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Sustainable Mulch MANAGEMENT

Plastic Mulches in Horticulture Production

Improved End-Of-Life of Plastic Mulches

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In This Issue...

Cover photo Julia Gray (WSU) evaluating a metalized mulch film during a field trial in Mount Vernon, WA. Photo credit: Louis Nottingham.

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Project Director's Note

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

Our team continues to make steady progress across multiple avenues of research, buoyed by the recent approval of our no-cost extension. With an additional year, we now have the time and resources needed to complete ongoing experiments and prepare our results for dissemination to both public and private audiences.

This newsletter truly offers something for everyone. We continue our long-standing focus on soil health with an update from Dr. Deirdre Griffin LaHue on how soil-biodegradable mulches influence soil properties. We also share the latest insights from California on mechanical retrieval methods for traditional plastic mulch designed for recycling. For those interested in the "creepy crawly," you'll enjoy a feature from a former Washington State University (WSU) undergraduate in entomology examining how different mulches affect pest and beneficial arthropod communities. In contrast, our human-dimensions team contributed an article exploring how waste-management infrastructure shapes the end-of-life fate of agricultural plastics in California.

If you're interested in soil-biodegradable mulch microplastics, our collaborators at Cal Poly offer an overview of their recent lab-based work. This is complemented by an article highlighting WSU graduate students' field research on soil-biodegradable mulch transformation in agricultural soils. For readers seeking an economic perspective, we also include an update from colleagues at the University of Connecticut and WSU examining the dimensions and costs of polyethylene and soil-biodegradable mulches.

Finally, we highlight several recent episodes of the Mulch Matters podcast, covering topics ranging from earthworm-based fertilizers from Wiggle Brew (not mulch, but fascinating!) to the inspiring story of Flipping Iron's efforts to transform agricultural plastic collection and recycling.

We hope you find this issue informative, timely, and reflective of the diverse and collaborative work happening across our project.

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Tracking the Soil Health Effects of Soil-Biodegradable Plastic Mulches Across Diverse Climates and Soils

Deirdre Griffin LaHue, Washington State University

What happens when plastic mulch is left in the soil? Polyethylene (PE) mulches are removed after the season but can contribute to microplastic contamination in soil when fragments are left behind. Alternatively, soil-biodegradable mulches (BDMs) are tilled into soil, where they are broken down by soil organisms. Both these scenarios prompt ongoing questions about how mulch fragments influence soil health.

In my previous article in the Sustainable Mulch Management Newsletter Summer 2025, I introduced the concept of soil health and the questions surrounding the long-term impacts of BDMs on soil processes. While short-term studies have generally shown minimal effects, it is important to evaluate how repeated incorporation of BDMs may influence soils over time, particularly across environments where breakdown rates may differ widely due to moisture and temperature variability. Addressing these questions is a key focus of our ongoing research.

As part of this SCRI project, we are evaluating soil health responses to BDM incorporation across four contrasting locations: California, Florida, Nebraska, and Washington. PhD candidate Nayab Gull has been leading this effort as part of her dissertation research. At each site, soil samples are collected at the end of each growing season and analyzed for a range of soil health indicators. We are comparing two BDM feedstock types (Mater-Bi and ecovio) to traditional PE mulch. While the sites in California, Florida, and Nebraska were new to BDM use in Year 1 of our trials, the Washington site has received six BDM incorporations to treatment plots since 2015 (one per year from 2015 to 2018, and repeated again in 2023 and 2024), allowing us to assess longer-term effects under cooler, wetter conditions (Griffin-LaHue et al., 2022). Together, this approach helps us understand how climate and management history shape soil health outcomes with BDM use.

A REFRESHER ON SOIL HEALTH

Soil health describes a soil's physical, chemical, and biological condition as it relates to many key functions we look for in agroecosystems, including nutrient cycling, decomposition, water retention and drainage, and resilience to disturbance. The main soil challenges may vary depending on the location and system, but in a comprehensive soil health assessment, we evaluate physical, chemical, and biological *soil health indicators* (Figure 1). These indicator measurements are like vital signs of the soil. In Figure 2, Nayab is analyzing soils for *potentially mineralizable carbon*, also referred to as *soil respiration*, which measures carbon dioxide released by microbes after soils in the lab are rewetted. See my previous article (pdf) to learn more on this topic.

WHAT WE HAVE FOUND IN OUR RESEARCH

After analyzing a suite of soil health indicators, we have not observed any differences between mulch treatments, even at the legacy mulch trial site in Washington. Figure 3 shows results of potentially mineralizable carbon and permanganate oxidizable carbon (POXC), a pool of soil organic matter that is sensitive to soil management and has chemically complex compounds (Christy et al., 2023). We focus on these two indicators as they are both related to different aspects of microbial processing of organic matter.

While there do not appear to be differences among mulch treatments regarding effects on microbial processing of organic matter, the quantity of microbes in the soil, or nutrient availability, we see clear differences in these measurements between locations, due to

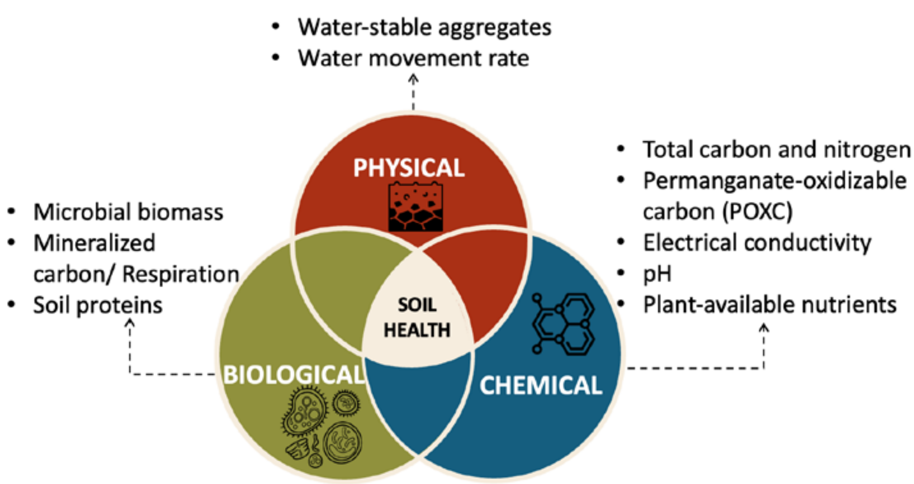

Figure 1. Diagram of physical, chemical, and biological soil health indicators being measured across four sites in our SCRI mulch project.

Figure 2. WSU PhD candidate Nayab Gull rewets soil samples to conduct a potentially mineralizable carbon (or soil respiration) assay.

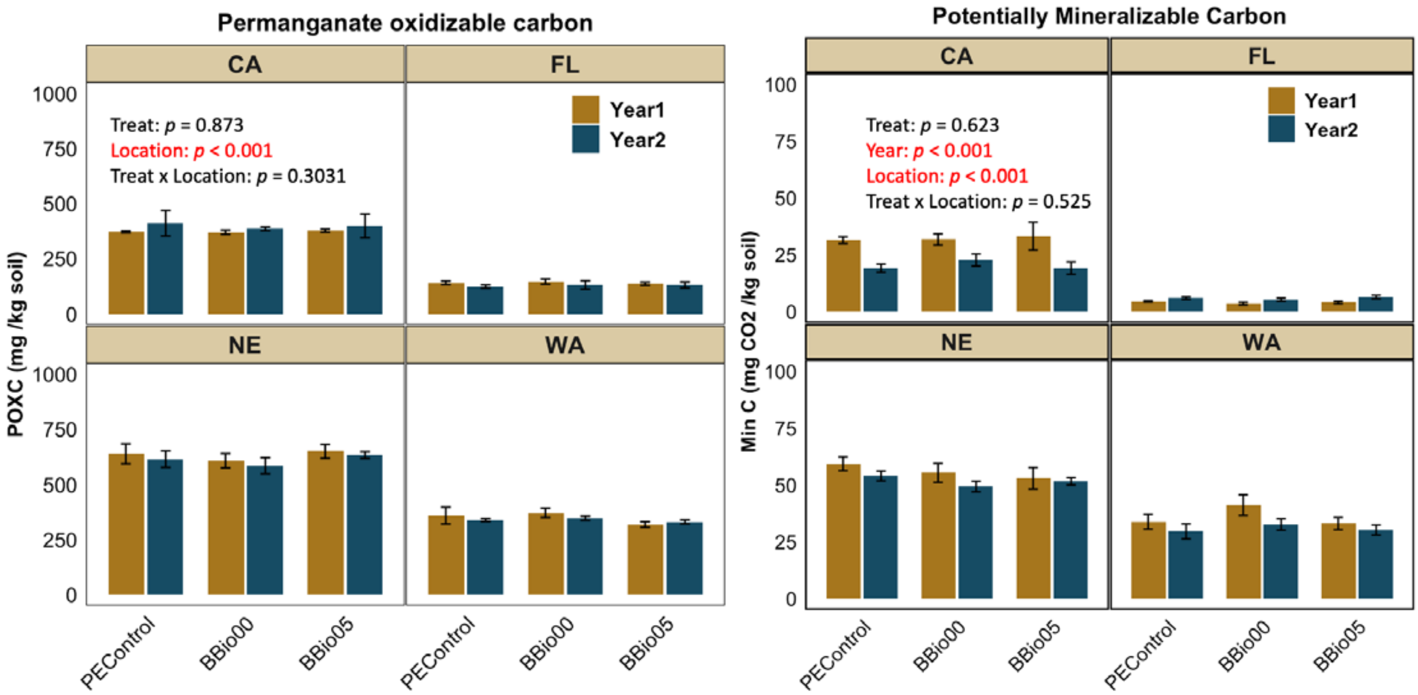

Figure 3. Unpublished data from the SCRI Mulch Project showing soil permanganate-oxidizable carbon (POXC; left) and potentially mineralizable carbon (MinC; right) under black polyethylene (PE) and soil-biodegradable plastic mulch (BDM) treatments: black Mater-Bi (BBio00), black ecovio (BBio05) at California, Florida, Nebraska, and Washington trial sites. Bars show mean values, and error bars indicate standard error. Figure courtesy of PhD Student Nayab Gull.

inherent variation in climate and soil properties. We also observed differences between years in the case of mineralizable carbon, a dynamic measurement that can be affected by things like soil moisture at the time of sampling. Our statistical analysis allows us to separate these factors from our mulch treatment effects.

While these results are in line with previous studies on soil health effects of BDMs (e.g., Sintim et al., 2020 and 2021), it should be noted that we sampled at only one timepoint per year, immediately prior to mulch removal and BDM incorporation. It's possible that these dynamic indicators could respond to mulch treatments if sampled at a different point in the season. Yet it is meaningful that we did not observe treatment effects in the long-term site in Washington, where mulch decomposition is likely slowest due to the cool, moist climate.

NEXT STEPS

We are still wrapping up analysis of a few more soil physical properties, including aggregate stability (how well the soil holds together with water disturbance) and the rate of water movement through soil. However, preliminary data indicates that the mulch treatments are similarly having no effects on these parameters. We look forward to sharing a complete dataset soon!

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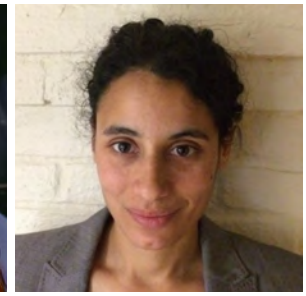

Mechanical Retrieval of Agricultural Mulch Films in California's Central Coast

Jazmine Mejia-Muñoz, California Marine Sanctuary Foundation and
Seeta Sistla, California Polytechnic State University

In California, over 19 million pounds of agricultural plastic mulch films are used annually in strawberry systems (Krone 2021 and California Marine Sanctuary Foundation internal assessments). Plastic mulch is used by most farmers in California for strawberry production, which accounts for about 43,726 acres in California and 90% of U.S. strawberry production (Turechek 2025).

Techniques for plastic mulch removal from strawberry fields vary from hand removal to mechanical retrieval. Many farmers rely on crews of 20-40 team members to manually pull mulch from the row-crop beds and wrap it into bundles for landfill disposal. Some farmers in Santa Maria, CA, have relied on implements such as the Double Reel Plastic Mulch Lifter-Wrapper (CropCare, Lititz, PA) or have created their own spooling systems to remove mulch films. Other farmers have opted to use the Mega Binder (Andros Engineering Corporation, Paso Robles, CA), a large retrieval implement that can simultaneously retrieve multiple lines of agricultural plastic into a spool to create a dense roll of plastic. Plastic mulch removal using equipment is referred to as mechanical retrieval in this article. Each farm operation decides for itself what is the best retrieval method.

In California, the adoption of mechanical mulch removal services provided by Flipping Iron Inc. (Bakersfield, CA) has increased from 1,958 acres in 2024 to a total of 6,720 acres in 2025 (Flipping Iron, Personal Communication, 2026). In this article, we share experiences we have gained from mechanical collection trials, commercialization of mechanical mulch collection, and current agricultural plastic recycling market trends.

PLASTIC RESIDUES IN FIELDS POST REMOVAL

Six commercial row-crop fields in California's Central Coast region were analyzed as part of this project, funded by a NOAA Sea Grant Marine Debris Challenge grant. At each farm, plastic mulch was removed using two methods: manual removal (control) and mechanically using a Mega Binder. The amount and weight of plastic mulch remaining on the soil surface in the field was extrapolated per hectare by collecting plastic visible on the soil surface from quadrants (1m^2) every 20 meters (m) along five 100 m transects. There were no significant differences between the amount of plastic residue left behind from hand-retrieval and mechanical retrieval (Figure 1). However, there was variation among field sites in the amount of residual plastic collected, likely due to historical plastic and end-of-season management practices. Anecdotally, plastic left behind from both hand-retrieval and mechanical collection seemed to come from the skirts of the bed, where the plastic was buried and would be more difficult to lift and remove.

Mulch manufacturers are collaborating with the California Marine Sanctuary Foundation to test fortified mulch films in fields with heavy, clay-rich soils, where conventional films frequently rip along the edges during removal due to the soil's density and adhesion. Trials are currently being hosted in Monterey County with a goal of improving the efficiency and completeness of plastic removal.

PLASTIC DISPOSAL POST REMOVAL

Plastic that is removed by hand is typically bundled by hand and loaded into a small flatbed truck or a bin. Depending on the size of the farm or ranch and its preferred practices, plastic bundles are often stored in a shed or barn onsite until they can be transported to the landfill.

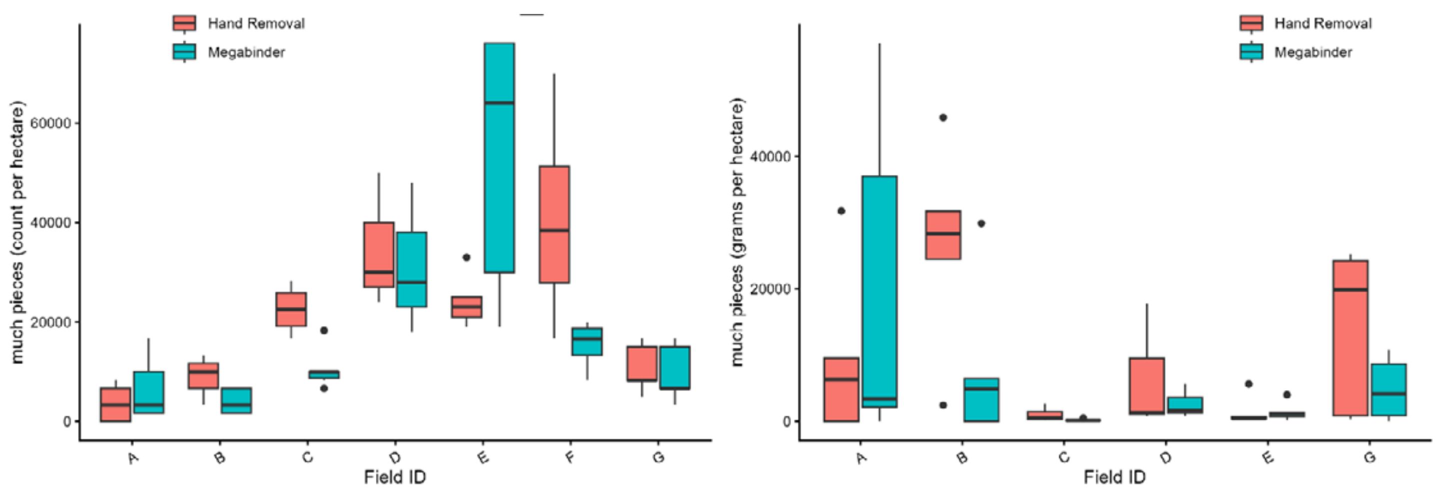

Figure 1. Difference in visible plastic mulch pieces by count (left) and fragment weight (right) when comparing hand removal verses mechanical removal with a Mega Binder. Fields (A – G) were anonymized; no significant difference in removal method on plastic fragment accumulation was observed. Field F was removed from the weight analysis due to extremely large fragments, which was an anomaly compared to all other sites.

Landfill tipping fees vary across California's Central Coast and have increased over time. For example, tipping fees in Monterey County for agricultural mulch films are $112 per ton, and in Santa Cruz County the tipping fee is $167.50 per ton. In 2025, tipping fees in Santa Maria were $158 per ton and this has increased to $250 per ton in 2026 (City of Santa Maria, Utilities Department 2025, 2026).

SEPARATE AND DENSIFY MULCH TO RECYCLE

Mechanical collection with the Mega Binder densifies the plastic directly from the field into large rolls weighing about 1,500 pounds each, depending on the plastic thickness and level of contamination with soil and plant material. The separation of mulch from other ag plastics such as drip tape along with the densification of plastic allows for a cost-effective way to transport the agricultural mulch films to a dry-wash processing station. The dry-wash processing station helps to reduce water and contaminant material and densifies the plastic to be sent out for recycling. Most agricultural plastic recycling programs and feedstock programs explicitly require that ag plastic be mechanically densified.

Costs associated with mechanical retrieval vary based on multiple factors including ownership versus rental of equipment, farm location, and mulch removal methods. While mechanical retrieval can be cost-prohibitive for small-scale growers that grow on less than 15 acres, the economics of medium-to-large scale growers vary. A comprehensive economic analysis is being conducted by Ms. Suzette Galinato at Washington State University.

RECYCLING CHALLENGES ON THE HORIZON

Across the United States about 257,000 tons of mulch are used annually, with about 50% of the film use attributed to sweetcorn, tomatoes, broccoli, and watermelon (Malarkey and Babbitt, 2025). The waste generated from plastic mulch use continues to challenge waste management efforts. In July 2025, Malaysia announced that they are no longer accepting plastic waste from countries that are not participating in the Basel Convention, such as the United States (Attorney General Chambers-Malaysia, 2025). The limited number of domestic plastic waste processing facilities, and a general lack of infrastructure and end-of-life plastic waste markets create a major barrier to domestic end-of-life recycling.

Plastic waste sale is further exacerbated by the high soil and plant debris that can be found adhering to mulch films. The Andros dry wash processing line, developed with support from NOAA Sea Grant, helps reduce contamination so post use plastic meets end of life market cleanliness requirements. To ensure long term recycling success, mechanical collection efforts from growers and dry wash processing and densification efforts by plastic service providers will require investment in domestic infrastructure and end-of-life plastic markets by the state, plastic manufacturers, and recyclers.

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Mulch Impacts on Pest and Beneficial Arthropods in Day-Neutral Strawberry

Julia Gray, Emma Rogers, Lisa W. DeVetter, and Louis Nottingham, Washington State University

Mulches are widely used in specialty crop production to suppress weeds, moderate soil temperature, and reduce evaporative soil-water loss. In addition to these well-established benefits, mulches can also influence pest and beneficial arthropod activity (McIntosh et al., 2021, 2023, and 2024; Nottingham and Beers 2020; Nottingham and Kuhar 2016). This occurs when mulches alter the plant microclimate in ways that make conditions more or less favorable for certain arthropods, such as when reflective mulches disrupt the visual cues needed to locate host plants (McIntosh et al., 2021 and 2023; Nottingham and Beers 2020; Nottingham and Kuhar, 2016). The multi-dimensional benefits of mulch for reducing pesticide needs while improving plant health make it an optimal fit for integrated pest management (IPM; Figure 1). However, the potential for negative effects on beneficial arthropods including predators, parasitoids, and pollinators is still unclear, highlighting the need for a holistic ecological approach to mulch research.

The aim of this study was to assess how different mulch treatments influence pest and beneficial arthropod populations within a strawberry production system. In the longer term, understanding how mulches affect these important arthropod communities can help identify practices that support more sustainable production with reduced reliance on pesticides.

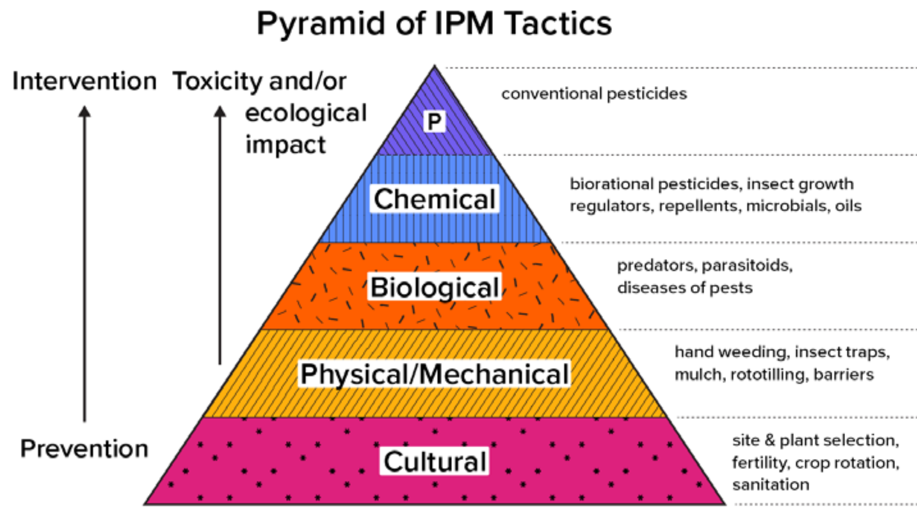

Figure 1. Integrated pest management (IPM) incorporates a diverse array of tactics to suppress pests with minimal reliance on pesticides.

APPROACH

Field experiments were conducted in northwest Washington during the 2023 and 2024 seasons using day-neutral 'Albion' strawberry established from bare-root plants. The experimental design was a randomized complete block with four replications. Five different treatments including a no-mulch control were applied each year and evaluated. Mulch treatments included Black BioGuard00, Green BioGuard00, black polyethylene, and metalized mulch. Both BioGuard treatments were made with Mater-Bi soil-biodegradable feedstock (i.e., a blend of polybutylene adipate terephthalate and starch) and differed only in color and film thickness, whereas the polyethylene and metalized films were not biodegradable. Following mulch application, a wide survey of arthropods was conducted using three sampling methods: visual counts, leaf-brushing, and yellow sticky cards (Figure 2). Measurements occurred weekly through the peak summer season (June and July), then transitioned to every other week until the end of August. Final sampling was timed to be after the final harvest in both years. A summary of results is presented in Table 1.

PEST SUPPRESSION

Mulch type had notable impacts on several key pests. Aphid (Aphidoidea) numbers were consistently lowest in the metalized mulch treatment, with Black BioGuard00 having lower counts of aphids compared to black polyethylene and the no-mulch control. Leafhoppers (Cicadellidae) and thrips (Thysanoptera) showed similar patterns on sticky cards, where metalized mulch produced the greatest reductions, and all mulched treatments outperformed the no-mulch control. Twospotted spider mites (*Tetranychus urticae*) showed a different trend, with number of eggs lowest in the no-mulch control and black polyethylene treatment and higher counts with metalized mulch. Overall, mulches generally helped suppress flying pests such as aphids, leafhoppers, and thrips.

IMPACTS ON BENEFICIAL ARTHROPODS

Parasitoid wasps (Hymenoptera) and rove beetles (Staphylinidae) were the most observed beneficials on sticky cards. In this sampling method, there were fewer parasitoid wasps in the metalized mulch treatment, and black polyethylene and Black BioGuard00 reduced their numbers compared to the no-mulch control. Rove beetle counts were highest in the no-mulch control and lower in all mulched treatments. Spider counts, including eggs, were influenced by mulch type in the visual assessment, with fewer present in plots on metalized mulch compared to Black BioGuard00 and Green BioGuard00. Although parasitoids and predators could be directly impacted by mulches, it is also possible that lower numbers are tied to the lower pest pressure in those treatments. Beneficial arthropods naturally fluctuate in abundance based on how many hosts or prey

Table 1. Mulch effects on pest and beneficial arthropod counts across various sampling methods.

Arthropod	Pest or Beneficial	Sampling Method	Mulch Effect	Summary
Aphids	Pest	Visual	Yes	Mulch treatment affected aphid counts overall, but no individual treatment effects were detected in Tukey-adjusted pairwise comparisons.
Aphids	Pest	Sticky card	Yes	Number of aphids was lower in the metalized mulch treatment compared to all other mulch types. Other mulch types showed reduced number of aphids compared to the no-mulch control.
Aphids	Pest	Leaf brush	Yes	Number of aphids were higher in the no-mulch control compared to all other mulch types.
Aphid mummies	Pest	Visual	No	*No treatment effects*
Aphid mummies	Pest	Leaf brush	No	*No treatment effects*
Leafhoppers	Pest	Sticky card	Yes	Number of leafhoppers was lower in the metalized mulch treatment compared to all other mulch types. Other mulch types showed reduced leafhoppers compared to the no-mulch control.
Thrips	Pest	Sticky card	Yes	Number of thrips was lower in the metalized mulch treatment compared to all other mulch types. Other mulch types showed reduced number of thrips compared to the no-mulch control.
Thrips	Pest	Leaf brush	No	*No treatment effects*
Twospotted spider mites	Pest	Leaf brush	No	*No treatment effects*
Twospotted spider mite eggs	Pest	Leaf brush	Yes	Number of twospotted spider mite eggs was lower in the no-mulch control compared to the metalized mulch treatment, with no differences detected in other mulch types.
Parasitoid wasps	Beneficial	Sticky card	Yes	Number of parasitoid wasps was lower in the metalized mulch treatment compared to all other mulch types. Black polyethylene and Black BioGuard00 showed reduced parasitoid wasps compared to the no-mulch control.
Rove beetles	Beneficial	Sticky card	Yes	Number of ove beetles was higher in the no-mulch control compared to all other mulch types.
Spiders	Beneficial	Visual	Yes	Number of spiders (including eggs) was lower in the metalized mulch treatment compared to Green BioGuard00 and Black BioGuard00.
Spiders	Beneficial	Sticky card	No	*No treatment effects*
Pollinators	Beneficial	Visual, sticky card	No	*No treatment effects*
Lacewings	Beneficial	Visual	No	*No treatment effects*
Predatory mites	Beneficial	Leaf brush	No	*No treatment effects*
Syrphids	Beneficial	Visual	No	*No treatment effects*
Syrphids	Beneficial	Sticky card	No	*No treatment effects*

Figure 2. Julia Gray conducting visual arthropod counts over a reflective polyethylene mulch plot.

are available, so fewer pests (i.e., predator food) often means fewer natural enemies as well. In addition to natural enemies, pollinators are another important group of beneficials. Mulch type did not appear to influence pollinator activity, although the plot sizes in this trial may have been too small to thoroughly study this group.

TAKEAWAYS: MULCH IS MORE THAN JUST WEED SUPPRESSION!

Overall, this study showed that mulch treatments influenced both pest and beneficial arthropod abundance in strawberry plantings. Non-flying pests such as aphids, leafhoppers, and thrips were generally lower in mulched plots, with metalized mulch often having the lowest pest counts, except for twospotted spider mites which were often higher in metalized mulch. Beneficial arthropods responded to these shifts in pest pressure. Parasitoid wasps, rove beetles, and spiders were all present in the treatments, and their numbers tended to reflect the availability of their host and prey. These findings highlight that mulch provides more than weed suppression within an IPM mulch program, as it can also help reduce arthropod pest pressure. Although not detailed in this summary, mulched plots showed improved plant growth and yields relative to the no-mulch control, and fruit quality was similar across all mulch types (Gull et al., in preparation). While some pest populations such as mites remained high regardless of treatment, results indicate that incorporating mulch, particularly metalized mulch, can be a helpful component of an IPM strategy in strawberry production.

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Waste Management Infrastructure Plays a Critical Role for Agricultural Plastic End-of-Life

Nicholas Williams, Kyle Cahitas, and Rory O'Toole, California Polytechnic State University

Agriculture's growing dependence on single-use plastics parallels plastic use in society overall and is of increasing environmental concern. For example, in addition to plastic packaging and irrigation tubing, plastic films used as mulch on top of soil provide weed suppression, temperature and moisture regulation, and disease control in various production systems. Because plastic mulch use offsets demand for other inputs and resources, mulch has become integral in the production of certain fruit and vegetable crops. However, the lifespan of plastic mulch is generally limited to a single season or crop cycle. In addition to soil and aquatic plastic particle pollution resulting from in-field weathering, plastic mulch contributes over 2.5 million metric tons (MMT) to the total global agricultural plastic waste produced annually (FAO 2021). Farmers, researchers, waste managers, and agricultural policymakers are being forced to consider how to best handle the growing agricultural plastic waste burden.

Significant strides have been made regarding the development of soil-biodegradable polymers that may help mitigate some of the negative environmental consequences associated with widespread agricultural plastic use. Many of our team members have worked to evaluate soil-biodegradable plastic mulch (BDM) and have documented their studies in this newsletter and elsewhere. The poor performance of some previously available BDM in the diverse agroecological, political, and economic landscapes in which farmers work has hindered widespread adoption of this technology in the United States (Conrad 2024).

As plastics manufacturers and agricultural research and extension specialists work to enhance future prospects of BDM, there is growing hope that various, ever-evolving recycling processes can provide additional means of reducing the current agricultural plastic waste burden (Sarpong et al., 2024). Complementing efforts from our team members and others to improve plastic mulch recycling methods, our project's Human Dimensions Working Group is examining how and why farmers are currently managing their plastic mulch and other agricultural plastics at the end of the products' lifespans, with the goal of identifying opportunities to increase more sustainable 'end-of-life' management.

DATA COLLECTION AND ANALYSIS METHODS

To better understand the dynamics of farmer decision-making, we developed a survey regarding agricultural plastic end-of-life management that we distributed via mail and electronically in November 2024 to farmers throughout California who cultivate strawberries. This grower population and crop were targeted because use of plastic mulch and irrigation drip tape is essentially ubiquitous in California strawberry production. Drawing on our survey data (n = 126), we are able to test which of the various farm and demographic characteristics, grower perspectives, or structural factors about which we collected information correlate with specific agricultural plastic end-of-life management behaviors, such as recycling, reusing, landfilling, stockpiling, burning or burying. We use ethnographic data—data regarding peoples' perspectives and experiences gathered through systematic interviews and observation—to gain additional insights into the patterns we observe in our survey results.

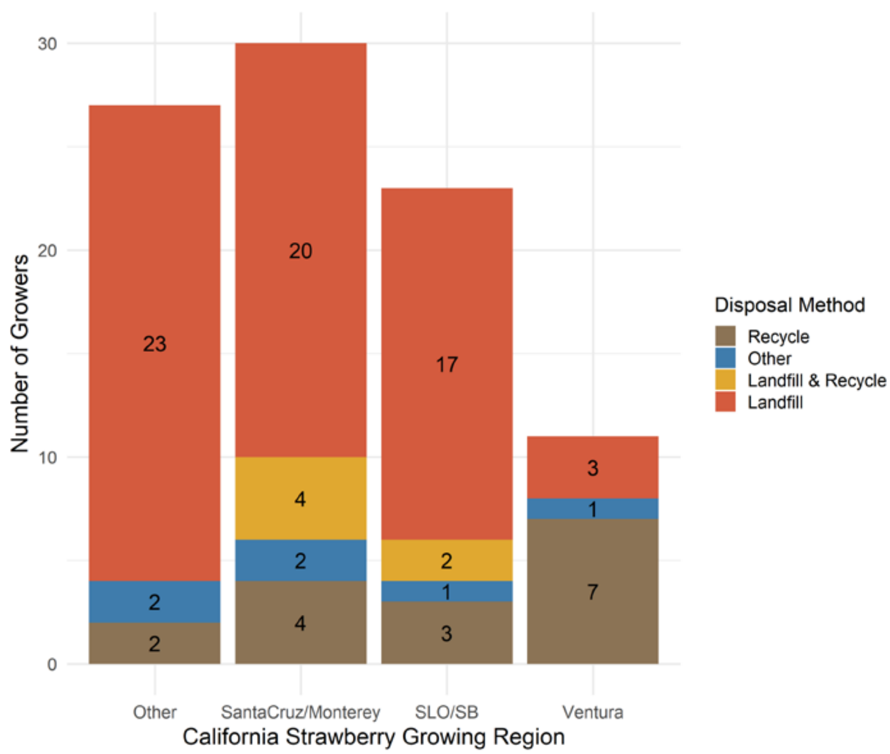

Figure 1. Plastic mulch disposal methods reported by survey participants (n=91) across the various California strawberry growing regions, which include outside of the Central Coast (Other), Santa Cruz and northern Monterey counties, San Luis Obispo and Santa Barbara (SLO/SB), and Ventura.

RESULTS AND INSIGHTS

Prior agricultural plastics research has focused on the importance of farmer perspectives regarding their management decisions, with the goal of encouraging behavior change through targeted information sharing via extension activities (see Goldberger et al., 2019). Importantly, our methodology enabled us to show that while many strawberry growers view plastic waste as a critical environmental issue, their decisions regarding end-of-life management, especially for plastic mulch, are shaped by the waste management landscape rather than their individual environmental values or attributes relating to their farming system (e.g., farm size/scale, crop diversity, years of operation/experience, organic certification).

Notably, the key survey data variable that strongly correlates with a farmer's plastic mulch end-of-life management method is the county in which the grower operates (n = 102; $p < 0.01$). For example, growers in Ventura County show higher plastic recycling rates (66%) than growers elsewhere (<10%) (Figure 1). Our ethnographic data provides an explanation for this pattern: in recent years a prominent strawberry company developed a pilot plastic mulch recycling program in collaboration with waste managers. Ventura County was chosen because in addition to its proximity to a major international port, the type of plastic commonly used and the soil conditions in this region, particularly in the summer growing season, result in a higher-value waste product with lower transportation costs than would be the case in other California strawberry growing regions.

These results have important implications for agricultural plastics management. They highlight that structural forces, not individual intentions or even agricultural extension efforts, must be addressed to optimize end-of-life management of agricultural plastic waste, thereby lessening its global burden.

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Laboratory Assessment of Soil-Biodegradable Microplastics Impacts on Soil

Casandra Leach, Ekta Tiwari, and Seeta Sistla, California Polytechnic State University,

WHY STUDY MICROPLASTICS DERIVED FROM BIODEGRADABLE PLASTIC MULCH IN SOILS?

Microplastics are increasing in abundance throughout our environment and are an emerging contaminant of concern. In agricultural landscapes, plastic mulch leads to soil contamination because plastic frays and tears under normal-use practices. To reduce the impact of plastic debris on agricultural soils, soil-biodegradable plastic mulch (BDM) has been promoted as a sustainable alternative to conventional plastic mulch that is not soil-biodegradable. BDM is designed to be tilled into the soil where it is meant to degrade. However, BDM degradation rate is affected by climate, polymeric composition, and potentially soil type. Slow biodegradation (which can take several years) leads to the accumulation of biodegradable microplastics (BDMPs) during the degradation period. The influence of BDMPs on soil characteristics, and how these impacts vary with intrinsic soil properties, are not well understood. This article is a summary of our journal article "Soil constituents mediate the effects of microplastics from biodegradable mulch on soil biogeochemical properties" (Leach et al., 2025).

A LABORATORY STUDY EXAMINES INTERACTIONS BETWEEN SOIL AND BDM MICROPLASTICS

To address this knowledge gap, we conducted a 2-month laboratory incubation study using laboratory-prepared loamy soils and BDMPs derived from polybutylene adipate terephthalate (PBAT)-based BDM. The goal was to assess whether organic matter content and/or clay mineralogy influence soil–BDMP interactions. We used PBAT-based BDM as PBAT is a primary feedstock for several commercially available BDM products. We used two organic matter concentrations, 0.5% and 5% derived from alfalfa (*Medicago sativa*) and two clay types, bentonite and kaolinite, sourced from Sigma-Aldrich. Prepared soil was used to limit experimental variability associated with field-based studies. Fresh (not field-weathered) BDM was cut with scissors until the average particle size was <5 mm in one dimension. The generated BDMPs had diverse shapes and sizes to represent BDMPs that may be found in field soil following BDM incorporation by tillage. BDMPs were incorporated into each soil mixture at 1% (w/w) concentration. This BDMP concentration rate is high and is the rate used in eco-toxicity tests in the standard EN17033. A no-BDMP control was included for each soil mixture. We assessed how clay mineralogy and organic matter content influence soil–BDMP interactions under controlled conditions (Figure 1) by evaluating a suite of soil health indicators, including physical soil properties, extractable nutrients, and microbial activities.

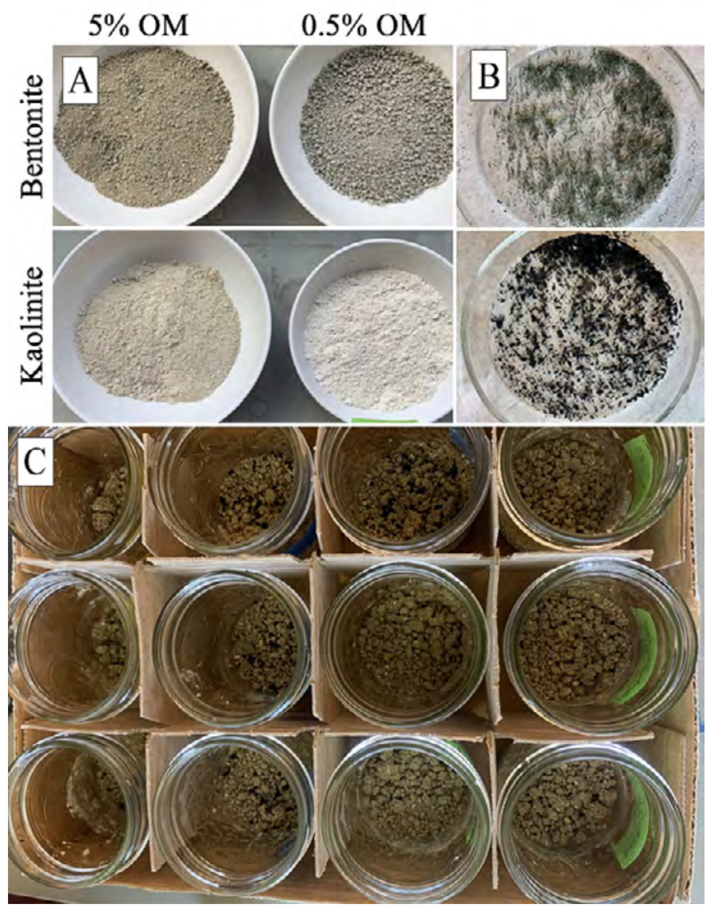

Figure 1. (A) Laboratory-assembled soil included two organic matter concentrations (5% and 0.5%) and two clay types (bentonite and kaolinite). (B) Laboratory generated BDM microplastic particles were added to the soil mixes.(C) The mason jar set up in which the soils were incubated in the dark with BDMPs.

The BDMP treatment consistently decreased soil moisture content throughout the study period across soil mixtures, an effect that may be driven by an increase in water evaporative surface area coupled with the strong water repellency of plastic (Fu et al., 2021; Wan et al., 2019). Wan et al. (2019) demonstrated that plastic particles incorporated into the soil can increase channels for water movement, increasing evaporative water loss. We also observed that the BDMPs increased microbial decomposer biomass and net nitrogen immobilization while stimulating phosphate and dissolved organic carbon release, especially in the lower organic matter soils. Although weathered BDM may degrade more rapidly due to embrittlement from UV, thermal, and mechanical degradation (Lucas et al., 2008), the BDMP particle

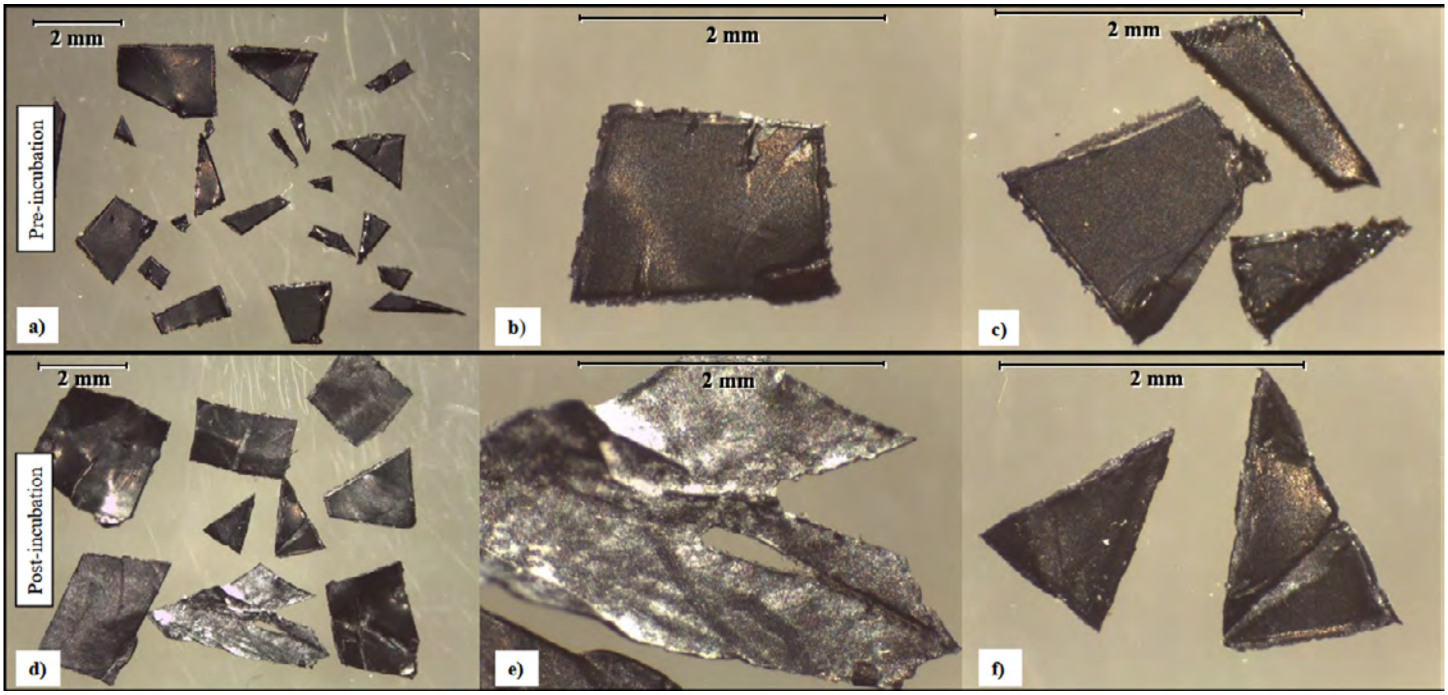

Figure 2. Images of biodegradable microplastics (BDMPs) at 10x (A, D) and 35x (B, C, E, F) magnification. Images A-C were taken before the BDMPs were added to the laboratory soil incubations. Images D-F represent BDMPs extracted from the soils post-incubation for 2 months.

stability that we observed over the 2-month incubation period of the BDM (Figure 2) suggests their presence and associated impacts may persist in field soils for a similar duration.

CONSIDERATIONS FOR BDM IN THE FIELD

Our study suggests that PBAT-based BDM microplastics can affect soil properties including water-holding capacity and plant-available nutrients when concentrations are very high. However, the directionality and magnitude of these effects are dependent on soil organic matter content, clay mineralogy, and associated soil characteristics such as moisture retention and aggregate formation capabilities. Additionally, this study used only a 2 month incubation period, and the effects observed may be muted or amplified over longer timescales as BDM microparticles continue to degrade. This research highlights the need to assess soil post BDM-tillage on a more site-specific basis that considers BDMP concentration, soil quality, and also temperature and moisture as they are key regulators of BDM breakdown in fields.

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Dimensions and Costs of Polyethylene and Soil-Biodegradable Plastic Mulch

Shuresh Ghimire, University of Connecticut, Suzette Galinato and Carol Miles, Washington State University

Farmers use mulch to control weeds, conserve soil moisture, and help improve crop yield and quality. We are providing this information on mulch roll length and width, thickness, weight, and cost to help farmers determine whether soil-biodegradable plastic mulch (BDM) (Figures 1 and 2) is a profitable option for their farm compared to nonbiodegradable polyethylene (PE) mulch.

Table 1 compares this information for PE mulch and certified BDM products (supported by biodegradation testing and standards). Table 2 provides information regarding the number of bed feet per acre based on the distance between bed centers. This information is used to calculate the number of mulch rolls required per acre based on roll length (Table 3), and farmers can calculate the cost of mulch based on price per roll and number of rolls needed. It is important to note that short roll length increases the cost of application if the farm is more than 1 acre as a new roll will need to be placed on the mulch laying machine more often.

At the end of the season, BDM can be tilled into the soil, which eliminates the cost of mulch removal, whereas PE mulch must be removed from the field and disposed of. Table 4 provides the time and cost associated with PE mulch removal, as well as the amount of soil removed with PE mulch. Removal time is based on a survey of Tennessee fruit and vegetable growers (Velandia et al., 2024), and removal costs are calculated using the 2025 median adverse effect wage rate ($17.74/hour) and a landfill fee of $17.80/acre for used PE mulch (assuming $58/ton; EREF 2024).

PE mulch that is removed from the field will have soil and other debris adhered. The contamination of field-retrieved PE mulch ranged from 33 to 87% on a dry weight basis (Adesina et al., 2026). Field-retrieved PE mulch was oven-dried at 80 °C for 30 minutes, weighed, then washed four times at a temperature of 50–60 °C to remove adhered soil and debris, oven-dried at 80 °C for 30 minutes, and reweighed. Soil contamination was calculated as the difference between these two weights (other contaminant debris was very minor), expressed as a percentage of the initial dry weight including adhered soils and debris.

For a list of BDMs that are commercially available in the U.S. as of 2025, see **Soil-Biodegradable Plastic Mulches (BDMs) Commercially Available in the U.S.** Before using a BDM, ask the distributor to confirm that it has been tested for biodegradability using recognized certification standards, and ask for documentation for your records. Match the mulch thickness to your crop and season, and field test with one or two rolls before scaling-up, to determine how the BDM will perform with your soil and climate and to ensure you are satisfied with laying and planting with your equipment. *Do not use* oxo-degradable plastics as they are not biodegradable and will fragment into microplastics. If your production system has any certifications (e.g., organic), talk with your certifier before using BDM to ensure it is allowable.

Figure 1. Laying soil-biodegradable mulch (BDM) by machine.

Figure 2. Pumpkins grown with several different BDM products in a field trial at WSU Mount Vernon NWREC.

Table 1. Dimensions of nonbiodegradable polyethylene (PE) mulch and certified soil-biodegradable mulch (BDM) rolls and purchase costs.

Attribute	PE Mulch	Certified BDM
Available roll length[1]	Up to 4,000 ft	Up to 8,000 ft
Available roll width[1]	3–6 ft	3–6 ft
Roll thickness[1]	1.0–1.5 mil	0.5–1.0 mil
Purchase cost (1,000 ft)[2]	$21–$107	$40–$175
Weight (1,000 ft)[1]	15–36 lbs	10–33 lbs
Allowed for certified organic production	Yes	No

1. *Information is from mulch distributor websites and includes most commonly used dimensions as of 2026.*
2. *Purchase costs are from mulch distributors and do not account for any discounts due to bulk orders, shipping charges, taxes and other fees; as of March 2026, purchase costs are for two certified BDM products.*

Table 2. Total length of beds requiring mulch, determined by bed spacing (center-to-center).

Spacing (bed center-to-center)	1 acre	3 acres	5 acres	10 acres
5 ft	8,712	26,136	43,560	87,120
6 ft	7,260	21,780	36,300	72,600
7 ft	6,223	18,669	31,115	62,230
8 ft	5,445	16,335	27,225	54,450

Table 3. Number of rolls of mulch for 1 acre based on roll length and bed spacing (center-to-center).

Roll Length (ft)	5 ft spacing	6 ft spacing	7 ft spacing	8 ft spacing
500	17.5[1]	14.5	12.5	10.9
750	11.7	9.7	8.3	7.3
1,000	8.8	7.3	6.3	5.5
3,000	3.0	2.5	2.1	1.9
4,000	2.2	1.9	1.6	1.4
6,000	1.5	1.3	1.1	1.0

1. *Number of rolls presented in decimal form to help farmers calculate the total number of rolls for more than 1 acre.*

Table 4. Cost for removal of 1,000 ft of nonbiodegradable polyethylene (PE) mulch from the field and weight of mulch after removal.

Attribute	1,000 bed feet	1 acre[1]
Time to remove mulch[2]	2.4 hrs	17.25 hrs
Cost of field removal and disposal[3]	$44	$323
Weight of mulch after removal from the field[4]	84 lbs	610 lbs
Amount of soil (% by weight) on mulch after removal at the end of the season[4]	33-87% (~28-73 lbs)	~200-530 lbs

1. *1 acre based on bed spacing 6 ft center-to-center.*
2. *Time for PE mulch removal based on Velandia et al., (2024).*
3. *Cost of PE mulch removal is based on 2025 median adverse effect wage rate of $17.74/hour, adding a $17.80/acre land field fee for used PE mulch (assuming $58/ton; EREF 2024).*
4. *Weight depends on soil type and soil moisture content*

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Plastic Waste to Soil Wealth: Turning Pollution into a Microbial Opportunity

Nataliya Shcherbatyuk, Washington State University, conversation with Sam Baker, CEO of Wriggle Brew

Across the globe, plastic waste continues to accumulate at an overwhelming pace, leaving researchers, industries, and policymakers urgently searching for solutions that go beyond traditional recycling. In a groundbreaking blend of biology, chemistry, and agricultural innovation, researcher and entrepreneur Sam Baker has been exploring a transformative approach: using earthworms and microbial systems to break down plastics and convert them into valuable organic fertilizers.

Baker, who began his career as a chemistry researcher before founding an earthworm based fertilizer company, never planned to become involved in plastic degradation research. His initial motivation came from a concern shared by many farmers, conservationists, and environmental scientists: the growing damage caused by synthetic nitrogen and phosphorus fertilizers. These fertilizers, while effective at stimulating crop growth, often come at the cost of soil health and aquatic ecosystems when over-applied. Runoff events can devastate fisheries, disrupt waterways, and compromise long term soil health. Baker's early work focused on creating high quality organic fertilizers using earthworm castings, aiming to offer a viable alternative that nourishes the soil without contributing to environmental decline.

Earthworms quickly proved to be powerful allies. Their castings are rich in fulvic substances and beneficial microbes, the very components of healthy topsoil. But one challenge stood in the way of making earthworm based fertilizers commercially feasible: shelf stability. When worm castings are diluted into liquid form, the environment shifts from aerobic to anaerobic, causing the living microbial product to "spoil" within 24 to 48 hours. This severely limits the ability to store, transport, and scale-up the product for farm use. Inspired by problems that mirror early food safety issues like milk spoilage, Baker and his team developed a stabilization method and microbial formulation that preserves the fertilizer's beneficial qualities while allowing farmers to apply it conveniently.

It was during this work that an entirely unexpected discovery shifted the direction of his research. While studying earthworm digestion, Baker encountered studies on *Zophobas morio*, a species of darkling beetle larva with an extraordinary ability: the capacity to chew and metabolize polystyrene, a plastic polymer. Intrigued, his team began experimenting with various beetle larvae and gut microbial cultures to determine whether these organisms could help break down plastic waste at meaningful scales.

The findings were promising. Under controlled conditions, 100 larvae could consume roughly 10 grams of polystyrene in 6 weeks. While this rate alone would not solve the plastics crisis, it revealed something more important: the larvae hosted specialized gut bacteria capable of chemically degrading polystyrene. When these bacteria were isolated and placed into a bioreactor, essentially a vessel that mimics the larvae's digestive environment, the rate of plastic breakdown increased dramatically. With direct feeding of pyrolyzed polystyrene components such as styrene, a single bioreactor could digest approximately 450 grams of plastic in 5 days. Even more remarkable, the final output contained no detectable micro or nanoplastics, instead forming an organic material similar to mid stage worm digestion, which could then be fed to earthworms to complete the transformation into usable fertilizer.

Scaling-up this process came with challenges. Pyrolysis produces volatile compounds like styrene, which can evaporate quickly, complicating measurements of true digestion rates. To address this, Baker and his team built a customized vapor recovery system, complete with modified refrigeration components, pressure controls, and an Arduino based controller, to recapture and reintroduce evaporated styrene into the bioreactor. They also had to devise new microscopy based techniques to quantify micro and nanoplastic residues, since standardized methods are still emerging.

Despite the technical complexity of the bacterial bioreactor, the potential impact is enormous. Traditional recycling often recovers only a small fraction of plastic waste, with polystyrene recycling rates remaining especially low. In contrast, Baker's bacterial bioreactor does not seek to convert old plastic into new plastic. Instead, the process removes plastic from the waste stream entirely and converts it into a valuable agricultural product. Vermicompost and "worm tea" derived from the bacterial bioreactor have already shown strong results in row crops such as corn and soy, improving soil structure, supplying nutrients, and reducing reliance on synthetic fertilizers.

As the research progresses, the team is already exploring larger scale partnerships that could turn this microbial driven bioreactor system into a regional waste management and fertilizer production pipeline. Local municipalities and businesses have begun supplying small quantities of plastic for pilot studies, and the long term vision includes bacterial bioreactor facilities capable of processing the waste stream of an entire community. For example, Baker notes that in Seminole County, Florida, polystyrene alone accounts for roughly 5% of the total waste stream volume that, if fully converted through the bacterial bioreactor system, could generate enough fertilizer for the region's farms.

Beyond polystyrene, the bacterial bioreactor shows potential for other plastics as well, including agricultural plastics like mulch film. This future direction could meaningfully support more sustainable farming systems.

Baker's work demonstrates how unexpected connections, such as between worms, beetles, microbes, chemistry, and agriculture, can drive innovative solutions to some of our most pressing environmental challenges. By turning plastic waste into soil health, this research illuminates a hopeful pathway toward reducing plastic pollution while strengthening the health of our agricultural ecosystems.

Listen to the full podcast from Mulch Matters.

Building a Circular Future: Theron Smith's Mission to Transform Ag Plastics

Nataliya Shcherbatyuk, Washington State University, conversation with Theron Smith, owner of Flipping Iron

In California's vast agricultural landscape, where strawberries and vegetables rely heavily on plastic mulch and other plasticulture materials, few challenges loom as large as what to do with all of the plastic waste at the end of each season. While plastic has become a cornerstone of modern crop production, its disposal remains one of the industry's most pressing sustainability concern. Standing at the center of this complex and evolving issue is Theron Smith, owner of Flipping Iron, a California based recycling company whose path into agriculture began decades ago with an entirely different material: metal.

Smith's introduction to recycling came early. At just 16 years old, he began working with his grandfather, who owned a small metal recycling operation in the Mojave Desert. That work was simple but formative: scrap iron, cleaning up mining sites, and learning the fundamentals of recovering value from waste. When Smith married at age 22, he and his wife, Alise, were given the opportunity to purchase the business. The couple stepped into ownership with determination in 2019.

Although the company's focus was metal, an unexpected suggestion from an employee in 2013 opened a new chapter: agricultural plastics. What began with hauling drip tubing for a nearby farmer led to additional requests, new clients, and eventually, a complete reimagining of what the company could offer and expanding it far beyond its original roots. Smith laughs when he recalls the irony, *"We once said we'd never get into plastics. Now it's half our business."* In 2019, they renamed the company to Flipping Iron.

Today, Flipping Iron handles metal and plastic from multiple sectors, including mining, oil, and agriculture, but it is their work with agricultural plastics that stands out as particularly impactful. California growers, especially those producing strawberries, grapes, and row crops, rely on miles of mulch film, fumigation film, vine covers, hoop house films, and drip tape. To put the amount in perspective, one acre of strawberries on 8 foot centers uses 1 mile each of plastic mulch and drip tape. And there are approximately 45,000 acres of strawberries in California alone. Collecting, cleaning, and processing these materials is a demanding yet essential part of sustainable farming systems.

What sets Flipping Iron apart, according to Smith, is diversification and adaptability. Many recycling companies specialize on a narrow slice of the plastics market, often out of necessity. But agricultural plastic is unpredictable. Markets shift. Regulations change. Export rules are tightened. A recycler reliant on a single product or outlet could quickly find itself without a viable path forward. Flipping Iron counters that risk by working across multiple industries, multiple plastic product types, and multiple recycling pathways. The company uses a combination of proprietary equipment, most notably the Andros Mega Binder, adapted for mulch and vine cover retrieval, to create efficient, mobile plastic recovery systems that can be deployed wherever growers need them.

Smith credits collaboration as the backbone of his company's success. Instead of viewing other recycling companies or waste haulers as competitors, he sees them as partners. *"There's more plastic out there than any one company can handle,"* he notes. *"If another hauler is already serving a region well, we support them. Where there's a gap, we step in."* Partnerships with engineering firms, agricultural organizations, and growers, particularly Driscoll's and their network of berry producers, have helped Flipping Iron refine its processes and expand its reach.

Still, the reality of agricultural plastic recycling remains challenging. California alone produces tens of thousands of acres' worth of mulch film each year, and mechanical recycling within the state is not yet capable of processing all of it. Much of the plastic recovered by Flipping Iron's is exported to Southeast Asia, primarily Indonesia and previously Malaysia, to be washed, pelletized, and reincorporated into low grade plastic products such as construction sheeting or trash liners. The company provides documentation to growers to show the plastics are truly recycled, not dumped overseas. The economics and foreign companies paying for the material support the credibility of this pathway.

Yet Smith remains clear eyed about the vulnerabilities of export based recycling. Policies like China's "Green Fence" (2013) and "National Sword" (2018) reshaped global scrap markets almost overnight, shutting off major pathways for United States plastic waste. More recently, new rules in Malaysia have restricted imports from non Basel Convention countries such as the United States, again limiting options. Smith describes export as a "band aid", necessary now, but not the long term answer.

So, what would it take to build more domestic recycling capacity? Smith points to logistics, economics, and government policy. Transporting film from California to recycling facilities in Texas is more than twice as expensive as shipping it overseas. Labor costs and regulations in California also complicate innovation. But Smith believes domestic progress is possible, especially with coordinated efforts among researchers, manufacturers, policymakers, and recyclers. Examples from other industries, like tire recycling, demonstrate that systematic solutions can be created when a product's end-of-life pathways are prioritized.

Despite the challenges, Smith remains optimistic. His team is pursuing new recycling options, exploring alternative fuel uses for plastic, and supporting research to integrate agricultural film into asphalt. Flipping Iron is expanding into several new states, bringing mobile solutions to more growers. Smith stresses that plastic isn't the problem; mismanaged plastic is. Agriculture will continue to rely on it, but progress comes from better end-of-life handling through recycling, repurposing, and responsible disposal. His practical, collaborative approach shows that real change will come from many partners working together to rethink what's possible.

Listen to the full podcast from Mulch Matters.

From Macro to Micro: Understanding How Soil-Biodegradable Mulch Fragments Transform Beneath the Soil

Nataliya Shcherbatyuk, Washington State University, conversation with Xueyu Zhou, Washington State University

Plastic mulch plays an essential role in modern specialty crop production, and soil-biodegradable plastic mulch (BDM) provides growers with a sustainable option for reducing plastic waste. Yet, what happens to BDM fragments that are tilled into the soil is largely unknown. Recent multi state research is bringing this hidden world to light, revealing how BDM fragments in the soil can degrade and transport under field conditions. By examining BDM behavior from larger pieces down to micro scale particles, scientists are uncovering important insights that can guide growers, improve sustainability, and inform future BDM technologies.

Strawberry production served as the core system for this study, and for good reason. Strawberry growers are among the largest users of plastic mulch in the United States, and their long growing-cycle demands consistent soil protection, weed suppression, and moisture and temperature regulation. Because strawberry production is intensive and mulch dependent, it provides ideal conditions for evaluating both conventional, nonbiodegradable polyethylene (PE) mulch and emerging soil-biodegradable plastic mulch (BDM) alternatives. When mulches perform well under these demanding expectations, they offer strong promise for broader adoption across other mulch-dependent crops.

To account for diverse environmental conditions, researchers implemented a coordinated field experiment spanning Washington, Nebraska, Florida, and California. Each location grew strawberries in raised beds covered with three mulch types: 1) conventional PE mulch; 2) a BDM made with a feedstock blend of poly(butylene adipate terephthalate)–polylactic acid (PBAT–PLA); and 3) a second BDM blend with PBAT and starch. After the growing cycle, mulches were tilled into the soil and the team began tracking how fragments changed over time.

Sampling mulch fragments in the field is a hands-on, meticulous process as described in Zhou et al. (2026). Researchers mark a 1-m^2 area on the soil surface and collect all visible mulch pieces on the surface. The top 15 cm of soil is then turned and all fragments are collected; this is the typical tillage depth and where microbial activity is highest (Cai et al., 2025). This method helps the team track not only how many fragments are present in the soil but also how their size and physical condition evolve over time.

Over the course of a year, clear trends have emerged. Larger BDM pieces often become thinner, more brittle, or begin to crack into smaller fragments. In many cases, the total number of BDM fragments decreases, signaling active microbial breakdown. Early results show BDM fragments are degrading and remain visible for a longer period of time under cooler or drier conditions. These results highlight the nuance that degradation is shaped by environmental conditions such as temperature and moisture levels. Additionally, not all BDM formulations break down at the same rate and not all soils support the same microbial activity. These differences highlight the complexity of predicting BDM degradation at any given site.

One of the study's most surprising findings is that the warmest site did not necessarily show the fastest breakdown of BDM. Although Florida's climate might seem ideal for rapid degradation, Washington's loamier soils actually supported more active decomposition. The soil's ability to hold moisture and sustain microbial communities proved more influential than temperature alone. This finding underscores a crucial point: mulch degradation is not solely determined by climate, but also by soil texture, structure, and biological activity.

Another important component of our BDM research involves distinguishing between macroplastics (pieces larger than 5 mm) and microplastics (2–5 mm), which are more easily transported through soil pores or water pathways. Larger fragments are relatively easy to detect and often degrade more quickly due to their surface area. Due to their small size, microplastics may move deeper into the soil profile or interact with soil organisms in ways that are still not fully understood. Differentiating these fragment size categories helps researchers form a clearer picture of environmental impacts and long term outcomes.

For growers considering BDMs as an alternative to PE, our research supports a cautious, informed approach. BDMs can provide sustainability benefits, but their performance depends on local soils, crops, and climate. Degradation takes time, and fragments may persist for months or even a few years. Not all regions have tested BDMs or developed clear guidelines. Starting small and observing how BDM behaves under local field conditions can help growers make confident, informed decisions.

Long term studies will be essential moving forward. Tracking BDM fragments over one to two seasons—and over multiple years—will clarify how quickly and completely they degrade in different field environments, as well as what intermediate particles may persist. Expanding research across additional cropping systems and regions will strengthen degradation predictions and support evidence-based recommendations for farmers, manufacturers, and policymakers. On-going work to understand BDM breakdown at both macro and micro scales remains critical. As these technologies evolve, insights from multi-state research will play a key role in ensuring BDMs meet performance expectations while protecting soil health and the broader environment.

Listen to the full podcast from Mulch Matters.

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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

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