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Economic Evaluation of Biodegradable Plastic Films in Tennessee Pumpkin Production

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Abstract: The use of polyethylene mulch in vegetable production is considered unsustainable because of its contribution to soil plastic pollution. Plastic biodegradable mulches (BDMs) are a more sustainable option because they are tilled into the soil or composted at the end of the cropping season, and designed to decompose into water, carbon dioxide, and microbial biomass, reducing soil plastic pollution. Regardless of the potential environmental benefits associated with the use of BDMs, farmers will have to evaluate the changes in profits when transitioning from polyethylene (PE) mulch to BDM before deciding to adopt BDMs. This study evaluates the factors associated with the economic feasibility of adopting BDM in pumpkin production using a partial budget and sensitivity analyses. Results suggest that the cost of BDM, labor costs, and sale price discounts, due to mulch adhesion in pumpkin fruit have the greatest impact on profits when transitioning from PE mulch to BDM. When assuming current market prices for PE mulch and BDM, the 2019 Tennessee Adverse Effect wage rate, and no price discounts, transitioning from PE mulch to BDM results in a positive impact on profits. When assuming a 5% price discount, this transition results in a negative impact on profits.

Keywords: biodegrdable plastic mulch; partial budgeting; Tennessee

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1. Introduction

Polyethylene (PE) mulch is the most common type of mulch used in US agriculture [1]. PE mulches provide multiple benefits, including soil moisture conservation, increased soil temperature, weed control, and improved yield and crop quality [2,3]. This mulch is used for one season and then needs to be removed and disposed of after the cash crops are harvested. The removal and disposal activities associated with using PE mulch impose an additional labor burden for farmers involved in already labor-intensive enterprises, such as vegetable production [4].

Disposal methods for PE mulch include incineration, taking them to landfills, and stockpiling them on the farm [3]. These methods are not considered environmentally sustainable [4,5]. Additionally, when removing PE mulches, , there are some fragments that are not recovered from the field, and over time these fragment residues contribute to soil plastic pollution [6]. Studies conducted in the Xinjiang region in China suggest that the concentration of PE mulch fragments in the soil could result in a 15% reduction in cotton production [7].

Plastic biodegradable mulches (BDMs) provide the same benefits as PE mulch, but they do not have to be removed or disposed of at the end of the season. BDMs are tilled into the soil or composted at the end of the season [8]. Therefore, there are labor savings associated with the use of this mulch [9,10]. After they are tilled into the soil, BDMs are decomposed by soil microbes into water, carbon dioxide, and microbial biomass [11], potentially eliminating the negative impacts of soil plastic pollution caused by the use of PE mulch [7].

An important consideration for farmers transitioning from PE mulch to BDM is the economic feasibility of adopting this type of mulch. Although there are savings (i.e., reduction of labor, for removal and disposal activities, and elimination of disposal cost) associated with the use of BDM, this type of mulch is more expensive than PE mulch [10]. Therefore, a farmer needs to evaluate whether these savings can offset the initial cost of the BDM.

Previous studies on BDMs have focused on the performance of BDM compared to PE mulch [12–14], the impact of BDM in soil, soil microbial communities and ecosystems functions [11], and consumer willingness to pay for products grown on BDM [15]. To date, only three studies have evaluated the profitability of using BDM [9,10,16]. One of these studies evaluated the profitability of eight BDM products in open-field pepper production [16]. They concluded that savings associated with the use of BDMs do not compensate for the additional cost of this type of mulch. Furthermore, they suggested that the current level of subsidies associated with BDMs in Spain does not cover the additional cost of the mulch product, deterring BDM adoption among Spanish farmers. Another study evaluated the changes in net profits when transitioning from PE mulch to BDM in pumpkin production [10]. They identify labor cost and price of BDM as the most important factors influencing the economic feasibility of adopting BDM. They limited their analysis to changes in costs and not revenue, and they do not evaluate the impact of disposal costs on the economic feasibility of adopting BDM. A similar analysis for pumpkins as Velandia et al.[10] was done, but for Washington State [9]. They find that it is more profitable to use BDM instead of PE mulch, assuming that 100% of the yield is marketable.

There is a limited number of studies that evaluated changes in both costs and revenue when transitioning from PE mulch to BDM on a large and heavy-fruited crop, such as pumpkin. Because its weight can rest on the mulch for an extended period, it may cause the mulch underneath to adhere to the crop—this may hurt the marketable yield—due to mulch adhesion [13]. Therefore, mulch adhesion could have an impact on the revenue side of profits [9].

In this study, we evaluate the factors influencing the profitability of adopting BDM in pumpkin production, with a particular emphasis on output price discounts, due to mulch adhesion, by using a partial budget and sensitivity analyses using data from a 2015 and 2016 Tennessee field study [13], a survey of Tennessee fruit and vegetable farmers, and other secondary data. These factors include labor costs, costs of the BDM and PE mulch products, and disposal costs. We specifically evaluate the net changes in profits for different output price discount scenarios under different BDM prices, wage rates, and disposal fees' assumptions.

2. Materials and Methods

2.1. Partial Budget Analysis

A marginal approach that utilizes a partial budgeting technique [17] is used to evaluate marginal changes in costs and revenue associated with the adoption of BDM. This approach will allow us to determine the marginal changes in profits (per ha), due to the adoption of BDM. The various components of a partial budget are shown in Table 1, and include increased costs and reduced revenue (left column), and increased revenue and reduced costs (right column) associated with transitioning from PE mulch to BDM.

Table 1. Components of a partial budget comparing the use of polyethylene (PE) mulch and biodegradable mulch (BDM).

Increased Costs	**Increased Revenue**
BDM cost	Potential marketable yield increase
Reduced Revenue	**Reduced Costs**
Potential marketable yield reduction	Reduced labor associated with removal and disposal No disposal cost (e.g., transportation, disposal fee).

A. Total increased costs and reduced revenue	B. Total increased revenue and reduced costs
Expected Change in Net Revenue (B–A)	

Profit is defined as gross revenue from production less total costs incurred:

$$\pi_P = R - C, \quad (1)$$

where π_P represents profits related to pumpkin production; R represents revenue associated with pumpkin production; C represents the total cost of pumpkin production (e.g., seeds, fertilizer, pesticides, irrigation, labor, gas, equipment, repair, and maintenance).

Revenue for a pumpkin operation using PE mulch could be described as:

$$R_{PE} = (p \times yield_{PE}) \quad (2)$$

Revenue for a pumpkin operation using BDM could be described as:

$$R_{BDM} = (p \times yield_{BDM}), \quad (3)$$

where p represents the price of pumpkins per 91 cm bin (US pumpkin wholesale prices are reported for 36-inch bins or 91 cm bins [18]), $yield_{PE}$ and $yield_{BDM}$ are pumpkin yields when using PE mulch and BDM, respectively. Changes in revenue, due to the adoption of BDM could be represented as:

$$\Delta R = \Delta p \times (\Delta yield) \quad (4)$$

where $\Delta yield$ is just the differences between $yield_{PE}$ and $yield_{BDM}$, and Δp are potential changes in price p, or potential price discounts associated with changes in fruit quality. In this study, we assume revenue changes are mainly associated with changes in price, as a previous study suggests pumpkin yield does not differ between PE mulch and BDMs, but there is uncertainty about the price discounts associated with mulch adhesion that was only observed in pumpkins grown on BDMs[13]. The pumpkin US standards for grades suggest that foreign matter materially affecting the appearance or marketing quality of the pumpkins could impact the score [19]. It is unclear how mulch adhesion would affect the pumpkin grade, and therefore, prices received for pumpkins [20].

Changes in costs associated with transitioning from the use of PE mulch to BDM can be represented by:

$$\Delta Costs = Costs_{BDM} - Costs_{PE} \quad (5)$$

The cost side of the budget is affected when transitioning from PE mulch to BDM, as there are differences in mulch product prices. Additionally, because BDM does not have to be removed and disposed of, there are other cost savings associated with the elimination of mulch removal and disposal activities, and disposal fees.

2.2. Data

This study uses field trial data, and other primary and secondary data to evaluate changes in revenue and costs when transitioning from PE mulch to BDM. We focused on changes in revenue, due to potential price discounts associated with mulch adhesion. For labor data associated with PE mulch removal and disposal, as well as disposal fees, we will use data from a survey of Tennessee fruit and vegetable producers.

2.2.1. Field Trials

Field trials were conducted in 2015 and 2016 at the University of Tennessee, East Tennessee AgResearch and Education Center in Knoxville, TN, USA (35°52′52″ N, 83°55′27″ W, elevation 270 m) to evaluate three plastic mulches marketed as biodegradable (BioAgri, Organix, and Naturecycle), one fully biodegradable paper mulch (WeedGuardPlus, Aurora, CO, USA), one experimental BDM consisting of polylactic acid (PLA) and polyhydroxyalkanoates (PHA), and polyethylene mulch. In this study, we will focus on results associated with plastic biodegradable mulches with a similar appearance to PE mulch currently available in the market. Therefore, we will exclude information associated with the biodegradable paper mulch, and the experimental PLA/PHA. The experimental PLA/PHA mulch was only developed for the field trials, and it is not available for purchase and will not be available for purchase in the future as the manufactured producing this mulch is no longer in business. Table 2 provides information about the plastic mulch treatments evaluated in the field trials that will be used in this study. All plastic mulch treatments evaluated in the current study were black [13].

Table 2. Plastic mulch treatments evaluated for pumpkin production in Knoxville, TN, USA, in 2015 and 2016.

Mulch Treatment	Manufacturer	Thickness (mm)
BioAgri	BioBag Americas, Inc., Dunedin, FL, USA	0.0180
Naturecycle	Custom Bioplastics, Burlington, WA, USA	0.0254
Organix	Organix Solutions, Maple Grove, MN, USA	0.0178
Polyethylene	Filmtech, Allentown, PA, USA	0.0254

A completely randomized split-split plot design with four replications was used to evaluate the performance of five BDMs compared to PE mulch and bareground treatments in pumpkin production. The mulch treatment plot assignments were not changed between 2015 and 2016 to avoid cross treatment mulch and soil contamination [13].

'Cinnamon Girl' pie pumpkins (Johnny's Selected Seed, Winslow, ME, USA) were direct-seeded on 15–20 cm high and 0.8 m wide raised beds over both years. This pumpkin variety was chosen because fruit weight and short-vine habit have the potential to maximize contact between the fruit and the mulch. Plots were five rows wide and 9 m long. Space between bed centers was 2.4 m, and space between plants was 0.9 m with plants in a single row. There were ten plants per row and 50 plants per plot [13]. Additional field trails details can be found in [13].

2.2.2. Fruit Yield

Using the data from Ghimire et al. [13], bins per ha were calculated, and bins per ha estimates and the percentages of fruit with mulch adhesion were used in the partial budget analysis. The two-year average yield across all plastic mulch treatments is about 69 91-cm bins. We ssume an average of 190 pie pumpkins per bin [21,22].

Yield did not differ across mulch treatments [13]. However, mulch adhesion was observed on fruit that laid on BDM treatments. Vine growth resulted in only a small percentage of fruit laying on the mulched bed, limiting the number of fruit with mulch adhesion. The yield of pumpkins with mulch adhesion was not significantly different across BDM treatments. An average of 9% of the total yield for the three BDM treatments included in this study had mulch fragments adhering to the fruit. The mulch fragments adhering to the fruit could be wiped off easily during the early morning hours when fruits were dewy, but it was more difficult to wipe the mulch fragments off the fruit when the fragments dry on the pumpkins [13]. For our base case scenario, we assume that mulch fragments will be wiped off when possible (e.g., morning harvest), but there is still a percentage of fruit with mulch adhesion that the producer will not make an effort to clean because we assume there will be no price discounts for fruit with mulch adhesion. Information about price discounts associated with much adhesion is not available. Given that U.S. pumpkin supplies mostly target ornamental uses and home processing [23], the outside of the pumpkin is traditionally not consumed, and therefore, it is hard to assess the potential impacts on price, due to mulch adhesion. We will evaluate how hypothetical price discount scenarios, due to mulch adhesion could affect the economic feasibility of adopting BDM in pumpkin production in the results section.

2.2.3. Farm Survey Data

Given the design of the field trial, labor data associated with removal and disposal of PE mulches do not accurately represent labor hours associated with these activities at the farm level. For example, labor data associated with removal and disposal activities gathered from five rows of 9 m long plots will inaccurately represent worker speed and practices used when removing and disposing of PE mulch from a hectare. Therefore, in order to estimate labor hours associated with removal and disposal activities, we used the average labor estimates for removal and disposal activities as reported by respondents to a 2019 Tennessee fruit and vegetable survey (Table 3).

We also used data from this survey to assess PE mulch disposal methods used by Tennessee farmers, as well as disposal costs (Table 3).

Table 3. Average removal and disposal labor hours, disposal practices, and disposal cost.

Variable Description	N	Mean	Std. Dev.	Min.	Max.
Labor_Hours (hours/ha)—Labor hours associated with removal and disposal of PE mulch per ha that would be eliminated if using BDM	101	42.61	39.14	0	197.68
Dumping = 1 if the farmer indicated dumping PE mulch at a landfill after using it.	110	0.75		0	1
Burying = 1 if the farmer indicated burying PE mulch in the field after using it.	110	0.15		0	1
Burning = 1 if the farmer indicated burning PE mulch after using it.	110	0.22		0	1
Disposal fee/ton ($/ton)	31	11.68	16.86	0	50

To conduct the 2019 Tennessee fruit and vegetable survey, we used a Tennessee Department of Agriculture list of 990 fruit and vegetable growers who participated in either of two state programs, one that aims to assist Tennessee farmers in marketing and the other that provides cost-share for farm improvements, during 2018 and 2019. All growers who completed the survey gave their informed consent before completing the survey. The study was conducted in accordance with the Declaration of Helsinki, and the survey instrument was approved by the University of Tennessee Institutional Review Board (IRB) (UTK IRB-18-04718-XM).

We use a mixed-mode survey involving mail and Web surveys that were conducted between January and April of 2019. We sent a Web version of the survey on January 29, 2019, to farmers with e-mail addresses. We sent reminder e-mails on February 5 and 12, 2019. A paper version of the survey was mailed on March 20, 2019, to individuals for whom we did not have e-mail addresses or had invalid e-mail addresses, and to those who did not respond to the Web survey. Reminder postcards were sent on March 30, 2019, and follow-up surveys were sent on April 5, 2019. From the 990 fruit and vegetable growers on our initial list, 98 do not farm, and 135 have e-mail or mailing addresses that were marked as undeliverable, and four more indicated they were not fruit and vegetable farmers, they retired from farming, or they were ill and unable to complete the survey. In total, we obtained 186 completed surveys. The overall survey response rate is 25%. The farm size distribution from the survey sample closely follows the farm size distribution of fruit and vegetable farms in Tennessee according to the 2017 Census of Agriculture [24], which suggests the survey sample is representative of the population of Tennessee fruit and vegetable growers.

This survey captured 47 producers of the estimated 322 Tennessee pumpkin producers, according to the 2017 Census of Agriculture [24]. The average acres in pumpkin production per farm, as reported by survey respondents, is 3.8 acres per farm, which is close to the estimated 4.3 acres per farm based on census data [24].

Results presented in Table 3 show that the average hours associated with PE mulch removal and disposal activities are 42 hours per ha. Pumpkin producers reported 47 hours per ha associated with removal and disposal activities, which is about five hours more than the average hours reported by survey respondents not growing pumpkins, but this difference in hours is not statistically significant. Additionally, results indicate that the majority of the survey respondents dispose of PE mulch in landfills after using it. Some producers indicated using more than one method to dispose of PE mulch after using it (Table 3). Similar to survey respondents not growing pumpkins, the majority of respondents who indicated growing pumpkins dispose of PE mulch in landfills (i.e., 74%). Therefore, in our analysis, we will assume that producers will dispose of PE mulch at landfills. Finally, respondents estimated an average cost of disposal of about $12/ton, with a minimum disposal cost of $0 and a maximum of $50 per ton. We assumed those producers who are disposing of PE mulches in landfills, have higher disposal costs than those using burning and burying as PE mulch disposal methods, and therefore, may be more likely to adopt BDMs.

It is important to acknowledge that labor hours, disposal methods, and disposal costs estimates might not be representative of pumpkin producers only, but of Tennessee fruit and vegetable producers in general. Nonetheless, the survey information is the best and only available information about Tennessee PE mulch removal and disposal practices. Furthermore, preliminary labor estimates associated with removal and disposal activities based on information collected from three TN farms, one producing pumpkins, one producing strawberries, and one producing peppers, suggest labor hours associated with PE mulch removal and disposal could be similar for different crops if removal practices are the same [4,10].

2.2.4. Secondary Data

PE mulch prices were obtained from online vendors and local input suppliers for different dimensions and thickness of mulches. BDM prices were obtained from the websites of input suppliers (Table 4).

Table 4. Secondary data used in the partial budget analysis.

Data	Definition	Source
Mulch Price		
PE mulch—dimension and price	1.2 m × 1219 m; 1 mil.; $106/roll—$115/roll; Average price of $111/roll	Average of two prices found online, and two prices gathered directly from local input suppliers
BDMs—dimension, and price	1.2 m × 1219 m; 0.6 mil.; $204/roll—$245/roll; Average price of $220/roll	Average online price from three suppliers
The required quantity of mulch (PE or BDM) per acre (based on space between bed centers of 24 m)	Pie pumpkin: 3.4 rolls/ha	Chen et al. [25]
Labor cost		
Fiscal Year 2019 Adverse effect wage rate	$11.63/hour	U.S. Department of Labor, Employment and Training Administration
Labor hours for removal of drip tape and tilling BDMs into the soil		
Removal of drip tape only	Average 3.7 labor hours/ha	Data from one on-farm trial

The quantity of mulch needed per hectare, which can be estimated given the space between bed centers, was derived using the Mulch Calculator Decision Aid [25]. For pie pumpkins, 3.4 1.2-by-1219 m rolls of mulch are required per ha when using a 2.4 m spacing between bed centers. The hourly minimum wage rate for manual labor used in this analysis is $11.63/hour, which is the 2019 Adverse Effect Wage Rate for Tennessee [26]. The Adverse Effect Wage Rate is the minimum wage rate established by the US Department of Labor as the one an employer needs to offer and pay to H-2A temporary agricultural workers and workers in corresponding employment so that wages of similarly employed US workers will not be adversely affected. Workers compensation insurance or social security contributions paid by growers are not included in this base rate. Because these additional costs vary depending on the location of the farm business, the subsequent analysis only takes into consideration the wage rates.

Output price is based on the Altlanta terminal market (closest terminal market to Tennessee) prices (wholesale) for pie pumpkins that are gathered daily [18]. Between October and November of 2018, the Atlanta terminal market weekly average price for non-organic pie pumpkins was $172 per 91 cm bin.

There are end-of-season activities associated with the use of BDM, such as the removal of drip tape before tilling BDM into the soil. There is no information associated with these activities from the farmer survey data. Therefore, we used information reported by a farmer testing BDM on his farm for the labor hours associated with drip tape removal. Although the process of collecting this information was not systematic or coming from an experimental design for labor data collection, it is the best information available at the time of analysis.

2.3. Assumptions

We evaluated the economic feasibility of adopting BDM in pumpkin production for the following base-case scenario: (1) A two-hectare mixed-vegetable farm decides to transition from PE mulch to BDM on one hectare of pumpkins; (2) pumpkins are planted using a 2.4 m space between bed centers; (3) although not all Tennessee farmers used plasticulture, and therefore, PE mulch and drip irrigation, for the production of pumpkins, we assumed plasticulture is used to be consistent with data collected from field trials, and to capture a production system that results in optimal plant growth and yield; (4) the grower will need 3.4 1.2-by-1219 m rolls to cover one hectare, but will purchase four rolls, as suppliers do not sell 0.4 rolls of mulch; (5) the grower pays $111 for a 1.2-by-1219 m roll of PE mulch and $220 for a 1.2-by-1219 m roll of BDM; (6) there is no price reduction associated with fruit showing mulch adhesion; (7) the cost of manual labor per hour is estimated at $11.63; (8) the cost of disposing of PE mulch is estimated at $12 per ton; (9) PE mulch weight will increase by 50% during the growing season, due to adherence of soil and plant material to the mulch [3]; (10) labor hours associated with PE mulch removal and disposal activities are estimated at 42 hours/ha; (11) the grower will till the BDM into the soil at the end of the cropping season, and it will take about 3.7 hours/ha to remove the drip tape before tilling; and (12) transitioning from PE mulch to BDM will have no impact on operator labor and machinery cost (e.g., gas, repairs, and maintenance). This last assumption is based on the fact that although a plastic lifter is used at the end of the season when using PE mulch and not when using BDM, a rototiller will have to be used to till the BDM into the soil. Operator labor and machinery costs associated with the PE mulch removal and tilling the BDM into the soil could be the same depending on soil and equipment conditions [10].

3. Results

We estimated the net changes in profits when transitioning from PE mulch to BDM on one hectare of pumpkins, for the base case scenario described in the assumptions presented above (Table 5). It is important to acknowledge that the results presented in this section are based on the assumptions presented above, and therefore, these results are hypothetical. Although the results presented in this section are useful in assessing the factors that could potentially influence the economic feasibility of adopting BDM in pumpkin production, they do not represent actual changes in revenue and costs at the farm level. The net change in profit when transitioning from PE mulch to BDM for the base case scenario is estimated at about $12 per hectare, which implies a positive impact on profits associated with the adoption of BDM.

Table 5. Net changes in profit per hectare associated with the adoption of BDM.

Factors Positively Influencing Profits		Factors Negatively Influencing Profits	
Additional Expenses (AE)	$479.03	Additional Revenue (AR)	$0.00
BDMs	$436.00	No changes in prices	
Labor for pulling drip tape	$43.03		
Reduced Revenue (RR)	$0.00	Reduced Expenses (RE)	$491.10
No changes in prices		Labor savings	$488.46
		Disposal savings	$2.64
A. Total AE and RR	$479.03	B. Total AR and RE	$491.10
Net Change in Profit (AR + RE) − (AE + RR) = 12.07			

Similar to Velandia et al. [10], the results presented in Table 5 suggest that the cost of BDM and labor savings associated with transitioning from PE mulch to BDM are the two factors that are more likely to influence the economic feasibility of adopting BDMs. In the next section, we evaluate how changes in the cost of BDMs, changes in the labor cost, and disposal fees will influence potential changes in the net profits when transitioning from PE mulch to BDMs, under different output price discounts scenarios.

Even though the results presented in Table 5 suggested the reduction in disposal costs when transitioning from PE mulch to BDM does not have a major impact on the changes in net profits, we want to evaluate how increases in disposal fees may affect the economic feasibility of adopting BDMs. Future changes in environmental legislation could cause significant increases in disposal fees to disincentivize the use of PE mulches in agriculture [10]. For example, although in Tennessee disposal fees could be anywhere between \$0 and \$50 per ton (Table 3), in Washington disposal fees could reach more than \$100 per ton depending on the county where the landfill is located [4].

There is uncertainty about the impact of mulch adhesion on the marketing quality of pumpkins [10]. Therefore, we assume three scenarios, one where mulch adhesion will have no impact on pumpkin prices (i.e., best-case scenario), one where there is a 1% price discount associated with the percentage of fruit with mulch adhesion (9%), and one where there is a 5% price discount associated with the percentage of fruit with mulch adhesion (i.e., worst-case scenario). The price discount scenarios are hypothetical as although the pumpkin US standards for grades suggests that foreign matter materially affecting the appearance or marketing quality of the pumpkins could impact the score [19], it is unclear how pumpkin prices received by farmers will be affected by mulch adhesion. For example, the main difference between a pumpkin classified as US No. 1 and US No.2 is maturity, not dirt or other external components. We assume there could be a price discount associated with mulch adhesion. For other crops, such as tomatoes, the average price difference between a tomato classified as US No. 1 and US No.2 is about 12% based on historical prices [18]. Therefore, we assumed a price difference between the base price and the discounted price, due to mulch adhesion could be less than 12%, as mulch adhesion does not affect fruit maturity which is the main component differentiating a pumpkin classified as US No.1 and a pumpkin classified as US No.2.

3.1. Sensitivity Analysis

Figure 1 shows the relationship between changes in net profits ($\Delta\pi_P$) when transitioning from PE mulch to BDM and the price of BDM. The BDM prices above the base BMD price (\$220) increase on \$10 increments, except for the BDM price that makes the profit associated with PE mulch use equal to the profit associated with the BDM use (\$223). These prices reflect BDM prices found online from various suppliers. Prices below the based BDM price, also decrease on \$10 decrements to be consistent with online prices above the base BDM price, and represent hypothetical scenarios where prices are below current average prices for BDMs. It is important to evaluate prices below the base case value, as it could be possible that as the demand for, and therefore, the supply of BDMs increases, the average cost of BDM will decrease, and also the gap between PE mulch and BDM prices. As expected, this figure suggests that increases in the price of BDM will cause the profits associated with the use of PE mulch to get closer to the profits associated with the use of BDM.

Assuming there are no changes in pumpkin prices, due to mulch adhesion, the price of BDM at which the profit associated with PE mulch is equal to the profit associated with the use of BDM ($\Delta\pi_P = 0$) is \$223/roll. When assuming a one and 5% price discounts on fruit with mulch adhesion, the prices for BDM at which the net change in profit between BDM and PE is zero ($\Delta\pi_P = 0$) are \$220/roll and \$210/roll, respectively. BDM prices above \$210/roll, \$220/roll, and \$223/roll for the with and without price discount scenarios for pumpkin prices, respectively, will lead to negative changes in profits when transitioning from PE mulch to BDM.

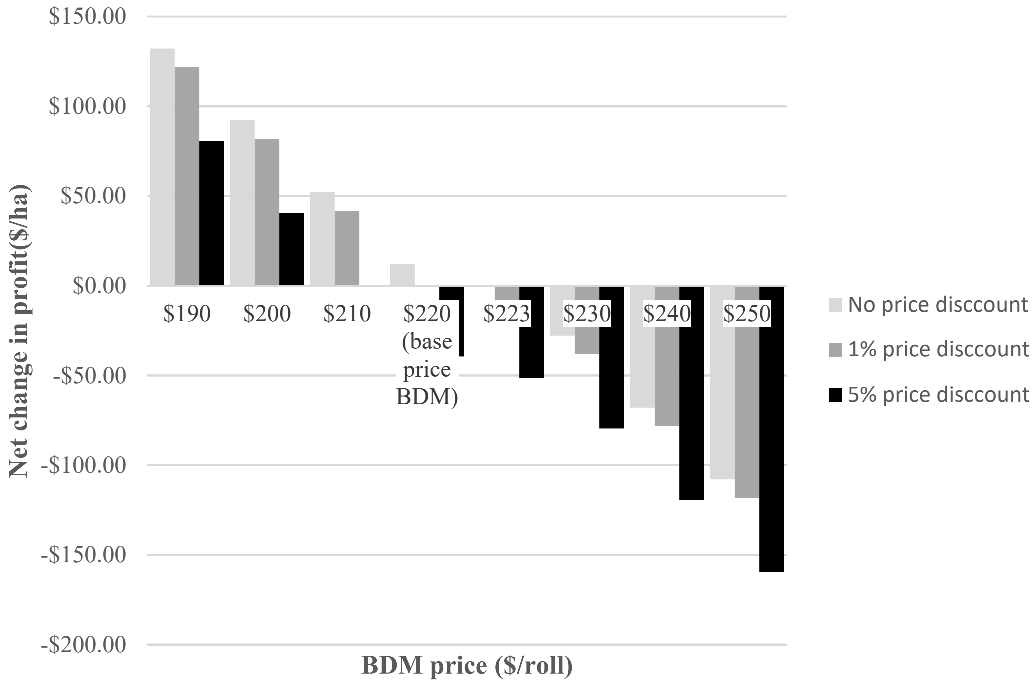

Figure 1. Net changes in profit associated with the adoption of BDM given different BDM prices and pumpkin price discounts (no pumpkin price discount; 1% and 5% pumpkin price discount).

Figure 2 shows the impact of changes in wage rates on profits when transitioning from PE mulch to BDM. The wage rates above the base wage rate ($11.63) increase on $0.5 increments, and reflect the 2019 Adverse Effect Wage Rates for neighboring states [26]. Figure 2 suggests that an increase in labor costs will have a positive impact on the economic feasibility of adopting BDM. As the hourly wage rate increases, the difference between the profit associated with the use of BDM and that associated with the use of PE mulch increases. At $11.31/hour, $11.63/hour, and $12.63/hour, the profit associated with the use of BDM is the same as the profit associated with the use of PE mulch for the no pumpkin price discount, the 1%, and the 5% price discount scenarios, respectively. Any hourly wage rate below the aforementioned figures will result in a reduction in profits when transitioning from PE mulch to BDM.

Figure 2. Net changes in profit associated with the adoption of BDMs given different hourly wage rates and pumpkin price discounts (no pumpkin price discount; 1% and 5% pumpkin price discount).

Figure 3 shows the relationship between disposal fees and net changes in profits when transitioning from PE mulch to BDM. Although the results presented in Table 5 suggest a minimal impact of disposal cost on the economic feasibility of adopting BDM, given the assumptions made in the partial budget analysis, we wanted to evaluate how changes in environmental regulations that may result in an increased disposal cost will affect the economic feasibility of adopting BDM. Disposal fees increase on $12 increments and represent disposal fees paid by Tennesse farmers, and disposal fees paid by farmers in other states with more strict environmental regulations, such as Washington [4]. Given the assumption presented above, and assuming no price discounts for fruit with mulch adhesion, the profit associated with the use of BDM will be higher than the profit associated with the use of PE mulch at any disposal fee level between $0/ton and $96/ton. Assuming a 5% price discount for pumpkins with mulch adhesion, the profit associated with BDM will be lower than the profit associated with the use of PE mulch for all disposal fees' scenarios.

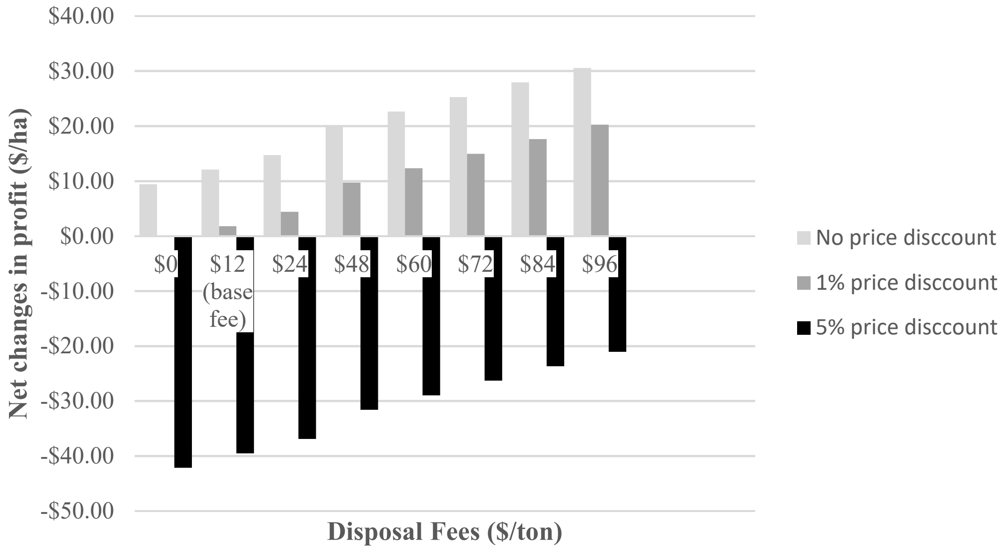

Figure 3. Net changes in profit associated with the adoption of BDMs for different disposal fees and pumpkin price discounts (no pumpkin price discount; 1% and 5% pumpkin price discount).

Finally, we estimated the output price discount that will make the net change in profit of using BDM equal to zero. We found that a 1.2% price discount for pumpkin with mulch adhesion leads to the same profits for BDM and PE mulch use, holding all assumptions from the base case scenario constant. Any price discounts above 1.2% will result in a negative change in profits associated with the adoption of BDM.

3.2. Comparison with Findings of the Case Study in Washington

This study and [9] similarly find a positive net change in profit when adopting BDM, and that the costs of labor and BDM are the main factors influencing the profitability of transitioning from PE mulch to BDM. The latter study finds a net change in profit of about $187/ha when using BDM, mainly due to savings in labor costs. As of 2019, Washington has the highest adverse effect wage rate in the US at $15.03 per hour [26]. Hence, the elimination of manual labor for PE mulch removal and disposal renders savings for growers.

In the Washington case study, the profits when using BDM and PE mulch become equal when the price of BDM is $270/roll, or when wage rate is $9.30 per hour, while holding all else constant. This study, on the other hand, finds the same case at a BDM price of $223/roll or a wage rate of $11.31 per hour. Differences in the estimates are mainly due to different crop yields, adverse effect wage rates, input prices, and disposal fees in the two production regions.

The Washington case study did not evaluate the net change in profit when there is a price discount for pumpkins with mulch adhesion.

4. Discussion

Concerns about the use of PE mulch as a contributor to soil plastic pollution have increased the interest in BDM as an alternative in fruit and vegetable production [3]. Regardless of the environmental benefits associated with the use of BDM, farmers using PE mulch will evaluate how the adoption of BDM will affect their profits before deciding to adopt BDMs. In this study, we evaluate the factors that could potentially influence the economic feasibility of adopting BDM on pie pumpkin production in Tennessee using partial budget and sensitivity analyses.

Similar to Galinato et al. [9] and Velandia et al. [10], results presented in this study suggest that the price of BDM compared to PE mulch, and the cost of labor are the factors that could have the highest impact on the changes in net profit when transitioning from PE mulch to BDM, at least in the short term. These results will hold even when assuming one and a 5% price discounts for fruit with mulch adhesion.

When assuming one and 5% discounts in the price of pumpkins, due to mulch adhesion, the minimum BDM price at which the profits associated with the use of PE mulch and BDM are the same is lower than if no output price discount is assumed. Therefore, manufacturers may have to evaluate lower price points to attract potential BDM adopters among farmers growing crops with the risk of mulch adhesion.

The disposal fee seems to have a small impact on the economic feasibility of adopting BDM in pumpkin production.

Finally, when changing the assumption for price discounts for the base-case scenario, we found that pumpkin price discounts associated with mulch adhesion that are more than 1.2% will negatively impact the adoption of BDM. There is still uncertainty about the impact of mulch adhesion on the revenue of crops that could come in contact with BDM during the production season. Mulch adhesion could be a more important issue in pumpkin production in Washington state when compared to Tennessee, as Ghimire et al. [13] estimated that 48% of the total pumpkin yield for four mulch treatments had mulch adhesion, while for Tennessee only about 9% of total pumpkin yield had mulch adhesion. The difference in the percentage of mulch adhesion is due to the percentage of fruit that rested in the mulch surface. Future studies should evaluate the impact of mulch adhesion on crop prices. The impact of mulch adhesion on prices is one that could also be interesting to evaluate for other crops that could come in contact with BDM during the production season, such as melons and winter squash.

The main limitation of the analyses presented in this study is that we focus on the short-term changes in profits when transitioning from PE mulch to BDM. In the long term, there may be other benefits of using BDM associated with the reduction of soil plastic pollution. Future studies should evaluate the long-term costs and benefits of using BDM relative to PE mulch use, incorporating the economic value of plastic pollution in the analysis.

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