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Understanding the Drivers of Egyptian Farmers' Intention to Adopt Biodegradable Plastic Mulch: A Structural Equation Modeling Approach

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Abstract

The biodegradable plastic mulch (BDM) was advanced as a promising alternative to address the environmental and management issues associated with conventional polyethylene mulch. However, its uptake remains low, and empirical evidence on the sociopsychological drivers of BDM adoption among farmers in Egypt is limited. This study incorporates an extended theory of planned behavior (TPB) to predict farmers' intention to adopt BDM. Three hundred and sixty farmers were selected in three governorates using a multistage sampling technique. Data analysis involved using partial least squares structural equation modeling (PLS-SEM). The findings indicated that the extended TPB model accounted for 51% of the total variation in predictive power. Three variables, including subjective norms, perceived behavioral control, and perceived self-identity, positively affected farmers' intentions to adopt BDM, with the influence of attitudes being not statistically significant. The most critical barriers to adopting BDM from farmers' perspectives encompassed limited local availability (71%), limited knowledge (56%), elevated cost (46%), field durability (39%), and limited use among other farmers (34%). These findings underscore the importance of broadening the focus beyond the technical benefits of BDM to urge and accelerate adoption. Accordingly, policymakers should focus on reducing adoption barriers and emphasize sociopsychological factors more through well-designed interventions to promote the adoption of BDM in agriculture.

Keywords: adoption intention; agricultural plastics; barriers; biodegradable plastic mulch; Egypt; farmers; sustainable agriculture; theory of planned behavior



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1. Introduction

Plastic mulch is a key enabling technology in contemporary crop production, especially in high-value and intensive farming systems. It improves the crop microenvironment and supports more efficient field operations management by covering the soil surface [1]. Through these functions, plastic mulch provides core agronomic benefits, including improved crop yield, efficient water use, moisture retention, soil temperature regulation, weed

suppression, and pest control [2–4]. Subsequently, these positive agronomic effects led to practical outcomes, such as improved crop quality and earlier crop establishment [5–7]. Notably, these agronomic improvements are highly valuable in unheated greenhouses [8,9] and in water- and resource-limited field conditions in arid and semi-arid regions [10,11]. Globally, these advantages have engendered widespread use of plastic films in horticultural production systems. In Egypt, black polyethylene mulch (PE) is commonly used in vegetable production in open fields and in protected agriculture, particularly in newly reclaimed areas [12]. Research on tomato, onion, and sugar beet in the Egyptian context demonstrated that plastic mulch can substantially boost crop yield, optimize weed control, improve water-use efficiency, enhance crop quality, and increase farm net income [13–15]. Despite these agronomic advantages, the growing reliance on conventional PE mulch has prompted concerns about long-term plastic pollution [16].

Undoubtedly, post-harvest plastic mulch residues inevitably become a problematic issue after harvesting because it is persistent and not readily degradable in soil [2]. This persistence has generated post-use management challenges in agricultural systems. Accordingly, Sarpong et al. [17] reported that the collection and removal of plastic mulch is often challenging, particularly when it is contaminated with soil and crop residues or fragmented. These conditions led to limited recycling; most are stockpiled, landfilled, incinerated, or burned on-farm, resulting in pollution [18]. Furthermore, accumulation of plastic mulch residues and microplastics threatens soil health and plant physiological functioning in agricultural ecosystems [19]. To this end, previous studies have documented that microplastics modify water-holding capacity, bulk density, hydraulic conductivity, aggregate stability, disturbing vital water–soil relations [20–22]. Apart from soil structure and water movements, microplastics also adversely influence microbial activity and community composition [21,23,24]. Within this context, microplastics can decrease plant germination and plant height, and plant tissues can absorb them, highlighting potential risks to the food chain [22,25,26]. On top of that, microplastics serve as long-term anthropogenic stressors that pose risks to soil functioning and agricultural sustainability [20,25,27]. Even though the severity of environmental problems is associated with plastic mulch use, the economic dimension is pivotal in sustainable mulch use. The literature provides evidence of labor demand for plastic mulch removal. For example, Madrid et al. [18] noted that field removal of PE mulch is a labor-intensive process. Additionally, farmers must pay for collection and separation, transport to the facility, and tipping fees at landfills [28,29]. In the Egyptian context, the impacts of economic factors on farmers' adoption of sustainable disposal practices of plastic mulch and inadequate awareness of microplastics risks have been alarming. In this regard, Kassem et al. [12] reported that most farmers either bury or burn plastic mulch residuals after use. Ultimately, these management and environmental concerns highlight the need for safer and more sustainable mulch alternatives.

Biodegradable plastic mulch (BDM) has emerged as a promising alternative to the management and environmental problems associated with conventional PE mulch in agriculture. These films are tilted into the soil after the growing season, degraded by soil microorganisms [30], and converted into products such as biomass, carbon dioxide, and water [31,32]. On the one hand, BDM films provide potential environmental and end-of-life advantages, such as reducing plastic waste accumulation [33], minimizing removal and disposal costs [34], reducing greenhouse gas emissions [35], and diminishing plastic pollution and associated toxicity in terrestrial and aquatic environments [32]. On the other hand, over the last decade, research on BDM effectiveness has raised concerns about its feasibility due to incomplete biodegradation, durability limitations, uncertain effects on soil health, possible soil residues, higher cost, and restricted availability [28,33,36]. Thus, these uncertainties and limitations may decrease farmers' confidence in BDM as a sustainable

alternative to PE mulch [37]. Nonetheless, technical feasibility alone is not adequate for uptake, and farmers' perceptions of both risks and benefits can shape their intention to adopt BDM [38].

The success of environmentally sustainable agricultural innovations ultimately depends on whether farmers are willing to adopt them [39]. Hence, promoting the adoption of BDM requires analyzing factors that influence the intention to adopt this practice and the driving forces behind their decisions [38]. Technical performance alone does not determine farmers' adoption of BDM, and social, economic, behavioral, and institutional factors are also pivotal. These determinants comprise the following: socioeconomic characteristics, attitudes toward environmental concerns, beliefs about usefulness, prior mulch experience, cost of BDM, expected productivity, profitability, availability in local market, extension support, and policy incentives [38,40,41]. As articulated by Chen et al. [42], the uptake of BDM could help reduce plastic pollution and support sustainable farming systems. Consequently, understanding farmers' intention to adopt BDM is critical, as intention is a key precursor of actual adoption behavior [43].

Analysis of previous BDM research demonstrated that most studies have primarily examined how BDM compares with conventional PE mulch on agronomic performance indicators. A few studies have implemented a farmer-centered approach to BDM adoption [38,41–53]. Nonetheless, these studies emphasize willingness to pay, perceived barriers, familiarity, interest in adoption, and stakeholder preferences. Behavioral analysis of adoption intention, however, has received limited attention. Given that most research was conducted across diverse contexts, primarily in China and the USA, a pressing need for an empirical study in the Egyptian context is evident. Based on the Theory of Planned Behavior (TPB), the current study aims to predict farmers' intentions to adopt BDM. This theory assumes that attitudes towards the behavior, subjective norms, and perceived behavioral control account for an individual's intention to demonstrate the behavior [54]. Considering the moral, environmental, or lifestyle dimension of the behavior, this study extends the TPB by incorporating a new attitudinal belief component: perceived self-identity. Therefore, the objectives of this study were to (i) explore how the sociopsychological factors (attitudes towards BDM, subjective norms, perceived behavioral control, and perceived self-identity) facilitate the prediction of farmers' intention to adopt BDM, and (ii) to examine the perceived barriers faced by farmers to adopt BDM. These findings are beneficial for promoting sustainable mulch alternatives in Egypt and provide valuable guidance for researchers and policymakers to launch awareness campaigns, capacity-building programs, subsidy schemes, product regulation, and support waste-reduction policies.

2. Literature Review

2.1. Theoretical and Research Model

According to Roger's diffusion of innovation theory [55], adoption is the decision an individual makes to adopt an innovation as the optimal course of action. It encompasses incorporating new concepts, services, or technologies into existing systems. Adoption intention refers to the readiness or willingness of target individuals to accept a particular innovation [56]. Various personal, socioeconomic, and institutional factors determine farmers' adoption of agricultural innovations, enabling or restricting their uptake. Numerous studies have examined these factors to understand how they impact farmers' intention to adopt sustainable agricultural practices [57–62].

The TPB theory remains one of the most effective, reliable, and broadly implemented theoretical foundations in the adoption literature [43]. The TPB model was developed to expand the idea of reasoned action to navigate actions that individuals might have limited control over. This model suggests that attitudes toward the behavior in question, subjective

norms, and perceived behavioral control all affect an individual's intention to engage in a particular practice [54]. Thus, intention represents an individual's motivation to allocate effort, thereby increasing the likelihood of performing the behavior [63]. The TPB model is implemented in this study because numerous studies have demonstrated its predictive power on farmers' adoption of pro-environmental technologies and practices.

Nevertheless, the TPB model has certain limitations, including neglecting moral norms and placing exclusive emphasis on self-interest and beliefs. Therefore, incorporating additional constructs based on both theoretical and practical considerations can help increase its predictive potential [64]. The following section presents the extended TPB model used in this study.

2.2. Extended TPB Model and Hypotheses

Attitude within the TPB model represents an individual's positive or negative evaluation of the behavior under investigation (the dependent variable). Gao et al. [65] suggest that a favorable attitude toward a particular behavior may lead to a stronger intention to engage in it. It is because the attitude depends on the overall assessment of that behavior and the individual's belief in its desirable results [66]. Many empirical studies reported that positive attitudes are associated with stronger farmer intentions to adopt sustainable or pro-environmental practices [67–69]. In this study, attitude refers to how positively or negatively farmers view adopting BDM in terms of profitability, usefulness, and environmental value. When farmers perceive that adopting might yield more favorable outcomes than current outcomes, they can develop a stronger intention to adopt it.

Subjective norms are personal perceptions of behavior that are substantially influenced by others' attitudes [54]. Consequently, subjective norms indicate how people assess the social expectations. High cognitive awareness of subjective norms is anticipated to support the achievement of behavioral goals [70]. This proposition is in line with previous research showing that subjective norms positively influence farmers' intention to adopt sustainable agricultural practices, including climate-smart agriculture and environmentally responsible farm management [68,69,71,72]. These studies showed that the approval and encouragement of peers and influential people can play an important role in motivating behavioral intention in rural settings. Within the current study, subjective norms are strong indicators of BDM adoption intention because they reflect perceived social pressures from important others, including family members, peers, progressive farmers, and extension workers, and are strongly felt by farmers. When farmers consider that these influential groups are likely to adopt BDM, they may be more inclined to do so themselves.

Perceived behavioral control refers to the perceived ease or difficulty of performing a specific behavior [66]. Notably, perceived behavioral control reflects an individual's readiness to engage in a behavior, based on their belief in their ability to acquire the necessary resources [73]. Previous studies reported that perceived behavioural control positively affects farmers' intention to adopt sustainable agricultural practices [61,74–76]. In this study, perceived behavioral control refers to farmers' beliefs in their ability to adopt BDM and in their possession of the knowledge, skills, and resources necessary for its use. When farmers feel more capable of navigating practical constraints, they can form a stronger intention to uptake BDM.

Based on our understanding of the TPB model, we developed the following hypothesis:

- H1.** *Farmers' attitudes towards BDM positively impact their intention to adopt BDM.*
- H2.** *Farmers' subjective norms positively affect their intention to adopt BDM.*
- H3.** *Farmers' perceived behavioral control positively influences their intention to adopt BDM.*

Even though the classical TPB assumes that these three factors are adequate predictors of intention, this assumption has received criticism over time. In this context, Ajzen [66] reported that the TPB model suggests a flexible framework in which additional factors may be incorporated when they significantly support the explained variance in behavioral intention. This is relevant in the case of BDM, which is promoted not only for its agronomic function but also for its role in reducing agricultural plastic waste, microplastic accumulation, and broader environmental harm. Farmers may be driven not only by perceived utility or feasibility but also by the alignment of BDM with their self-identified farmer identity, such as being sustainability-oriented, environmentally responsible, or morally committed. On this basis, perceived self-identity was incorporated into the TPB model to capture an additional layer of motivation that may be crucial in explaining intention toward pro-environmental agricultural innovations.

Perceived Self-Identity

Perceived self-identity assesses how people view a certain practice or behavior as consistent with their values, who they are, and the type of person they believe themselves to be [77]. Within the TPB model, self-identity often serves as an additional construct to reinforce the prediction of intention, particularly when the behavior is socially, ethically, or environmentally important [78]. To that end, individuals who view themselves as morally committed, socially conscious, or environmentally responsible are more likely to adopt a particular behavior [79]. Within this research context, BDM functions as a farm input and a pro-environmental practice associated with human well-being, responsible farming, and environmental safety. Therefore, farmers may intend to adopt BDM not only for technical or economic reasons, but also because they feel that it supports the type of farmer they wish to be. Hence, we hypothesize that:

H4. *Perceived self-identity for BDM positively influences farmers' intention to adopt this innovation.*

In addition to testing the main model's hypothesis, the study included age, education, farming experience, farm size, and net income as control variables (Figure 1). However, in the present study, these variables were not introduced as part of the core explanatory mechanism of the extended TPB model, but rather as control variables included to assess whether the main relationships between the psychological constructs and intention remained robust after accounting for farmers' background characteristics.

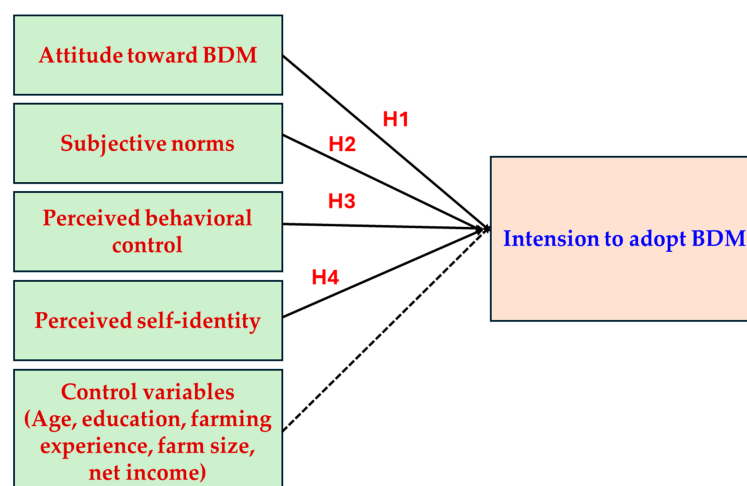


Figure 1. Extended TPB model to predict farmers' intention to adopt BDM. Solid arrows represent the hypothesized relationships in the extended TPB model, whereas the dashed line indicates the direct effect of socio-economic control variables on intention to adopt BDM in Model 2.

3. Methodology

3.1. Measures

The study used a questionnaire with four sections to collect primary data from the respondents. The first part delineated the study's purpose and objectives and declared the participants' right to confidentiality and anonymity. Moreover, we obtained verbal consent from all farmers prior to data collection. The informed consent procedures were formulated and approved in accordance with the ethical standards set by the University of Reading (Ref# APD 1911D). The second section comprised demographic information, including age, education, farming experience, farm size, and net income. The third section included an open-ended question about barriers to adopting BDM. The fourth section listed TPB variables to evaluate farmers' intention to adopt BDM. The items' development was based on the literature review and operationalized to be consistent with the study's context. The scale of farmers' intention to adopt BDM involved 17 items classified into five main constructs: Attitude (three items), subjective norms (three items), perceived behavioral control (three items), perceived self-identity (three items), and intention to adopt (five items). All items were measured using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Appendix A presents all measures.

3.2. Participants

We used a multistage sampling method to collect data from the targeted population. The study population comprised 3542 farmers who adopted plastic mulch during the 2022/2023 agricultural season in the study area of Egypt. Accordingly, we purposively selected three governorates according to the number of farmers who use mulch films, namely Dakhalia governorate (from the Northern East Region), Giza governorate (from the Central Region), and Minya governorate (From the Upper Region), as depicted in Figure 2.

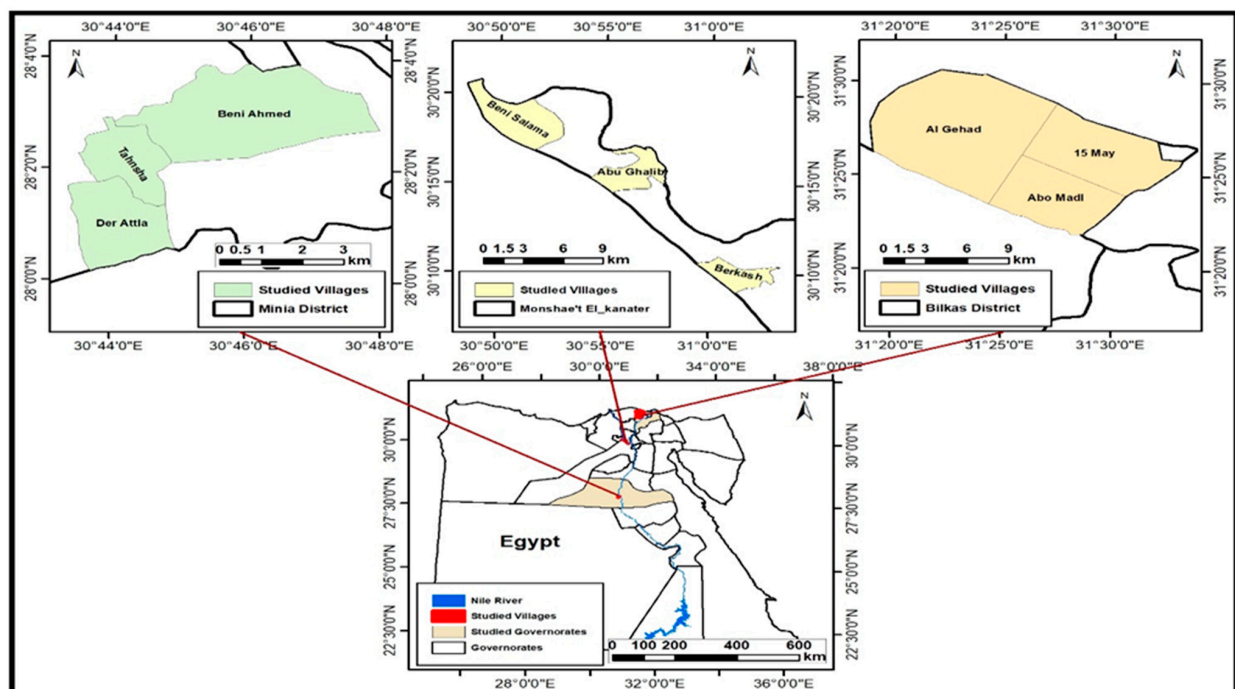


Figure 2. Map of the study area. Source: Kassem et al. [39].

One district was randomly selected from each governorate. Three randomly selected villages were selected from each district. In each village, data collection was based on stratified, proportional random sampling by farm size. Based on the farming area, farmers were categorized into four groups: large (more than 10 hectares), medium (4 to 10 hectares),

semi-medium (2 to 4 hectares), and small (2 hectares or less). The survey targeted 360 farmers determined using Yamane's sample size calculation (95% confidence level; 5% margin of error) [80]. The sample was proportionally allocated across the four farm-size categories. Thus, data were collected from 40 farmers in each village using a semi-structured questionnaire through face-to-face interviews. The survey lasted from April 2023 to July 2023. To evaluate the content validity of the survey items, we pre-tested the questionnaire on ten farmers outside the sampling frame. Minor adjustments were implemented, leading to the rephrasing of some questionnaire statements.

3.3. Data Analysis

We used the PLS-SEM approach to test the model-suggested hypotheses in SmartPLS 4. This methodology assesses the interconnections among elements in the internal model and determines their association with latent indicators in the external model. According to Hair et al. [81], this method performs satisfactorily with sophisticated models that incorporate several structural relationships. Furthermore, the technique decreases the unexplained variation in the model. Additionally, its efficacy is satisfactory for small to medium data samples and non-normally distributed data. In this study, we used two models to predict farmers' intentions to adopt BDM. We evaluated the first model to explore how attitudes, subjective norms, perceived behavioral control, and perceived self-identity affected intention. A second model included education, age, farming experience, and net income as control variables, measured directly on the intention variable. The practical significance of each predictor in accounting for the dependent variable was estimated using Cohen's effect size (f^2) threshold [82], where f^2 values of 0.02 to less than 0.15 indicate small, 0.15 to less than 0.35 medium, and 0.035 and more large effect sizes, respectively.

We used two PLS-SEM structural models to estimate farmers' intention to adopt BDM. The first model included the four latent predictors derived from the extended TPB framework:

$$\text{INT} = \beta_1 \text{ATT} + \beta_2 \text{SN} + \beta_3 \text{PBC} + \beta_4 \text{PSI} + \zeta$$

The second model additionally included socio-economic control variables:

$$\text{INT} = \beta_1 \text{ATT} + \beta_2 \text{SN} + \beta_3 \text{PBC} + \beta_4 \text{PSI} + \beta_5 \text{AGE} + \beta_6 \text{EDU} + \beta_7 \text{EXP} + \beta_8 \text{FS} + \beta_9 \text{INC} + \zeta$$

where INT denotes intention to adopt BDM; ATT = attitude; SN = subjective norms; PBC = perceived behavioral control; PSI = perceived self-identity; AGE = age; EDU = education; EXP = farming experience; FS = farm size; INC = net income; β = path coefficients; and ζ = error term.

The explanatory power of the two models was assessed using the coefficient of determination (R^2) of the endogenous construct, and the practical contribution of each exogenous variable was evaluated using Cohen's effect size (f^2), calculated as [82]:

$$f^2 = (R^2_{\text{included}} - R^2_{\text{excluded}}) / (1 - R^2_{\text{included}})$$

where R^2_{included} is the R^2 value of intention when the predictor is included in the model, and R^2_{excluded} is the R^2 value when that predictor is omitted.

4. Results

4.1. Socioeconomic Characteristics of the Respondents

Table 1 summarizes the demographic profile of farmers. The average age of the respondents was 47.04 years. Approximately 40% were aged 35–47, and 30% were aged 48–59. Less than half (44.7%) had a secondary education, and only a few had a higher educa-

tion (13.9%). Many farmers (48.9%) had 14–25 years of experience, with an average of 25.26 years. More than one-third of farmers (35%) were categorized as small-scale farmers, followed by the semi-medium category (2–4 hectares), with 29.7%. The largest farm size was 30 ha, whereas the smallest was 0.4 hectares. Regarding net income, most respondents (65.4%) fell in the USD 1501–5000 range, and only 7.5% of farmers earned more than USD 5000 annually; the average net income was USD 2580.80.

Table 1. Socioeconomic profile of the respondents.

Category	Frequency (<i>n</i> = 360)	Percentage
1—Age (Years) (Min = 20; Max = 85; Mean = 47.04; SD = 11.50)		
<35	46	12.8
35–47	141	39.2
48–59	108	30
>59	65	18
2—Education		
Illiterate	51	14.2
Primary school	98	27.2
Secondary school	161	44.7
University	50	13.9
3—Farming experience (years) (Min = 2; Max = 55; Mean = 25.26; SD = 11.78)		
<14	47	13.1
14–25	176	48.9
26–37	76	21.1
>37	61	16.9
4—Farm size (Hectares) (Min = 0.4; Max = 30; Mean = 6.39; SD = 9.23)		
≤2	126	35
>2–4	107	29.7
>4–10	63	17.5
>10	64	17.8
5—Net income (USD) (Min = 88; Max = 14,000; Mean = 2580.80; SD = 3780.75)		
<500	55	15.3
500–1500	46	12.8
1501–5000	232	65.4
>5000	27	7.5

4.2. Barriers to Adopting BDM

Field discussions conducted during data collection indicated that none of the respondents had prior direct experience with BDM or had attended demonstration activities related to its use. Figure 3 depicts the barriers to adopting BDM among farmers. The respondents identified 13 items as obstacles to their uptake. These items could be grouped into six main categories: cognitive and knowledge barriers (limited technical knowledge), economic barriers (higher cost than conventional plastic mulch), attitudinal and preference barriers (lower interest and satisfaction with current mulch practices), technical and operational barriers (concerns about compatibility, durability, and reusability), performance and uncertainly barriers (uncertainly about effects on soil health, yield, quality, and weed

control), and market, social, and institutional barriers (limited availability, weak peer adoption, and absence of organic approval). In descending order, the five most important factors constraining farmers from adopting were limited local availability (71%), limited knowledge (56%), high cost of BDM (46%), field durability (39%), and limited use among other farmers (34%).

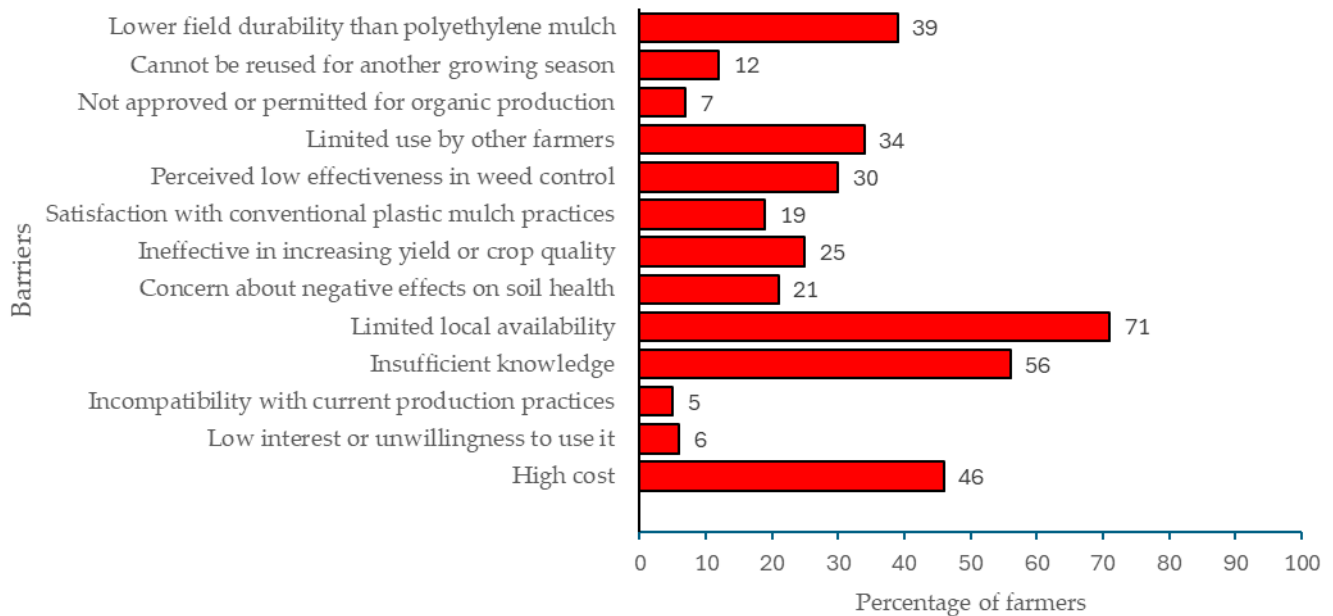


Figure 3. Barriers to adopting BDM from the farmers' perspective.

4.3. Measurement Model

Table 2 presents data on the reliability and construct validity of the measurement model. Internal reliability was evaluated using Cronbach's alpha. All constructs exceeded the recommended 0.7, indicating an adequate reliability [83]. Moreover, the composite reliability (CR) exceeded the threshold of 0.7, indicating high internal consistency [83]. Additionally, convergent and discriminant validity were used to determine the measurement model's validity. The validity of the constructs' Average Variance Extracted (AVE) values was higher than Fornell & Larcker's [84] recommended cutoff of 0.5. Hence, convergent validity was adequate.

Following Fornell and Larcker's [84] methodology, we substantiated discriminant validity, demonstrating that each construct's square root of its AVE (bolded in Table 3) exceeded the correlations between that construct and every other construct (see Table 3). Furthermore, we used the heterotrait–monotrait (HTMT) ratio of correlations, which is endorsed as a more reliable technique than Fornell and Larcker's [85], to enhance the evaluation of discriminant validity. The discriminant validity of the measurement items for the constructs was verified by all ratios falling below the specified threshold of 0.9, as illustrated in Table 2. The Variance Inflation Factor (VIF) was also calculated to assess potential multicollinearity. No collinearity problems are evident if the VIF is less than five [83]. Our model's highest VIF of 4.774 indicated that multicollinearity was not an issue. Therefore, the measurement model's validity was confirmed based on the outer loadings' values and statistical significance, as well as the values of CR, AVE, and HTMT.

Table 2. Reliability and construct validity.

Latent Variables	Loadings	α	CR	AVE	VIF
Attitude		0.953	0.970	0.914	
ATT1	0.952				4.581
ATT2	0.972				4.115
ATT3	0.945				4.743
Social norms		0.939	0.961	0.892	
SN1	0.928				3.409
SN2	0.960				3.031
SN3	0.946				4.774
Perceived behavioral control		0.924	0.952	0.868	
PBC1	0.917				3.053
PBC2	0.948				4.685
PBC3	0.929				3.627
Perceived self-identity		0.923	0.951	0.867	
PSI1	0.929				3.556
PSI2	0.946				4.391
PSI3	0.918				3.064
Intention to adopt BDM		0.920	0.940	0.760	
INT1	0.793				1.964
INT2	0.871				3.143
INT3	0.891				4.179
INT4	0.910				4.482
INT5	0.889				3.294

Table 3. Discriminant validity of the constructs based on the Fornell and Larcker and HTMT methods.

Constructs	ATT	SN	PBC	PSI	INT
ATT	0.956				
SN	0.782 [0.661]	0.945			
PBC	0.673 [0.624]	0.699 [0.625]	0.931		
PSI	0.662 [0.602]	0.675 [0.532]	0.715 [0.698]	0.931	
INT	0.570 [0.418]	0.595 [0.487]	0.611 [0.546]	0.680 [0.511]	0.872

Note: Bold values refer to the square root of the AVE for each construct.

4.4. Structural Model

A bootstrapping procedure with 5000 subsamples was implemented to determine path significance, as illustrated in Table 4. The results of the bootstrapped path coefficients indicated that social norms ($\beta = 0.143$, $t = 2.030$, $p < 0.05$) significantly and positively impacted farmers' intentions to adopt BDM, with a small effect size ($f^2 = 0.102$). Furthermore, perceived behavioral control positively affected intention ($\beta = 0.163$, $t = 2.444$, $p < 0.05$), with a medium effect size ($f^2 = 0.184$). Lastly, perceived self-identity also impacted intention ($\beta = 0.421$, $t = 7.392$, $p < 0.01$), with a medium effect size ($f^2 = 0.204$). These findings support H2, H3, and H4. However, attitude ($\beta = 0.069$, $t = 1.121$, $p = 0.262$) did not positively and significantly influence farmers' intention to adopt BDM, leading to the rejection of H1. The bootstrapped R^2 value (Figure 4) indicated that the combined effect of all constructs accounted for 51% of the variance in farmers' intention to adopt BDM, suggesting moderate predictive power. In the second model, five socioeconomic characteristics were used as control variables to assess their direct impact on intention (Table 4). Despite a marginal

increase in the R^2 of INT (0.526) in the model after the control variables were added, none of the investigated control factors were significant.

Table 4. Hypotheses results.

Paths		Model 1			Model 2			Results
Hypotheses		β	t	p-Value	β	t	p-Value	
ATT -> INT		0.069	1.121	0.262	0.083	1.345	0.179	Reject H1
SN -> INT		0.143 *	2.030	0.042	0.141 *	1.964	0.050	Support H2
PBC -> INT		0.163 *	2.444	0.015	0.176 **	2.675	0.007	Support H3
PSI -> INT		0.421 **	7.392	0.000	0.413 **	6.972	0.000	Support H4
Control variables								
Age -> INT					−0.108	0.929	0.353	NA
Education -> INT					−0.143	0.707	0.480	NA
Farming Experience -> INT					0.007	0.045	0.964	NA
Farm size -> INT					−0.038	0.333	0.739	NA
Gross income -> INT					0.063	0.535	0.593	NA

** $p < 0.01$, * $p < 0.05$. NA (Not Applicable).

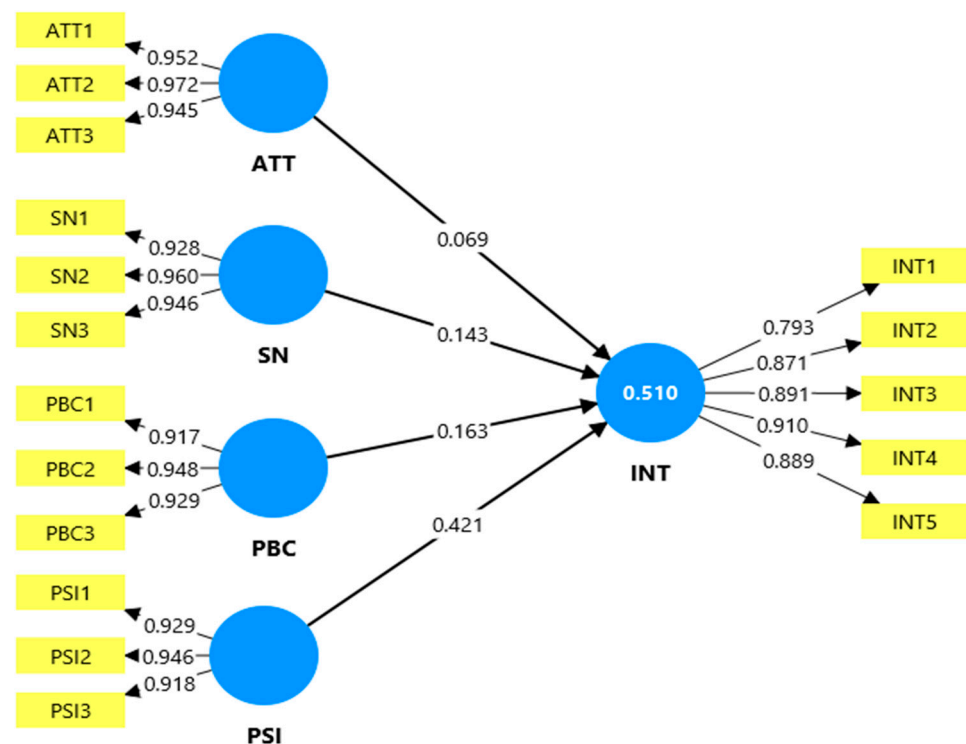


Figure 4. The structural and measurement model.

5. Discussion

The results demonstrate that sociopsychological factors captured by the extended TPB theory modify farmers' intention to adopt BDM. Altogether, subjective norms, perceived behavioral control, and perceived self-identity are pivotal in explaining the variation in intention. Nevertheless, incorporating the demographic characteristics as control variables did not significantly alter the main construct's significance, suggesting the model's robustness. These findings underscore the importance of affirming the perceptual and behavioral drivers of adoption, rather than focusing solely on the technical benefits of BDM.

The findings indicated that subjective norms positively impacted farmers' intention to adopt BDM. This result demonstrates the importance of social pressure and reference-group approval in shaping adoption decisions. Hence, the respondents are more likely to adopt BDM when relatives, neighbors, progressive farmers, rural leaders, extension agents, or other influential groups encourage or support them. These results align with previous studies that have shown the positive and significant role of subjective norms in intention to adopt climate-smart agriculture [61,86–90]. Even though the BDM literature did not explicitly investigate subjective norms within the TPB model, some farmer-centered studies documented that institutional and social interactions are pivotal for BDM adoption. For example, Goldberger et al. [41] noted that farmers' socioinstitutional relations with other farmers, extension agents, and input suppliers shape farmers' adoption of BDM in the USA. Likewise, Muddassir et al. [48] found that membership in agricultural cooperatives positively impacted Saudi farmers' willingness to adopt BDM. In the Egyptian context, these results are critical because BDM remains a relatively unfamiliar innovation, and farmers may rely heavily on trusted sources within their institutional and social networks when making adoption decisions. Therefore, future interventions should involve a multistakeholder approach to ensure a broader acceptance of BDM among farmers in Egyptian agriculture.

As hypothesized, perceived behavioral control positively affected intention, suggesting that intention elevates when farmers perceive they possess the necessary knowledge, skills, access, and financial capacity to uptake BDM. This finding implies that respondents are more likely to use BDM when they feel capable of navigating barriers related to technical know-how, application in their real conditions, product availability, and affordability. This conclusion aligns with the descriptive findings of barriers in this study. These findings confirm previous studies that examined the influence of perceived behavior control, a construct of the TPB model, on intention to adopt sustainable agricultural practices [61,86,91]. In the BDM use among farmers, Goldberger et al. [41] and Shrestha et al. [51] underscored that inadequate knowledge, higher costs, and uncertainty regarding degradation were the most critical constraints to adopting BDM among U.S. farmers. For Egypt, the results demonstrate that efforts to promote BDM should go beyond awareness by reinforcing farmers' perceived control through capacity-building programs, field demonstrations, extension support, improved market access, and financial and policy support.

Perceived self-identity was the strongest factor influencing farmers' intention to adopt BDM, suggesting that farmers' intention is strengthened when they believe adopting BDM aligns with their identity and ideal farmer style. Stated differently, farmers may wish to adopt BDM when they view themselves as progressive producers, environmentally responsible, or sustainability-oriented. Across several empirical studies [92–94], self-identity positively affected farmers' intention to adopt pro-environmental behavior. Even though BDM research has rarely directly explored this construct, this finding is supported by the conceptual insights of Dentzman and Goldberger [45], who argued that BDM intention is associated with the concepts of good farming, cultural meaning, and environmental aesthetics. The same authors [46] also reported that organic farmers favored BDM adoption because it aligns them more closely with the concept of environmentally responsible agriculture than PE mulch. For Egypt, the results indicate that BDM adoption may be supported when framed as part of being a responsible, proactive farmer, rather than as a mere technical replacement for PE mulch.

Contrary to our expectation, attitude did not notably affect farmers' intention to adopt BDM. This finding suggests that attitudes toward BDM as an alternative to PE mulch were not a crucial determinant of adoption intention, possibly because most respondents have limited knowledge of BDM's agronomic and environmental benefits. Such a condition

would not help farmers form favorable perceptions of BDM use, which, in turn, would not translate into a stronger intention to adopt. However, this interpretation should be treated cautiously, as limited knowledge and uncertainty were not directly modelled as mediating variables in the structural analysis. Accordingly, this interpretation should be understood as a plausible contextual explanation supported by the descriptive findings of the study. In particular, farmers identified limited local availability, insufficient knowledge, high cost, and field durability as the most important constraints to BDM adoption, indicating that their evaluations of BDM may still be shaped by practical constraints rather than by well-formed personal assessments of the innovation itself. Moreover, field discussions conducted during data collection indicated that none of the respondents had prior direct experience with BDM or had attended demonstration activities related to its use. This lack of prior exposure may have limited farmers' ability to develop favorable attitudes toward BDM and may help explain why attitude did not emerge as a significant predictor of intention. From the perspective of Rogers' decision-making process of innovations, the findings may reflect that BDM in Egypt is still situated closer to the knowledge stage than the persuasion stage, where farmers are aware of the innovation's existence but have not yet accumulated sufficient practical familiarity to form stable and influential attitudinal judgments. Theoretically, this implies that in the case of relatively novel sustainable agricultural technologies, intention may depend more on whether the technology is perceived as feasible, socially supported, and consistent with farmers' self-concept, and less on favourable evaluation alone. Practically, this result also suggests that efforts to promote BDM should move beyond general awareness messages to strengthen farmers' exposure to the technology through field demonstrations and locally accessible supply channels, which may help transform abstract approval into intention and, eventually, actual adoption.

Even though such results diverge from the TPB's core assumptions, some studies demonstrated that attitude was not a significant predictor of intention. For example, Placencia et al. [95] found that attitude was not a significant predictor of intention to adopt sustainable agricultural practices among Cacao farmers in the Philippines. Likewise, Nguyen and Drakou [61] noted that the influence of attitude on the intention of coffee Vietnamese farmers to adopt sustainable agricultural practices was unsupported. Nonetheless, these results seem inconsistent with prior BDM research. Hence, Goldberger et al. [41] noted that environmental benefits and reduced waste are "key bridges" to BDM adoption, suggesting that favorable attitudes toward BDM can facilitate adoption. Similarly, Chen et al. [42] documented that agricultural stakeholders prioritized attributes, including profitability-related benefits, reduced field-borne residue, and improving soil health, indicating that positive assessment of BDM characteristics is pivotal in adoption decisions. Nevertheless, this contradiction may posit an important distinction: previous BDM studies primarily focus on perceived benefits, interests, preferences, or willingness to pay, rather than exploring the predictive effect of attitude on intention within a multivariate behavioral model. Yang et al. [38] support this interpretation, who concluded that technology-specific factors are more critical than adopter-specific characteristics in explaining Chinese farmers' willingness to pay for BDM. This finding suggests that practical feasibility may surpass favorable attitudes. Thus, in Egypt, a positive attitude toward BDM may be evident at a neutral level and may not be adequate to drive intention unless social support, greater confidence, and practical application under local farming conditions reinforce it.

An additional issue that requires further attention is the high proportion of farmers who reported that the limited local availability of BDM was a barrier to adoption. In fact, this was the most frequently reported constraint in the current study, exceeding insufficient knowledge, high cost, and durability concerns. This result suggests that, even when farmers show some degree of interest in BDM, adoption may remain unlikely if the product

is not physically accessible through local agricultural input markets. In the Egyptian context, this likely reflects the early-stage diffusion of BDM and the still-limited presence of reliable distribution networks for this relatively new technology. Similar concerns have been reported in earlier BDM studies. Goldberger et al. [41] identified low availability, along with insufficient knowledge and high cost, as important barriers to adoption among specialty crop stakeholders in the United States. Likewise, Muddassir et al. [48] found that Saudi farmers' willingness to adopt BDM was constrained by weak market presence and recommended that government and extension services improve both the availability and affordability of the technology. Additionally, evidence from China also suggests that the adoption of BDM is limited when new technologies are not yet well established in local farming systems and distribution structures [38]. Taken together, these studies support the interpretation that product availability is not a secondary logistical issue, but a central precondition for adoption. In the absence of regular local supply, farmers may perceive BDM as impractical regardless of its potential benefits.

The socioeconomic variables incorporated into the extended TPB model as control variables did not directly affect farmers' intention to adopt BDM. This finding suggests that the demographic profile of the respondents, including age, education, farming experience, farm size, and net income does not directly account for intention, considering the investigated constructs. Put differently, sociophysiological factors rather than personal attributes shape farmers' intentions more strongly. Additionally, these findings support the robustness of the examined model, indicating that the main relationships remain stable even after controlling for the socioeconomic variables.

The main theoretical gap addressed by this study lies in the limited use of theory-driven behavioral frameworks to explain farmers' intention to adopt BDM, particularly in developing-country contexts. Even though prior BDM studies have largely emphasized agronomic, environmental, and economic aspects, less is known about the sociopsychological determinants of adoption intention. By applying the TPB and incorporating perceived self-identity, this study contributes to the literature by showing that the intention to adopt BDM may be shaped not only by the original TPB constructs but also by identity-based motivations linked to environmentally responsible farming. The results have broader theoretical implications for the application of the TBP in sustainable agricultural behaviour research. In the present study, the non-significant effect of attitude does not necessarily indicate that TPB is inapplicable to BDM adoption; rather, it suggests that favourable evaluations of a relatively unfamiliar technology may remain too general or abstract to translate into intention unless they are accompanied by stronger perceptions of feasibility and social legitimacy. On the contrary, the significant effects of subjective norms and perceived behavioural control indicate that intention is more strongly shaped by social endorsement and perceived capacity to adopt the technology under real farming conditions. The significant role of perceived self-identity further suggests that, for sustainability-related agricultural innovations, the original TPB may be strengthened by incorporating identity-based motivations. This does not mean that BDM adoption is driven by identity expression instead of rational decision-making; rather, it indicates that farmers' decisions combine practical assessment, social influence, and self-concept. In this sense, the study supports the continued usefulness of TPB, while also indicating that its extension with perceived self-identity may be particularly valuable for explaining pro-environmental agricultural intentions in contexts where technologies are novel, values-laden, and not yet fully institutionalized. On top of that, the non-significant effects of the control variables strengthen the view that sociopsychological factors, rather than socioeconomic characteristics, modify intention. Finally, this study extends TPB-based research on BDM adoption

and expands the literature by providing evidence from Egypt, an underexplored context in this field.

Additionally, the findings have practical implications for policymakers, agricultural cooperatives, extension services, input suppliers, and other stakeholders seeking to promote uptake of BDM in Egypt. The positive influence of subjective norms on intention posits that extension agents, agricultural cooperatives, rural leaders, and progressive farmers should participate in awareness campaigns, demonstrations, and field days to build trust and social acceptance about BDM. Using participatory approaches, such as peer-to-peer learning and farmer field schools, is also beneficial for building trust and accelerating adoption. Furthermore, the positive effect of perceived behavioral control suggests that efforts to promote adoption should emphasize building confidence in using BDM in real-world settings through capacity-building programs and field-based demonstrations. The positive influence of perceived self-identity on BDM intention suggests that extension strategies should encompass economic and technical aspects of BDM. Moreover, they should be an essential part of forward-looking, environmentally responsible farmers. Concurrently, the non-significant effect of attitudes demonstrates the importance of accompanying the environmental benefits messages with practical support and social influence to strengthen adoption. Synchronously, the non-significant impact of socioeconomic control variables suggests that more emphasis is needed to address institutional and behavioral factors that facilitate BDM adoption. Overall, promoting BDM adoption in Egypt requires an integrated strategy that combines practical training, cooperative engagement, financial incentives, extension support, and identity-based communication within agricultural sustainability efforts.

This study has certain limitations. First, it did not explore some other potentially important determinants, including policy incentives, access to extension services, prior exposure to alternatives to PE mulch, market availability of BDM, or waste management conditions. These variables may indirectly affect intention through subjective norms, attitudes, and perceived behavioral control. Second, this study underscored the intention to adopt as a dependent variable rather than actual adoption behavior. As intentions do not always translate into implementation, future research should examine whether TPB constructs predict BDM uptake. Third, the cross-sectional design of the current study prevents the capture of the attitude changes over time, in which favorable attitudes may be established after frequent exposure to demonstrations or direct experience with innovation, especially with comparatively unfamiliar technologies such as BDM. Fourth, the study was conducted across three governorates in Egypt, and the country's current agricultural, environmental, and institutional conditions may have altered the relative importance of the predictors. Accordingly, we may not be able to generalize the results to other regions or countries. Future research should consider comparative studies across countries to furnish a better comprehensive understanding of BDM adoption.

6. Conclusions

This study provides a deeper understanding of Egyptian farmers' intention to adopt BDM by extending the TPB model. It indicated that subjective norms, perceived behavioral control, and perceived self-identity, rather than socioeconomic attributes, primarily shape farmers' intention to adopt BDM. A broad adoption of BDM requires special attention to the most essential barriers farmers face, including limited market access, technical knowledge, and current prices. Adopting BDM requires a holistic strategy that considers adoption as a process, rather than a single decision. In this respect, extension services should launch awareness campaigns to align BDM technology with the real problems: plastic waste accumulation and the adverse effects of microplastics on agroecosystems. Policymakers

should acknowledge the various cognitive, economic, and social barriers to adopting BDM and devise policies and financial incentives to address them. Moreover, efforts for building trust and confidence should involve close collaboration with rural leaders, progressive farmers, and agricultural cooperatives. Additionally, extension services should prioritize reducing the risks associated with BDM adoption by crafting cost–benefit communication materials, conducting demonstrations, and piloting activities under real farm conditions. Altogether, these efforts may help generate favorable attitudes toward BDM and increase the likelihood of moving from intention to adopt to actual adoption.

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Appendix A. Measurement Used

Table A1. Statements used in the questionnaire.

Factors/Code	Statements
Attitude (ATT)	
ATT1	I believe that adopting BDM would help reduce microplastic pollution in agricultural soils.
ATT2	I believe that BDM would be beneficial for human health and well-being.
ATT3	I believe that adopting BDM would be economically viable for my farm.
Subjective norms (SN)	
SN1	My family members would encourage me to adopt BDM.
SN2	My friends' opinions would influence my decision to adopt BDM.
SN3	My peers would recommend that I adopt BDM.
Perceived behavioral control (PBC)	
PBC1	I have access to the resources needed to adopt BDM.
PBC2	I am confident in my ability to adopt BDM successfully.
PBC3	I believe that adopting BDM would be easy for me.
Perceived self-identity (PSI)	
PSI1	I believe that I possess high morals to adopt BDM because it is environmentally safe and good for human well being
PSI2	I see myself as a farmer who should adopt environmentally responsible agricultural practices such as BDM.
PSI3	Adopting BDM would give me peace of mind because it reduces the risk of microplastic contamination.

Table A1. Cont.

Factors/Code	Statements
Intention to adopt BDM (INT)	
INT1	I am currently initiating the plan to adopt BDM
INT2	I will adopt BDM when it is less expensive
INT3	I will adopt BDM when it is subsidised by the government
INT4	I will adopt BDM when it is available
INT5	I will make a plan in the future to adopt BDM

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