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Understanding farmer preferences and trade-offs for adopting sustainable crop production: a systematic review

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Abstract
Despite the potential benefits of sustainable agricultural practices and their positive effects on the environment and sustainable food systems, adoption levels have remained relatively low. To better understand the underlying issues, this study conducts a systematic literature review to synthesize farmer preferences for adopting sustainable agricultural practices, focusing on both stated and revealed preferences. The study combines the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) approach and thematic analysis. The synthesis resulted in six broad themes in which preferences and trade-offs are elicited. They include soil management, water management, pesticide use reduction, fertilizer use reduction, smart farm technologies, and sustainable intensification. The review also examines features used to elicit preferences and their interconnections, and how they shape farmer decision-making on the adoption of sustainable crop practices. By focusing on preferences, we uncover critical insights into farmers' adoption behavior and decision-making, shedding light on the trade-offs farmers face when adopting sustainable practices. Results reveal significant heterogeneity in farmer preferences, which are highly context-specific and shaped by socio-economic and environmental factors. These findings underscore the need for context-specific strategies rather than one-size-fits-all solutions. The insights offer valuable guidance for designing targeted interventions to scale the adoption of sustainable agricultural practices effectively.

Keywords Crop farmer, Sustainable crop production practices, Stated preferences, Revealed preferences, Trade-offs heterogeneity

1 Introduction

The transition to more sustainable agricultural practices is not just a promising alternative but an urgent necessity for mitigating adverse health and environmental impacts stemming from agricultural practices. This transition further fosters resilience in farming systems in the face of climate change [1]. In recent years, there has been a growing recognition of the urgency to adopt more sustainable practices in the agricultural sector as a pathway for creating sustainable agricultural and food systems [2]. Furthermore, there are increasing consumer concerns about food safety, therefore exacerbating the need to transition towards more sustainable farming systems [3].

Despite the potential benefits of adopting sustainable agricultural practices, widespread adoption of these practices has remained relatively low [4]. While [5] notes that improving environmental performance often incurs costs, a critical policy dilemma lies in promoting the adoption of sustainable agricultural practices while simultaneously improving farm outcomes, such as improved crop productivity and on-farm profits [6]. The adoption of sustainable agricultural practices while maintaining production output may require the adoption of several complementary technologies and modified practices. For instance, a single innovation may not be able to replace all types of agro-ecological practices to maintain their crop yields [7].

While low adoption rates have been greatly attributed to socio-economic bottlenecks, understanding preferences for sustainable agricultural practices and the trade-offs they make when adopting these practices could potentially provide crucial insights that can be used to promote adoption levels [2, 8, 9]. The use of experimental approaches has gained significance over the years in designing agricultural and environmental policies since they allow assessments of trade-offs and welfare estimates ex-ante, and allow incorporation of farmer behavioral aspects [10, 11].

In line with this, researchers have shown increasing interest in quantifying how farmer preferences influence the decision-making process when adopting sustainable agricultural practices. However, the existing literature on farmers' preferences is highly mixed and inconclusive. Some authors attribute the inconclusiveness of the current evidence to the spatial heterogeneity of farms and farmers [12, 13]. Recent studies, such as [14] systematically examine farmers' decisions to adopt sustainable crop protection practices and evaluate the potential of policy measures to support this transition. Similarly, Möhring et al. [15] highlights the adoption of organic agriculture and provides insights to support policymakers in reaching policy goals.

Although prior reviews have broadly examined socio-economic factors influencing the adoption of sustainable practices, they rarely integrate the dual lens of stated and revealed preferences to unpack farmers' underlying motivations and decision-making complexity. This review uniquely addresses this gap by systematically analyzing the literature on both preference types, complemented by a thematic analysis to identify emergent themes in adoption preferences for sustainable crop production practices. By shedding light on the discrepancies between adoption intentions and actual behaviors, our work offers valuable insights into designing more targeted and effective interventions to bridge these gaps and scale sustainable agricultural practices.

Therefore, this study aims to systematically examine the role of farmer preferences in the adoption of sustainable crop production practices by exploring four research questions with the following objectives:

i. To identify the primary areas of focus in research on farmer preferences and trade-offs for adopting sustainable crop production practices
ii. To assess the design features used when eliciting farmer preferences for sustainable crop production.
iii. To evaluate the extent of knowledge on farmer preferences and their implications for the adoption of sustainable crop practices.

iv. To highlight the limitations of current research and identify open areas for future research.

To achieve these objectives, we thematically synthesize various domains of sustainable agricultural practices where farmer preferences have been studied, identifying areas of convergence and highlighting areas where evidence is mixed. We then identify various design features included in experimental studies to estimate farmer preferences and highlight the most common and under-researched features. Lastly, we highlight the limitations of the current research and provide potential areas of improvement for future research. This integrated approach not only bridges gaps in understanding farmer decision-making but also informs the design of more effective, context-specific interventions.

The outcome of this review has potential theoretical and policy implications. From a theoretical perspective, understanding how farmers' preferences and trade-offs influence adoption preferences for sustainable agricultural practices would enrich the current knowledge, offering a valuable contribution to the extant literature. Moreover, in terms of policy implications, gaining insight into the factors shaping experimental designs and their impact on farmer preferences could prove instrumental and effective in better targeting policy measures aimed at promoting the transition towards more sustainable practices.

The other parts of the paper are structured as follows: in Sect. 2, we discuss the methodology used in this synthesis, highlighting the search string and study selection, the screening process, the inclusion and exclusion criteria, data extraction and analysis. In Sect. 3, we describe the results of the synthesis, followed by the discussion (Sect. 4) and lastly the conclusion (Sect. 5).

2 Methods

2.1 Search string and study selection

We used the Population, Intervention, Comparison, and Outcome (PICO) approach to develop the search strategy and to answer our research questions [16, 17]. Once the keywords (sustainable crop production, stated preference, revealed preference, and farmer) were identified, as shown in Table 1, the next step involved identifying their synonyms and combining them using Boolean operators.

The first term of the search string denotes our population of interest in the literature review. We included terms that would identify whether the subjects included were farmers. The second part of the search string represents the intervention of focus. In this section, we included 'sustainable crop production' and its close variations following [18]

Table 1 PICO approach

Population	Intervention	Comparator	Outcome
Farmer	Adoption of sustainable crop production	Preference analysis	Stated and revealed farmer preferences
Grower			
Producer			
Plot manager			
Landowner			

Note: PICO denotes Population, Intervention, Comparison, and Outcome approach and [2] approach of clustering environmentally friendly approaches. The search terms referring to practices were kept broad enough to cover most sub-types and practices of sustainable crop production as opposed to including specific practices that would make the search string so long and potentially exclude important papers for review [2]. The final part of the search string defined the outcomes of interest and included terms such as 'choice modelling', which are common terms in the preference elicitation literature. The search string was tested, queried, and redefined several times to capture all the relevant literature. The final search string included the following terms (Table 2).

2.2 Screening process

The literature search was performed in the Scopus electronic database and the Web of Science in January 2024. The literature search in SCOPUS returned 1508 studies, while the literature search in the Web of Science returned 1157 papers, resulting in a combined total of 2665 studies. These studies were then exported to Zotero reference management software, which was used to identify and remove duplicates. A total of 388 duplicates were identified and removed, leaving 2277 unique studies for the first-level screening of titles and abstracts. Subsequently, 316 studies underwent eligibility checks based on a full-text basis and were further subjected to critical appraisal. This resulted in 48 papers that were included for synthesis in this review.

2.3 Inclusion and exclusion criteria

The following inclusion criteria were used: (1) studies that were conducted with crop farmers since they are key decision-makers when adopting sustainable agricultural practices, (2) studies that either assessed stated or revealed preferences, (3) studies that addressed farmer preferences for sustainable crop practices and lastly studies that were published in the English language. Similarly, we defined the exclusion criteria that was used to narrow down to the specific studies of interest. This included (1) papers that were not published in the English language, (2) studies that were not published in peer-reviewed journals, for example, working papers and conference proceedings, (3) papers that involved livestock farmers, (4) papers that only assessed farmers willingness to pay or willingness to accept without making references to farmer preferences for sustainable agricultural practices, (5) studies that addressed consumer preferences for agricultural commodities grown using sustainable practices without reference to preferences for sustainable agricultural practices, (6) studies assessing preferences but does not explicitly refer to sustainable practices and lastly studies that assessed farmer preferences for

Table 2 Search terms

farmer* OR "landowner*" OR "land owner" OR producer* OR grower* OR "plot manager"
AND
"sustainable crop production" OR agroecolog* OR biodiversity OR diversity OR diversification OR ecological OR ecology OR organic OR integrat* OR silvopastoral OR "agri-environment*" OR "ecosystem service*" OR agroforestry OR agrobiodiversity OR "eco-scheme*" OR "conservation scheme*" OR "agri-environmental scheme*" OR "integrated pest management" OR IPM OR "pesticide reduction" OR reduce pesticide* OR "pesticide-free"OR "pesticide free agriculture" OR "sustainable pest practices" OR "sustainable crop protection" OR "good agricultural practice*" OR precision OR sustainab* OR "crop residue management" OR environment* OR "resilient agriculture*" OR "climate-smart- agriculture" OR permaculture OR "holistic farming"
AND
"stated preferenc*" OR "revealed preferenc*" OR "choice modelling" OR "stated choic*" OR "revealed choic*" OR preferenc*

agri-environmental schemes or provision of ecosystems service without direct reference to farmer preferences for specific sustainable agricultural practices.

Further, the studies were subjected to a critical appraisal strategy that was adapted and modified from [11, 19]. The critical appraisal aimed to assess the quality of conduct of the papers that passed the inclusion and exclusion criteria. This stage was assessed using the following questions: (1) are the aims of the study in relation to farmer preferences for sustainable agricultural practices clearly stated?, (2) are the scope, context and experimental design clearly defined?, (3) what is the rationale of the attributes and features included in the design of the experiments?, (4) How sampling of data was done and how data was collected, (5) is the research process documented adequately and all research questions answered? and lastly, whether the main findings of the study are well stated and whether policy recommendations and conclusions were drawn from the study findings.

The search strategy and screening process used in this synthesis are outlined in the following PRISMA flow chart (Fig. 1), which has been adopted and modified from [20].

2.4 Data extraction and analysis

Key data were extracted from each study in line with the objectives of this review. The data extraction sheets (see supplementary material 1) captured the characteristics of the studies (e.g. authors, year, country and scope of the study), the sustainable agricultural practices, type of farmers, sample size, methodologies applied, features considered in preference elicitation, key findings and policy implications. To delve deeper into the nuances of the studies, we implemented a thematic analysis in NVivo software. The data extraction file was converted into a codebook that was further developed through deductive and inductive coding. Deductive coding refers to a provisional list of codes that are predetermined to explore the study's research questions, while inductive approaches refer to the identification of emergent, data-driven coding that ultimately identifies themes during the synthesis of studies [21] (see supplementary material 2) that shows the codebook used in NVivo, highlighting the parent and child nodes.

3 Results

The study characteristics highlighting the authors, year of publication, country where the study was conducted, type of experimental approach, data collection settings and methods applied are summarized in Table 3. Most studies were categorized under soil management and pesticide use reduction themes and mainly implemented in the global North. The use of choice experiments to elicit farmer preferences for sustainable crop production practices was the most common experimental approach, and more than three-quarters of the studies reviewed collected data through face-to-face interviews. As shown in Fig. 2, research towards pesticide use reduction has been increasing over the years, showing the importance of reducing pesticide use as a key factor in achieving sustainable crop production goals. Interestingly, the papers reviewed showed that the research focusing on farmer preferences for sustainable crop production with smart farm technologies appears to be a recent development.

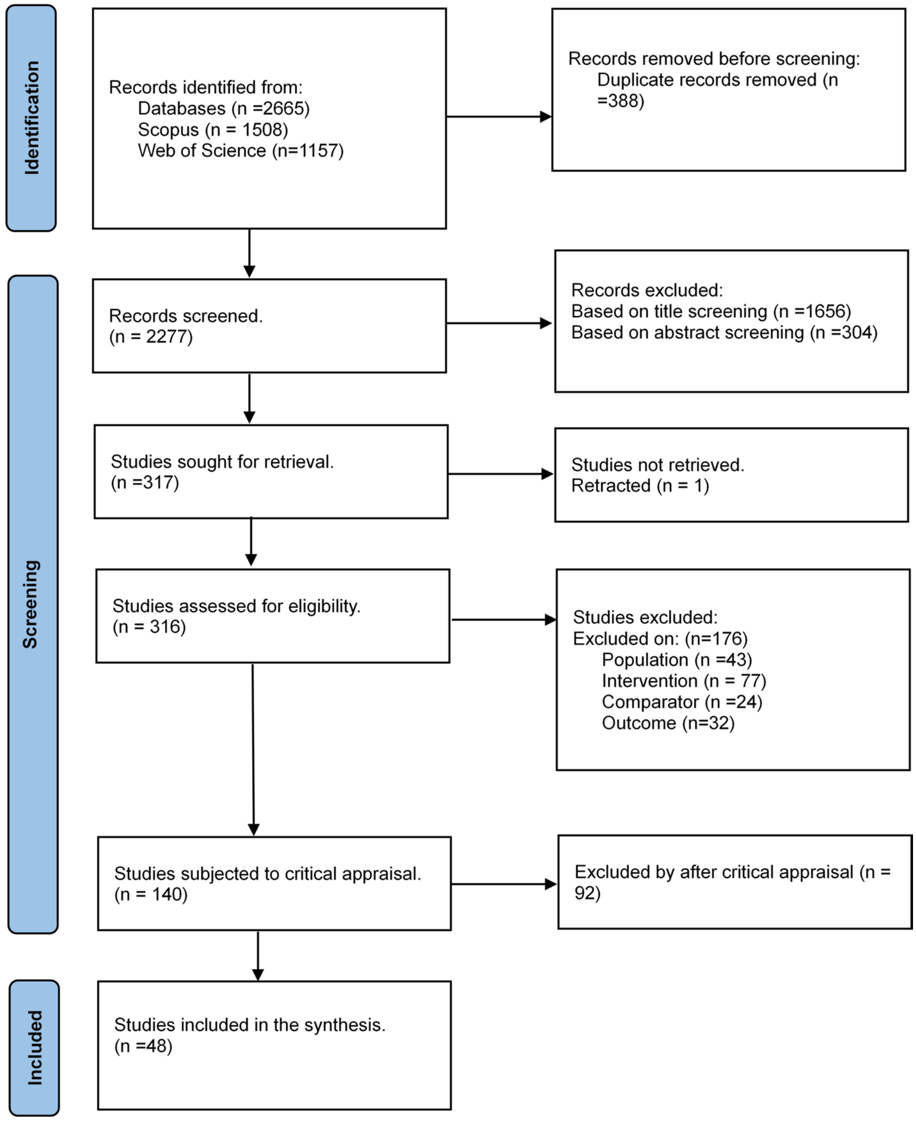

Fig. 1 PRISMA flow diagram

3.1 Preferences for sustainable crop production

Following the thematic analysis of the selected studies using NVivo, as highlighted in Sect. 2.4, we clustered preferences for sustainable crop production practices into five main themes, namely fertilizer use reduction, pesticide use reduction, soil management, water management, sustainable intensification, and smart farm technologies. Recognizing the interconnected nature of these themes, which both influence and are influenced by one another, we aim to highlight their linkages to provide a more integrated perspective on adoption preferences for sustainable crop production. In the following subsections, each theme is discussed in detail, highlighting their interrelationships.

3.1.1 Fertilizer use reduction

The literature on preferences for fertilizer use is mainly centered around farmer preferences for reduced amounts of fertilizer application and precision application of the required amounts of nutrients or application of alternative sources of plant nutrients

Table 3 Study characteristics

Study	Year	Country	Sample size	Approach	Setting	Statistical technique/method
Ciliberti et al.	2020	Italy	198	Choice-based conjoint	Face-to-face interview	Multinomial logit model
Blasch et al.	2022	Italy	250	Choice experiment	Face-to-face interview	Mixed logit model, latent class analysis
Xin et al.	2021	China	120	Choice experiment	Face-to-face interview	Multinomial logit model
Tur-Cardona et al.	2018	Belgium, Denmark, France, Netherlands, Germany, Hungary, Croatia	550	Choice experiment	Face-to-face interview, online survey	Random parameter logit, latent class analysis, conditional logit model
Liu et al.	2023	China	142	Choice experiment	Face-to-face interview	Random parameter logit, latent class logit
Houngbo et al.	2021	Benin	400	Choice experiment	Face-to-face interview	Latent class logit
Tiet et al.	2021	Vietnam	586	Choice experiment	Face-to-face interview	Hybrid choice model
Lévesque et al.	2021	Canada	1875	Choice-based conjoint	Online survey	Latent class analysis, hierarchical Bayesian
Nong et al.	2021	China	501	Choice experiment	Face-to-face interviews	Random parameter logit, conditional logit model
Blazy et al.	2011	French West Indies	607	Choice experiment	Face-to-face interviews	Random parameter logit, latent class analysis
Chèze et al.	2020	France	90	Choice experiment	Face-to-face interviews, online surveys	Random parameter logit
Bjørnåvold et al.	2022	France	110	Choice experiment	Online survey	Latent class analysis
Nong et al.	2021	China	501	Choice experiment	Face-to-face interviews	Conditional logit model, random parameter logit
Colin Castillo et al.	2022	Mexico	146	Choice experiment	Face-to-face interviews	Latent class analysis
Vidogbéna et al.,	2015	Benin	558	Choice experiment	Face-to-face interviews	Scaled multinomial logit model, Generalized multinomial logit model
Ridier et al.	2021	France	71	Referendum discrete choice experiment	Face-to-face interviews	Random parameter logit model
Liu et al.	2023	China	1193	Weighted frequency approach	Face-to-face interviews	Two-stage Heckman model
Colombo et al.	2006	Spain	345	Choice experiment, Contingent valuation	Face-to-face interviews	Conditional logit model-Random Parameter Logit
Schaafsma et al.	2019	Malawi	198	Choice experiment	Face-to-face interviews	Mixed logit model estimated in preference-space
De Salvo et al.	2018	Italy	125	Choice experiment	Face-to-face interviews	Mixed logit model, multinomial logit model
Haile et al.	2019	Ethiopia	200	Choice experiment	Face-to-face interviews	Generalized multinomial logit, latent class conditional logit model
Silberg et al.	2020	Malawi	215	Choice experiment	Face-to-face interviews	Random parameter logit
Sooriyakumar et al.	2019	Sri Lanka	211	Choice experiment	Face-to-face interviews	Conditional logit model

Table 3 (continued)

Study	Year	Country	Sample size	Approach	Setting	Statistical technique/ method
Hills et al.	2021	USA	90	Choice experiment	Written surveys	Multinomial logit model
Barrowclough & Alwang,	2018	Ecuador	233	Choice experiment	Face-to-face interviews	Random parameter logit
Jaeck & Lifran,	2014	France	104	Choice experiment	Face-to-face interviews	Random parameter model, latent class analysis
Tarfasa et al.	2018	Ethiopia	359	Choice experiment	Face-to-face interviews	Random parameter logit
Alcon et al.	2022	Spain	396	Choice experiment	Face-to-face interviews	Conditional fixed effects model, mixed logit models
Krah et al.	2019	Malawi	226	Choice experiment	Face-to-face interviews	Conditional logit model, random parameter logit
Sardaro et al.	2021	Italy	400	Choice experiment	Face-to-face interviews	Latent class analysis
Snapp et al.	2019	Malawi	668	Choice experiment	Face-to-face interviews	Random parameter logit, latent class model
Palm-Forster et al.	2016	USA	49	Field experimental auctions	In-person auctions	Becker–DeGroot–Marschak mechanism
Hope et al.	2008	India	640	Choice experiment	Face-to-face interviews	Multinomial logit model, latent class analysis
Franzén et al.	2016	Sweden	135	Choice experiment	Online survey	Generalized linear mixed model
Cason et al.	2003	Australia	8	Laboratory experiment	Computerized laboratory experiment	English auction
Crastes et al.	2014	France	619	Choice experiment	Face-to-face interviews	Random parameter logit
Alhassan et al.	2022	Ghana	500	Contingent valuation	Face-to-face interviews	Double-bounded contingent valuation
Liu & Brouwer,	2022	Canada	120	Choice experiment	Online surveys	Multinomial choice model
Anugwa et al.	2022	Nigeria	96	Contingent valuation	Face-to-face interviews	Probit model
Tao et al.	2023	China	1300	Choice experiment	Face-to-face interviews	Mixed logit model
Sok & Hoestra,	2023	Netherlands	156	Best-worst scaling survey experiment	Online survey	Multinomial logit, uncorrelated mixed logit, correlated mixed logit
Weituschat et al.	2023	Italy	314	Choice experiment	Phone interviews, self-administered surveys	Random parameter logit
Canales et al.	2024	USA	237	Choice experiment	Face-to-face interviews	Random parameter logit
Badolo et al.	2022	Mali	700	Choice experiment	Face-to-face interviews	Mixed logit model, multinomial logit model
Jourdain et al.	2020	Laos	120	Choice experiment	Face-to-face interviews	Mixed logit model with error-component
Ward et al.	2016	Malawi	1709	Choice experiment	Face-to-face interviews	Random parameter logit

Table 3 (continued)

Study	Year	Country	Sample size	Approach	Setting	Statistical technique/method
Krupnik et al.	2017	Bangladesh	300	Choice experiment	Face-to-face interviews	Random parameter logit, multinomial logit model
Pham et al.	2022	Vietnam	300	Choice experiment	Face-to-face interviews	Cluster analysis, multinomial logit models

Notes. From the literature, random parameter logit and mixed logit models are used interchangeably

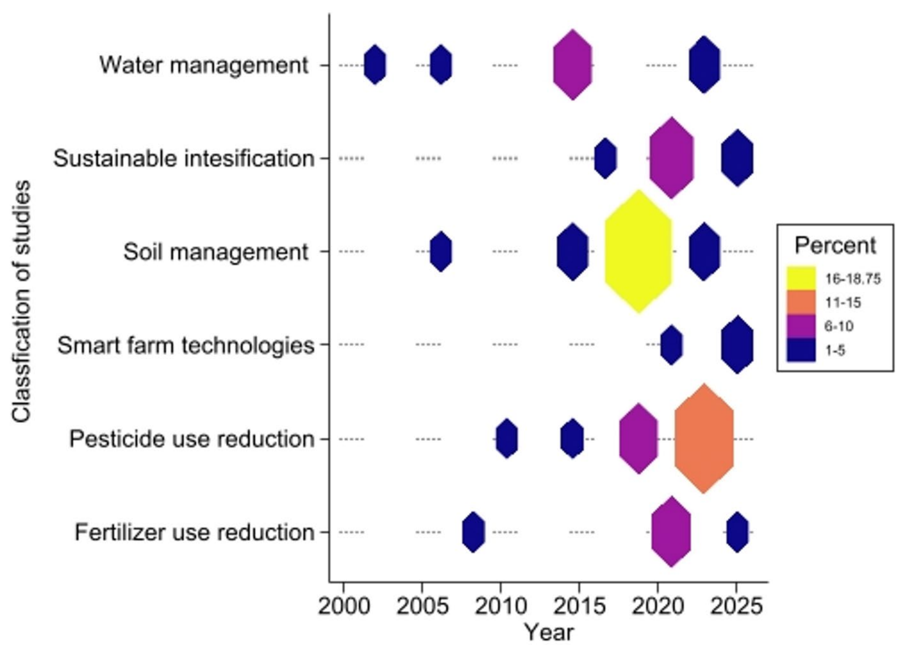

Fig. 2 A hexplot showing the clustering of studies and publications over the years

such as the use of bio-based fertilizer. While fertilizer application is important to achieve higher crop productivity and related household welfare outcomes such as increased farm income and nutrition, the overarching aim of the papers reviewed was to enhance higher productivity levels while aiming to reduce the negative effects of fertilizer use on the environment. This theme is closely related to pesticide use reduction, water management, and soil management, as reducing fertilizer use can decrease nutrient runoff that in turn affects water quality, enhance soil fertility through alternative nutrient sources, and complement agroecological practices that minimize pesticide reliance.

In a multi-country study across several European countries, Tur-Cardona etal. [25] assessed farmers' preferences for bio-based fertilizers to reduce reliance on chemical fertilizers. Results revealed that farmer preferences are highly heterogeneous within and across countries, and farmers prefer bio-based fertilizers that have almost similar characteristics as chemical fertilizers. Additionally, Xin et al. [24] noted gender-based preference heterogeneity, with male farmers showing a stronger preference towards the use of leguminous green fertilizer and having a higher WTP compared to female farmers.

In France, Canada, China, Benin, and the French Indies, farmer preferences for agroecological approaches to reduce fertilizer use, such as the use of cover crops, crop rotation, intercropping, tree planting, integrated pest management, and establishment of riparian buffer zones were reported [7, 27, 29–31]. Preferences are heterogeneous in the French West Indies, banana farmers tend to prefer intercropping practices, while new crop varieties are generally not preferred due to the perceived risks and complexities associated with new innovations. In China, preferences for crop rotation are higher in single cropping systems, while preferences for intercropping are tied to technical assistance, but generally, farmers prefer practices that have a shorter adoption period. In France, practices with higher nitrogen restitution are preferred, while in Canada, the WTP for restoration of hydric resources such as riparian zones and wetlands is reduced by 10%.

In Italy, preferences for the use of precision farming techniques like optimized nutrient application is largely influenced by factors such as the degree of automation, costs of adoption, and technical assistance [22, 23]. Moreover, farmers familiar with precision farming technologies through peer networks express higher preferences in various aspects of precision farming. On the contrary, findings from durum wheat farmers on their preferences for optimized nitrogen application were inconclusive in a separate study conducted in Italy [22]. Regarding reducing fertilizer use to control the eutrophication of lakes, Liu et al. [26] highlights how cash compensation influences farmer preferences for fertilizer reduction programs. Higher compensation amounts are required to incentivize farmers to reduce chemical fertilizers by large margins.

3.1.2 Pesticide use reduction

Studies covering farmers' preference for pesticide use reduction mainly cover four domains, namely, a complete ban on pesticide use, reducing the application amount, use of eco-friendly alternatives, or use of agroecological practices that limit the number of pesticides required. Pesticide use reduction is intricately linked to fertilizer reduction, soil management, and water management, as minimizing chemical inputs use can enhance overall soil health, reduce nutrient leaching into water bodies, and support biodiversity. Furthermore, the adoption of smart farming technologies, such as precision application systems, can lead to a reduction in pesticide use.

Farmers' willingness to adopt chemical-free inputs, specifically phasing out the use of glyphosate, was assessed among crop farmers in Mexico. While farmers showed a strong preference to receive management support from the authorities, a higher proportion of farmers were not willing to transition to a chemical-free input regime. Nevertheless, farmers with higher education levels, extensive farming experience, and greater social capital are likely to prefer collaborative arrangements that may influence the transition to chemical-free inputs [32]. On the contrary, vegetable farmers in Benin exhibited positive preferences for the use of eco-friendly nets to reduce the amount of pesticide used owing to their perceived effectiveness, durability, and environmental benefits, although they disliked the intensive labor requirement associated with the use of eco-friendly nets [12]. Similarly, rice farmers in China value and prefer the use of biopesticides and physical trappings for pesticide use reduction [64].

Preference for pesticide use reduction is highly influenced by farmer perceptions and beliefs. Reducing the negative effects on health and environmental impacts of pesticides is a significant motivator for farmers who believe that pesticides affect the environment. Further, farmers who earn off-farm income and believe that farm yields can be maintained while reducing pesticide use are more likely to prefer and adopt low-pesticide use practices [10]. Innovative monetary incentives such as sales contracts with guaranteed prices are highly preferred among organic farmers in Vietnam as an incentive to reduce pesticide use. On the other hand, preferences for non-monetary incentives such as product labels with traceable codes can influence preference for pesticide use reduction among farmers [28]. Other studies documented a preference for using organic methods over the use of chemical fertilizers due to perceived environmental benefits and improvement in irrigation practices [30].

3.1.3 Water management

Farmers' preferences for sustainable water management practices are mainly driven by the need to mitigate erosive runoff and protect groundwater. These preferences include controlling nutrient leaching, such as excess nitrates from chemical fertilizers, preventing eutrophication, and enhancing water retention in soils. This highlights the strong interconnection between water management and both fertilizer and pesticide use.

A study in the United States of America (USA) using field experimental auction for best management practices such as planning cover crops, filter strips and subsurface drainage control systems revealed that perceived transaction costs influence preferences for reducing eutrophication in lakes, and perceived monetary incentives increased farmers' willingness to enroll in agri-environmental programs aimed at reducing phosphorus run-off [47]. Similarly, 70% of farmers interviewed in Sweden cited the perceived costs of establishing wetlands to control eutrophication as the biggest hindrance. However, prior knowledge of water directive policies increased willingness to control for eutrophication by 30%, and annual compensation and subsidies significantly increased farmers' willingness to establish wetlands [49]. Additionally, land certification programs in India positively influenced farmers' preferences for organic farming to control water pollution by acting as a self-enforcing mechanism that links farmer incomes with wetland conservation benefits [48].

Preferences for water management practices such as planting of cover crops, establishment of buffer strips, and restoration of wetlands are only preferred in cases where farmers are already implementing these practices [53]. Similarly, Crastes et al. [51] observed that farmers prefer practices such as sodded bunds and water retention techniques. However, the study does not clearly establish whether these preferences are tied to the farmers' current practices or not. Farmers exposed to information about the effects of groundwater pollution on human health are willing to pay more on average for water conservation than those exposed to information about the effects of groundwater pollution on the environment [52]. Similarly, in Australia, through a laboratory experiment, Cason et al. [50] highlights how information can be used to enhance regulatory efficiency to reduce non-point source pollution of water; for example, when information on environmental benefits is revealed, landholders often misrepresent their costs compared to when information is concealed. Therefore, the total abatement of non-point source pollution is lower, and landholder profits are higher.

3.1.4 Soil management

Preferences for sustainable soil management practices are broadly grouped into three seemingly mutually inclusive groups: management of soil erosion, management of soil fertility, and control of weeds; a higher proportion of studies reviewed were skewed towards soil fertility management, which potentially points to the importance that soil fertility plays in agricultural production. Further soil management may be enhanced through sustainable intensification and smart farm technologies, which promote soil health through precision techniques and diversified cropping systems.

Maize farmers in Malawi had positive preferences for various intercropping techniques and planting options to improve soil fertility. Farmers with multiple plots are more likely to prefer soy-maize rotation systems, whilst single-plot owners prefer groundnut-maize intercropping and preferences for tree adoption, often promoted to improve or maintain soil quality [35]. On the contrary, in Ethiopia, farmers had a strong preference for a lower number of "fertilizer tree" *fidherbia albida* which is useful in fixing atmospheric nitrogen and general improvement in soil fertility, and were willing to accept about 0.18 dollars per ha per year if they had to plant an additional tree on their farm plot [13]. This finding is corroborated by [44] where farmers had a significant positive preference for nitrogen-fixing trees and plants such as gliricidia and pigeon peas.

While farmers in Ethiopia are willing to adopt soil management practices, their preferences are greatly influenced by land tenure systems and access to microcredits. They show a significant preference for practices such as vegetative bunds, terracing, and composting [42]. Similarly, wheat farmers in China had positive preferences for different attributes of leguminous green fertilizer, and improvement in the quality and fertility of cultivated land had the highest WTP values [24]. Farmers in Sri Lanka had positive preferences for improved soil quality, an increase in biodiversity, and a reduction of nitrates leaching as techniques for improving soil fertility [38], while maize farmers in Malawi had positive preferences for diversifying maize mono-crops with legumes as a solution to the declining soil fertility [46].

Cereal farmers in Italy reported positive preferences towards the maintenance of soil fertility and the control of the risk of soil erosion. In particular, turfing sloping surfaces was preferred to furrows-sinks. Additionally, among furrow sinks, farmers indicated a preference for more closed sinks [36]. Similarly, farmers in Spain had positive and significant preferences for reducing soil erosion, improving biodiversity and carbon balance in monoculture farming systems by diversifying to other farming systems through intercropping [43]. On the contrary, farmers in Ecuador had significantly negative preferences for controlling soil erosion, although they acknowledge it to be an important consideration in their farming, they are unwilling to pay much to abate soil erosion [40].

Farmers' preferences for weed control technologies to improve soil health are heterogeneous across farmers; some rice farmers in France show a positive preference for manual weed removal and mechanical weed, while others show no preference for moderated chemical use and strongly exhibit a significant preference for intensive chemical weeding [41]. Similarly, some farmers prefer while others do not prefer intercropping systems to control for Striga in maize farms [37].

3.1.5 Sustainable intensification

Research classified within this category focuses primarily on farmers' preferences for increasing crop productivity while mitigating negative environmental impacts and promoting positive environmental outcomes. Sustainable intensification may integrate fertilizer and pesticide use reduction, soil and water management, and smart farm technologies to enhance productivity while minimizing environmental impacts.

The emphasis of the studies reviewed revolves around how farmers can achieve higher yields in their existing agricultural land without expanding the land area under cultivation and mitigate potential side effects such as soil erosion, water pollution, and loss of biodiversity.

Sorghum farmers in Mali expressed strong preferences for transitioning from their existing sorghum-based cropping systems to sustainable intensification. However, there were diverse preferences among the smallholder farmers, majorly characterized by their social networks and agroecological zones, sorghum production options that increase grain and fodder yields, improve household nutrition, enhance soil fertility, and save labor are preferred by farmers [59]. Similarly, rice farmers in Bangladesh had significant preferences for intensification practices such as alternative irrigated crops and crop management options, for example, positive and significant preferences for rainfed or partially irrigated mung bean as an alternative to land fallowing [62].

Crop productivity in mono-cropping systems can be potentially improved using alternative sustainable intensification techniques. Specifically in maize monocrop in Laos, farmers' preferences for intensification practices such as maize-soybean crop rotation, maize intercropping with rice bean, and direct seeding mulch-based cropping systems were elicited. While farmers reported substantial heterogeneity, the most important attributes were related to effects on soil fertility and potential impacts on income [60]. Likewise, coffee farmers in Vietnam were willing to adopt sustainable intensification practices, they prefer practices that are likely to increase farm profits, lower risks, and contribute to environmental benefits. However, they express concern about the potential effects of these practices on time requirements and additional workload [63].

In some other cases, farmers may require both monetary and no monetary-based incentives to adopt sustainable intensification practices. Despite the potential benefits of conservation agriculture, farmers in Malawi were not willing to adopt intensification practices without receiving subsidies. However, the provision of subsidies may create perverse incentives; for example, they increased the adoption of intercropping and residue mulching, but the adoption of these practices may crowd out the adoption of zero tillage, leading to partial compliance [61]. This notwithstanding, [58] observed that incentive payment requirements by farmers who have previously adopted sustainable intensification practices are significantly lower than the payment requirements by non-adopters, which points to higher costs of additionality compared to continuity. In Italy, the establishment of contractual mechanisms was reported to significantly increase farmers' preferences for adopting sustainable intensification practices [57].

3.1.6 Smart farm technologies

Smart farm technologies serve as a cross-cutting theme that supports fertilizer and pesticide use reduction, water and soil management, and sustainable intensification by enabling efficiency and precision agriculture. Relatively fewer studies were categorized as “smart farm technologies”. Research on farmer preferences for “smart farm technologies” and how they enhance sustainable crop production is gaining interest. In a study to assess farmers' preferences for smart agricultural technologies, [54] argue that a relatively small portion of farmers use these technologies. Nevertheless, farmers mostly preferred smart drip irrigation and drainage management systems and weather-based agro advisories. On the contrary, many maize farmers in China use smart drip irrigation

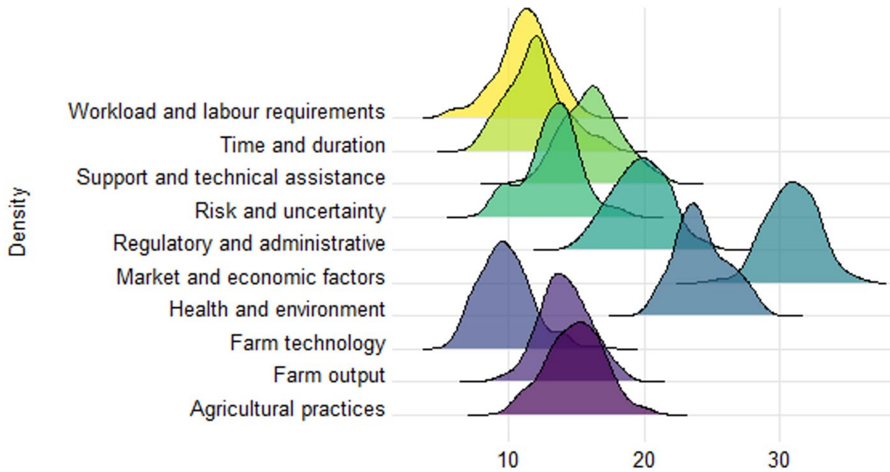

Fig. 3 A ridgeline plot of features for eliciting farmer preferences for sustainable crop production practices

technologies and have a strong preference for sustainable drip irrigation systems in general and their specific functions of smart sensing and smart control. However, farmers do not have a preference for the function of region-level agronomic planning [55]. Preferences are heterogeneous across farmers and preferences are associated with their education, experience of using computers, household income, access to credit extension visits, group membership, and holding of land.

In a study to elicit preferences for using electric farm tractors among Danish farmers to mitigate climate change and the use of fossil fuel, the farmers surveyed viewed investments in electric tractors as not feasible due to financial implications. In particular, they expressed concerns about the reliability of the tractors, their durability, and depreciation costs [56].

3.2 Design features for preferences for sustainable crop production

The features used to assess farmer preferences for sustainable crop production in the studies reviewed were classified depending on the attributes that were considered in the experimental designs. Following [11] the features were broadly organized into five broad sections with ten interlinked categories, namely, support and technical assistance, regulatory and administrative factors, time and duration, workload and labor requirements, health and environment, risk and uncertainty, market and economic factors, farm output, farm technology and agricultural practices. As shown in the ridgeline plot (Fig. 3), market and economic factors emerged as the most prevalent features included across the studies reviewed, followed by environmental and health factors and regulatory and administrative considerations. This underscores their importance when eliciting farmer preferences and trade-offs for sustainable crop production practices. In the subsequent sub-section, each category is discussed in detail.

3.2.1 Support and technical assistance

Adoption of sustainable agricultural practices may require extensive knowledge for proper application and usage; some practices may require specialized technical assistance and capacity building of farmers, while other practices that are less complex may require simple advisory services for their application. The provision of technical assistance and support, therefore, may influence the adoption preferences of farmers.

Studies reviewed included different aspects such as the inclusion of technical and practical support, advice and training, and the inclusion of specific technical aspects of farming practices.

Preference for technical assistance and support was elicited through different approaches, for example, through individual training or group training [53], provision of technical support through advisory follow-up, through farmer networks or no advisory support [31], through collaboration forums [49], and whether farmers would prefer advisory lessons or not [63]. Other authors explored farmer preferences by asking whether they would prefer the provision of technical support or not [23, 44]. Additionally, some studies elicited preferences for specific aspects of farming practices aimed at reducing pesticide use, such as the advice on the appropriate volume of bio-based versus chemical fertilizers, and on the use of chemical pesticides and fertilizers [25, 32].

3.2.2 Regulatory and administrative factors

The regulatory and administrative environment plays an important role in shaping farmers' adoption preferences for sustainable agricultural practices. While some regulations may incentivize the adoption of these practices, others may create unintended bottlenecks that may limit adoption on a large scale. Different aspects of regulation and administration have been considered in experimental designs. Some authors included temporal dynamics and long-term commitment features that reflect government policies, programs, and agricultural initiatives, for example, the duration of the program and engagement [29, 45], contract length [13, 42, 53] and the time frame for subsidy commitment [49]. Such features highlight how the structure and duration of regulatory frameworks influence farmer preferences.

Aspects related to contractual agreements and insurance schemes [32], payment schemes and conditions [29, 58], traceability of agricultural goods, and sales contracts [63] is often considered. They highlight the importance of ensuring transparency, accountability, and fair compensation within agricultural supply chains, which may incentivize farmers to adopt agricultural practices. Other studies focus on broader institutional and policy contexts within which farmers operate, such as the management of markets [32], program implementation [61], geographical scale and tenure systems [29, 42]. They highlight the regulatory constraints and support mechanisms that shape farmers' decision-making processes.

3.2.3 Time and duration

A few studies have tried to assess farmer time preferences specifically related to either the time taken for farmers to start adopting sustainable agricultural practices, the duration that farmers are willing to adopt sustainable practices, or their effectiveness, defined by the time it takes for the sustainable agricultural practices to be effective. As noted earlier in Sect. 3.2.2, the majority of studies included the aspect of time from the contract design and duration lens.

Including the aspect of time preferences may give insights into farmers' commitment to adopting sustainable agricultural practices given that, often, benefits of sustainable cropping technologies are not always realized in the short term as they involve long-term and cascading effects on crop yield and soil quality. Studies reviewed included aspects such as duration of engagement and duration of adoption. Farmers exhibited preferences for shorter adoption periods [30]. Similar observations were reported by [7] and [45].

Pham et al. [63] included the aspect of time required to set up sustainable agricultural practices, farmers preferred practices that would take a short duration to set which points to farmers' negative preference for time and labor-intensive practices. Other studies assessed the temporal aspects associated with the implementation and effectiveness of sustainable agricultural interventions, for example, the time required for practices to be effective [63] and the time taken until improved yields can be observed [35]. In the same line, Chèze et al. [10] assessed farmer preferences for temporal considerations associated with transitioning from conventional to sustainable farming practices, acknowledging the gradual nature of change.

3.2.4 Workload and labor requirements

Relatively few studies incorporated the aspects of workload and labor requirements of adopting sustainable agricultural practices. This aspect is largely represented in three dimensions, whether sustainable agricultural practices increase, reduce or maintain the existing labor requirements and were either expressed quantitatively or qualitatively. Jourdain et al. [60] expressed labor requirement as the percentage change from the average labor requirements of their current cropping systems while [7, 37] expressed workload and labor requirements in more simplistic approaches like a general percentage increase or decline in labor requirements. Hope et al. [48] estimated labor requirements by defining labor in terms of labor days, for example, the labor days needed to compost one trolley. Of the studies reviewed, only [46] expressed labor using qualitative aspects, for example, eliciting farmer preferences for adopting sustainable agricultural practices with low or high labor requirements.

3.2.5 Health and environment

Sustainable agricultural production is key to achieving positive health and environmental outcomes while ensuring adequate farm profitability and adequate food production. Therefore, potential effects on health and the environment are key features that may influence farmers' preferences. Some studies only consider wider dimensions of human health and environmental concerns without mentioning specific aspects; for example, they may express these outcomes as a percentage reduction of pesticide residues in the environment, a percentage improvement of health outcomes, or qualitative measures such as low medium, or high improvement [10, 27, 31].

A few studies delve into specific environmental indicators such as air and water quality [24], soil quality [38] and surface and groundwater quality [34] while other studies focused on ecosystem health and resilience-related attributes, including biodiversity, carbon balance, and diversity of landscapes [43], infrastructure against erosive runoff [51], flora and fauna quality [34]. Some attributes may have indirect impacts on human health, such as the amount of chemical residues and the amount of labor requirements to implement agricultural practices, which could be potentially detrimental to farmers [63]. Overall, environment and health are intricately interconnected, with the well-being of one directly impacting the other.

3.2.6 Risk and uncertainty

Risk perceptions and risk preferences greatly influence farmers' decision-making process when adopting sustainable agricultural practices. Farmers exhibiting high-risk aversion behaviors are more likely to use more pesticides in agricultural production and their adoption of sustainable practices is likely to be low [65]. The papers reviewed assessed three dimensions of risks and uncertainty, namely, risks related to yield, risks related to farm income, and risks of pest management on human health and the environment.

Risks related to output losses are expressed in different but seemingly related ways, for example, risk was defined as the frequency of below-average yields, which is expressed in terms of years [41], a percentage reduction in yields over a certain time-period [59], frequency of years in which production declines [10] and in a qualitative measure such as high, medium or low [63]. On the other hand, risks related to farm income were expressed as the probability of changes in net returns and average changes in profits over a certain time duration [58].

3.2.7 Market and economic factors

Economic and market factors are key determinants influencing farmers' preferences for adopting sustainable agricultural practices. Farmers are often concerned with the financial and market implications of such an adoption. Variables such as market price, price changes, and price premiums are commonly used to reflect market conditions and farmers' willingness to pay for specific attributes. These premiums, particularly for sustainably cultivated or organic products can expand market opportunities by appealing to environmentally conscious consumers [22, 25, 32, 57]. In parallel, the costs associated with adopting sustainable practices are frequently assessed alongside potential cost savings [12, 23, 39, 48].

Profit-related attributes such as gross margin, income, profit, and net returns are used to capture the financial implications of adoption. These metrics reflect both cost reductions and revenue gains, helping to evaluate the profitability of competing options and thus influencing farmers' preferences for sustainable crop production [10, 33, 58, 60]. Additionally, attributes related to subsidies, compensation, and taxation are used to capture the influence of government policies and incentives in shaping farmer decision-making. Annual subsidy, tax regimes, compensation, and government cost share are examples of such features that capture the financial support or burdens imposed by regulatory frameworks [34, 49, 51, 53].

3.2.8 Farm output

The potential effects of sustainable agricultural practices on farm output are of central concern among farmers as well as policymakers. Practices that are likely to increase farm output may increase farmers' preferences for adopting such practices, while those likely to impact yield negatively may not be attractive for farmers. Studies reviewed included different dimensions of farm input in the design of their experiment. An increase in yields and reduction of yield losses are common features that highlight the importance of enhancing productivity and minimizing losses [23, 27].

Other studies have included crop-specific attributes such as sorghum grain yield and fodder yield [59], legume yield and maize yield [37, 46], and an increase in maize yield [35] which provide nuanced preferences for sustainable agricultural practices on yields of specific crops. Other studies included temporal aspects of yield outcomes by including short and long-term yield projections, for example one one-year yield and four-year yield aspects [40]. This may offer insights into the expected yield trajectories over different time horizons after adopting sustainable agricultural practices. Lastly, other studies incorporate the aspect of risk and yield, for example increase in output loss, which may capture farmers' trade-offs between potential yield outcomes and the associated risk [63].

3.2.9 Agricultural practices

Different authors have utilized various agricultural practices-related features in experimental designs to understand farmers' preferences and decision-making processes. Adoption preferences for sustainable agricultural practices highly depend on the nature of the actual practices. In this category, we classified attributes that were directly linked to actual agricultural practices. These attributes encompass a range of practices aimed at enhancing agricultural sustainability and productivity. Some researchers have focused on conservation tillage and zero tillage, which minimize soil disturbance and promote soil health [30, 47, 61]. Others have explored the use of cover crops and intercropping, including whether farmers practiced intercropping or different intercropping systems using different crops depending on the kind and type of farmers [35], 61.

Furthermore, soil fertility measures and improvement strategies have been integral components of experimental designs, reflecting farmers' interest in maintaining and enhancing soil productivity. Studies expressed levels in terms of whether the sustainable agricultural practice would improve, increase, or maintain some quality after the adoption of the practice [37, 38]. Crop rotation, another important attribute, offers benefits such as pest and disease management, nutrient cycling, and weed control [41, 57]. Others considered the use of biopesticides to mitigate pest resistance, minimize environmental impacts [64] and breeding for tolerant varieties [66, 67].

3.2.10 Farm technology

Some sustainable agricultural production practices may require simple or more complex farm technologies for successful implementation, for example, the degree of automation, ranging from basic automation to advanced systems such as automatic and remote irrigation control and automatic and precise fertilizer application [23, 55]. The degree of automation and complexity may potentially influence farmer preferences substantially.

Another aspect that was considered is the scalability and adaptability of farm technology solutions. While some attributes focus on region-level agronomic planning, others examine the feasibility and effectiveness of technology at the local and land parcel level [55]. This distinction reflects the varying needs and contexts of farmers and emphasizes the importance of tailoring technology solutions to specific agricultural settings. Moreover, factors such as the reliability and persistence of technology, time for technology to be effective, and associated costs are crucial considerations in farmers' decision-making processes [12, 56].

4 Discussion

Many of the studies reviewed assess farmers' preferences for sustainable agricultural practices using stated methods compared to revealed preference methods. While the use of stated preferences, especially discrete choice experiments, has gained a lot of focus from researchers, the use of revealed preference techniques could be useful to examine different adoption rates for actual sustainable agricultural practices and why they differ as opposed to the use of hypothetical sustainable agricultural practices. Additionally, using complementary approaches like comparing stated preference data with revealed preference data can potentially increase the robustness of results, which can offer a deeper understanding of the decision-making process of farmers when adopting sustainable practices [63].

Some studies reviewed pointed out to potential biases, including non-random sampling, selection biases, and small sample sizes that may not be representative [10, 32, 35, 56]. This further constrains the validity and reliability of the findings. Over-representation of certain farmer demographics, for example, oversampling of men and overlooking women and other marginalized groups of farmers, especially in developing countries contexts [57] where online surveys are prevalent, over-presentation of farmers with larger farm sizes and higher education levels is common [31].

Moreover, inadequate sensitivity analysis of the elicited preferences, the possibility of hidden preferences among farmers, and the presence of a significant share of farmers' heterogeneity that remains unobservable and difficult to explain were observed in the studies reviewed [31, 33]. This underscores the need for more robust methodological approaches and deeper exploration of farmer decision-making processes. Further, the studies reviewed used cross-section data to make inferences; future studies can include longitudinal data to assess how farmer preferences for sustainable crop practices may change over time. The absence of adequate controls when designing experimental designs, for example, controlling for the differences in the existing sustainable crop production practices, may raise questions about the true nature of farmer preferences for sustainable agricultural adoption [12].

Few studies incorporated the behavioral aspect of farmers in the design of experiments, except for the aspect of risk, for example [10, 27, 41, 58, 58, 59]. Incorporating other behavioral aspects and psychological constructs in experiments could provide a more holistic approach to elicit farmer preferences for sustainable agricultural production. In the studies reviewed, some authors included a wide range of measures for cognitive and dispositional behavioral variables, from single-item to multiple-item constructs that were converted into a factor before being included in regression models, for example [44]. While this may be helpful in accounting for farmer preference heterogeneity, it may not capture the actual behavior of farmers during the decision-making process.

Adoption of sustainable agricultural practices is characterized by temporal dynamics, which is exhibited as the time lag between implementation and observation of good outcomes such as increased farm yield, improved soil fertility, and suppression of weeds. Our review noted that few studies incorporated this element, for example, see [63]. Farmers are more inclined to adopt chemical-based practices due to their perceived effectiveness. Therefore, future research could try to assess how time lag may influence the adoption preferences of farmers. Further, the role of land tenure systems, network and neighborhood effects and the impact of a practice change on farmers' work schedule and labor requirements needs more research attention to assess their impact on farmer preferences for sustainable crop production [10].

A recent development in the literature looking at farmer preferences for smart farm technologies showed how such technologies can be harnessed to promote the adoption of sustainable practices. More research in this area would be critical in understanding farmer preferences for such technologies to increase their adoption. Many studies reviewed focus on issues centered around chemical and pesticide use reduction. This points out the growing concern about the effects of pesticides and fertilizers on the environment, human health, and biodiversity. It is worth noting that most studies were centered around countries in the global North compared to countries in the global South, see [23, 25, 31, 33]. However, there is growing interest in shifting to pesticide-free agricultural systems. This review identified one paper that sought to elicit farmer preferences for chemical-free inputs [32]. Therefore, more research to understand farmer preferences and trade-offs for adopting chemical-free agricultural systems would help policymakers better target structures and systems to support this shift.

5 Conclusions

We conducted a systematic literature review that offers valuable insights into farmer preferences for sustainable agricultural production. We provide a comprehensive overview of the existing evidence and, in particular, adoption preferences for sustainable agricultural practices, features that are included in the design of the experiment. Through a rigorous synthesis of the studies, we identified common themes related to sustainable agricultural practices and features included in the experimental designs for assessing preferences among farmers. Based on our results, we identified limitations and existing gaps and highlighted areas where future research is needed to better understand farmers' adoption preferences for sustainable agricultural practices, existing gaps and possible areas of future research.

We found that studies focused on various aspects related to sustainable agricultural production for example pesticide use reduction, sustainable intensification, water management, soil management, fertilizer use reduction, and use of smart farm technologies. The majority of the studies synthesized in this review focused on soil management and pesticide use reduction. However, most of these studies were conducted in developed country contexts, which points out the overall policy concern on the effects of pesticide use on the environment. In contrast, countries in the global South are more focused on issues related to access and costs of fertilizer and pesticides.

Various types of features were included in the experimental designs, for example, duration, time, and workload; support and regulation; environmental and risk concerns; economic and market dynamics; technological and operational factors. These factors are important in assessing trade-offs that farmers have to make when adopting sustainable agricultural practices. As expected, all studies reviewed included economic and market features that enable the estimation of welfare estimates.

Despite the growing interest in how farmers' preferences shape the adoption of sustainable agricultural production, our synthesis identified potential limitations in the current studies and highlights areas for future research. There is a need for more consideration for including more behavioral and farmer psychological constructs, how social norms influence farmer preferences, and longitudinal studies to track changes in preferences over time and assess the long-term impacts of sustainable agricultural interventions. This would be useful in providing a holistic understanding of the farmer decision-making process and assist policymakers in designing tailor-made sustainable agricultural practices interventions that can be adopted at scale.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Data availability
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Declarations

Ethics approval and consent to participate
The study received ethical approval from the ZALF Ethics Committee (Ref. 20231201).

Competing interest
The authors declare no competing interests.

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