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SYSTEMIC REVIEW
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A Systematic Review on Adoption of Biodegradable Mulches Among Farmers

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ABSTRACT

With the rapid increase in world population, food insecurity has become a serious challenge to agriculture production. In response to food insecurity, biodegradable plastic mulch is an innovative technology that increases plant production. Biodegradable mulching has the potential to reduce evaporation and transpiration, reduce labor costs, improve soil fertility, conserve water, reduce runoff, and improve microbial activities. This study systematically reviews the adoption of biodegradable mulches among farmers. The study found that there were a limited number of studies conducted to assess the adoption, willingness to pay, and awareness of farmers toward biodegradable mulch. The review found that few studies revealed less biodegradable adoption in some areas. Various reasons have been discussed in the literature, such as the influence of demographic characteristics, awareness, and cost, etc., on its adoption. We call for more inclusive and targeted research on adopting biodegradable mulch. To make headway, there is a need for a collaborative effort by researchers from many disciplines to conduct multidimensional studies on biodegradable (economic, social, environmental, institutional, agronomic) sustainability and food security.

Keywords: Adoption, Biodegradable Mulch, Farmers, Review

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INTRODUCTION

Food and agricultural sectors are facing the challenge of feeding the growing population around the globe. The major stressors to agricultural production are climate change and environmental destruction (Muneer et al., 2024). These stresses are escalating the effects of climate change, such as drought, flood risks, variation in temperature, precipitations, and soil erosion, resulting in reduced crop production (Mirzabaev et al., 2023)For instance, the US has confronted adverse climate events such as changes in rainfall patterns and drought conditions, which are anticipated to reach a level where all counties may continually exceed the baseline variability of occurrence by 2050 under the Representative Concentration Pathway (RCP) 8.5. (Batibeniz et al., 2020; Cook et al., 2015). By 2050, it has been estimated that crop production at the global level will bear an average decline of 10% because of climate change, environmental destruction, and land degradation. Some regions could face up to 50% reduction in crop production (IPBES, 2018). These adverse impacts of environmental destruction on agricultural development appeal adaptations towards innovative sustainable agricultural practices (Piñeiro et al., 2020; Smith et al., 2020). The transition towards innovative agricultural practices could reduce and reverse environmental (FAO, 1989) risks, food security, and soil health (Kassem et al., 2021; Kassie et al., 2013).

Climate change reduced staple food-crop production and threatened farm incomes. For instance, negative effects of climate change, such as rise in temperature and decline in rainfall on crop production in the KSA, are reported (Allbed et al., 2017). The Kingdom holds a leading position among oil producers around the world. It is estimated that greenhouse gas emissions (GHG) in the kingdom will increase by 2030 compared to 2014 levels, and is highly suspected that climate shocks (UNEP, 2017). Wheat, sorghum, barley, millets, dates, vegetables, and citrus fruits are important crops in the Kingdom.

Climate change intensifies water scarcity; more than 90% of crops are dependent on irrigation; thus, significant crop production losses could be possible

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without enough groundwater irrigation in climate change. It has been reported that more than 30% of crop yield has been reduced due to climate change (Alam et al., 2011; Alotaibi et al., 2023) Several countries used low-density polyethylene-based mulches to reduce the negative effects of environmental destruction and climate change on land productivity and soil health (Muddassir et al., 2024).

Low-density polyethylene-based mulches improve soil moisture and maintain soil temperature. Moreover, it minimizes weed growth and soil evaporation (Cook et al., 2015; Eswaran et al., 2019; Liu et al., 2021). These valuable roles of plastic mulch decrease irrigation requirements, reduce the application of weedicide and leaching of plant nutrients (Samuelson et al., 2022; Vox et al., 2013). For instance, plastic mulch increased crop yield, crop quality, water use efficiency (Steinmetz et al., 2016) as Wu et al. (2017) reported 15.2%–23.2% improvement in maize production under black plastic film as compared to without using plastic mulching. The same study revealed a large difference among mulch types, white transparent plastic film and maize straw mulch resulted in much smaller increases in maize yield as compared to without using mulching (Wu et al., 2017).

With the agricultural advantages of plastic mulch, literature highlighted long-term environmental and ecological detrimental effects associated with its long-term use have been identified. For instance, the application of plastic mulch in the agricultural field required more labore and financial investment for removal, disposal and removal of plastic waste after growing season (Velandia et al., 2018; Akhir & Mustapha, 2022; Madrid et al., 2022). Moreover, micro and nano particles of plastic may persist in the soil and adversely affect microbial activities, soil health such as physical soil properties and nutrient availability (Gao et al., 2019; Shah & Wu, 2020).

In response to detrimental effects of plastic mulch, biodegradable mulches are being developed as a sustainable alternative to plastic mulch and are designed to be degraded into the soil by local soil organisms (Akhir & Mustapha, 2022; Muddassir et al., 2024). Biodegradable mulch is designed to break down into natural components and leave less harmful residual as compared to plastic mulch. Moreover, Biodegradable mulch reduces labor cost and is eco-friendly. Therefore, adoption of BDM among farmers could provide economic and environmental advantages (Shan et al., 2022; Muddassir et al., 2024). Based on various studies, this review compiles evidence from literature on the perception, awareness and adoption of biodegradable mulch among farmers. Therefore, the current study aims to collect research evidence in terms of social perspective and cover the rural sociology domain, for instance, the influences of socio-economic factors on farmers' awareness, adoption of biodegradable mulch, and their willingness to pay. Moreover, the overall direction of previous research in agricultural extension will be identified.

MATERIALS & METHODS

The current systematic review was conducted to answer specific and relevant research questions. We followed several steps to conduct a systematic review. Khan et al. (2003) suggested five steps, including framing research questions for a review, summarizing the evidence, and interpreting findings. Based on these steps, research synthesizes the evidence on awareness, adoption, and perceptions of biodegradable mulch that promote environmental sustainability. Only those reviewed articles mainly focused on social perspectives such as perception, awareness, and adoption of biodegradables among farmers.

Scope of Search

The literature search was conducted in two phases. Searches in the first phase were run in January 2024. We subsequently updated these searches on 12th August 2024. In this second phase we limited the search to all articles published during or after 2016. Both phases of literature searching used the same search terms and interrogated the same databases. The following online databases were searched for relevant literature and data: Scopus, SSCI Web of Science, JSTOR, and Google scholar.

The question for this research was related to farmers' awareness, perception and their willingness to adopt biodegradable mulch. The key words used were Biodegradable/familiarity/awareness, mulch and adoption. However, after the screening process 15 articles that matched with the study objectives were included in the study.

Assessing the Quality of Studies

For Inclusion criteria only, those articles that discussed social dynamics such as awareness/familiarity, perception and adoption of BDM among farming communities were selected. The published articles from 2016 to 2024 were considered for systematic review. Only research articles were selected which contain title, abstract, introduction, literature review, research methodology, results, and discussion, conclusion and references sections. For exclusive criteria, Journal articles that do not use biodegradable and lacked social work were excluded.

Article Screening

Studies were assessed for inclusion in the systematic review based on a hierarchical assessment of relevance by scanning article titles, followed by reading the abstract of articles with relevant titles, followed by reading the full text of articles with relevant titles and abstracts (Fig. 1). Decisions were inclusive at the title and abstract stages when the relevance of the study was unclear. The objectivity and repeatability of the article selection process was determined during title, abstract and full text appraisal. Two investigators independently assessed the same randomly selected subsets of articles at each stage, in Step-1 of our systematic review process (Fig. 1). To be included, studies had to (1) have a focus on biodegradable mulch; (2) be related to the research title of this study and, (3) be written in English. Studies were classified into either national-level assessments or household-level studies.

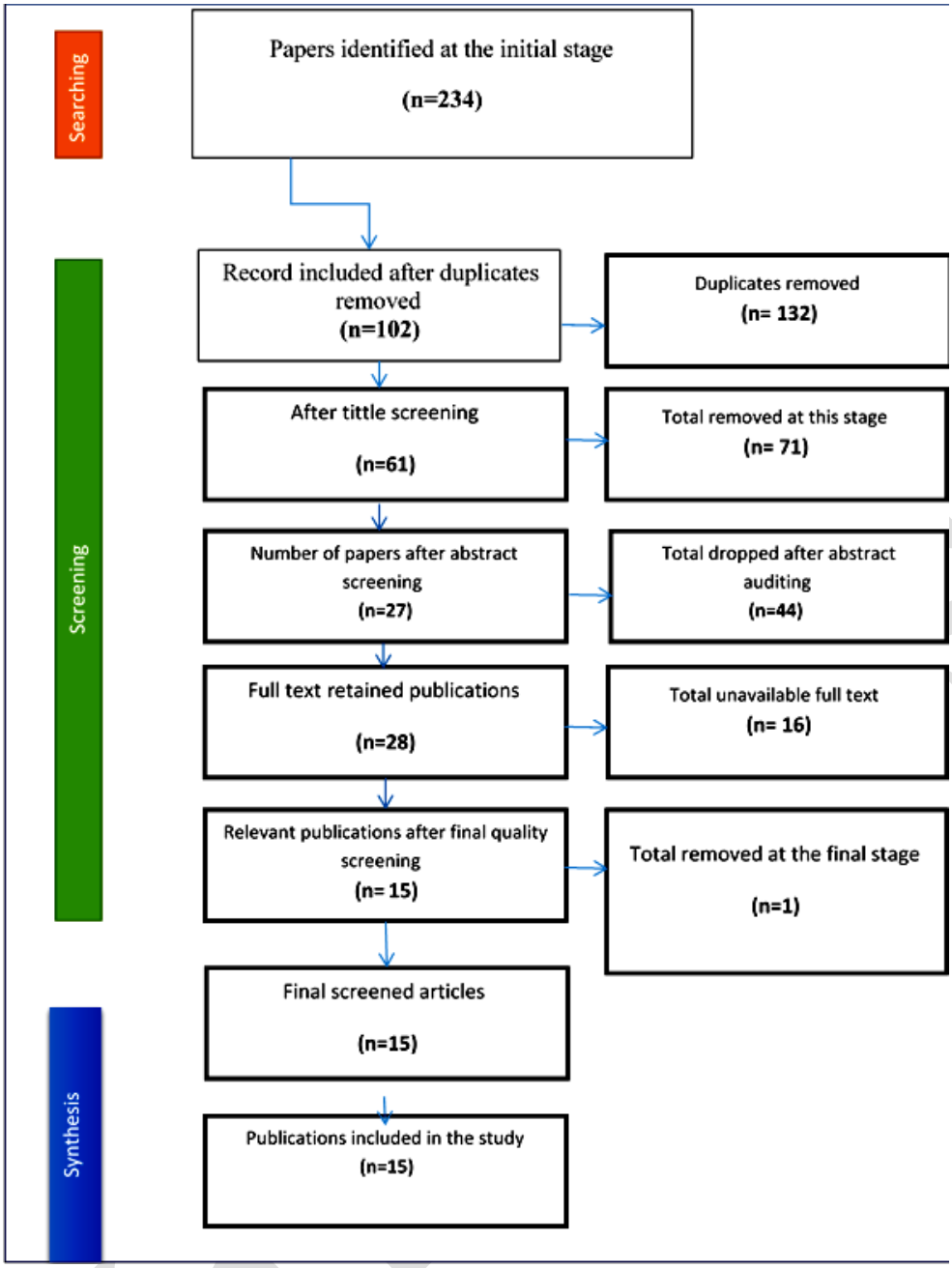

Fig. 1: Flowchart of the Systematic Review Process used in the Study

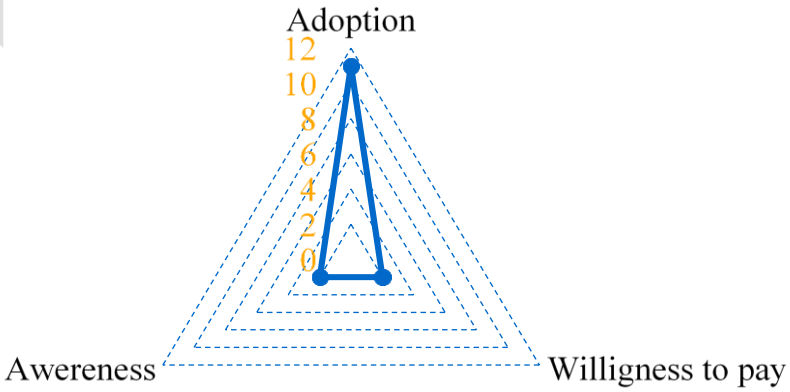

Fig. 2: Distribution of articles based on the objective of the study.

Summarizing the Evidence and Findings Interpretation

In Table 1, evidence was summarized based on inclusive and exclusive criteria. Furthermore, articles that met the criteria were grouped according to the research objectives (Fig. 2). Finally, the findings of the selected research articles during inclusion criteria were presented which consisted of the relationship between socioeconomic characteristics and farmers' awareness, perceptions and their willingness to adopt BDM.

Table 1: The review process yielded 15 studies for final synthesis

Authors' name	Tittle	Findings
Scaringelli et al. (2016)	Adoption of biodegradable mulching films in agriculture: is there a negative prejudice towards materials derived from organic wastes?	Italian farmers' willingness to pay for BDM depends on quality of product (strength, durability, mechanical harvesting, transparency, etc.)
Scaringelli et al. (2017)	Are farmers willing to pay for bio-plastic products? The case of mulching films from urban waste.	Adoption of BDM is higher among growers who previously use the mulch. Farmers who use conventional films are willing to pay a premium price for BDM. In addition, quality of the product, including durability and strength improved farmers' Willingness to Pay
Arribas Herguedas (2018)	Are poplar plantations really beautiful? On Allen Carlson's aesthetics of agricultural landscapes and environmentalism	Traditional growers who had already adopted BDM, changed their aesthetic perception due to their experiences with the BDMs as compared to those who had not experienced the application of BDM.
Goldberger et al. (2019)	Polyethylene and biodegradable plastic mulches for strawberry production in the United States: Experiences and opinions of growers in three regions	Farmers in California, the Pacific Northwest, and the Mid-Atlantic showed several regional differences, California farmers were more likely to adopt biodegradable plastic mulch, and the farmers in Pacific Northwest seemed more concerned to adverse effects of plastic mulch than farmers growers in the Mid-Atlantic. Regardless of region, most growers were intent to gain more knowledge about BDM
Velandia et al. (2019a)	The economic feasibility of adopting plastic biodegradable mulches in pumpkin production.	Capital, labor and natural resources, crop production, farm practices, agricultural input and output cost, management skills, size of the operation, accurate information to farmers about BDMs influenced adoption among growers.
Chen et al. (2020)	Willingness to pay for attributes of biodegradable plastic mulches in the agricultural sector	Growers in the USA assigned the greatest value to BDM characteristics that provide a price premium opportunity for the crop grown, enhance soil health, or lower plastic residue, thereby improving sustainability. Furthermore, growers who are less sensitive to cost are highly willing to adopt BDMs in their fields.
Dentzman & Goldberger (2020)	Plastic scraps: biodegradable mulch films and the aesthetics of 'good farming'in US specialty crop production	Organic status, membership in a strawberry growers' association and experience with plastic mulches were significantly influenced the adoption of BDMs. The growers who had never used BDM nor PE mulch seemed less likely to be interested in trying BDM
Velandia et al. (2020)	Tennessee fruit and vegetable farmer preferences and willingness to pay for plastic biodegradable mulch	The adoption of BDM seemed low among U.S. farmers due to high cost. Price, on-farm income, and understanding of BDM influenced adoption.
Madrid et al. (2022)	Risk and uncertainty of plastic mulch adoption in raspberry production systems.	High prices of BDM identified as barrier to BDM adoption
Yang et al. (2023)	Factors affecting farmers' adoption of and willingness to pay for biodegradable mulch films in China	Chinese farmers were willing to adopt and pay for BDM due to its technology-specific characteristics
Shrestha et al. (2023)	Building Agricultural Knowledge of Soil-biodegradable Plastic Mulch.	At the local level, 60% change of knowledge among farmers for BDMs used in organic production. At a regional level, 23% to 35% of farmers learned "a lot" and 35% to 51% learned "some new information" about BDMs from the webinar. At the national level, 48% responded that they learned "a lot" and "some new information" through training on BDM. Farmers were trained about BDMs by attending field days, on-farm demonstrations and field trials. The farmers noted the same results of PE and BDM mulch regarding weed control and fruit yield.
Ramadhani et al. (2024)	Potentials of Synthetic Biodegradable Mulch for Improved Livelihoods on Smallholder farmers: A Systemic Review	Besides of product quality, the adoption of BDM faces challenges like high initial costs, farmers' preferences, and the regulatory framework.
Muddassir et al. (2024)	Willingness to adopt biodegradable mulch among farmers in Saudi Arabia: implications for agricultural extension	Majority of the farmers in Saudi Arabia were unfamiliar with BDM. A substantial portion revealed their willingness to adopt BDM in the future. The education level, farm size, and membership in agricultural cooperatives considerably influenced their familiarity with BDM. Education level, farming experience, and membership in agricultural cooperatives also confirmed significant relationships with their willingness to adopt BDM in the future. Moreover, the farmers were not well informed of the possible advantages of BDM.
Velandia et al. (2020)	The Economics of Adopting Biodegradable Plastic Mulch Films	Labor costs required to remove PE mulches will help determine potential savings associated with the adoption of BDM
Miles et al. (2017)	Suitability of Biodegradable Plastic Mulches for Organic and Sustainable Agricultural Production Systems	The US National Organic Program (NOP) restricted the adoption of BDM because available BDM are not 100% biobased

DISCUSSION

Adoption of biodegradable mulch has an immense value in environmental protection. It is designed to reduce plastic waste and soil and water pollution. It improves soil and water productivity by conserving soil moisture which ultimately reduces erosion and runoff. Adoption of BDMs has some economic benefits as it reduces the cost of production by reducing labor and disposal cost. By improving the soil structure, the decomposed mulch will enhance soil fertility, thereby increasing yield and profitability.

Results of the finding indicate that 73% (11 articles) of the screened articles focused on the adoption of BDM, this testifies that most research on BDM gives more emphasis to the adoption. The studies were Scaringelli et al. (2016); Arribas Herguedas (2018); Goldberger et al. (2019); Velandia et al. (2019a); Dentzman and Goldberger (2020); Velandia et al. (2020); Velandia et al. (2020); Yang et al. (2023); Ramadhani et al. (2024). Most of the studies indicated that growers had higher adoption of BDMs. However, the adoption of BDM was found to be low among U.S. farmers due to high cost. Price, on-farm income, and limited knowledge about innovation among the growers. Three studies pointed out that the low adoption of BDM is connected with the high cost of its establishment.

In relation to the willingness to pay, two studies, one in China (Yang et al., 2023) and one in USA (Scaringelli et al., 2017), found that farmers are willing to pay and adopt BDMs despite the cost mainly due to the technology-specific characteristics. Another study by Scaringelli et al.

(2016) in Italy outlined that Italian farmers' willingness to pay for BDM depends on the quality of the product (strength, durability, mechanical harvesting, transparency). Their study shows that mulching film adoption is independent of raw material type. The lack of a negative bias among adopters is expected to encourage investors to engage with these innovative products, thereby supporting the sustainability of agricultural practices while also providing an environmentally friendly approach to the management of waste from municipalities (Yahya et al., 2024). The findings of a study conducted by Goldberger et al. (2019) suggest that the likelihood of adopting biodegradable plastic mulch increases when such products are accessible locally, demonstrated to be non-detrimental to soil health, and reasonably priced. To address the issue of agricultural plastic pollution in strawberry production across the United States, it is essential for Extension educators and service providers to customize their educational and outreach programs concerning polyethylene and biodegradable plastics for various regional grower communities (Muddassir & Alotaibi, 2023; Muddassir et al., 2024).

The socio-economic factors including farmers' education level, farm size, and membership in agricultural cooperatives considerably influenced their familiarity with BDM (Muddassir et al., 2024). Education level, farming experience, and membership in agricultural cooperatives also confirmed significant relationships with their willingness to adopt BDM in the future. Moreover, the farmers were not well informed of the possible advantages of BDM (Muddassir et al., 2024). Another study suggested that farm size, farmer environmental stewardship, and labor savings from BDM use showed a strong relationship with the adoption of BDMs among Tennessee farmers, specifically among those growers who had experienced PE mulch use (Velandia et al., 2020). Capital, labor and natural resources, crop production, farm practices, agricultural input and output cost, management skills, size of the operation, accurate information to farmers about BDMs influenced adoption among growers (Velandia et al., 2019b).

Regarding awareness, merely two studies were carried out, as illustrated in Fig. 2, which accounts for 13.3% of the articles screened. The studies show that there was less awareness about BDM among Saudi Arabian farmers (Muddassir et al., 2024). However, a substantial portion revealed their willingness to adopt BDM in the future. This clearly indicates that more information is needed to improve farmers' awareness about BDM technology. The study also indicated the influence of socioeconomic indicators in adopting BDM (Muddassir et al., 2020).

The adoption of biodegradable mulch among growers in the developed countries is not unconnected to their readiness for environmental protection. Biodegradable mulch reduces waste sent to landfills and minimizes the production of greenhouse gases. The weed suppression effect of the BDM also reduces the use of herbicides, this not only improves environmental health but also reduces production cost (Scaringelli et al., 2016). The willingness of the conventional farms to pay is associated with the multiple benefits of the BDM which out weight the cost. Farmers are aware of the carbon sequestration effect of mulch. Waste management and its ability to utilize organic waste materials reduce disposal issues. Some studies (Scaringelli et al., 2016; Yang et al., 2023) also pointed out that adoption of BDM in developed nations is as a result of regulation by the states encouraging sustainable farming practices in line with smart agriculture beside environmental, social and economic benefits. The study by Chen et al. (2020) opined that the farmers' willingness to pay for BDM is associated with their support for biodiversity regulation. The study further claimed that mulch provides conducive habitat for microorganisms and insects that are beneficial to humans. From the study by Velandia et al. (2019a); Goldberger et al. (2019) it can be observed that adoption of BDM is limited due to many factors; including economic; education and awareness; policy regulation; technical and logistic; cultural and social and industry and market as well.

Velandia et al. (2019a) mostly outlined economic constraints (capital, labor, cost), and institutional constraints (skill and information). High upfront cost and limited availability and distribution are among the serious adoption challenges. Additionally, lack of sufficient knowledge as outlined by (Muddassir et al., 2024) about the benefits of BDM coupled with limited understanding of proper application and maintenance as well as misconceptions about BDM effectiveness are also important constraints. He further affirmed that the education level, farm size, and membership in agricultural cooperatives considerably influenced their familiarity with BDM (Muddassir et al., 2024). The farmers were not well informed of the possible advantages of BDM. Resistance to change and inadequate social norms to promote environmentally smart agricultural practices is also a challenge as stated by Dentzman and Goldberger (2020). Other challenges which are very critical as outlined by Miles et al. (2017); Ramadhani et al. (2024) are over dominance of synthetic mulch, insufficient competition and innovation as well as weak investment in BDM investment. Some BDMs are also found to be not 100% biodegradable as such some governments put regulatory measures to the use of BDM. This review further highlights the scarcity of studies regarding the willingness to pay and the awareness among farmers concerning biodegradable mulch. The limited studies conducted showcased that adaptation of biodegradable mulch is limited due to lack of awareness, cost constraints, limited access to research and knowledge gap between farmers and researchers.

With these findings it is clear to note that although BDM has associated benefits ranging from environmental protection, soil conservation, production cost reduction, biodiversity and host of many other benefits, its adoption is halted by some constraint. On this basis it is therefore imperative for all the farming stakeholders across the world to intensify adoption of BDM for sustainable agriculture. To do this, it is required that education and training should be given priority, especially in the

developing countries where poverty, poor production practices and food insecurity are high. Regulatory standards and incentives should be given priority so as to harness farmers' minds for adoption. Similarly, investment in research and development together with improvement in infrastructure and waste management modalities are critical.

Several researchers are seeking literature and information about the adoption and awareness of biodegradable mulch among farmers to succeed in their future research. According to researcher knowledge, the current review article might be among a few studies that mainly focus on social perspective. Regarding contribution to existing literature, the present study contributes to ongoing literature in different ways. First, we explored the awareness of biodegradable mulch among farmers clearly explained with research findings. Secondly, we explained the adoption rate of biodegradable mulch among farmers and briefly mentioned the factors that influence on adoption. Moreover, the current review article could make easy access to literature for researchers for building theoretical framework. It provides an in-depth understanding of the influence of socio-economic relationships between the level of awareness and adoption of biodegradable mulch among farmers and knowledge on different types of pollution. Finally, our study promotes a mechanism by which institutions would act to design materials related to environmental knowledge.

Conclusion and Research Gaps for Future Studies

The review indicated a scarcity of research on biodegradable mulch. While limited research has been undertaken, most of it has concentrated on the aspect of adoption. Only a limited number were carried out regarding the willingness to pay and the awareness among farmers. In a similar vein, there has been no investigation into the production process, environmental consequences, or the economic and social ramifications. No research has specifically examined the perceptions and attitudes of farmers regarding BDM. No research has been conducted in Africa from a regional perspective, and very little has been done in Asia. Therefore, it is recommended that more incentives be provided to encourage the adoption of BDM. Addressing these research gaps will help improve the efficiency and sustainability of BDM in agricultural production.

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