Tennessee Fruit and Vegetable Farmer Preferences and Willingness to Pay for Plastic Biodegradable Mulch

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Abstract

Regardless of the potential economic and environmental benefits associated with plastic biodegradable mulch (BDM) use in fruit and vegetable production, BDM adoption among U.S. farmers remains relatively low. One of the factors influencing low BDM adoption is its cost. Using a 2019 Tennessee fruit and vegetable farmer survey, the contingent valuation method, and a probit regression, this study evaluates farmers' preferences and willingness to pay (WTP) for BDM. Results suggest price, on-farm income, and familiarity with BDM are factors influencing farmer adoption of BDM. However, results suggest producer WTP for BDM is below current BDM market prices.

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Introduction

Traditionally polyethylene (PE) mulch is used in fruit and vegetable production because of the benefits it provides, including soil moisture and temperature conservation, weed control, higher yields, and better crop quality (Emmert, 1957; Kasirajan and Ngouajio, 2012). Regardless of the benefits of PE mulch, there are concerns regarding the environmental sustainability associated with its use (Velandia et al., 2020b). At the end of the cropping season, PE mulch is removed and farmers use various methods to dispose of it, including disposing of it in landfills, burying it on-farm, or burning it (Kasirajan and Ngouajio, 2012; Velandia et al., 2020a). The choice of disposal method likely varies by location, depending on environmental regulations, regulation enforcement, costs, and producer preferences. However, each of the above disposal methods negatively impact the environment and directly or indirectly contribute to soil plastic pollution (Valavanidis et al., 2008; Velandia et al., 2020a; Velandia et al., 2020b). Furthermore, when removing PE mulch, fragments may remain in the soil. The accumulation of these mulch fragments over time generates plastic pollution that could negatively impact soil health, yield, and, therefore, the profitability of farm businesses (Liu, He, and Yan, 2014; Touchaleaume et al., 2016).

Plastic biodegradable mulch (BDM) is a more sustainable alternative to PE mulch. It provides the same benefits of PE mulch (e.g., soil moisture and temperature conservation, weed control, higher yields, and better crop quality), but does not have to be removed at the end of the cropping season, rather it is tilled into the soil, as it is designed to decompose into water and carbon dioxide (Waterer, 2010; Goldberger et al., 2013; Cowan et al., 2014; Ghimire et al., 2018; Sintim et al., 2019). It is important to acknowledge that the performance of both PE mulch and BDM in terms of weed control could be affected by the specific weed community and weed pressure at each farm (Moore and Wszelaki, 2019). Additionally, the benefits provided by BDM, like higher yield and better crop quality, are affected by the crops grown and environmental conditions, which vary by location and from one year to another (Ghimire et al., 2018). The long-term impact of tilling BDM into the soil needs to be investigated further (Sintim and Flury, 2017; Sintim et al., 2019), but for now, BDM seems to be a viable option to reduce plastic pollution associated with the use of PE mulch. Furthermore, Chen et al. (2019) suggest consumers are willing to pay a price premium for products grown on BDM. Specifically, they suggest that U.S. consumers, on average, are willing to pay a 10.3% premium above the market price for a 1-pound box of strawberries grown on BDM. Their results imply that BDM not only offers end-of-the-season cost savings because it reduces activities related to the removal and disposal of PE mulch, but it may also provide revenue opportunities for farmers.

While BDM is more environmentally friendly than PE mulch and there are potential cost savings and revenue opportunities associated with its use, the level of BDM adoption among fruit and vegetable farmers is relatively low. A 2020 survey of Tennessee fruit and vegetable farmers, the same survey data used in this study, revealed that only 15% of the 181 respondents had ever used BDM in their fields (Velandia et al., 2020a). Furthermore, results from a survey of strawberry farmers in California, the Pacific Northwest, and the Mid-Atlantic region of the United States showed that only about 19% and 9% of the respondents in California and the Mid-Atlantic region, respectively, had used BDM in their strawberry fields. None of the survey respondents in the

Pacific Northwest indicated BDM use in their strawberry fields (Goldberger, DeVetter, and Dentzman, 2019). Additionally, a 2012 survey of Tennessee, Washington, and Texas fruit and vegetable farmers found that only 29% of 34 respondents indicated they had used BDM in the past (Goldberger et al., 2013).

Potential explanations for the low adoption rate of BDM among fruit and vegetable farmers include: lack of information about these mulch products; the high price of BDM compared to PE mulch; uncertainty about the performance of BDM compared to PE mulch; concerns about the impact tilling BDM would have on the soil in the long run; product availability; and previous poor experiences with mulch products that were incorrectly labeled as BDM but that were not actually designed to biodegrade, such as oxo-degradable mulches (Goldberger et al., 2013; Velandia et al., 2020a). Goldberger et al. (2013) and Velandia et al. (2020a) suggested that the price of BDM is the most common barrier to adoption listed by fruit and vegetable farmers.

As stated above, one of the most important considerations by farmers in evaluating the use of BDM is its cost relative to prices of other mulch options (e.g., PE mulch, straw, paper-based mulch, no mulch). In general, BDM is more expensive than PE mulch. Previous studies suggest BDM can be twice as expensive as PE mulch (Velandia, Galinato, and Wszelaki, 2019). Using information from various input suppliers' websites, we estimated that the price of BDM could be 75% to 200% higher than the price of PE mulch.

For those producers currently using PE mulch, the cost savings (i.e., reduced labor) associated with not having to remove and dispose of BDM is an additional consideration when evaluating the use of BDM (Velandia, Galinato, and Wszelaki, 2019). For example, using the same survey data from this study, Velandia et al. (2020a) suggested that producers could save between 0 and 80 hours per acre due to the elimination of removal and disposal activities. These savings vary greatly from farm to farm, depending on the crop grown, soil and environmental conditions, and removal and disposal methods (Velandia et al., 2018). Respondents who stated that there are no labor savings associated with the elimination of PE mulch removal and disposal activities likely perform these tasks themselves or with the help of unpaid family labor. As a result, they would not assign a dollar value to this labor. On the other hand, cost savings associated with PE mulch disposal vary greatly from farm to farm, depending on disposal method (e.g., burying, burning, dumping it in landfills) and location (i.e., county). In general, the cost of burning or burying PE mulch on farm is close to $0. However, there may be penalties associated with burning PE mulch because of the negative environmental impacts associated with this practice (Velandia et al., 2020a). The costs associated with disposing PE mulch in landfills include transportation, labor, and landfill disposal fees. In Tennessee, disposal fees vary by county from $0 to $50 per ton (Velandia et al., 2018; Velandia, Galinato, and Wszelaki, 2019). Using the same survey data from the analyses presented in this study, Velandia et al. (2020a) found that the majority of Tennessee fruit and vegetable farmers (75%) dispose of PE mulch in landfills.

BDM is already available in the marketplace. However, due to its relatively low market penetration, it may be important for manufacturers to not only understand the factors influencing farmers'

willingness to use BDM at various price levels but also to compare farmer willingness to pay (WTP) for BDM with market prices at which the product is currently being offered.

A few studies have evaluated the factors that could be correlated with the use of BDM (Goldberger, DeVetter, and Dentzman, 2019; Velandia et al., 2020b). Using the same Tennessee fruit and vegetable farmer survey data analyzed in this study, Velandia et al. (2020b) suggested that labor savings and environmental stewardship are two factors correlated with the use of BDM, specifically among farmers with previous experience using PE mulch. Goldberger, DeVetter, and Dentzman (2019) found that, on average, more than 50% of respondents to a survey of strawberry farmers in California, the Pacific Northwest, and the Mid-Atlantic region would be moderately to very likely to consider the use of BDM if the price drops, and university researchers indicate BDM does not harm the soil.

Only two studies have explored farmer willingness to adopt BDM at various price levels (Scaringelli et al., 2016; Velandia et al., 2020a). Using the same survey data analyzed in this study, Velandia et al. (2020a) suggested that, as expected, the percentage of Tennessee fruit and vegetable farmers willing to use BDM decreased as the price of BDM increased, but found that even at prices higher than the current average market price for BDM, some farmers preferred BDM over PE mulch. This preference was likely due to the potential labor savings and the reduced environmental impact associated with its use. However, Velandia et al. (2020a) did not estimate farmers' WTP for BDM or the factors influencing their WTP. Another study by Scaringelli et al. (2016) evaluated Italian farmers' WTP for BDM derived from organic waste. They found that farmers using conventional mulch products, such as PE mulch, were willing to pay a higher price for BDM derived from organic waste when compared to similar products already available on the market. A recent study by Chen et al. (2020) evaluated various U.S. agricultural stakeholders' (e.g., farmers, crops advisors, educators located in the Pacific Northwest) WTP for various BDM attributes. They found that less risk-averse stakeholders who were less sensitive to the cost of BDM were more likely to adopt BDM. They also found that a potential price premium for products grown on BDM and the percentage of BDM plastic residue left in the field after harvesting were desirable BDM attributes for farmers. No studies have evaluated the factors influencing U.S. farmers' willingness to purchase BDM when facing various price scenarios. Furthermore, to the authors' knowledge, no studies have compared U.S. farmers' WTP for BDM to actual BDM market prices.

Understanding the difference between farmers' WTP for BDM and actual BDM market prices could inform policy makers interested in reducing soil plastic pollution from the use of PE mulch. For instance, estimates of the differences between WTP and market prices could assist in developing policy instruments, such as subsidies, to motivate the use of BDMs among fruit and vegetable farmers. Using the same survey data from this study, Velandia et al. (2020a) estimated that the majority (about 60%) of the respondents to a survey of Tennessee fruit and vegetable farmers use PE mulch to produce fruits and vegetables. Therefore, there is plastic waste generated by these farmers, and incentivizing the transition from PE mulch to BDM could be beneficial to the environment due to the reduced plastic pollution resulting from BDM. The adoption of BDM could result in increased revenue due to increased yield and crop quality associated with

transitioning from no mulch or a natural mulch option (e.g., straw) to a synthetic mulch option (Lamont, 1996). Farmers using other mulches might be interested in the benefits of PE mulch, but may also have concerns about the negative environmental impacts associated with its use. Therefore, these farmers might consider BDM a better alternative to PE mulch but may not be able to afford it. Future policies could incentivize the use of BDM with the goal of averting future negative environmental impacts associated with the use of PE mulch.

The primary objective of this study is to develop a measure of WTP for BDM. This study also seeks to identify non-price factors, such as farmer demographics, farm characteristics, and farmer attitudes, that may influence the probability of choosing BDM. This information is useful in building market profiles of those more willing to purchase BDM to aid in the marketing of this type of mulch to farmers. The study also provides comparisons of the farmers' WTP for BDM with current BDM market prices. This information is helpful in the development of policy instruments, such as subsidies to incentivize the use of BDM.

Conceptual Framework

Following Lusk and Hudson (2004), in this study we assume farmers maximize their profits, subject to a given production function. We assume the farmer chooses the level of inputs to be used, and assume the mulch product use, m, is fixed. Given a vector of input prices, w, except the mulch input m, and a vector of output prices, p (e.g., assuming there is no price premium associated with crops grown on BDM), the farmers choose the optimal level of inputs and outputs, which yield to the indirect restricted profit function, $\pi(p,w,m)$.

We assume a farmer considers changing the mulch option currently being used to produce fruits and vegetables from m^0 (e.g., PE mulch, natural mulch such as straw) to BDM (m^{BDM}), where m^0 and m^{BDM} define the quantity of mulch currently being used (e.g., two rolls of PE mulch) and the quantity of BDM to be used, respectively. A farmer's WTP function, also called the variation function d (Zapata and Carpio, 2014), is defined as,

$$d = \pi_{BDM}\,(\boldsymbol{p}, \boldsymbol{w}, m^{BDM}) - \pi_0\,(\boldsymbol{p}, \boldsymbol{w}, m^0) \tag{1}$$

If transitioning from the current mulch option m^0 used by a farmer to BDM (m^{BDM}) results in an increase in profits, $d > 0$, then equation (1) represents the maximum amount a farmer will be willing to forgo to obtain the potential benefits of transitioning to BDM (e.g., reduced labor costs, reduced plastic pollution). Some farmers may not be willing to forgo any money to transition from m^0 to m^{BDM}, because they may perceive no cost savings and only potential environmental benefits, such as the reduction of plastic pollution associated with the use of BDM. Therefore, we also consider the scenario where $d = 0$. According to equation (1), the maximum amount a farmer is WTP for BDM is given by the difference between the *ex post* (after adopting BDM) and *ex ante* (before adopting BDM) farm business's profit levels (Zapata and Carpio, 2014).

We do not observe d, but we do observe whether a farmer, i, is willing to choose BDM at a specific price level,

$$y_{iBDM} = \begin{cases} 1 & \text{if } y^*_{iBDM} \geq 0, \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where y^*_{iBDM} is a latent variable capturing the underlying differences in profits driving the decision to choose BDM, thus farmer i's propensity to purchase BDM. The variable y_{iBDM} is the dependent variable to be used in the regression model evaluating the factors correlated with farmer willingness to use BDM. This variable takes the value of 1 if the farmer selected BDM, and 0 if the farmer selected PE mulch or no plastic mulch (e.g., neither PE mulch nor BDM). Survey respondents who indicated they would choose neither BDM nor PE mulch were included in the analysis to better reflect the choices farmers face when deciding which mulch option they want to use on their farm operations. A farmer growing fruits and vegetables could use PE mulch, BDM, a natural mulch such as straw, or no mulch at all (Velandia et al., 2020b).

The latent variable y^*_{iBDM} is a function of observable and unobservable variables and can be described as,

$$y^*_{iBDM} = \boldsymbol{x}'_i\boldsymbol{\beta} + \varepsilon_i, \tag{3}$$

where $\boldsymbol{x}_i$ is a vector of observable variables that could be correlated with farmer i's decision to purchase BDM, such as price and familiarity with this mulch product, but also farmer and farm business characteristics, environmental stewardship, and risk attitudes; $\boldsymbol{\beta}$ is a vector of coefficients capturing the correlation between the observable variables and the decision to purchase BDM; and ε_i is the random disturbance term.

Data and Methods

Survey

The survey of Tennessee fruit and vegetable farmers was conducted between January and March 2019. Farmers were surveyed using both web-based and mail versions of the survey. Both versions of the survey instrument contained identical questions. We used a mixed-mode survey (i.e., web and mail [paper] versions) to improve response rates and reduce coverage and nonresponse error (Dillman, Smyth, and Christian, 2009). The web version of the survey was sent on January 29, 2019, to individuals with email addresses. We sent email reminders on February 5 and 12, 2019, to participants who had not completed the survey. The paper version of the survey was mailed to individuals who had mailing addresses but did not have or had invalid e-mail addresses, or did not respond to the web survey on March 20, 2019. Reminder postcards and follow-up surveys were sent on March 30 and April 5, 2019, respectively. The survey contained several sections, including a question that elicited Tennessee fruit and vegetable farmers' preferences for BDM, reasons for choosing and not choosing BDM, familiarity with BDM, risk attitudes, environmental stewardship, and farmers and farm business characteristics. Details of the overall survey instrument, including sections not used in this study, can be found in Velandia et al. (2020a). As stated in the introduction section, previous studies have used data from various sections of this survey (Velandia et al., 2020a; Velandia et al., 2020b). None of them have used data from the question that elicited

Tennessee fruit and vegetable farmers' preferences for BDM, or estimated WTP for BDM or the factors correlated with farmers' willingness to use BDM at alternative price levels.

Data

A comprehensive list of 990 Tennessee fruit and vegetable farmers was obtained from the Tennessee Department of Agriculture that included growers participating in a program that promotes and advertises food grown in Tennessee (Pick Tennessee Products), and in a program that provides cost sharing for long-term investments for Tennessee farms (Tennessee Agricultural Enhancement Program). The selection criteria for these two voluntary programs are very general. They include being 18 years of age or older, operating a farm in Tennessee, and growing products for sale, which provided a farmer contact list that minimized potential biases associated with farmer participation in these programs (Velandia et al., 2020a). After eliminating respondents who indicated they were not farming, not growing fruits and vegetables, were ill or retired, or had email or mailing addresses that were marked as undeliverable, we obtained a final list of 753 Tennessee fruit and vegetable farmers (Velandia et al., 2020a). From this list, we obtained 186 completed surveys; 49% of those surveys were completed online, and 51% were sent via mail. The overall survey response rate was 25%. After eliminating observations with missing values, 125 observations were used in estimating the probit regression.

Survey Sample Representativeness

As in Velandia et al. (2020a, 2020b), the representativeness of the sample used in the regression analysis was examined by comparing the distribution of this sample according to acres in fruit and vegetable production to the same distribution according to acres in vegetable production based on data from the 2017 Census of Agriculture (U.S. Department of Agriculture, 2020). As suggested by Velandia et al. (2020b), the criterion "acres in vegetable production" is a good basis of comparison, because most respondents reported either growing vegetables only or growing a combination of fruits and vegetables. Figure 1 shows the farm distribution comparison between the 2017 Census of Agriculture and the sample included in the probit regression. Overall, the sample included in the probit regression follows closely the distribution of farms based on farm size according to the 2017 census. As shown in Figure 1, according to the 2017 Census of Agriculture, a large percentage of the Tennessee farms have less than 5 acres in vegetable production (i.e., 80%). Similarly, more than half of the farms included in the survey sample (63%) have less than 5 acres in vegetable production. Nonetheless, it is important to note that the sample included in the probit regression tends to underrepresent farms in the 0.1- to 0.9-acre category and overrepresent farms in the 5- to 25-acre (medium-sized) categories. The overrepresentation of medium-sized farms in the regression sample could be explained by the fact that these farmers were more likely to respond to the survey, since as farm size increases, farms may be more interested in synthetic mulch products that provide benefits such as weed control (Velandia et al., 2020b). For larger farms, weed control without the use of a mulch option may not be economically feasible because it is a labor-intensive task.
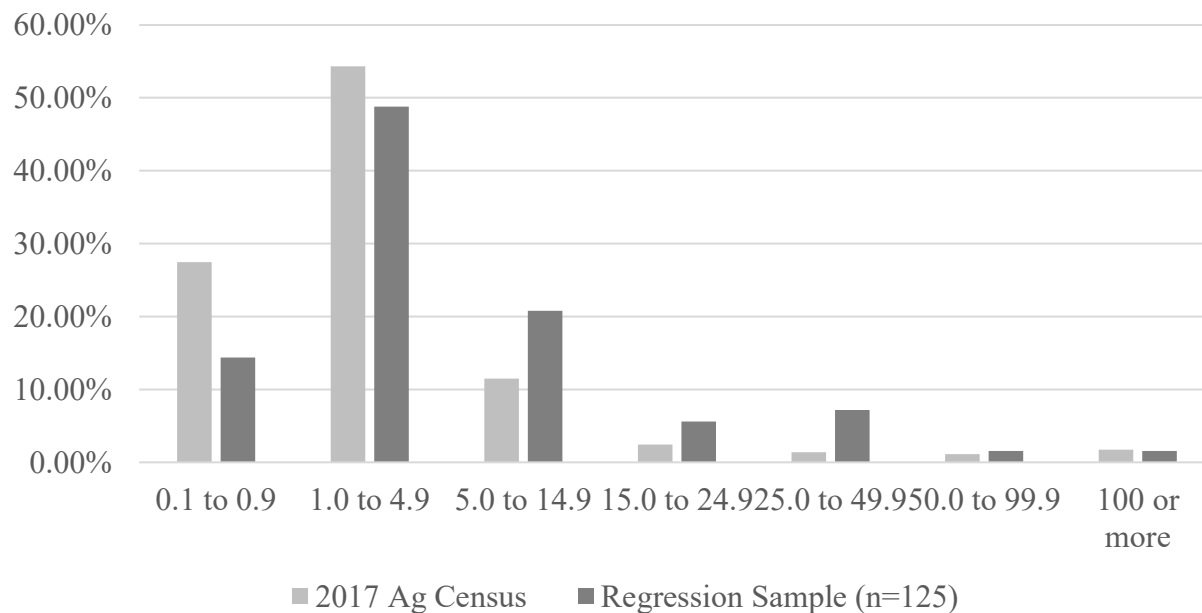
Figure 1. Percentage of Farms in Each Farm Size Category Based on Acres in Vegetable Production According to Data from the 2017 U.S. Census of Agriculture and the Sample Included in the Probit Regression

Contingent Valuation

The Contingent Valuation (CV) method was used to elicit Tennessee fruit and vegetable farmers' willingness to adopt BDM over PE mulch at various price points. This method has been used by several researchers to determine consumer and producer willingness to adopt various products (e.g., Dobbs et al., 2016; McKay et al., 2019a; McKay et al., 2019b; DeLong et al., 2020). The elicitation method used in this study is a single-bounded dichotomous choice framework, where the price of BDM is varied across surveys, and the average WTP is estimated by examining how willing the population is to purchase BDM at alternative price levels (Lusk and Hudson, 2004; Dobbs et al., 2016; McKay et al., 2019a; McKay et al., 2019b; DeLong et al., 2020). In contrast to Chen et al. (2020), the goal of this study was not to evaluate farmer WTP for BDM attributes but to assess farmer WTP for BDM, farmer willingness to adopt BDM, and the factors, including BDM price, farmer demographics, and farm characteristics, that contribute to their decision to adopt BDM.

Before eliciting Tennessee fruit and vegetable farmers' preferences for BDM, we provided the following details about BDM:

"BDMs are used in the same manner as PE mulches with the additional benefit of being 100% biodegradable. Below, you are presented with two 4' x 4,000' mulch rolls. Option A is a roll of black polyethylene (PE) mulch (plastic mulch). Option B is a roll of black plastic biodegradable mulch. Both products provide the same benefits (i.e., weed control, soil moisture conservation, and yield improvements); both products can be laid using a mechanical plastic layer. The only

difference is that BDMs do not have to be removed, but rather they are tilled into the soil or composted at the end of the season."

To examine Tennessee fruit and vegetable farmers' preferences for a 4' x 4,000' roll of BDM, farmers were next presented with a contingent valuation question involving two 4' x 4,000' rolls of mulch. The first roll was PE mulch, priced at $100 according to current market prices gathered from various input suppliers. The second roll of mulch provided similar benefits to PE mulch but was the 100% biodegradable BDM and was priced at one of four price points ($100, $200, $250, or $300). Each survey participant was randomly assigned to one of the price categories for the BDM. The survey respondent could select the PE mulch, the BDM, or neither product. The BDM price scenarios were not distributed symmetrically around the average BDM market price (i.e., $220). Although the average market price (i.e., $220) is a likely anchor for our analysis, the inclusion of a $100 BDM price option is important because it provides a BDM option at the same market price as PE mulch, which is the closest alternative to BDM. It is unlikely that a BDM would ever be sold at this low price, but this option allowed for gauging farmer interest in BDM at the same price point as PE mulch. The other price scenarios (i.e., $200, $250, and $300) were created based on the most common BDM prices found at various input suppliers' websites. An example CV question is shown in Figure 2. Following the CV question, respondents were asked the number of acres on which they were willing to use BDM to measure the potential intensity of BDM adoption, as well as the main reason associated with their choice of mulch product (i.e., PE mulch, BDM, neither PE mulch nor BDM).

	Option A	*Option B*	*Option C*
Product	**Polyethylene Mulch (plastic mulch)**	**Plastic Biodegradable Mulch**	I would not purchase either of the mulches
Laying	Can be laid with a mechanical plastic layer	Can be laid with a mechanical plastic layer	
End of season activities	Has to be removed and disposed of at the end of the growing season	Does not have to be removed, but rather it is tilled into the soil or composted at the end of the season	
Pictures of mulch used in bell peppers (both mulches can be used for growing fruits and vegetables)			
Mulch price (per 4' x 4,000' roll)	$100	$300	
Please select one <u>(mark with an X)</u>	☐ **Please go to Q1**	☐ **Please go to Q2**	☐ **Please go to Q4**

Figure 2. Example Contingent Valuation Question for Mulch Options

Probit Regression

The probability of farmer i choosing BDM is defined as (Greene, 2012),

$$P(y_{iBDM} = 1 \mid \boldsymbol{x}_i) = P(y^*_{iBDM} \geq 0 \mid \boldsymbol{x}_i) = P(\boldsymbol{x}'_i\boldsymbol{\beta} + \varepsilon_i \geq 0 \mid \boldsymbol{x}_i) \qquad (4)$$

$$= P(\varepsilon_i \geq -\boldsymbol{x}'_i\boldsymbol{\beta} \mid \boldsymbol{x}_i) = P(\varepsilon_i \leq \boldsymbol{x}'_i\boldsymbol{\beta} \mid \boldsymbol{x}_i)$$

$$= F(\boldsymbol{x}'_i\boldsymbol{\beta}) = \Phi(\boldsymbol{x}'_i\boldsymbol{\beta}),$$

where $F(.)$ is the cumulative distribution function for the random variable ε_i. We assume ε_i is normally distributed, therefore $\Phi(.)$ is the cumulative normal distribution. Hence, the binary choice model described in equation (4) is estimated using a probit regression model (Greene, 2012).

The average marginal effects for the discrete and continuous variables were calculated following Greene (2012). The statistical package Stata was used to estimate the probit regression using the probit command (StataCorp, 2017). The associated marginal effects were computed following the probit regression by using the Stata command margins.

Diagnostics Tests

The overall significance of the probit regression was tested using a Wald test distributed $\chi^2(k)$ (StataCorp, 2017). A condition index was used to detect collinear relationships among the independent variables included in the probit regression (Belsley, Kuh, and Welsch, 1980). A condition index below 30 suggests that multicollinearity is not a concern for the variance estimates, and, therefore, not a concern for the potential inferences drawn from the regression results (Belsley, 1991).

WTP Estimation

Results from the probit regression were used to estimate average farmer WTP for BDM with the formula:

$$\widehat{WTP}_{iBDM} = -\frac{\hat{\beta}_0 + z_i{'}\hat{\boldsymbol{\beta}}_{-p}}{\hat{\beta}_p}, \tag{5}$$

where $\hat{\beta}_0$ is the estimated intercept, $\hat{\boldsymbol{\beta}}_{-p}$ is a vector of estimated parameters excluding the BDM price coefficient, z is the vector of independent variables excluding BDM price, and $\hat{\beta}_p$ is the estimated parameter for the price of BDM (Dobbs et al., 2016). The WTP for BDM was determined as the average WTP evaluated for each farmer.

Hypothesis for Explanatory Variables

In this section, we describe the criteria used for including the various independent variables in the analysis, specifically how previous studies support the inclusion of these variables. The independent variables hypothesized to be correlated with farmers' decisions to adopt BDM at various price levels are described in Table 1. It is assumed that as the price of BDM increases, farmers will be less likely to purchase BDM. This assumption is consistent with previous studies suggesting the cost of BDM has a negative impact on farmers' willingness to use BDM (Goldberger et al., 2013; Goldberger, DeVetter, and Dentzman, 2019; Velandia et al., 2020a).

Table 1. Probit Regression Variable Definitions, Means, and Standard Deviations (*n* = 125)

Variable	Description	Hypothesis Sign	Mean	Std. Deviation
BDM	= 1 if the respondent chose BDM over PE mulch		0.4320	0.4973
Price	BDM price levels (for a 4' x 4000' roll) of $100, $200, $250, and $300	−	210.80	72.5637
Farm revenue	= 1 if gross on-farm revenue is greater than $25,000	+/−	0.4960	0.5019
Age	Respondent's age in years		55.3920	14.7007
BS degree or higher	= 1 if farmer has a bachelor's degree or higher; 0 otherwise	+	0.6400	0.4819
Acres F&V	Acres in fruit and vegetable production	+/−	11.4979	37.3901
Risk attitudes	Average of the scores associated with the statements below	+	2.6770	0.9945
"I like taking financial risks with my farm business."	Likert-scale question[a] -		2.3440	1.1785
"I accept more risk in my farm than other farmers."	Likert-scale question[a] -		3.0080	1.0813
Environmental stewardship	Average of the scores associated with the statements below	+	3.0640	1.0219
"I only buy products in packages that can be recycled."	Likert-scale question[a]		2.728	1.1457
"I try to convince my family or friends not to buy environmentally harmful products."	Likert-scale question[a] 3		3.4000	1.2572
Familiarity with BDM	Likert scale, 1 = Not Familiar at all, 2 = Slightly Familiar, 3 = Moderately Familiar, 4 = Very Familiar	+/−	2.0800	0.8762
Percentage of respondents on each familiarity category	1 = Not Familiar		0.2960	
	2 = Slightly Familiar		0.3760	
	3 = Moderately Familiar		0.2800	
	4 = Very Familiar		0.0480	

Notes: [a]1 = Strongly Disagree, 2 = Somewhat Disagree, 3 = Neutral, 4 = Somewhat Agree, and 5 = Strongly Agree.

Given the relatively low adoption of BDM among U.S. farmers (Goldberger, DeVetter, and Dentzman, 2019; Goldberger et al., 2013; Velandia et al., 2020a), as well as farmer uncertainty about BDM performance and the potential impact on soil health (Goldberger, DeVetter, and Dentzman, 2019; Chen et al., 2020; Velandia et al., 2020a), we hypothesized that familiarity with BDM would be positively correlated with farmers' willingness to adopt BDM. Respondents' familiarity with BDM was captured by a 4-point Likert scale variable, where 1 indicated the respondent had no familiarity with BDM, and 4 indicated the respondent was very familiar with BDM (Table 1).

Previous studies evaluating farmer WTP for inputs with potential economic and environmental impacts suggest farm income has a positive impact on farmers' willingness to adopt inputs with these characteristics (Kenkel and Norris, 1995; Kuwornu et al., 2017). In this study, we hypothesized that gross on-farm revenue would have a positive impact on farmers' willingness to adopt BDM. We hypothesized that farmers with higher on-farm income are in a better financial position to invest in agricultural inputs that may result in positive economic and environmental impacts. In this study, gross on-farm income is captured by a dummy variable taking the value of 1 if reported annual gross on-farm income was higher than \$25,000. This cut-off point was chosen based on the survey sample distribution, where 50% of the respondents indicated a gross on-farm income higher than \$25,000 per year.

Similar to Kuwornu et al. (2017), we hypothesized that farm size has a positive impact on farmers' willingness to use BDM. Use of BDM has labor-saving implications that may be more important for larger farms using PE mulch than for smaller farms that either might not be using PE mulch or might be using PE mulch but use farm operator and family labor to complete end-of-season activities on their farms (Velandia et al., 2020b). Farm size was captured by a continuous variable estimating the number of acres in fruit and vegetable production (Table 1).

Previous studies have found that age and education positively influence farmers' willingness to purchase inputs that could have positive economic and/or environmental impacts (Kenkel and Norris, 1995; Adetonah et al., 2008; Garming and Waibel, 2009; Kuwornu et al., 2017). For example, Kenkel and Norris (1995) suggest that older farmers with more farming experience may be more aware of farming risks that could have economic and environmental implications, and, therefore, more likely to be willing to pay for inputs that have the potential to reduce those risks. Additionally, they contend that more educated farmers are more likely to understand the new input benefits; thus, they are more likely to be willing to pay for this input. Garming and Waibel (2009) and Kuwornu et al. (2017) suggest that age could have a positive effect on the WTP for inputs with environmental benefits, such as a low-toxic pesticides or excreta pellet fertilizer, as older farmers may have been exposed to negative environmental and/or health impacts of traditional inputs for a longer time. Therefore, they may be more aware of the negative impacts of less environmentally friendly inputs. On the other hand, they suggest older farmers may not be willing to pay for more environmentally friendly inputs because the potential long-term impacts associated with the use of these inputs may not be important to them. They also assert that more educated farmers have higher WTP for inputs with potential environmental benefits because they may better understand the potential benefits associated with the use of these inputs. Similar to Garming and Waibel (2009),

we hypothesized that age could have a positive or negative impact on farmer willingness to adopt BDM. Although older farmers might be more aware of or exposed to the potential risks associated with the plastic pollution generated by mulch products such as PE mulch, they might not be concerned about or understand the long-term impacts of soil plastic pollution. We also hypothesized that more educated farmers are more willing to adopt BDM at various price levels because they may be more likely to understand the potential benefits associated with the use of BDM (Velandia et al., 2020b).

Previous studies evaluating the use and adoption of BDM suggest that farmers who are risk-tolerant are more likely to use or adopt BDM (Chen et al., 2020; Velandia et al., 2020b). Chen et al. (2020) found that farmers who are more willing to take risks are more likely to choose BDM. Velandia et al. (2020b) suggest the adoption of a new mulch product creates uncertainty about the unknown performance of the product compared to other mulch products (e.g., PE mulch), especially for farmers located in a state such as Tennessee where the adoption of BDM is fairly low. Similar to Velandia et al. (2020b), we captured farmers' risk preferences using the simple average of two scores for statements associated with farmers' risk preferences, which are presented in Table 1. Respondents were asked to express their level of agreement with the presented statements using a 5-point Likert scale, where 1 represents strong disagreement and 5 represents strong agreement. One of the statements captured farmer preferences for taking financial risks with the farm business, whereas the other captured farmer acceptance of risks compared to other farmers. In this study, we hypothesized that farmers with a higher risk preference score or farmers who are more risk tolerant are more likely to purchase BDM.

Similar to Velandia et al. (2020b), we hypothesized that farmers' environmental stewardship or concerns for the impact their actions and their close network of individuals' actions could have on the environment would have a positive impact on farmers' willingness to use BDM. Therefore, we hypothesized that farmers' environmental stewardship would also have a positive effect on their willingness to adopt a mulch product exhibiting potential environmental benefits associated with the reduction of soil plastic pollution. Similar to Velandia et al. (2020b), we captured farmer environmental stewardship using the simple average of two scores for statements associated with farmers' use of products that have the potential to reduce plastic pollution and farmers' influence on others regarding the purchase of products that can be harmful to the environment. Respondents were asked to express their level of agreement with the statements using a 5-point Likert scale, where 1 represents strong disagreement and 5 represents strong agreement. In this study, we hypothesized that farmers with a higher score of environmental stewardship would be more willing to use BDM at various price levels.

Results

Sample Descriptive Statistics

The means and standard deviations of the variables included in the probit regression are presented in Table 1. The respondents' average age was 55 years old. More than half of the respondents (64%) reported having a bachelor's degree or higher. The average number of acres in fruit and

vegetable production reported by respondents was 11.5, and 50% of the respondents reported gross on-farm revenue greater than $25,000 per year. On average, farmers were slightly familiar with BDM (i.e., 2 on the 4-point Likert scale, where 1 is not familiar at all and 4 is very familiar). More than half of the respondents (67%) indicated they were slightly to not at all familiar with BDM.

Figure 3 shows the percentage of respondents willing to purchase BDM at various price levels. As expected, as the price of BDM increased, the percentage of respondents willing to purchase BDM decreased (Velandia et al., 2020a). The percentage of respondents willing to purchase BDM at the $200 per roll and $300 per roll price levels and at the $250 per roll and $300 per roll price levels was not statistically significantly different at the 5% significance level. However, a significantly lower percentage of respondents (30%) were willing to purchase BDM at the $250 per roll price point compared to the percentage of respondents willing to purchase BDM at $200 per roll (45%), which was the closest price option to the current average BDM market price point (i.e., $220 per roll).
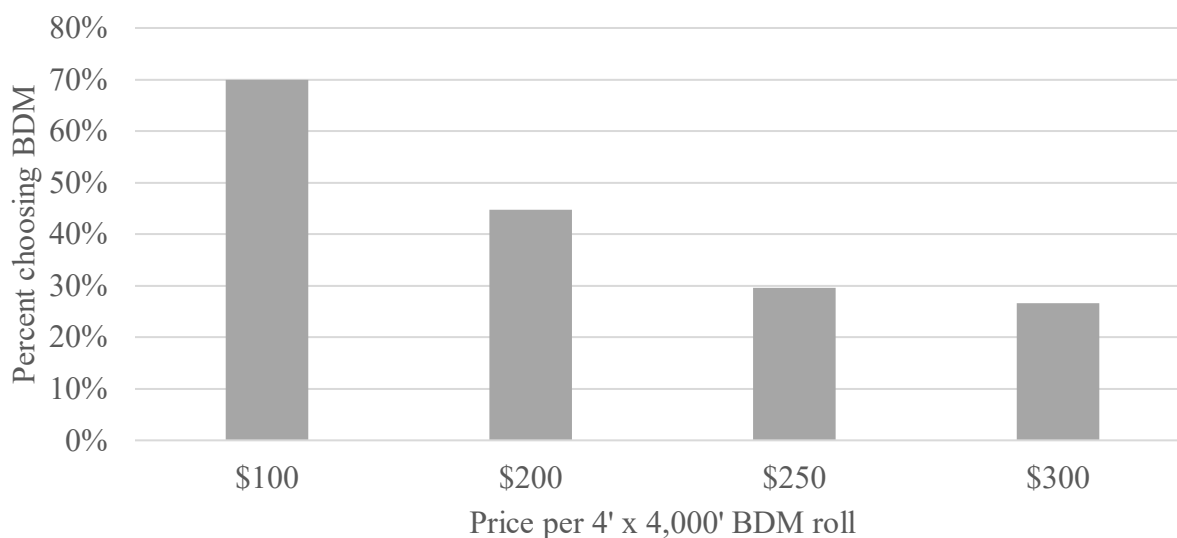

Figure 3. Percentage of Respondents Choosing BDM Instead Of a 4' x 4,000' PE Mulch Roll Priced at $100

Notes: Using a *t*-test, the percentage of respondents who chose BDM versus PE mulch was not significantly different at the 5% level of significance among the following price ranges: $200 and $300; $250 and $300.

Probit Regression Results

Estimated probit regression coefficients and the associated marginal effects are presented in Table 2. The estimated conditional index number associated with all independent variables included in the probit regression is 22.85, which suggests no significant concerns with multicollinearity in the estimated regression (Belsley, Kuh, and Welsch, 1980).

Table 2. Probit Regression Results and Marginal Effects for BDM Preferences ($n = 125$)

Variable	Coefficient	Marginal Effect on the Probability of Adopting BDM
Price	−0.0068***	−0.0023***
	(0.0018)	(0.0005)
Farm revenue	−0.5104**	−0.1717**
	(0.2612)	(0.0845)
Age	0.0029	0.0009
	(0.0094)	(0.0032)
BS degree or higher	−0.2288	−0.0769
	(0.2598)	(0.0864)
Acres F&V	0.0009	0.0003
	(0.0026)	(0.0009)
Risk attitudes	−0.0576	−0.0194
	(0.1351)	(0.0455)
Environmental stewardship	−0.1035	−0.0348
	(0.1384)	(0.0463)
Familiarity with BDM	0.2867**	0.0965**
	(0.1466)	(0.0471)
Wald statistic $\chi^2(8)$	19.8500**	
Log-pseudolikelihood	−73.9141	

Notes: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.01$, *** $p < 0.001$

As expected, the price of BDM had a negative impact on the farmers' choice of BDM. With a dollar increase on the price of BDM, a farmer is 0.2% less likely to indicate they would purchase BDM, or a $10 increase in the price of BDM decreased the likelihood of the farmer responding they would purchase BDM by 2%. Farmers with yearly gross farm revenue above $25,000 were 17% less likely to choose BDM. This result is the opposite of what was expected and suggests that farmers with higher gross farm revenue, and perhaps a higher dependence on on-farm income, are less likely to purchase BDM. Although farmers with higher gross on-farm revenues might be willing to purchase a mulch that is more expensive than options such as PE mulch, they may also be unwilling to risk using a mulch that might be ineffective in controlling weeds and maintaining soil temperature and humidity. Finally, a 1-point increase in farmer familiarity with BDM on a 4-point Likert scale increased the likelihood of farmers choosing BDM by 10%. Like Velandia et al. (2020b), the regression results suggest the choice of BDM among Tennessee fruit and vegetable farmers is not influenced by farmers' demographic characteristics, such as age and education. Although Velandia et al. (2020b) argue that the number of acres in fruit and vegetable production has a positive impact on the likelihood of Tennessee fruit and vegetable farmers using BDM, the results of this study indicate acres in fruit and vegetable production do not impact farmers' willingness to purchase BDM after controlling for BDM price and gross on-farm revenue.

WTP Estimates

Using the estimated coefficients from Table 2, equation (6) and the respondent data, the WTP estimates were calculated. On average, survey respondents were willing to pay $182.59 per 4' x 4,000' roll of BDM (Table 3), with a lower bound (95% confidence level) of $127.52 per roll and an upper bound (95% confidence level) of $216.75 per roll. Given that we assumed the price for a 4' x 4,000' roll of PE mulch was $100, this finding represents an average WTP premium of $82.24 per roll for BDM, or an 82% price premium over the PE mulch price. The average WTP was about $40 below the average BDM market price (Velandia, Galinato, and Wszelaki, 2019), excluding shipping costs. This result implies that the current average BDM market price point (i.e., $220 per roll) is still above the average price point that Tennessee fruit and vegetable farmers are willing to pay for this type of mulch. The estimated average WTP is influenced by the inclusion of a relatively low price point of $100, which is slightly below the BDM average market price ($200), and two price points that are greater than the average market price of $220 (i.e., $250 and $300). Specifically, our WTP is biased toward prices lower than the average market price because of the inclusion of a price point that is $100 below the average BDM market price. As stated in the Data and Methods section, the inclusion of the $100 price point is important to evaluate farmer WTP relative to the price of a mulch option that is used by a large percentage of Tennessee farmers (i.e., PE mulch) and that offers the same benefits as BDM.

Table 3. Average WTP and WTP by Market Segment for a 4' x 4,000' Roll of BDM

Market Segment	WTP for 4' x 4,000' BDM roll[***]
Mean	$182.59
Gross on-farm revenue < $25,000, Not Familiar with BDM	$174.68
Gross on-farm revenue > $25,000, Not Familiar with BDM	$99.11
Gross on-farm revenue < $25,000, Very Familiar with BDM	$300.86
Gross on-farm revenue > $25,000, Very Familiar with BDM	$225.71

[***]All possible combinations of WTP are statistically significantly different at $p < 0.001$.

We also estimated WTP among various market segments (i.e., gross farm revenue > $25,000 versus gross farm revenue < $25,000, Not Familiar with BDM versus Very Familiar with BDM). As shown in Table 3, respondents who indicated having an annual gross on-farm revenue above $25,000 had a lower WTP than those reporting an on-farm gross revenue below $25,000. Those farms reporting gross on-farm revenue above $25,000 may be more dependent on farm income and more cautious about the increased costs associated with the adoption of new inputs or production practices. Also, the results presented in Table 3 suggest that respondents who are very familiar with BDM have a higher WTP than those who are not familiar at all with BDM, regardless of on-farm gross revenue. This result suggests that farmer familiarity with BDM, specifically increased familiarity with the benefits associated with the use of BDM (e.g., labor savings, reduced plastic pollution), could have a significant impact on the price farmers are willing to pay for BDM. Respondents were also asked, "If you were to adopt BDMs at the price offered, on how many acres do you believe you would use it?" On average, Tennessee fruit and vegetable farmers were willing to use BDM on 6.64 acres ($n = 46$). On average, those respondents expecting to pay BDM prices higher than $100 per 4' x 4,000' roll were willing to use BDM on 8.33 acres. As can be seen in

Figure 4, farmers expecting to pay BDM prices higher than $100 per roll were willing to use BDM on more acres than those facing a BDM price of $100 per roll. At $200 per roll, which is close to the current average BDM market price point, respondents were willing to commit the largest number of acres to BDM, although this acreage was not significantly different from the number of acres on which respondents were willing to use BDM at the $250 per roll and $300 per roll price points (Figure 4).
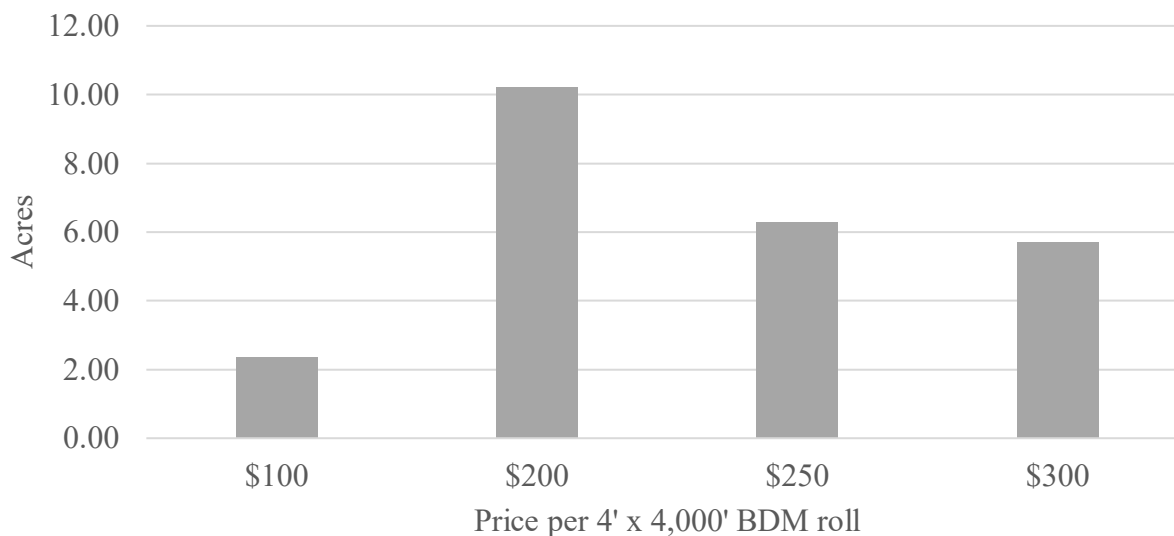

Figure 4. Acres Respondents Would Use BDM

Notes: Using a *t*-test, the acreage on which respondents would use BDM was not significantly different at the 5% level of significance among the following price ranges: $200 and $250; $250 and $300; and $200 and $300.

Reasons Associated with WTP for BDM

The most important reasons listed by respondents for explaining their WTP a higher price for BDM were related to potential cost savings and reduction of plastic pollution associated with the use of BDM (Table 4).

Table 4. Reason for Willingness to Pay a Higher Price for BDM Than for PE Mulch

	Price				
	$100 (*n* = 21)	$200 (*n* = 17)	$250 (*n* = 8)	$300 (*n* = 8)	All prices (*n* = 54)
I believe there are production cost savings associated with the use of BDMs.	47.62%	76.47%	75.00%	37.50%	59.26%
I believe using BDMs reduces plastic pollution.	57.14%	70.59%	25.00%	62.50%	57.41%
I believe BDMs would allow my plants to grow or produce better than PE mulches.	0.00%	5.88%	0.00%	0.00%	1.85%
I believe the use of BDMs would improve the health of my soil.	23.81%	23.53%	0.00%	12.50%	18.52%
Other	4.76%	29.41%	12.50%	0.00%	12.96%

In contrast, the most important reason respondents listed for choosing PE mulch instead of BDM at the various price levels was the uncertainty about the performance of BDM, specifically, the perception that BDM would break down too fast, and, therefore, would not control weeds (Table 5). The percentage of respondents indicating cost savings as one of the main reasons for paying a higher price for BDM was statistically significant across price level categories. A higher percentage of respondents who paid the $200 per roll and $250 per roll price levels listed this as one of their main reasons compared to the percentage of respondents who listed this reason among those respondents facing the $100 per roll and the $300 per roll price level categories.

Table 5. Reason for Choosing PE Mulch Over BDM

	Price				
	$100 **(*n* = 9)**	**$200** **(*n* = 21)**	**$250** **(*n* = 19)**	**$300** **(*n* = 21)**	**All prices** **(*n* = 70)**
I think BDMs will break down too fast and will not control for weeds.	11.11%	19.05%	26.32%	28.57%	22.86%
I don't think I have enough information about BDMs.	0.00%	23.81%	21.05%	19.05%	18.57%
I'm concerned about the effect tilling BDMs would have on my soil.	0.00%	9.52%	5.26%	19.05%	10.00%
I have used a mulch that was labeled as biodegradable mulch, and I did not like it.	0.00%	4.76%	15.79%	4.76%	5.71%
Cost	0.00%	0.00%	5.26%	28.57%	10.00%
Certified organic unable to use BDM	11.11%	4.76%	0.00%	4.76%	4.29%
Other	0.00%	9.52%	31.58%	9.52%	14.29%

Discussion

Alternatives to PE mulch, such as BDM, offer options with the same benefits as PE mulch while reducing potential plastic pollution associated with the use of PE mulch, as well as potential labor savings and revenue opportunities. Nevertheless, the use of BDM among Tennessee farmers remains relatively low. Previous studies have reported the cost of BDM as one of the significant barriers to adoption, as BDM tends to be more expensive than other mulch options such as PE mulch. In this study, we evaluated Tennessee fruit and vegetable farmers' WTP for BDM and the factors correlated with farmer willingness to use this mulch product. We found that while the price of BDM and gross on-farm revenue were negatively correlated with farmers' willingness to use BDM, increased familiarity with BDM was positively correlated with their willingness to use it.

The negative correlation between gross on-farm revenue and farmer willingness to use BDM, and the positive correlation between farmer familiarity with BDM and farmer willingness to use BDM could have similar implications or could be related. Although farmers reporting higher gross on-farm revenue might be in a better position to invest in an input that could result in labor savings and reduced negative environmental impacts associated with the use of other mulch products such

as PE mulch, they also have more to lose if the performance of BDM is not comparable to other mulch products. Previous studies suggest that farmer beliefs associated with how fast BDM will start breaking down, and therefore, the uncertainty of potential losses associated with the use of BDM, affects their willingness to adopt this mulch product. The uncertainty about the performance of BDM compared to other mulch products could be reduced by making more information about BDM available to farmers. More information about BDM in the hands of farmers will increase farmers' familiarity with BDM, which as suggested by this study, could increase farmers' willingness to adopt BDM. Nonetheless, it is important to acknowledge that more information in the hands of growers would help them make more informed decisions about the adoption of BDM, which could be to adopt or not adopt BDM. Each grower should carefully weigh the crops they intend to grow, their weed pressure and community, the seasonal environmental conditions of their location, and the labor costs associated with their current mulch practices when determining whether to adopt BDM. As indicated by Velandia et al. (2020b), BDM manufacturers and extension personnel have a critical role in providing information about BDM to farmers to reduce uncertainty about the use of and increased familiarity with BDM.

Regarding the demand for BDM at the various price levels, we found a significant difference between the percentage of farmers willing to purchase BDM at the $200 and $250 price levels. This difference has important implications for BDM manufacturers and input suppliers. Although not considered in this study, shipping costs could be high depending on the farm location, supplier, mode of shipping, and size of the order (Velandia et al., 2018). High shipping costs could increase the base price of BDM, which is estimated at about $220 per roll (Velandia, Galinato, and Wszelaki, 2019), resulting in a negative impact on the number of farmers willing to purchase BDM. These costs could be reduced if local input suppliers decide to carry BDM based on the market potential for this type of mulch.

Estimates from this study can be used in a "back-of-the-envelope" analysis of the potential size of the market. The numbers of mulch rolls used per acre were determined by the space between bed centers. Space between bed centers varies by crop, possibly between 5 and 8 feet (Velandia et al., 2018). For this analysis, we assumed an average of 6' spacing between bed centers, which requires two mulch rolls per acre (Chen et al., 2018). With an average of 6.64 acres per farm covered in BDM and an average of 2 rolls per acre, an average of 13 rolls would be used per farm. Because the majority of survey respondents reported growing either vegetables only or a combination of fruit and vegetables, we used the number of vegetable farms reported in the 2017 U.S. Census of Agriculture to estimate the total number of rolls of and total expenditures on BDM at the state level. Assuming there are 1,961 vegetable farms in Tennessee (U.S. Department of Agriculture, 2020), and 34% of these farms adopt BDM at $182.24 per roll, based on the percentage of survey respondents indicating they would use BDM at prices above $100 per roll, the total number of rolls used by Tennessee vegetable farmers would be 8,668. This amount represents about $1.5 million in total expenditures on BDM per year.

As noted earlier, market prices are around $220 per roll, which is higher than the estimated average WTP for BDM of $182.24 per roll. Therefore, for example, if a 34% participation rate is desired, a subsidy of $37.76 per roll would be needed. If a total of 8,668 rolls were subsidized, the total

program cost would be $327,304 per year. The estimated cost of this program assumes no labor savings associated with the use of BDM, or no dollar value associated with labor savings, which is a possible scenario for farm operators who perform the end-of-season activities of removal and disposal of PE mulch by themselves or with the help of unpaid family labor. When assuming potential average labor savings of 17.25 hours per acre due to the elimination of PE mulch removal and disposal activities (Velandia et al., 2020a), valued at $12.40 per hour (the Tennessee 2020 adverse effect wage rate), we estimated labor savings of $1,420 per farm. These savings are higher than the estimated subsidy of $491 per farm for those farms transitioning from PE mulch to BDM. Labor savings associated with transiting from mulches other than PE mulch (e.g., straw, no mulch) are uncertain and are not considered in this analysis. Therefore, production costs would need to be weighed against potential labor savings, which vary greatly depending on the type of mulch used (e.g., PE mulch, straw, no mulch), removal and disposal methods, and farm size, among other factors (Velandia et al., 2018).

Additionally, program costs would need to be weighed against potential environmental benefits (e.g., reduced plastic pollution), which are not only beyond the scope of this study but have not been evaluated by previous studies. However, additional research should examine the cost/benefit trade-off when both agronomic and environmental benefits from BDM are considered. Furthermore, the study region should be expanded across several states that capture a variety of fruit and vegetable growing conditions. Future studies should evaluate the impact of disposal costs and mulch practices used by farmers on their willingness to adopt BDM, factors that were not considered in this study because of the lack of data (i.e., number of missing observations, no data available from the survey).

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