Soil-Biodegradable Mulches: *Workshop*

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Authors:
Carol Miles[1]
Shuresh Ghimire[2]

[1]Washington State University
[2]University of Connecticut

Synopsis:
Soil-biodegradable mulches (BDMs) are increasingly used in agriculture to replace conventional plastic mulch. This is an overview of the primary aspects of BDM with special focus on weed control.

Editors:
Carol Miles, Washington State University
Lisa DeVetter, Washington State University
Huan Zhang, Washington State University
Srijana Shrestha, Washington State University
Shuresh Ghimire, University of Connecticut

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Soil-biodegradable Plastic Mulch: Overview and Weed Control

This workshop series provides slide presentations on soil-biodegradable mulches (BDMs). These notes provide additional information for presenters. Numbers in the text correspond to the slides in each presentation. Information in this document was summarized from publications listed in the Reference section.

1. This presentation provides information on overall aspects of BDM such as standards and feedstocks that define BDMs, BDM application, crop production, fumigation, deterioration and degradation with a focus on percent soil exposure (PSE) measurement, and crop-weed competition.
2. Global use of polyethylene (PE) mulch was 4 million metric tonnes in 2016, and with 4.5% average annual increase, the estimated use of PE mulch in North America in 2020 is 126,400 metric tonnes. Research funded by USDA SCRI (2009-2021) and Washington State Department of Agriculture SCBG (2017-2021) assessed BDM in annual and perennial vegetable and fruit crop production. BDM can be a sustainable alternative to PE mulch if it provides benefits equal to PE mulch, reduces labor costs for removal and disposal of mulch, can completely biodegrade, and has no impact on soil health. Research has shown that the primary barriers to BDM adoption are insufficient knowledge about BDMs, high purchase

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cost, and uncertainty regarding breakdown.

3. BDM provides crop production benefits comparable to PE mulch such as weed control, moisture retention, soil temperature modification, early harvest, and increased yield and quality. BDMs are designed to be tilled into the soil after use, eliminating waste and disposal challenges. Note that BDMs should NOT go into recycling facilities as they will contaminate other recycled material.

4. BDMs are made from feedstocks that are: (i) biobased, (ii) derived from fossil fuels, or (iii) a blend of the two. Biobased polymers are divided into 3 categories (Table 1): **a)** extracted directly from natural materials such as starch, thermoplastic starch (TPS), and cellulose; **b)** produced by chemical synthesis from biologically derived monomers, such as synthetic polymerization of lactic acid into polylactic acid (PLA); and **c)** produced by microorganisms, such as polyhydroxyalkanoates (PHA). The most common biobased BDM feedstocks are TPS, PLA, and PHA. High-amylose starch is processed into TPS by extrusion with water and alcohols at relatively high temperatures. TPS costs less than other starch feedstocks and now is the most common biobased feedstock used in plastic BDMs. PLA can be produced relatively inexpensively in large quantities compared to other biobased biopolymers. Poly(hydroxybutyrate) (PHB) and poly(hydroxyvalerate) (PHV) are the two most important commercial PHAs. Polymers such as PLA or PHA have low mechanical properties compared to PE. Plasticizers are additives which improve the mechanical properties of the plastic during processing, and can affect post-extrusion characteristics of the plastic. The primary plasticizers that are added to TPS are alcohol (principally glycerol), polyoxyalkenes, and surfactants.

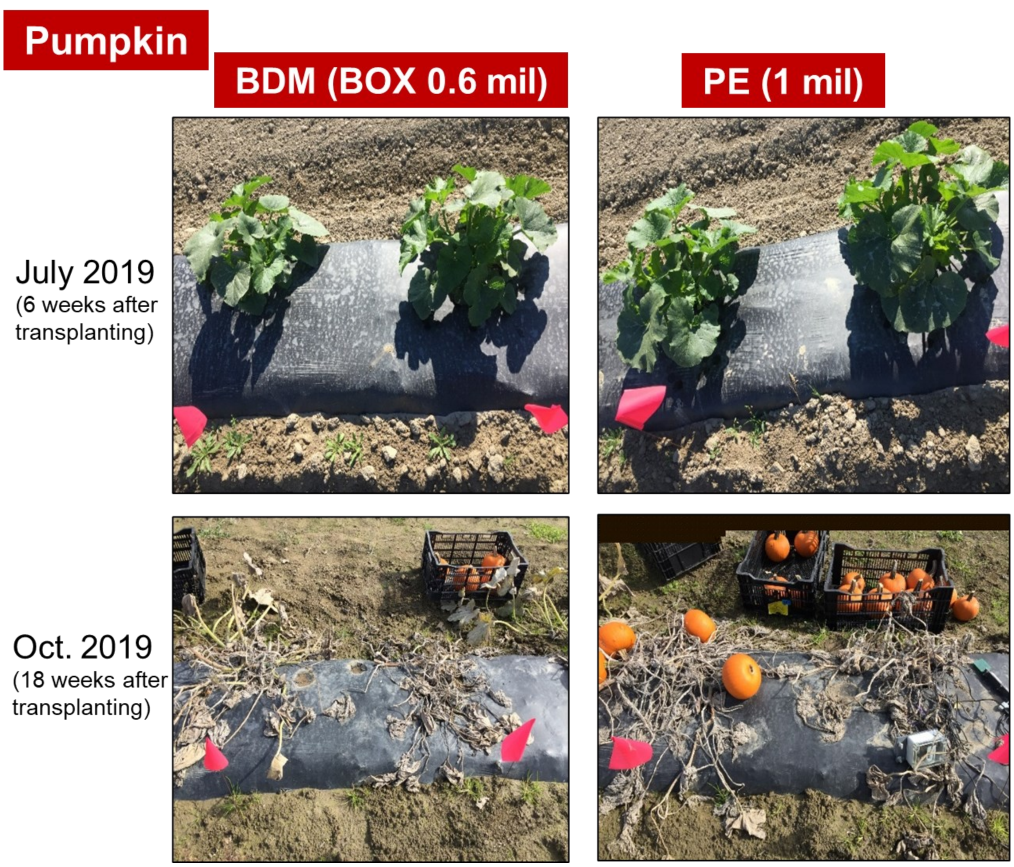
Table 1. Categories of biobased polymer feedstocks.

Extracted from natural materials	Produced by chemical synthesis	Produced by microorganisms
starch, thermoplastic starch (**TPS**), and cellulose	synthetic polymerization of lactic acid into polylactic acid (**PLA**)	polyhydroxyalkanoates (**PHA**)
TPS processed from high-amylose starch, cheaper than other starch feedstocks	PLA produced relatively inexpensively compared to other biobased biopolymers	Poly(hydroxybutyrate) (PHB) and poly (hydroxyvalerate) (PHV) most important commercial PHAs

5. The procedure for laying BDM is similar as for PE mulch with a few adjustments. First feed the end of the mulch roll through the roller bar then reduce the bar tension so the mulch rolls easily (Fig. 1). Pull the mulch under the guide wheels; the wheel(s) should rest lightly on the mulch or float just above it (Fig. 2). Slowly drive the tractor forward, and increase speed until same as for laying PE mulch.
6. Weed control is a primary function of mulch. Weeds compete with the main crop for nutrients, water, and light which causes adverse effects on crop growth. PE mulch is very effective for weed control, but what about BDMs?
7. This (Fig. 3) is how Black Organix BDM (BOX) and Black PE mulch (BPE) look in July 2019 and October 2019 in pumpkin production. They are both intact with essentially no weeds.

Figure 1. Feed mulch through roller bar; adjust tension.

Figure 2. Pull mulch under guide wheels.



Zhang et al., 2020

Figure 3. Comparison of BDM (BOX) (left) and PE mulch (right) during pumpkin production.

8. The graphs (Fig. 4) show the percent soil exposure (PSE) during the pumpkin growing season, which is about 16 weeks in Mount Vernon, WA, in 2018 and 2019. When the mulch deteriorates, the soil gets exposed and there is potential for weed growth. 0% PSE denotes completely intact mulch while 100% PSE denotes completely deteriorated mulch. PSE was highest for Clear Organix mulch in both years (63% in 2018, and 74% in 2019). All other BDMs reached a maximum of 10% PSE in 2018 and 15% in 2019.
9. This table (Table 2) shows the weed population per m² under mulch at three different times, early season, mid-season, and late season in 2018 and 2019. Weed number was low for all the treatments except Clear Organix mulch (COX) in 2018 and 2019 plus Clear polyethylene mulch (CPE) in 2019. Weed growth occurred beneath the clear plastic mulch treatments because they allowed light transmission. However, weeds continued to grow in Clear Organix mulch (COX) due to splitting early in the season. The higher weed number in Clear polyethylene mulch (CPE) in 2019 was likely due to higher soil moisture than in 2018. Weed growth in late season was due to mulch deterioration. Other BDM treatments provided effective weed control similar to black polyethylene mulch.

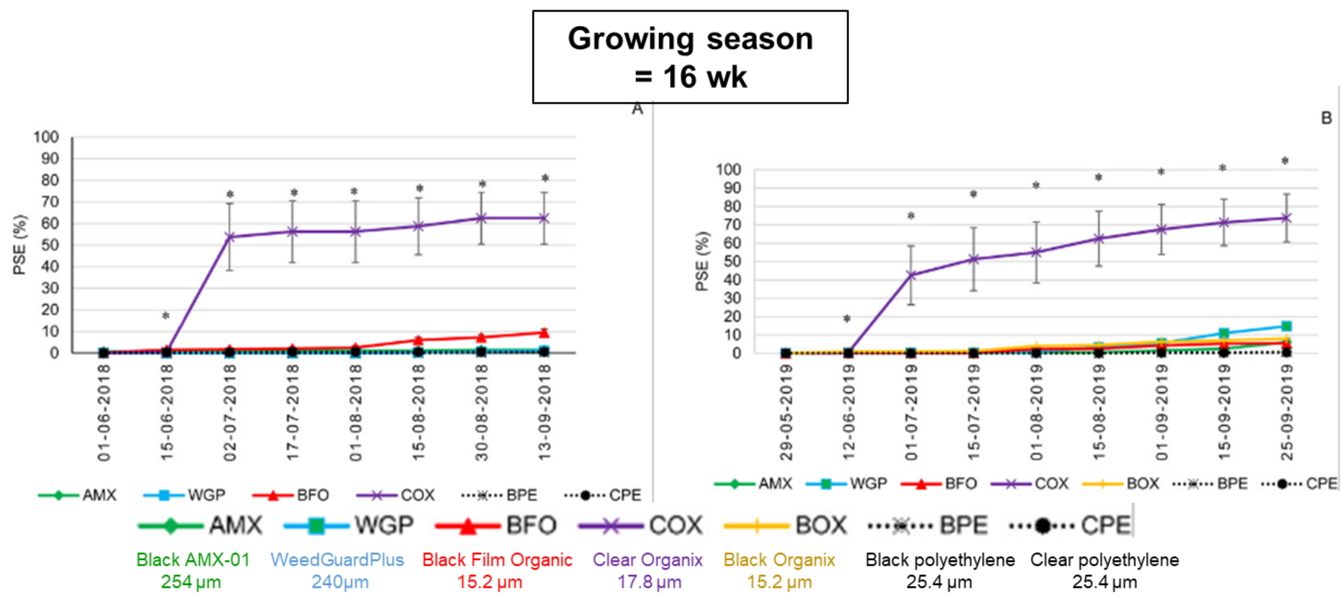


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Figure 4. PSE during pumpkin growing season in Mount Vernon, WA; 0% = completely intact, 100% = fully deteriorated, ratings in 1% increments up to 20%, and 5% increments thereafter; error bar is ± one standard error of the mean.

Table 2. Weed populations per m² under mulch in pumpkin.

	Weed number per m²					
	2018			2019		
Treatment	Early season (3 WAT[z])	Mid-season (10 WAT)	Late season (15 WAT)	Early season (3 WAT)	Mid season (10 WAT)	Late season (16 WAT)
AMX	0 b[y]	0 b	0.5 b	2.3 ab	0 b	0.3 bc
WGP	0 b	0 b	0 b	2.0 ab	0 b	4.0 b
BFO	0 b	0 b	0.8 b	1.3 ab	0 b	0 c
COX	2.0 a	10.0 b	21.0 a	6.8 a	77.5 a	89.5 a
BOX	—[x]	—	—	7.0 a	0 b	0.3 bc
BPE	0 b	0 b	0 b	0.3 b	0 b	0 c
CPE	2.5 a	0 b	0.5 b	2.3 a	16.5 ab	39.0 a
P value	0.04	0.03	0.03	0.02	0.02	0.02

[z]Weeds were collected 3 weeks after transplanting (WAT; 22 June 2018 and 20 June 2019), 10 WAT (9 Aug. 2018 and 8 Aug. 2019), 15 WAT (14 Sept.) in 2018, and 16 WAT (26 Sept.) in 2019.

[y]Means followed by the same letter in the same column are not significantly different at $P < 0.05$, using a nonparametric multiple comparisons Wilcoxon test.

[x]This treatment was not included in 2018.

Weed number per m² in plots with 'Cinnamon Girl' pie pumpkin grown with clear and black polyethylene (CPE and BPE) and soil-biodegradable mulch treatments [AMX-01 (AMX), WeedGuardPlus (WGP), Black Film Organic (BFO), Clear Organix (COX), and Black Organix (BOX)] in 2018 and 2019.

Zhang et al., 2020

10. This (Fig. 5) is how BDM and PE mulch look in June 2017 and December 2017 in raspberry. BDM is deteriorated and has weed growth while PE mulch is intact with no weeds.

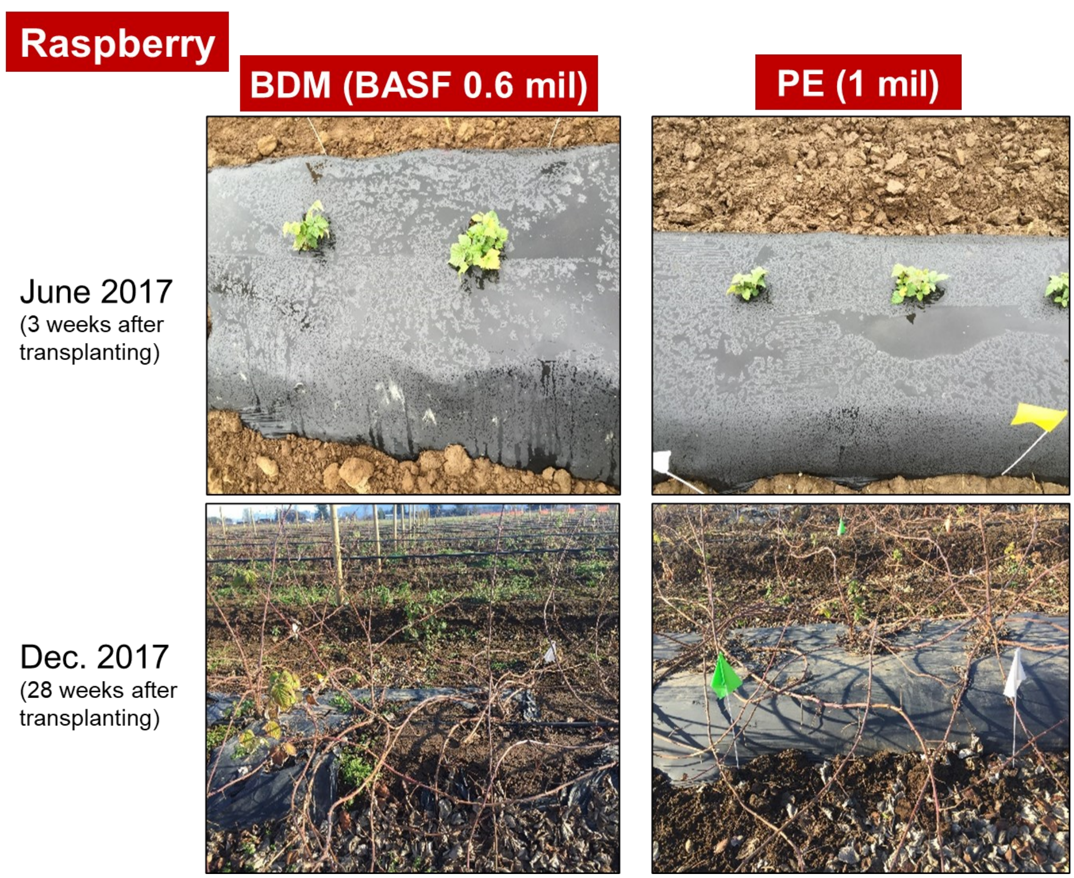

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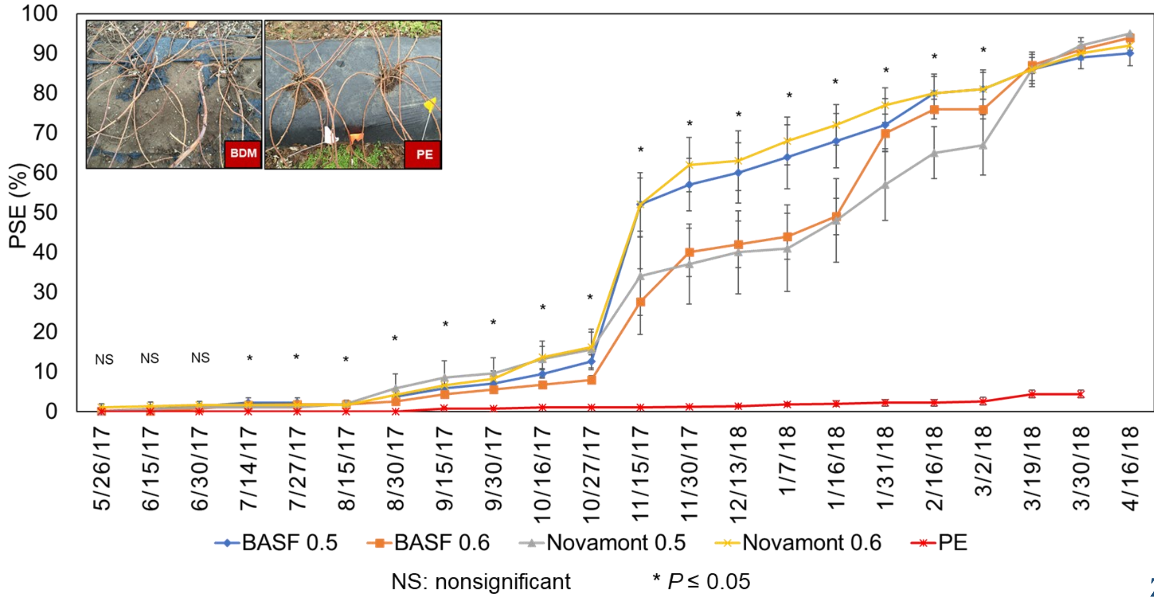
Figure 5. Comparison of BDM (BASF) and PE mulch during raspberry production.

11. This graph (Fig. 6) represents the PSE for a period of almost 1 year during raspberry production in Lynden, WA. At 16 weeks, BDM deterioration was about 8% on average, similar as with pumpkin. But 1 year after application, all the black plastic BDMs reached about 90% PSE while PE mulch remained almost completely intact.

12. A review of crop production with BDMs is shown in Table 3. Yield is greater compared with bare ground and essentially the same as with PE mulch. Weed control varies between BDM and PE mulch depending on crop and location.



Zhang et al., 2020

Figure 6. PSE of mulch (0.5 = 12.7 µm thickness, 0.6 = 15.2 µm thickness) in raspberry production in Lynden, WA; 0 = completely intact, 100 = fully deteriorated, ratings in 1% increments up to 20%, and 5% increments thereafter; error bar is ± one standard error of the mean.

Table 3. Crop production with BDM.

	Yield		Weed Control
Crop	**vs. Bare ground**	**vs. PE**	**vs. PE**
Broccoli	+[1]		
Cucumber	+	=	=
Eggplant	+	=	-
Lettuce		-=[2]	
Melon	+	+=	≅
Pepper	=	=	-
Raspberry	+	=	=
Strawberry	+	-=+[2]	-
Sweet Corn	+	-=	-
Sweet Potato	+	+=	+
Tomato	+	=	≅
Zucchini		=	

[1] + BDM performed better; = BDM performed equivalent to; - BDM did not perform as well; empty cell not measured.

[2] Reports provide variable results.

Adapted from: Cowan and Miles, 2018

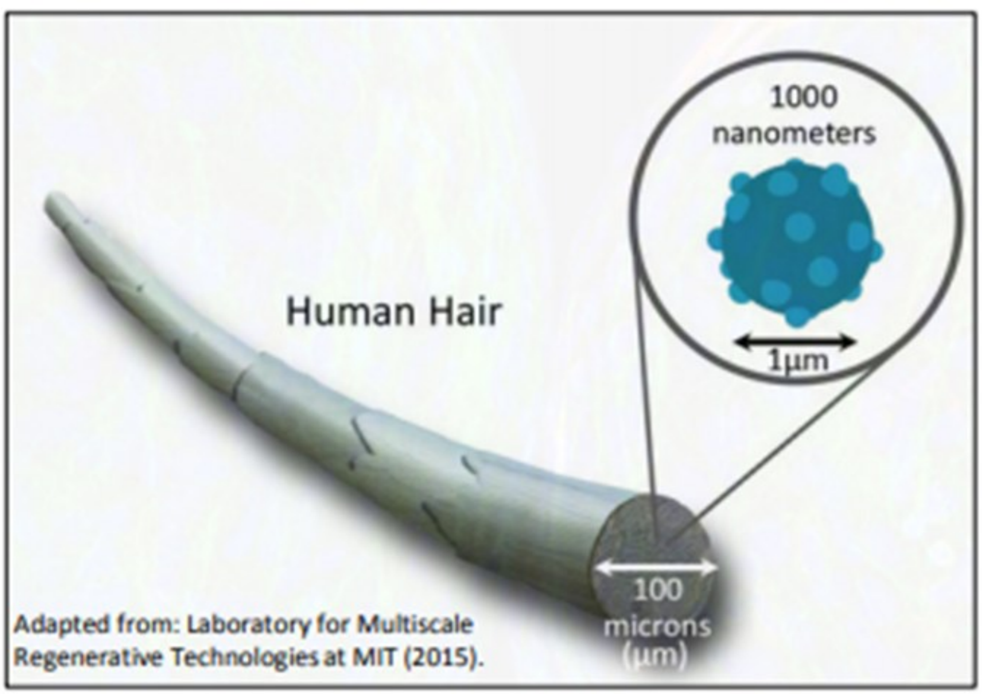
13. Environmental Protection Agency (EPA) has a list of tarps tested for permeability that qualify for buffer zone reduction credits. Like standard PE tarps, BDMs are not currently on this list. Applicators and handlers need to be legally consistent with fumigant labels. BDMs can only be applied after the fumigant's REI has expired, or BDMs may be applied during fumigation but don't qualify for buffer zone reduction credits.

14. Here is the link to the video that shows BDM incorporation into the soil after the cropping season.

15. **Deterioration** is loss of physical or mechanical strength, observed through physical testing, microscopic imaging, or macroscopic observation (e.g. rips, tears, and holes). **Degradation** is the conversion or mineralization of carbon (C) to carbon dioxide (CO_2) resulting in changes in the chemical structure, physical properties or appearance. ASTM defines biodegradable plastics as plastics that degrade from the action of naturally resulting organisms such as bacteria, fungi and algae. Polyethylene mulch (PE) is not readily biodegradable as polymers have chemical bonds that microbes do not have the metabolic pathways to break apart. Biodegradable plastics use natural or synthetic polymers that have similar bonds, but can be quickly broken apart by microbes.

16. The degradation process takes place sequentially from film to fragment to microparticles to nano-particles to the final stage of CO2 + biomass in the soil. A human hair demonstrates the relative size of micro- and nanoparticles (Fig. 7).

17. The graph (Fig. 8) shows the percent mulch recovery in Mount Vernon, WA using the soil quartering method after incorporation in the field. Mulch was applied once a year for 4 years (2015 - 2018). Plots were rototilled in spring after collecting samples and in fall before collecting samples. Paper BDM (WeedGuardPlus) shows complete biodegradation each year while plastic BDMs have different rates of biodegradation. One year after the last soil-incorporation



Hayes, 2019

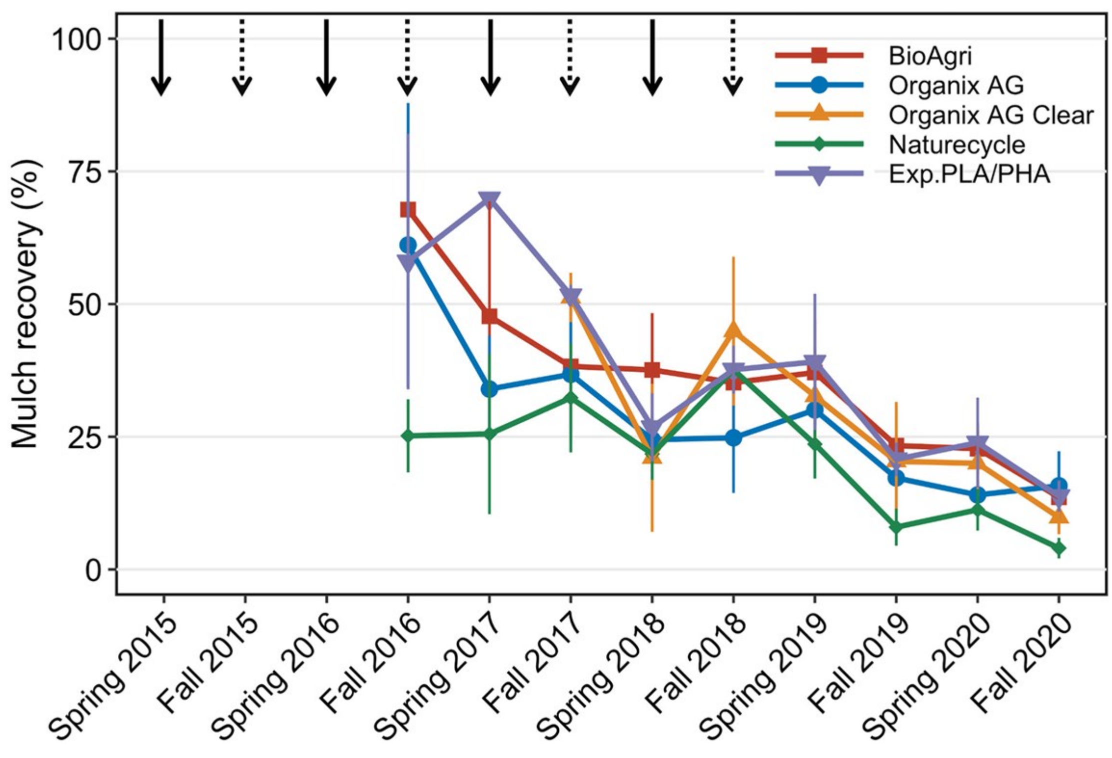
Figure 7. A human hair demonstrates the relative size of microns and nanometers.

of BDM, recovery ranges from 10% to 30%, indicating that all of these BDMs are degrading at this field site.

18. There are several BDM standards written by different countries as shown in Table 4. For example, TUV Austria certifies that plastic materials will biodegrade fully and will not promote ecotoxicity in the soil.

19. Oxo- and photo-degradable plastics are made with conventional plastic: HDPE, LDPE, PP, PS, PET or PVC. Also included are additives that cause the material to become brittle and break apart into fragments when exposed to UV light, heat and/or oxygen (Fig. 9). Oxo- and photo-degradable mulches are not biodegradable, compostable, or recyclable, and cannot be placed in anaerobic digesters. There is a resurgence in their use, due to the interest in BDMs and the low cost of oxo- and photo-degradable mulches. European Union (EU) will prohibit single-use plastic products and products made from oxo-degradable plastic according to European Parliament Directive (EU) 2019/904 and the council of 5 June 2019 under Article 5. The member states shall apply the measures necessary to comply with Article 5 from 3 July 2021.

20. The USDA National Organic Program added biodegradable biobased mulch film to its list of allowed substances in October 2014. However, to be used the BDM **MUST**: **a)** be 100% biobased (*ASTM D6866)*; **b)** be produced without use of synthetic polymers (minor additives such as colorants and processing aids not required to be biobased); **c)** be produced without organisms or feedstock derived



Griffin-LaHue et al., 2022

Figure 8. Percent recovery of BDM fragments in Mount Vernon, WA using the soil quartering method; mulch was applied once a year for 4 years (2015-2018), indicated by solid black arrows, plots were rototilled in spring after collecting samples and in fall before collecting samples, indicated by dotted arrows; error bar is ± one standard error of the mean.

from excluded methods (i.e., synthetic or GMO); **d)** meet compostability specifications (ASTM D6400, ASTM D6868, EN 13432, EN 14995, or ISO 17088); and **e)** reach ≥ 90% degradation in soil within 2 years (*ISO 17556* or *ASTM D5988)*. No commercially available plastic BDMs are currently allowed for use in certified organic agriculture, only paper mulch (For e.g. WeedGuardPlus™) is allowed.

21. We have developed PowerPoint presentations, presenter notes, factsheets, and videos about BDMs.
22. If you want to learn more about BDMs you can visit our webpage https://smallfruits.wsu.edu/plastic-mulches/ .

Table 4. BDM standards.

Standard Organization	Standard Name	Comments
European Committee for Standardization (CEN)	**EN 17033** (2018) Plastics– Biodegradable Mulch Films for Use in Agriculture and Horticulture– Requirements and Test Methods	First international standard directly pertaining to biodegradable mulches by an international organization. Includes specifications for both biodegradable material/ feedstock and biodegradable mulch product such as dimensional, mechanical and optical properties, ecotoxicity, and biodegradation.
Ente Nazionale Italiano di Unificazione (UNI)	**UNI 11495** (2013) Biodegradable Thermoplastic Materials for Use in Agriculture and Horticulture - Mulching Films - Requirements and Test Methods	Italian standard pertaining to biodegradable mulches
ASTM, International	**ASTM D6400** (2012) Standard Specification for Labeling of Plastics Designed to be Aerobically Composted in Municipal or Industrial Facilities	Pertains directly to biodegradation under industrial composting conditions, and is often misrepresented[1]
TUV Austria (formerly Vincotte)[2]	**OK Biodegradable SOIL** (label)	Certifies that plastic materials will biodegrade fully and will not promote ecotoxicity in the soil

[1] ISO (International Organization for Standardization) has equivalent standards

[2] TUV Austria is not a standards organization but is a certification body authorized by European Bioplastics, an association representing the interest of the European bioplastics industry.

Source: Dentzman and Hayes (2019)

Figure 9. Oxo- and photo-degradable plastic includes additives that cause the material to turn brittle and break into fragments when exposed to UV light, heat, and/or oxygen.