proposal Award. Through this award—and with support from the California Marine Sanctuary Foundation—they organized and hosted a July 2026 webinar focused on plastic disposal pathways, with an emphasis on pyrolysis. The event featured speakers representing research, environmental policy, life cycle assessment, and industrial commercialization, including Dr. Karl Englund (WSU), Jianying



Wang (WSU), Oluwatunmise Dada (WSU), Dr. Anja Brandon (Ocean Conservancy), and Kevin DeWhitt (PDO Technologies). Together, the speakers provided a broad perspective on pyrolysis, covering environmental impacts, regulatory considerations, and the challenges and opportunities associated with scaling the technology. Cynthia was also featured in a Mulch Matters Podcast (Turning Plastic Mulch into Opportunity: Cynthia Sigira on Pyrolysis, Recycling Challenges & Circular Solutions) where she talked about her work on pyrolysis, challenges surrounding pyrolysis as a recycling pathway for plastic mulch, and her insights into circular solutions.

Cynthia is currently conducting lab scale pyrolysis experiments on contaminated mulch films, with a focus on optimizing temperature and residence time to maximize fuel yield. Her goal is to advance more sustainable recycling pathways for agricultural plastics and deepen scientific understanding of how contamination affects their conversion. She is enthusiastic about the future of this work and its potential contributions to agricultural plastic management, environmental sustainability, and the broader scientific community.

RECENT ACHIEVEMENTS

Publication

Sigira, C. B., Englund, K. R., DeWhitt, K., Li, H. 2026. Soil contamination impacts feedstock characteristics and drives pyrolysis outcomes in the conversion of polyethylene mulch films to fuel. Waste Management, 224, 115760. DOI: 10.1016/j.wasman.2026.115760

Award

USDA SCRI Graduate Student Proposal Award for Professional Development (November 2025 to July 2026)

Poster Presentations

Sigira, C., Englund, K., Li, H. 2026. Valorization of End of Life Polyethylene Mulch Films via Pyrolysis: Feedstock Suitability for Fuel Production. Forest Biomaterials Symposium, Raleigh, NC.

Sigira, C., Englund, K. R., DeWhitt, K., Li, H. 2026. Soil contamination impacts feedstock characteristics and drives pyrolysis outcomes in the conversion of polyethylene mulch films to fuel. Microplastics and Nanoplastics Workshop, Mobile, AL.

Podcast Feature

Shcherbatyuk, N. 2026. Turning Plastic Mulch into Opportunity: Cynthia Sigira on Pyrolysis, Recycling Challenges & Circular Solutions [Audio podcast episode]. In Mulch Matters. Libsyn. <https://sites.libsyn.com/474648/turning-plastic-mulch-into-opportunity-cynthia-sigira-on-pyrolysis-recycling-challenges-circular-solutions>



Cynthia Sigira touring the Baldwin County Recycling Center, a mechanical recycling facility in Summerdale, Alabama (AL). This site visit was a part of the micro- and nano-plastics workshop in Mobile, AL to show attendees plastic recycling in action.

Kevin Morris GRADUATE STUDENT SPOTLIGHT

Kevin Morris, a graduate student in Washington State University, has distinguished himself through a series of academic achievements, including earning the James C. Nelson Fellowship in Transportation Economics in 2024, completing an intensive international workshop on survey design and experimental methods at Michigan State University the same year, and successfully defending his preliminary dissertation in the spring of 2026. These accomplishments reflect both his dedication to his field and the steady progression of his graduate studies.

Kevin's current research centers on understanding how both strawberry consumers and growers think about plastic use and pollution in agricultural systems. As part of the economics working group, he designs and conducts surveys that explore how environmental attitudes translate into real purchasing decisions. He recently contributed to the newsletter with a report he helped write titled *"Consumer WTP for strawberries produced under sustainable plastic disposal practices"* discussing the price premium consumers would be willing to pay to reduce terrestrial plastic waste pollution. His work with growers focuses on their interest in products and practices that reduce plastic waste accumulation within strawberry production. This dual perspective allows Kevin to connect consumer sentiment with producer behavior, offering a more complete picture of how environmental concerns shape the agricultural marketplace.

Beyond his work on the SCRI EOL project, Kevin is deeply interested in the global plastic waste trade. A significant portion of contaminated plastic—sometimes as high as a quarter of all material sent to recycling facilities—cannot be recycled and is instead exported to countries with weaker environmental institutions. This often leads to improper disposal and additional pollution in waterways and oceans. Kevin's research bridges domestic attitudes and international consequences, highlighting how everyday decisions can ripple outward into global environmental impacts.

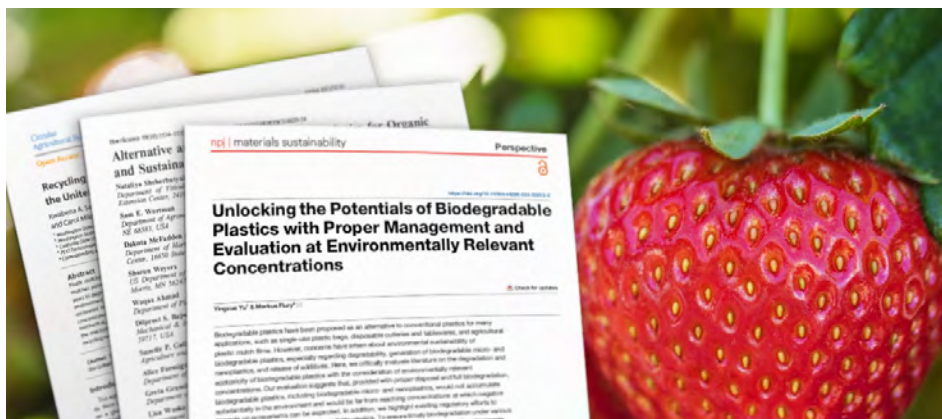


Kevin's path to environmental economics began in North Central Washington, where he grew up on Lake Chelan. He arrived at Washington State University in 2015 to study economics, but his interest in environmental issues was shaped much earlier. During summers spent on the Bering Sea visiting his father, a commercial king crab fisherman, he witnessed firsthand the natural beauty and biodiversity of the region, as well as the strong sense of stewardship held by those who worked there. These experiences inspired him to pursue a field that examines the intersection of environmental responsibility and natural resource management.

Throughout his time at Washington State University, Kevin found mentors who encouraged him to consider graduate school. His introduction to academic research came when Tom Marsh, now his doctoral committee chair, hired him as an undergraduate research assistant on the SCRI EOL grant. That opportunity sparked his interest in research, shaped the direction of his dissertation, and allowed him to collaborate with experts across multiple disciplines. Today, Kevin's work continues to reflect his commitment to environmental stewardship and his desire to contribute meaningful insights to sustainable agricultural systems.



Beachcombing for hand-blown glass fishing weights around the Izembek National Wildlife Refuge (2017)



Upcoming Events

If you know of an event you think would be of interest to the agricultural plastics and recycling community, please contact Lisa DeVetter (lisa.devetter@wsu.edu) or Nataliya Shcherbatyuk (n.shcherbatyuk@wsu.edu).

Recent Publications

- Clements, J. W., McKinney, M. L., DeBruyn, J., Hayes, D. G., Schaeffer, S. M. 2026. **Contextual Recalcitrance of Polylactic Acid (PLA) in Soils: Degradation Mechanisms, Microbial Traits, and Fate-Relevant Endpoints.** *Journal of Xenobiotics*, 16(6), 183.
- Dada, O.I., Wang, J., Liyanage, T.U.H., Dahal, K., Liu, H., Chi, T., Yu, L., Chen, S. 2026. **Life cycle assessment of biodegradable mulch films in strawberry production under alternative end-of-life scenarios.** *Journal of Environmental Management* 417, 130888.
- Ghimire, S., Miles, C., Galinato, S. P., Wortman, S. E., Velandia, M. 2026. **Soil-biodegradable Plastic Mulches: Certification Status and Economic Considerations for Growers and Extension Professionals in the United States.** *HortTechnology*, 36(5), 1049–1057. doi:10.21273/HORTTECH05993-26.
- Leach C, Tiwari E, Sistla S. **Exploring the influence of microplastics on soil biogeochemical traits using an artificial soil approach.** *Science of The Total Environment*. 2026 Oct 1;1050:182206.
- Williams, A. R., Goldberger, J. R., DeVetter, L. W. (2026). **Public perceptions of agricultural plastic: Comparing shopper views of polyethylene and biodegradable mulch in Washington State.** *Renewable Agriculture and Food Systems*. 41: e22. doi:10.1017/S1742170526100477.

Connect and Tune In!

INSTAGRAM  Mulch_Matters	LINKEDIN  MulchMatters	LIBSYN  Mulch Matters Podcast
---	---	--

The Mulch Matters Podcast is also available on your favorite streaming platform including **Audible**, **Spotify**, and **Apple Podcasts**.