Polyethylene and Biodegradable Plastic Mulches for Strawberry Production in the United States: Experiences and Opinions of Growers in Three Regions

Jessica R. Goldberger¹, Lisa W. DeVetter²,
and Katherine E. Dentzman³

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SUMMARY. Although agricultural plastic mulches can have significant horticultural benefits for specialty crops such as strawberry (*Fragaria × ananassa*), there can also be significant economic and environmental costs. In particular, polyethylene (PE) plastic mulch requires labor and financial investments for removal and disposal. Micro- or nanoparticles may persist in soil and negatively affect microbial activity, physical soil properties, and nutrient availability. A possible alternative to PE mulch is biodegradable plastic mulch, which has similar horticultural benefits but does not need to be removed from the field at the end of the growing season. Biodegradable plastic mulch can be tilled into the soil, where it is converted by soil microorganisms into water, carbon dioxide, and microbial biomass. Although horticultural and environmental research into the impacts of PE and biodegradable plastic mulch is ongoing, it is also important to understand farmers' practices and perceptions related to these mulches. We conducted a survey of strawberry growers in three growing regions of the United States: California, the Pacific Northwest, and the Mid-Atlantic. Our results indicate several regional differences, with California farmers being more likely to have used biodegradable plastic mulch, and growers from California and the Pacific Northwest being more likely to perceive negative impacts of PE mulch compared with growers in the Mid-Atlantic. Regardless of region, a majority of growers were interested in learning more about biodegradable plastic mulch. We conclude with several suggestions for biodegradable plastic mulch development and outreach that may promote strawberry growers' adoption of this technology.

The widespread use and disposal of plastics are associated with significant environmental impacts, such as accumulation in landfills and the natural environment, and

threats to wildlife via entanglement and ingestion (Thompson et al., 2009a, 2009b). Of the 6.3 billion tonnes of plastic waste generated since the 1950s, an estimated 79% has accumulated in landfills and the natural environment (Geyer et al., 2017). Plastic pollution in marine environments has been well documented (Law, 2017; Worm et al., 2017). More recent research has focused on the contamination of terrestrial ecosystems, including agroecosystems, by microplastic particles (<5 mm) and nanoparticles (<0.1 µm) (Machado et al., 2018a, 2018b; Ng et al., 2018; Rillig et al., 2017; Rodríguez-Seijo and Pereira, 2019). Of particular concern are the

environmental impacts associated with the use and disposal of low-density polyethylene plastic mulch films for crop production (He et al., 2015; Kasirajan and Ngouajio, 2012; Liu et al., 2014; Steinmetz et al., 2016).

PE mulch offers many benefits to farmers, such as improved weed management, moderated soil temperature, increased soil moisture, higher yields, improved crop quality, and higher profits (Freeman and Gnaeyem, 2005; Garwood, 1998; Lamont, 1993, 2005). Because PE mulch does not biodegrade, disposal options include recycling, incineration, on-farm burning, and landfilling (Hempill, 1993; Moore and Wszelaki, 2016). The number of recycling facilities that accept PE mulch is limited because of contamination with soil and/or vegetation (up to 50% by weight) (Kasirajan and Ngouajio, 2012). Moreover, the labor and transport costs associated with recycling, burning, and landfilling force some farmers to stockpile, bury, or illegally dump their spent PE mulch. Plastic fragments and additives can accumulate in soil, thus altering soil physical properties, nutrient availability, and microbial activity (Bandopadhyay et al., 2018; Steinmetz et al., 2016).

Introduced in the 1990s, biodegradable plastic mulch is a potential alternative to PE mulch (Kasirajan and Ngouajio, 2012; Miles et al., 2017; Sintim and Flury, 2017). Made from starch and other biodegradable polymers, biodegradable plastic mulch is designed to perform comparably to PE mulch while also biodegrading in soil or composting environments at the end of its useful lifetime (Miles et al., 2017). The long-term environmental impacts of biodegradable plastic mulch require further investigation (Bandopadhyay et al., 2018; Brodhagen et al., 2017; Li et al., 2014; Razza and Cerutti, 2017; Sintim et al., 2019). Nevertheless, biodegradable plastics are one possible way to mitigate global agricultural plastic pollution (Cassou, 2018).

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¹Department of Crop and Soil Sciences, Washington State University, P.O. Box 646420, Pullman, WA 99164

²Department of Horticulture, Northwestern Washington Research and Extension Center, Washington State University, 16650 SR 536, Mount Vernon, WA 98273

³Department of Agricultural Economics and Rural Sociology, University of Idaho, 875 Perimeter Drive, Moscow, ID 83844

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J.R.G. is the corresponding author. E-mail: jgoldberger@wsu.edu.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
25.4	inch(es)	mm	0.0394
1	micron(s)	µm	1
0.9072	ton(s)	tonne(s)	1.1023

Although polymer scientists, soil scientists, toxicologists, and related scientists conduct research on the environmental impacts of plastic mulching practices, it is instructive also to study the human dimensions of plastic use and disposal in agriculture. For example: What are farmers' perceptions of the advantages and disadvantages of PE mulch? How do farmers typically dispose of PE mulch? Is biodegradable plastic mulch perceived to be a viable alternative to PE mulch? What is the likelihood that farmers would consider using biodegradable plastic mulch? To answer these and related questions, we surveyed strawberry growers in California, the Pacific Northwest (Oregon and Washington), and the Mid-Atlantic (New York and Pennsylvania) in 2016 to explore regional differences in strawberry growers' experiences and opinions related to the use of PE and biodegradable plastic mulches. Strawberry growers were chosen as the study population because of their widespread use of plastic mulch, high crop value, and potential interest in biodegradable plastic mulch products. Two hundred and nineteen strawberry growers completed the survey, for a response rate of 21%. Our study not only contributes to the nascent literature on farmers' adoption of biodegradable plastic mulch (Cowan et al., 2015; Goldberger et al., 2015; Scaringelli et al., 2016) but also meets the call for more research on stakeholders' perceptions of the environmental impacts of agricultural landscapes under plastic mulch (Steinmetz et al., 2016).

In 2017, the United States produced 3.6 billion pounds of strawberries, valued at \$3.5 billion [U.S. Department of Agriculture (USDA), 2018]. Fresh market strawberries accounted for 83% of total strawberry production, and processing strawberries (i.e., frozen, freeze-dried, or included in strawberry-based food products) accounted for the remaining 17% (USDA, 2018). According to the 2012 U.S. Census of Agriculture, 10,388 farms grew strawberries on a total of 67,467 acres in 2012 (Table 1). California produced 91% of the strawberry crop in 2017 (USDA, 2018). The other top 10 strawberry-producing states are located in the South Atlantic (Florida,

Table 1. Strawberry production in the United States and selected states. Data from the 2012 Census of Agriculture (USDA, 2014).

State	Farms (no.)	U.S. rank for no. of farms	Total area (acres) ^z	U.S. rank for total area	Mean area (acres)
California	995	2	40,926	1	41.1
Pacific Northwest					
Oregon	399	9	2,121	3	5.3
Washington	614	3	1,514	4	2.5
Mid-Atlantic					
New York	588	4	1,220	5	2.1
Pennsylvania	1,015	1	1,049	6	1.0
U.S. Total	10,388		67,467		6.5

^z1 acre = 0.4047 ha.

North Carolina), Mid-Atlantic (New York, Pennsylvania), Pacific Northwest (Oregon, Washington), and Midwest (Ohio, Michigan, Wisconsin). Globally, the largest producer of strawberries is China, followed by the United States, Mexico, Egypt, Turkey, and Spain (Food and Agriculture Organization of the United Nations, 2017).

U.S. strawberry production and marketing practices vary by region (Samtani et al., 2019). For example, most California strawberries are annual plantings for fresh market (Fennimore, 2017); the Pacific Northwest is known for the production of high-quality processing fruit in a perennial matted row system (Finn, 2017); and the Northeast and Mid-Atlantic states exhibit a combination of perennial matted rows and raised-bed plasticulture for fresh-market strawberries (Pritts, 2017). Plastic mulch is increasingly popular across all U.S. strawberry production regions because of its ability to suppress weeds, moderate soil temperature, conserve water, and protect plants (DeVetter et al., 2017; Fernandez et al., 2001; Freeman and Gnayem, 2005). Biodegradable plastic mulch has been shown to perform comparably to PE mulch for strawberry production in terms of weed suppression (Andrade et al., 2014), soil moisture retention (Costa et al., 2014), fruit quality (Bilck et al., 2010), crop yield (DeVetter et al., 2017), and material functionality from planting to harvesting (Kapanen et al., 2008). Biodegradable plastic mulch costs two to three times more than PE mulch (Velandia et al., 2018; Zhang et al., 2018); however, because it does not need to be removed and discarded at the end of its useful lifetime, farmers

do not incur the removal and disposal costs associated with PE mulch. Economic research has shown that U.S. consumers are willing to pay more for strawberries grown with biodegradable plastic mulch, which may in part offset the higher upfront cost of the mulch (Chen et al., 2018).

Our human dimensions study, which focuses on farmers' experiences and opinions related to PE and biodegradable plastic mulch, is part of a larger project, "Performance and Adoptability of Biodegradable Plastic Mulch for Sustainable Specialty Crop Production," funded by the USDA National Institute of Food and Agriculture's Specialty Crop Research Initiative program (award no. 2014-51181-22382). The survey was conducted by the project's Technology Adoption Working Group with guidance from a transdisciplinary team of scientists, Extension personnel, farmers, mulch manufacturers, and other stakeholders.

Materials and methods

The population for this study included growers in three strawberry production regions: California, the Pacific Northwest (Oregon, Washington), and the Mid-Atlantic (New York, Pennsylvania). These five states were ranked in the top 10 U.S. states for number of strawberry farms and strawberry acres according to the 2012 U.S. Census of Agriculture (Table 1). The three regions were selected for this study because of their known differences in farm scale, production characteristics, and marketing practices. These regional differences were hypothesized to influence growers' experiences with and opinions about the use of PE and biodegradable plastic mulches for strawberry production.

Other top 10 U.S. states for strawberry production (e.g., Florida, Michigan, North Carolina, Wisconsin) could have been included in our study; however, limited research funds prevented us from administering the survey to growers in all production regions. Future research should focus on the U.S. South and Midwest.

The majority of the grower names and postal addresses were purchased from Meister Media (Willoughby, OH), a corporation that publishes periodicals on fruit and vegetable production. Because the Meister Media list included relatively few names in the Pacific Northwest, the list was supplemented with addresses from Oregon Tilth, the Oregon Strawberry Commission, the Washington State Department of Agriculture Organic Program, and the Washington Strawberry Commission. The survey was conducted by the authors in association with staff at Washington State University's (WSU's) Social and Economic Sciences Research Center. The survey project ("2016 Survey of Strawberry Growers") received exemption status by the WSU Institutional Review Board (IRB) in Feb. 2016 (IRB no. 15010).

Following the tailored design method (Dillman et al., 2014), a pre-notification letter and questionnaire (titled "Use of Plastic Mulch Films in U.S. Strawberry Production: Growers' Experiences and Opinions") were sent to 1497 strawberry growers in Feb. 2016. A reminder postcard and replacement questionnaire were sent to nonrespondents in Mar. 2016. The survey consisted of 60 questions related to growers' experiences with and opinions about PE

and biodegradable plastic mulches, strawberry production and marketing practices, fumigation practices, decision-making and sources of agricultural information, farm characteristics, and demographics. Growers could opt to complete the survey on paper or online.

ANALYSIS. The primary objective of this study is to compare strawberry farm characteristics, as well as growers' experiences and opinions about PE and biodegradable plastic mulches, across three U.S. production regions. Because the data set contained continuous and categorical variables, two tests for statistical significance were employed to assess regional differences: analysis of variance was used for continuous variables, and Pearson's chi-square was used for categorical variables. Some of the categorical variables were recoded into fewer categories for the purpose of analysis. Pairwise comparisons of column proportions were examined using the Bonferroni correction. All statistical analyses were conducted using IBM SPSS Statistics (version 25.0 for Macintosh; IBM Corp., Armonk, NY).

Results and discussion

Two hundred and nineteen strawberry growers completed the survey: 32 in California, 30 in Oregon, 28 in Washington, 41 in New York, and 88 in Pennsylvania. After accounting for ineligible (i.e., individuals who did not grow strawberries or no longer farmed) and bad addresses, the initial response rate was 16%. Because of the low response rate, 300 nonrespondents were contacted by phone in

Apr. 2016. The phone calls indicated a higher proportion of ineligible names on the mailing list than anticipated. The sample disposition was adjusted based on the prevalence of ineligible, resulting in a final response rate of 21%.

FARM CHARACTERISTICS. Survey results indicate that strawberry operations vary in acreage, production characteristics, and marketing practices by region. California growers had more strawberry acreage (125.4 acres per grower on average) than growers in the Pacific Northwest (15.0 acres) and Mid-Atlantic (3.2 acres) [$F(2, 213) = 21.78, P \leq 0.001$]. Nearly all Mid-Atlantic strawberries (99.8%) were produced for the fresh market compared with 93.3% in California and 74.3% in the Pacific Northwest [$F(2, 219) = 30.12, P \leq 0.001$]. Given that our mean acreages are higher than the USDA averages (Table 1), larger scale growers were likely overrepresented in our survey sample.

Table 2 presents additional production and marketing characteristics for survey respondents in the three regions. Respondents in California and the Pacific Northwest were more likely to grow at least some certified organic strawberries compared with Mid-Atlantic respondents. Respondents in California and the Pacific Northwest were also more likely to report that strawberries were their primary agricultural product in terms of value of sales. California respondents were more likely to use the hill system of strawberry production (i.e., raised beds with or without plastic mulch), and matted rows were more

Table 2. Production and marketing characteristics of strawberry farms in California, Pacific Northwest (Oregon, Washington), and Mid-Atlantic (New York, Pennsylvania). Data from 2016 survey of U.S. strawberry growers.

	California	Pacific Northwest	Mid-Atlantic				
Farm characteristic	(% respondents) ^z			N	χ ^{2y}	df	P
Certified organic—some or all acres	61.2 a	41.1 a	4.7 b	214	60.97	2	<0.001
Strawberry—primary farm product	50.0 a	29.3 a	7.8 b	218	33.36	2	<0.001
Hill system	71.4 a	44.4 b	42.7 b	206	7.75	2	0.021
Matted row system	25.0 a	55.6 b	64.5 b	206	14.58	2	0.001
Fumigation of strawberry fields	62.1 a	7.1 b	7.0 b	213	60.95	2	<0.001
Wholesale marketing	69.0 a	26.8 b	18.0 b	213	31.04	2	<0.001
Direct-to-retail marketing ^x	69.0 a	32.1 b	21.9 b	213	24.57	2	<0.001
Direct-to-consumer marketing ^w	37.9 a	64.3 a	92.2 b	213	47.43	2	<0.001
U-pick operation	6.9 a	39.3 b	46.1 b	213	15.28	2	<0.001

^zEach subscript letter denotes a subset of region categories whose column proportions do not differ significantly from each other ($P \leq 0.05$, Bonferroni correction).

^yPearson's chi-square.

^xDirect-to-retail marketing includes direct to conventional supermarket, food cooperatives, natural foods stores, restaurants, schools, or hospitals.

^wDirect-to-consumer marketing includes farmers markets, community supported agriculture schemes, roadside stands, and farm stores.

prevalent in the Pacific Northwest and Mid-Atlantic. Runners are removed in a hill system to encourage the production of large plants and berries, whereas runners spread freely and root within the row in a matted row system (Strik, 2017). California respondents were more likely to fumigate their strawberry fields compared with respondents in the other two regions. Wholesale and direct-to-retail marketing channels were more common in California, and U-pick operations were more prevalent in the Pacific Northwest and Mid-Atlantic. Mid-Atlantic respondents were much more likely to use direct-to-consumer marketing channels compared with respondents in California and the Pacific Northwest.

It is important to appreciate these regional differences in production and marketing practices because they may influence farmers' experiences with and opinions about PE and biodegradable plastic mulches. First, farmers with certified organic strawberries cannot use biodegradable plastic mulch given the current National Organic Program standards (Miles et al., 2017). PE mulch, however, is allowed in U.S. certified organic crop production if the mulch is removed from the field after production and no fragments remain in the soil. Second, plastic mulch is incompatible with the matted row system of strawberry production because this perennial system relies on annual renovation and the formation of runners and daughter plants from June-bearing strawberry plants. Plastic mulch would interfere with renovation as well as the rooting and formation of daughter plants. Third, California growers often need to manage several soilborne diseases and plant-parasitic nematodes to maintain production and profitability, necessitating fumigation or other alternative soilborne disease management practices (Bolda et al., 2017; Mazzola et al., 2018). Soil fumigation often entails the use of plastic tarps to improve fumigation efficacy and reduce buffer zones around an application site. For bed fumigation, plastic tarps that are totally or virtually impermeable can be used and retained in a planting to function as a mulch after fumigation is complete. Tarps must be approved by the U.S. Environmental Protection Agency

(EPA) by active ingredient, and currently no biodegradable plastic mulches are approved for this application (DeVetter et al., 2018; EPA, 2019). However, a grower could choose to remove a tarp after fumigation is complete and transition to using a biodegradable plastic mulch, particularly in situations where a field is broadcast fumigated and the tarp needs to be removed before bed formation. Fourth, farmers engaged in on-farm marketing activities [e.g., U-pick, community supported agriculture (CSA)] may not be interested in plastic mulch because of fear that customers could rip or otherwise disturb the plastic mulch films while visiting the strawberry fields. Moreover, U-pick and CSA customers may not like the aesthetics and/or environmental impacts associated with black plastic (Stevens et al., 2007).

POLYETHYLENE MULCH. In 2015, 49% of survey respondents used PE mulch on some or all of their strawberry fields. However, Fig. 1A reveals statistically significant regional differences. Growers in California were the most likely (88%) to have used PE mulch in their strawberry fields, followed by growers in the Mid-Atlantic (51%) and Pacific Northwest (23%). Likely reasons for the popularity of

PE mulch among California respondents include the use of day-neutral/remontant cultivars in annual hill systems on raised beds, larger operations, prevalence of certified organic production, and the practice of drip or bed fumigation in conventional systems combined with the use of approved tarps that can function as mulches later in the life of the planting (Bolda et al., 2017; EPA, 2019). PE mulch use is less common in the other two regions because of farmers' preference for the matted row system of strawberry production with June-bearing cultivars and use of direct marketing practices.

Survey respondents were also asked about PE mulch use for crops other than strawberry (Fig. 1B). In 2015, 55% of all survey respondents used PE mulch for other crops, such as tomato (*Solanum lycopersicum*), pepper (*Capsicum* sp.), melons (*Citrullus* sp. and *Cucumis* sp.), squash (*Cucurbita* sp.), and cucumber (*Cucumis sativus*). A higher percentage of respondents in the Mid-Atlantic (71%) and California (52%) used PE mulch for crops other than strawberry compared with respondents in the Pacific Northwest (17%).

PE mulch disposal methods varied by region (Fig. 2). Transporting

A. Did you use PE mulch in your strawberry fields in 2015?

B. Did you use PE mulch on crops other than strawberry in 2015?

Fig. 1. Use of polyethylene (PE) mulch in California, Pacific Northwest (Oregon, Washington), and Mid-Atlantic (New York, Pennsylvania). Pearson's chi-square (χ^2) test used to assess regional differences. Data from 2016 survey of U.S. strawberry growers.

Fig. 2. Disposal of polyethylene mulch after use in strawberry fields in California, Pacific Northwest (Oregon, Washington), and Mid-Atlantic (New York, Pennsylvania). Pearson's chi-square (χ^2) test used to assess regional differences. Data from 2016 survey of U.S. strawberry growers.

PE mulch after use in strawberry fields to a landfill or other dumpsites was the most common disposal method. Burying was rarely reported in the three regions. A significantly larger percentage of California growers recycled their used PE mulch compared with growers in the Pacific Northwest and Mid-Atlantic. Mid-Atlantic growers were more likely to burn their used PE mulch compared with growers in the other regions. These findings are not surprising because of recycling programs and incentives California has undertaken to reduce waste (CalRecycle, 2018) and because some states and local ordinances allow burning of plastic waste as a method of disposal (EPA, 2018).

Survey respondents were asked to indicate the extent to which they disagreed or agreed with five statements about PE mulch (Table 3). A small percentage of respondents in

Table 3. Opinions about polyethylene mulch among strawberry growers in California, Pacific Northwest (Oregon, Washington), and Mid-Atlantic (New York, Pennsylvania). Data from 2016 survey of U.S. strawberry growers.

	California	Pacific Northwest	Mid-Atlantic				
Statement ^z	(% respondents) ^y			N	χ ^{2x}	df	P
Polyethylene (PE) mulch is environmentally friendly.							
Disagree	56.3 ab	62.7 b	35.4 a				
Neither disagree or agree	21.9 a	33.3 a	43.3 a				
Agree	21.9 a	3.9 b	21.3 a				
Total	100.0	100.0	100.0	210	17.37	4	0.002
PE mulch harms the soil.							
Disagree	62.5 a	34.0 b	69.0 a				
Neither disagree or agree	21.9 ab	46.0 b	27.0 a				
Agree	15.6 a	20.0 a	4.0 b				
Total	100.0	100.0	100.0	208	23.60	4	<0.001
Disposal of used PE mulch is a big environmental problem.							
Disagree	25.0 a	5.9 b	17.6 ab				
Neither disagree or agree	18.8 a	23.5 a	25.6 a				
Agree	56.3 a	70.6 a	56.8 a				
Total	100.0	100.0	100.0	208	6.87	4	0.143
Recycling is a viable option for used PE mulch.							
Disagree	31.3 a	39.2 a	37.9 a				
Neither disagree or agree	18.8 a	43.1 a	29.8 a				
Agree	50.0 a	17.6 b	32.3 ab				
Total	100.0	100.0	100.0	207	10.97	4	0.027
Proper disposal of used PE mulch is economically burdensome.							
Disagree	18.8 a	9.8 a	16.0 a				
Neither disagree or agree	25.0 a	23.5 a	26.4 a				
Agree	56.3 a	66.7 a	57.6 a				
Total	100.0	100.0	100.0	208	2.00	4	0.736

^zDisagree includes "disagree" and "strongly disagree" answers. Agree includes "agree" and "strongly agree" answers.

^yEach subscript letter denotes a subset of region categories whose column proportions do not differ significantly from each other ($P \leq 0.05$, Bonferroni correction).

^xPearson's chi-square.

the Pacific Northwest agreed that PE mulch is environmentally friendly compared with significantly higher percentages in California and the Mid-Atlantic. Respondents in California and the Pacific Northwest were more likely than respondents in the Mid-Atlantic to agree that PE mulch harms the soil. One half of California respondents agreed that recycling was a viable option for used PE mulch compared with smaller percentages in the Mid-Atlantic and Pacific Northwest. These results suggest U.S. West Coast (California, Oregon, Washington) strawberry growers may be more environmentally minded regarding the impacts of farming practices (particularly plastic mulching) on the agroecosystem. However, a majority of respondents (ranging from 56% to 71%) in all three regions agreed that the disposal of used PE mulch is a big environmental problem and economically burdensome; however, no statistically significant regional differences were apparent.

BIODEGRADABLE PLASTIC MULCH.

The survey included several questions about biodegradable plastic mulch in strawberry production (Fig. 3). The percentage of respondents familiar with biodegradable plastic mulch did not differ significantly across the three regions; however, respondents in the Pacific Northwest and California were more likely to report a lack of familiarity with biodegradable plastic mulch (Fig. 3A). Nearly one-fifth of California respondents had used biodegradable plastic mulch in their strawberry fields, compared with 9% in the Mid-Atlantic and 0% in the Pacific Northwest (Fig. 3B). A majority of respondents in all three regions expressed an interest in learning more about biodegradable plastic mulch for strawberry production; however, higher percentages of respondents in the Pacific Northwest (36%) and the Mid-Atlantic (20%) expressed no interest compared with California respondents (7%) (Fig. 3C). Nearly half (48%) of respondents in the Pacific Northwest were not at all likely to consider using biodegradable plastic mulch in their strawberry fields in the next 5 years, compared with significantly smaller percentages in California (10%) and the Mid-Atlantic (26%) (Fig. 3D). In sum, California strawberry growers had the most experience with biodegradable plastic

mulch and most ($\geq 90\%$) expressed the desire to learn more and consider using such mulch in the future. Interest in biodegradable plastic mulch is likely due to California growers' current use of PE mulch and the annual hill system of strawberry production. Because adoption is more likely when innovations are compatible with existing practices (Rogers, 2003), California growers could potentially replace PE mulch with biodegradable plastic mulch with little change to their overall strawberry production system. However, if California growers bed fumigate using tarps for soil fumigation and subsequently maintain the tarps as a mulch, currently available biodegradable plastic mulch products will be incompatible given the legal requirements for tarps (EPA, 2019). In the other two regions, the majority of survey respondents use perennial matted rows, which are not necessarily compatible with annual plastic mulch use.

Survey respondents were asked to indicate the extent to which they disagreed or agreed with five statements about biodegradable plastic mulch (Table 4). The high percentage of "neither disagree nor agree" responses in Table 4 suggests that many respondents likely lacked sufficient knowledge of biodegradable plastic mulch to disagree or agree with the statements provided. More than 40% of respondents in the three regions agreed that biodegradable plastic mulch is environmentally friendly. Respondents in California and the Pacific Northwest were more likely than respondents in the Mid-Atlantic to agree that biodegradable plastic mulch harms the soil. A significantly higher percentage of Mid-Atlantic respondents (38%) agreed that there are no disposal costs associated with the use of biodegradable plastic mulch compared with respondents in California (10%). Nearly 60% of respondents in California agreed that biodegradable plastic is an unproven technology compared with significantly smaller percentages in the Pacific Northwest and Mid-Atlantic. One-third or more respondents across the three regions agreed that biodegradable plastic mulch can replace PE mulch; no statistically significant regional differences were apparent.

It is worth noting that some U.S. specialty crop growers (including

some of our survey respondents) may have had negative experiences with oxo-degradable plastic mulch films erroneously labeled as "biodegradable." Such films (made with PE, polypropylene, polystyrene, or other plastics) undergo fragmentation when exposed to ultraviolet light, heat, and/or oxygen but are not necessarily biodegradable, compostable, or recyclable (Miles, 2017). At least one plastics manufacturer misled the public regarding the biodegradation of oxo-degradable plastics (Miles, 2017); thus, some growers may be suspicious of agricultural products marketed as "biodegradable." Outreach may be necessary to reeducate these growers about currently available biodegradable plastic mulch.

Survey respondents were also asked about the importance of 18 traits (e.g., different colors, biobased content, equipment compatibility, compostability, timing of biodegradation, durability, etc.) for biodegradable plastic mulch used in strawberry production. The top five traits (based on mean importance on a scale from 1 = "not at all important" to 4 = "very important") differed among the three strawberry production regions. Respondents in all three regions attributed high importance to compatibility with irrigation equipment and remaining intact until the end of the growing season. California respondents wanted a product available in black that could be laid with a plastic mulch layer and would completely biodegrade in soil within 1 year. The desire for complete biodegradation in 1 year can be attributed to the practice of rotating land used for strawberry production to other specialty crop producers [e.g., lettuce (*Lactuca sativa*)] within 7 to 14 months after strawberry planting. Subsequent producers do not want plastic mulch fragments in their soil, regardless of whether it is biodegradable. Pacific Northwest respondents wanted a 100% biobased product that could be tilled into the soil or composted on-farm at the end of the growing season. Mid-Atlantic respondents wanted a product that could be laid with a plastic mulch layer, could be tilled into the soil at the end of the growing season, and would completely biodegrade within 2 years. The traits of least importance to respondents were availability in clear (all three regions),

A. How familiar are you with biodegradable plastic mulch?

B. Have you ever used biodegradable plastic mulch in your strawberry fields?

C. How interested are you in learning more about biodegradable plastic mulch for U.S. strawberry production?

D. How likely are you to use biodegradable plastic mulch in your strawberry fields in the next 5 years?

Fig. 3. Biodegradable plastic mulch in California, Pacific Northwest (Oregon, Washington), and Mid-Atlantic (New York, Pennsylvania): familiarity, past experience, interest, and future use. Pearson's chi-square (χ^2) test used to assess regional differences. Data from 2016 survey of U.S. strawberry growers.

availability in reflective silver (all three regions), produced with 50% biobased materials (California and Pacific Northwest), and produced without genetically modified organism feedstocks

(California and Mid-Atlantic). In sum, these results suggest that a one-size-fits-all approach is not appropriate given the regional differences in desirable (and undesirable) biodegradable

plastic mulch traits. Manufacturers need to be cognizant of these regional differences when developing and marketing their portfolio of biodegradable plastic mulch products.

Lastly, survey respondents were presented with seven hypothetical scenarios and asked about the likelihood of considering using biodegradable plastic mulch in their strawberry fields (Table 5). More than 50% of

respondents were moderately or very likely to consider using biodegradable plastic mulch if the price dropped, research indicated no harmful soil impacts, or products were available locally. There were no statistically

significant regional differences except for the scenario relating to approval of biodegradable plastic mulch for use in U.S. certified organic production. One-third (33%) of respondents in California were “very likely” to

Table 4. Opinions about biodegradable plastic mulch among strawberry growers in California, Pacific Northwest (Oregon, Washington), and Mid-Atlantic (New York, Pennsylvania). Data from 2016 survey of U.S. strawberry growers.

Statement ^z	California	Pacific Northwest	Mid-Atlantic	N	χ^{2x}	df	P
	(% respondents) ^y						
Biodegradable plastic mulch is environmentally friendly.							
Disagree	19.4 a	12.8 a	6.7 a				
Neither disagree or agree	38.7 a	44.7 a	32.8 a				
Agree	41.9 a	42.6 a	60.5 a				
Total	100.0	100.0	100.0	197	8.56	4	0.073
Biodegradable plastic mulch harms the soil.							
Disagree	20.7 ab	21.3 b	42.6 a				
Neither disagree or agree	65.5 a	66.0 a	55.7 a				
Agree	13.8 a	12.8 a	1.7 b				
Total	100.0	100.0	100.0	191	16.57	4	0.002
There are no disposal costs associated with use of biodegradable plastic mulch.							
Disagree	40.0 a	23.4 a	25.0 a				
Neither disagree or agree	50.0 a	55.3 a	37.1 a				
Agree	10.0 a	21.3 ab	37.9 b				
Total	100.0	100.0	100.0	193	12.91	4	0.012
Biodegradable plastic mulch is an unproven technology.							
Disagree	9.7 a	8.7 a	25.2 a				
Neither disagree or agree	32.3 a	69.6 b	50.4 ab				
Agree	58.1 a	21.7 b	24.3 b				
Total	100.0	100.0	100.0	192	22.17	4	<0.001
Biodegradable plastic mulch can replace polyethylene mulch.							
Disagree	10.0 a	4.3 a	18.1 a				
Neither disagree or agree	56.7 a	54.3 a	47.4 a				
Agree	33.3 a	41.3 a	34.5 a				
Total	100.0	100.0	100.0	192	6.01	4	0.199

^zDisagree includes “disagree” and “strongly disagree” answers. Agree includes “agree” and “strongly agree” answers.

^yEach subscript letter denotes a subset of region categories whose column proportions do not differ significantly from each other ($P \leq 0.05$, Bonferroni correction).

^xPearson’s chi-square.

Table 5. Likelihood of considering use of biodegradable plastic mulch in strawberry fields: seven hypothetical scenarios. Data from 2016 survey of strawberry growers in five U.S. states: California, New York, Oregon, Pennsylvania, and Washington.

Hypothetical scenario	Not at all likely (%)	Slightly likely (%)	Moderately likely (%)	Very likely (%)
The price of biodegradable plastic mulch drops significantly.	20.5	23.7	26.3	29.5
University research indicates biodegradable plastic mulch does not harm the soil.	22.6	25.8	33.2	18.4
Biodegradable plastic mulch is readily available at local agricultural input supply stores.	27.9	21.6	32.6	17.9
Use of biodegradable plastic mulch improves good agricultural practices or sustainability audit score.	18.8	32.3	32.8	16.1
Consumers are willing to pay a premium for products grown with biodegradable plastic mulch.	38.1	19.1	25.8	17.0
Biodegradable plastic mulch is approved for use in U.S. certified organic production.	35.5	26.9	23.7	14.0
Biodegradable plastic mulch use is required by a processor, wholesale buyer, or retailer.	45.1	20.5	23.6	10.8

consider using biodegradable mulch if approved for certified organic production compared with 17% in the Pacific Northwest and 8% in the Mid-Atlantic [$\chi^2(6,186) = 18.92, P = 0.004$]. This finding is not surprising given that certified organic strawberry production was more common in California than in the other two regions (Table 2).

Conclusions

This research focused on the human dimensions of plastic mulch use and disposal in agriculture. Specifically, we explored U.S. strawberry growers' perceptions of PE mulch, their PE mulch disposal practices, their thoughts on biodegradable plastic mulch as a viable alternative to PE mulch, and their likelihood of adopting biodegradable plastic mulch products in the future. We compared growers' perceptions and experiences across three U.S. strawberry production regions and found significant differences. California growers were far more likely to have used PE mulch compared with growers in the Mid-Atlantic and Pacific Northwest. California and Pacific Northwest growers appeared to be more concerned about the environmental impacts of plastic mulching compared with Mid-Atlantic growers. Nonetheless, a majority of respondents of all three regions expressed an interest in learning more about biodegradable plastic mulch for strawberry production. Our survey results indicated that the adoption of biodegradable plastic mulch may be more likely if products are locally available, proven not to be harmful to soil health, and affordable. In an effort to mitigate agricultural plastic pollution in U.S. strawberry production, Extension educators and other service providers may need to tailor education and outreach initiatives relating to PE and biodegradable plastic to different regional grower groups.

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