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Key factors influencing farmers' adoption of sustainable innovations: a systematic literature review and research agenda

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Abstract Despite the benefits of sustainable innovations in the agricultural sector being widely recognized, their adoption rate remains below the level designated by the 2030 Sustainable Development Goals. To understand the reasons behind this phenomenon, the current systematic literature review (SLR) provides a comprehensive overview of factors affecting farmers' innovation adoption behavior in developed countries. A total of 44 studies, published since 2010, were identified, analyzed, and summarized. The analysis revealed that specific innovation characteristics foster the innovation adoption process, together with individual psychological and socio-demographic features. It emerged that the path to adopting sustainable innovations can be driven by environmental values; for example, when comparing organic and conventional farming, organic farmers have a stronger environmental view and are more likely to take less into account economic gains. On the contrary, complexity of innovation, a high degree of innovation aversion, and a low perceived control over innovation are among the core barriers to the innovation adoption. Findings provide important insights on potential research avenues that could further depict farmers' adoption dynamics of sustainable innovations.

Keywords Sustainable agriculture · Organic agriculture · Farmers' behavior · Pro-environmental behavior · PRISMA framework

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Introduction

The adoption of sustainable agricultural innovations offers a promising alternative for mitigating the environmental impacts stemming from agricultural practices (Foguesatto et al. 2020). In recent years, there has been a growing recognition of the urgency to adopt more sustainable strategies in the agricultural sector, driven by a desire to assess their positive environmental effects (D'Amato et al. 2021). MacRae et al. (1990) asserted that the achievement of sustainability in agriculture relies on the pursuit of specific agricultural practices that aim to curtail the long-term repercussions of human activities on natural resources. Among the various options available, organic farming, precision farming, regenerative agriculture, and agroecology undoubtedly stand out as effective approaches (Ferreira et al. 2022; Ndaba et al. 2022; Sachet et al. 2021; Newton et al. 2020). These offer innovative solutions to tackle the challenges of agricultural sustainability, safeguarding the environment while ensuring the production of wholesome,

high-quality food. By embracing these modalities, farmers can promote ecological resilience, conserve natural resources, and respond to the pressing need for sustainable agricultural systems. Organic farming, in particular, is widely regarded as the most sustainable and responsive method in the primary sector (Ferreira et al. 2022; Canaj et al. 2021). It emphasizes the adoption of natural techniques and the exclusion of pesticides and chemical fertilizers, thereby promoting soil health and preserving biodiversity (Chiriacò et al. 2017; Lee and Yun 2015).

Even if organic farming has its roots in the 1990s (Kuepper 2010; Joachim 2006), it still represents a true innovation in the agricultural system by incorporating cutting-edge concepts of technology and research (Padel, 1994). This approach places ecological balance as a priority and strives to minimize the environmental impact of agricultural practices through the utilization of organic inputs and sustainable farming methods (Canaj et al. 2021).

Nevertheless, there are still several obstacles that slow down the implementation of sustainable practices that are useful for the ecological transition (Manta et al. 2022). Among them, development and technology transfer capacity and an attitude of resistance of farmers themselves to innovations appear to be the most relevant obstacles (Niggli et al. 2017).

It follows that, despite the recognition of the sustainable practice benefits, the adoption rate of sustainable innovations remains below the level designated by the Sustainable Development Goals (SDGs) identified by the United Nations for 2030, as many farmers are reluctant to adopt innovations (D'Amato et al. 2021; Foguesatto et al. 2020; Zeweld et al. 2017, 2018). To understand where the obstacle to the innovative adoption may lie, several studies and reviews have been proposed to deepen the analysis of the innovation adoption process among farmers and the multiple factors that may influence their behavior (Guerin 2001). It turned out that psychological factors play a strategic role in influencing the process of innovation adoption and diffusion among farmers (Caffaro and Cavallo 2019; Zulfiqar and Thapa 2018; Price and Leviston 2014), as well as socio-economic factors, including farmer's age, income, and education (Akimowicz et al. 2021; Serebrennikov et al. 2020; Caffaro and Cavallo 2019), and some contextual factors, such as the size of the farm, and the environmental and political context in which it operates (Piñeiro et al. 2020; Foguesatto et al. 2020; Hernandez-Vivanco et al. 2018; Bravo-Monroy et al. 2016). Nevertheless, psychological, socio-demographic, and contextual determinants that influence the farmer's innovation adoption process are often analyzed separately, producing in some cases conflicting results.

The presence of poorly defined and sometimes contradictory results in empirical studies may stem from the tendency to primarily rely on a variance-based approach, whereas a configurational approach might be more suitable.

The variance-based approach aims to identify the most influential factors on a particular phenomenon or outcome by analyzing correlation or regression coefficients. In contrast, the configurational approach examines complex patterns and configurations of variables that lead to specific results. Indeed, this approach recognizes that the combinations of variables or conditions can produce unique or different outcomes compared to individual variables (Furnari et al. 2021). The configurational approach argues that the different combinations of attributes lead to adoption, thereby explaining the existence of multiple pathways and potentially resolving contradictory findings (David et al. 2021; Fürstenau et al. 2021). Therefore, if this is indeed the case, employing a variance-based approach to analyze innovation adoption becomes futile, as it fails to fully illuminate the phenomenon under investigation. Concentrating solely on measuring correlations or cause-and-effect relationships between individual variables may prove inadequate in achieving a comprehensive understanding (Meyer et al. 1993). Innovation adoption, being a complex phenomenon, necessitates a thorough examination of the interactions between various variables and conditions. This approach acknowledges nonlinearity, where variables that are found to determine the development of a given phenomenon in one situation might yield different results in another situation (Fiss et al. 2013).

In this view, the current SLR uses a configurational theorization: past findings may be contradictory because they acknowledge that a given cause would affect all farmers in the same way, irrespective of its combination with other factors. When this assumption is challenged, it is necessary to revisit and reanalyze previous findings to provide a better account of the paths that lead to adoption.

The configurational approach acknowledges the concept of equifinality, understanding that different paths can lead to success in various contexts. For instance, a company might thrive through business innovation or a niche strategy, whereas the same approaches could result in failure for another organization. This approach recognizes the significance of disorder, diversity, and nonlinear relationships in shaping outcomes (Meyer et al. 1993).

Bearing in mind this scenario, the current SLR challenges the idea that there can be only one path to success during the innovation process, rather it sets out to identify all the factors that might come into play, aware that these may interact with each other in a multitude of ways and for a multitude of reasons. In doing so, the variables found in various studies will be categorized around two major reasons driving adoption: desirability and feasibility (Gatewood et al. 1995). Both dimensions are relational so that they result from interplay of agency (what farms can do and what innovations can do) and structure (what regulation or routines allow to do). It is assumed that if an innovation is seen as strongly desirable, farmer may make it feasible, by actively seeking to financial or technical aids. And conversely, if it is not deemed feasible, the desirability will be curtailed.

The results of this review could have both theoretical and policy implications. From a theoretical perspective, understanding the factors influencing the farmer's adoption of innovations would enrich the current knowledge, providing a valuable addition to the available literature. In terms of policy implications, a clear picture of the factors underlying the dynamics of farmer's adoption of product and process innovations could be useful in better targeting policy measures tailored to encourage sustainable innovations in the agricultural sector.

Research procedure

Review protocol

Writing an SLR entails the use of a protocol that systematically describes all the steps to be followed, from the definition of the research question to the careful analysis of the selected manuscripts. The study was conducted based on the following research question: "What are the main factors influencing the sustainable innovation adoption process by farmers?" Subsequently, a six-step selection process was followed starting in March 2021, according to the preferred reporting items for systematic reviews and meta-analyses approach-PRISMA (Page et al. 2021). Initially, the search results were manually tabulated in a spreadsheet, and duplicates were removed. Then, filters concerning the type of manuscript, the years and place of publication, and the English language were applied to select the documents, and later the titles and abstracts of the studies have been read. After this step, full texts were analyzed, and further exclusions were made when necessary. Furthermore, a quality assessment of the selected studies was performed in order to critically evaluate scientific studies to determine the quality, reliability, and validity of their results. The main objective of quality assessment is in fact to assess whether a study has been conducted in a rigorous manner and whether the results obtained are reliable and can be considered valid (Tummers et al. 2019). The development of a meta-analysis was excluded because, to make a correlation between variables, it is necessary to use homogeneous samples and results (Pati and Lorusso 2018). Indeed, it synthesizes econometrically the data from various sources to obtain a global estimation of the effect or association between the variables of interest. Instead, this review investigated studies of different nature (qualitative and quantitative) and studies using samples with different numbers of participants and diverse selection modes (mainly random convenience samples). More in depth, an integrative approach was chosen to explore the investigated studies due to their heterogeneity in designs and outcomes preventing quantitative analysis (Torraco 2005). When different studies exhibit significant differences in methodology, samples, outcome measures, or other aspects, conducting a traditional quantitative analysis such as a meta-analysis can be challenging or inappropriate. Instead, the integrative approach aims to obtain a comprehensive view of the results from the included studies, seeking to identify patterns, trends, or common themes that emerge through the analysis of both qualitative and quantitative evidence.

For each study, information about the year and country in which the research was conducted was identified, and information about the methodology used and the main

outcomes obtained was extracted. Finally, the factors influencing the innovation process were extrapolated.

The procedure was carried out by three researchers simultaneously, following the suggestion of Pati and Lorusso (2018), and the final outcomes were the results of a common agreement. The SLR was completed in December 2022.

Study selection criteria

Given the aim of the systematic literature review, a Boolean algorithm was applied as follows:

((organic OR sustainable OR green) AND (innovation OR practices OR product) AND (agricult OR farm* OR entrepr* OR producer OR food) AND (factors affecting OR risk OR driver OR barrier OR attitude OR behavior OR adopt* OR motives))*

The Boolean algorithm was launched on the Scopus and Web of Science platforms. Specifically, key terms were searched in the titles, keywords and abstracts of manuscripts contained in the Scopus database and searched in "topic" for the Web of Science database.

The output led to many studies (8167 in Scopus and 5784 in Web of Science). The two databases Scopus and Web of Science were chosen due to their thoroughness and reliability (Page et al. 2021). First, before implementing a manual selection screening, a time constraint was inserted (only papers published after 2009) and only English language studies published in journals were used. It was chosen to investigate this time frame because in the field of social sciences it is important to cover at least a minimum of 10 years for a SLR (Paul and Criado 2020); additionally, this time spam coincides with the recent growth of sustainable innovations in agriculture. Furthermore, book, general reports, and conference proceedings were also excluded as lacking peer review and with more limited availability (Alves et al. 2016). Finally, only studies reporting results from the primary data collection were included in the analysis, as they are suitable for collecting useful information (e.g., sample number, country, methodology, and factors that influenced farmers) to achieve the intended goal.

After applying these filters, the number of papers was reduced to 5746 on Scopus and 2853 on Web of Science (applying the "Advanced Search" window). Of these, the title and abstract were read to make an initial sorting, excluding studies involving consumer behavior, performed in developing countries, and studies not examining factors influencing farmers during the innovation process. In addition, only studies investigating process and product innovations were selected. This resulted in a total of 89 reports assessed for eligibility. The current study explores the adoption of product and process innovations by farmers, as both are essential for a company's long-term competitiveness (Damanpour and Gopalakrishnan 2001). These innovations drive significant structural changes on farms, necessary for achieving sustainability in the medium and long term (Gaziulusoy 2010). Process innovation, closely linked to product innovation, improves resource efficiency, promotes sustainable product design, and enhances product quality and range (Li et al. 2017; Damanpour 2010). Product and process innovations are interconnected and play a crucial role in driving agricultural development and competitiveness (Xie et al. 2019). Therefore, to have all the factors that may intervene in the process of innovation adoption is important to analyze both product innovations and process innovations. Furthermore, Zanello et al. (2016) pointed out that innovation is costly and risky; thus, pioneering innovation is mainly concentrated in few rich countries. Innovation requires appropriate institutions and policies to drive incentives and facilitate the process, as well as strong local capabilities to identify the right technology and appropriate transfer mechanism and to absorb and make adaptations based on local economic, social, technical, and environmental conditions (Fu and Gong 2011). Therefore, only innovation adoption in developed countries was analyzed, as these countries seem to possess the necessary scientific and technical knowledge to drive incentives and facilitate the process and the possibility to acquire the appropriate technology and transfer mechanism (Zanello et al. 2016).

Following this initial screening, the authors read the full manuscripts and applied the selection criteria, which brought the number of studies to 44. The applied procedure is fully shown in Fig. 1.

Results

Year of publication of the investigated studies

Figure 2 shows the years in which the studies analyzed in current SLR were published. Many of them were performed in recent years, highlighting the growing importance of the topic among scholars.

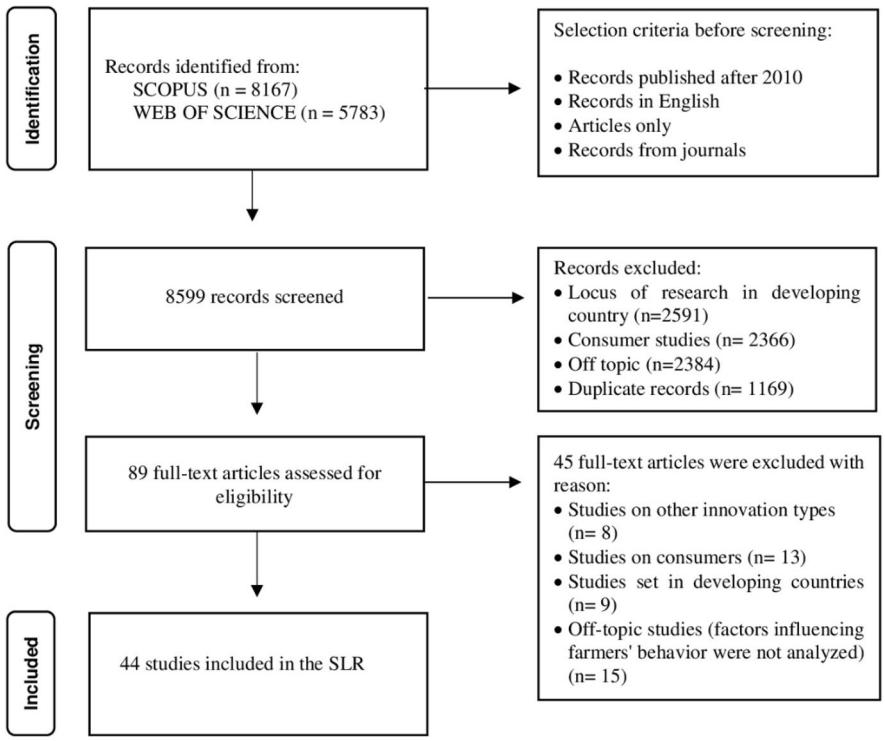

Fig. 1 PRISMA flow diagram

Countries included in the reviewed studies

The 44 studies in the review were carried out in 15 different countries. Most of the studies were conducted in Italy (9 studies), the USA and Germany (both with 8 studies), followed by the Netherlands and the UK with 7 studies. Four studies per country were conducted in Spain, France, and Australia, followed by Greece and Belgium with three studies, Switzerland, Hungary, and Denmark with two studies, and finally Poland with one study. The main geographical area of data collection was Europe. Six studies applied a multi-country sample, which is why the number of countries investigated is greater than the total number of papers selected. For more details, please see the Appendix (Table 4).

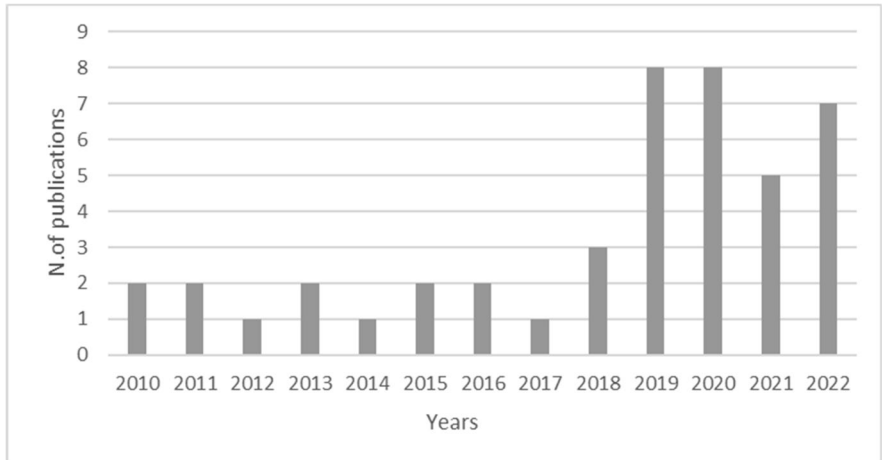

Fig. 2 Number of publications per year

Theoretical backgrounds of the studies

The main theories and models applied by the investigated studies were also detected. It was found that most of the studies were not built on a theory or model, but their reasoning was only supported by previous empirical studies. Indeed, only 19 studies referred to a theoretical strand. There have been many theories used (e.g., the theory of planned behavior, the reasoned action theory, the theory of technology acceptance and diffusion of innovation, the AKAP sequence, and the classification of internal and external barriers and risk management strategies), but always referred in some way to the psychological sphere of the entrepreneur.

Research methodologies of the studies

The methodologies applied by the studies were quite heterogeneous: 25 studies were developed through quantitative research approaches, 12 of the studies presented a qualitative methodology, and 7 studies were based on mixed-method approaches. In particular, the first category included semi-structured questionnaires and the use of national databases, the second involved face-to-face interviews, and the last one consisted of exploratory questionnaires and workshops, or focus groups, or application of experimental economics mechanisms. Almost all studies relied on convenience samples and data collection methods were generally, briefly described.

Quality assessment procedure and outcomes

The 44 studies included in the review were assessed for overall quality. This assessment was carried out by applying the eight quality criteria presented by van Dinter et al. (2021) (Table 1). Each study was evaluated based on the satisfaction of eight different requirements. A score equal to 1 was given when the criterion was fully met, a score equal to 0.5 in the case of incomplete information, and a score of 0 if the criterion was not met in the study. The quality assessment was developed independently by two scholars and all discrepancies were deeply discussed to reach a common final judgment. The concluding scores obtained ranged from the lowest score of 4.5 to the highest of 8. The mean was 6.21 and the median 6. 37.3% of the documents examined received a score below 6, 29.5% were between 6 and 6.5, and 33.2% were between 7 and 8.

Narrative summary of the studies

This section outlines the factors affecting the innovation process found within the analyzed documents.

From each study, the factors affecting the adoption of innovations in agriculture were extrapolated and then, were grouped into the two components of desirability and feasibility (Table 2). Indeed, the intention to innovate, which is considered an important antecedent to the implementation of innovation itself (Krueger NFand Carsrud 1993), is related to attitudes regarding perceived desirability and feasibility (Gatewood et al. 1995). Since intentions have been shown to be a good predictor of behavior (Ajzen 1991), understanding the identity and nature of antecedent factors that influence entrepreneurial intentions is of crucial importance to the study of entrepreneurial innovation behavior (Shane and Venkataraman 2000). However, the relationship between these factors is quite complex (Krueger and Kickul 2006).

Therefore, considering this complexity and drawing on configurational theory, factors influencing the

Table 1 Quality assessment criteria (van Dinter et al. 2021)

Quality criteria	Question
Q1	Are the aims of the study clearly stated?
Q2	Are the scope, context and experimental design clearly defined?
Q3	Is the proposed solution clearly explained and validated by an empirical study?
Q4	Are the variables in the study likely to be valid and reliable?
Q5	Is the research process documented adequately?
Q6	Are all the study questions answered?
Q7	Are the negative findings presented?
Q8	Are the main findings stated clearly in terms of creditability, validity, and reliability?

Table 2 Main factors affecting sustainable innovation adoption process

	Contextual and socio-demographic factors	Psychological factors
Desirability	Education Age Gender Continuous updating Organic certification	Attitude towards innovation Perceived relative advantage of implementing the innovation (e.g., ease of use or better market positioning) Subjective norms towards innovation Perceived behavioral control on innovation Awareness of the importance of innovation Environmental attitude
Feasibility	Compatibility Complexity Economic incentives Advice support Clear regulation Working conditions (e.g., morphological and structural) Company size Planned long-term management Cost due to implementation of the innovation Time employment Network structure	Risk attitude Absorptive capacity for new knowledge Knowledge of sustainable agriculture Adaptation/reinvention

adoption process of sustainable innovations were grouped within these two dimensions to understand what might influence one and/or the other. For comprehensive information regarding the sources of the different factors identified and general details about the selected papers, please refer to Tables 4 and 5 available in the Appendix.

This review underlined that the perceived advantages of using an innovation is among the most influential factors. Indeed, innovation characteristics such as "relative advantage" and "compatibility" significantly increased the probability of adopting sustainable innovations among farmers. If potential adopters do not perceive any relative advantage in the innovation and good compatibility of the innovation with the farm, they generally do not consider it further (Tey and Brindal 2012). Following this reasoning, farmers often have conflicting goals (Dessart et al. 2019), as they want to introduce sustainable innovations while protecting their production activity (Gosling and Williams 2010). Therefore, sustainable innovation is adopted only where farmers expect it to help them achieve their economic goals tolerance (Pannell et al. 2006). These results agree also with Ferlie et al. (2001) and Rogers (1995) as they also found the power of the variables described above. On the contrary, some authors argued that the implementation of sustainable innovations is negatively correlated with economic goals, and positively correlated with pro-environmental attitudes (Greiner 2015; Greiner and Gregg 2011; Kallas et al. 2010). This result may be surprising in that some sustainable practices yield more than conventional ones (Dessart et al. 2019). However, it is possible to assume that if farmers have a strong environmental vision, they may disregard economic gains. Thus, a path to adoption may be guided by environmental values so that farmers are willing to change their routines to adopt. These environmental values are stronger among organic farmers (Siepmann and Nicholas 2018).

The psychological and socio-demographic characteristics of adopters significantly influence their willingness to embrace innovations. According to Piñeiro et al. (2020) and Chams and García-Blandón (2019), farmers with higher levels of education, a proactive approach to staying informed about potential innovations, a positive attitude towards sustainability, adherence to social norms, and a sense of control over adopting new practices are more likely to engage in the adoption process of innovations within the agri-food sector. These factors are crucial in shaping the strategic role of individuals in embracing innovative practices.

Similarly, Pierpaoli et al. (2013) by a selection of 20 studies identified the acquisition of good information and education level as the socio-demographic factors most influencing the adoption of innovations.

On the contrary, in accordance with previous studies (e.g., Gupta et al. 2020; Kernecker et al. 2019; Lawrence and Tar 2018; Eastwood et al. 2017), it was found that the complexity of innovation, a high degree of innovation aversion, and the low perceived control over innovation are strong barriers to innovation adoption as they make the adopter insecure (e.g., Bechini et al. 2020; Aubert et al. 2012). At the same time, low education, poor advice support (Lindblom et al. 2017), and unfavorable working conditions (Caffaro et al. 2019; Bijttebier et al. 2018) turn out to be rather common hindering factors. Finally, the change of work routine and the increase in the market cost of the product also negatively influence the innovation process (Ghadge et al. 2020; Al-Rahmi et al. 2019) as it reduces the farmer's certainty in implementing innovation. In fact, resistance to change in work routines and the personality of the entrepreneur are related (Creissen et al. 2021; Dessart et al. 2019). Farmers who are not predisposed to change in general may be particularly against change in general (Bonke and Musshoff 2020; George and Zhou 2001), as changing routines triggers a high perception of risk in them (Bakker et al. 2021; Trujillo-Barrera et al. 2016). However, high-risk perception can be mitigated by a good risk tolerance (Trujillo-Barrera et al. 2016; Arbuckle et al. 2013). Despite this, a lot of farmers reject the change (Barreiro-Hurle et al. 2018; Hellerstein et al. 2013).

Regarding the age and gender of farmers, the current review has returned conflicting results, and therefore it is still quite problematic to understand the real impact of these personal features on the innovation adoption process. Indeed, different studies have produced contrasting findings regarding the relationship between age and innovation adoption among farmers. While some studies suggest that older farmers are more inclined to embrace innovation (García-Cortijo et al. 2019; Vezina et al. 2017), others highlight the significance of younger farmers in driving agricultural innovation (Jack et al. 2022**;** Bianchi et al. 2022). Similarly, the influence of sex on innovation adoption varies across studies, with both women and men being identified as active adopters in certain contexts (Aznar-Sánchez et al. 2020; Thorsøe et al. 2019). Finally, contextual factors are also influential. Indeed, this review showed that the possibility of having a comparison with other peers and technical and/or financial support significantly increases the likelihood that the innovation will be adopted (see, among others, De Steur et al. 2020; Bordbar 2014). One of the reasons for this is that policies can enhance the farmers' confidence and incentivize the adoption of sustainable practices. By offering tangible guidelines and support, policies can help farmers mitigate income volatility and foster a greater sense of security in embracing sustainable approaches. For example, through direct payments decoupled from production decreed by the European CAP, the risk tolerance of European farmers has increased (Koundouri et al. 2009). In addition, the ability to have advisory services can improve the farmers' awareness, their environmental concerns, and the significance they place on preserving natural environment (Cullen et al. 2018). Likewise, long-term planning and teamwork have been found to help the implementation of innovation. These findings are consistent with Pierpaoli et al. (2013) who state that the observability of innovation results, good work design, and perceived ease of use were ranked as determinants to be considered. Finally, farm size and years of experience have also been found to affect the innovation process, although in literature there are conflicting opinions. For example, regarding the size of the farm, Dalla Corte et al. (2015), Rosenbusch et al. (2011), and Cohen (2010) found that a smaller farm size gives the company a greater agility to change routines for innovation implementation. This agrees with Bonney et al. (2007) who state that small- and medium-sized farms have always adapt and innovate to remain competitive in the market. In contrast, Muzira and Bondai (2020), Serebrennikov et al. (2020), and Borgen and Aarset (2016) found that larger farms are better able to administer the innovation process because they have more funds, more workers, and strategic planning of the work to be done. About years of experience in the industry, García-Cortijo et al. (2019) and Vezina et al. (2017) found that older farms are more likely to adopt new practices or products because the farmer at their helm possess the experience that can guide them on the new path. Conversely, Gütschow et al. (2021) and Rosenbusch et al. (2011), in their study of SMEs, pointed out that younger farms benefit more from innovation because mature farms have already routines that are difficult to change in terms of organizations, cost, and time than new farms that have yet to consolidate their routines.

Type of innovation

The analyzed manuscripts were classified into four innovation categories: organic farming, precision farming, regenerative agriculture, and agroecology. Nine articles were found that investigated the adoption of precision farming by farmers. These studies highlighted the increasing interest in this practice and analyzed its positive effects on agricultural productivity and resource efficiency. Organic farming was examined in ten articles, indicating a growing interest in this sustainable cultivation method. The results of these studies highlighted the benefits of organic farming in terms of soil conservation, biodiversity promotion, and improved food quality. Regenerative agriculture was discussed in thirteen articles, demonstrating the growing attention towards this practice aimed at restoring and enhancing the health of agricultural ecosystems. Studies on agroecology, on the other hand, amounted to twelve, revealing significant interest in integrating ecological and social principles into agricultural practices.

The analysis of the selected studies in this SLR has shown that there are no particular factors influencing the adoption of one type of innovation over another. However, an attempt was made to summarize key factors that could help farmers adopt specific practices for each type of innovation. Table 3 below summarizes the results.

It has been found that the adoption of sustainable agricultural practices is facilitated by some common elements that play a crucial role in promoting change. Education serves as a fundamental starting point by providing in-depth information about specific practices and their benefits. This type of training enables farmers to understand the scientific rationale and positive impacts of sustainable practices. Similarly, technical support is equally important as farmers require hands-on assistance in implementing practices correctly. Expert consultants can provide personalized advice, helping farmers overcome technical challenges and optimize crop management strategies. Furthermore, economic incentives play a key role in motivating farmers to transition to sustainable practices. Subsidies, favorable financing, or tax incentives can reduce initial costs and mitigate financial risks associated with the transition. These incentives provide a financial boost and are an important encouragement for farmers to adopt sustainable practices. The networking structure is another important factor. Interaction and collaboration among farmers, experts, organizations, and research institutions facilitate the exchange of knowledge and mutual learning. Sharing best practices, experiences, and challenges allows farmers to benefit from the expertise of others and adopt more effective approaches. In addition to these elements, adaptation and reinvention are necessary. Sustainable practices require a flexible approach tailored to the specificities of individual farms and different regions. Farmers need to be willing to experiment with new methods, integrate traditional knowledge with innovations, and modify their existing practices to achieve more sustainable outcomes.

Lastly, continuous education is essential in this context. The agricultural sector is constantly evolving, with new scientific discoveries, technologies, and practices emerging regularly. Farmers need to stay informed about the latest trends and update their skills to adopt the best available solutions.

Research agenda

The results of the present SLR highlighted that scholars have detected several core factors influencing the adoption of sustainable innovations among farmers, including innovation characteristics,

Table 3 Key factors for each type of innovation

	Organic farming	Precision farming	Regenerative agriculture	Agroecology
Key factors	Advice support Economic incentives Education Network structure	Absorptive capacity for new knowledge Advice support Economic incentives Education Network structure	Adaptation/reinvention Economic incentives Education Network structure	Adaptation/reinvention Advice support Continuous updating Education Network structure

various socio-demographic and psychological features of farmers, and some contextual elements in which farms operate. Nevertheless, it is clear that this topic has not been completely probed, and there exist some under-explored research areas that require further investigation. Firstly, new studies should aim to investigate farmers' innovation adoption detecting contextual, psychographic, and socio-demographic characteristics together with innovation-specific features, providing a detailed picture of the factor enabling/hindering innovation adoption, and offering practical insights tailored to distinct typologies of innovation.

Secondly, from a methodological point of view, studies on the subject should be based on established theories or models. Indeed, in the current review, only 19 out of 44 analyzed studies referred to a theoretical model or theory. The literature points to multiple models and theories, and it would be wise to always choose the most appropriate one with respect to the intended goal. Third, future research should aim to achieve greater external and internal validity by involving larger/representative samples of farmers (since almost all studies have relied on limited convenience samples) and applying robust and transparent (and thus replicable) data collection methodologies typical of experimental studies. However, it should be kept in mind that this is quite difficult to do practically, and that the accuracy and reliability of the work also depend heavily on the theoretical models used and from the context of reference. Configurational theory suggests that there is no single path to pursue in implementing sustainable innovations, as there are infinite combinations of factors. In this view, researchers can reduce the possibility of reaching erroneous conclusions by formulating a priori hypotheses that can be pursued in multiple ways and by assessing the sensitivity of study conclusions to bias of varying degrees.

Concerning internal validity, scholars should apply validated data collection methods based on efficient designs and robust data quality control. Finally, data collection procedures (including all variables collected and exact protocols applied) should be fully disclosed in future studies, allowing researchers to replicate the analysis and effectively extend previous results.

Analyzing in detail the results of this SLR, some general considerations can be performed.

Firstly, a low number of studies have considered the socio-demographic characteristics of farmers as factors affecting the adoption of sustainable innovations. Moreover, when these factors were examined, the results were inconsistent. For example, Nastis et al. (2019) investigated the role of older farmers and, consequently, their years of experience on the farm as an important factor affecting the individuals' innovation adoption strategies. On the contrary, Barnes et al. (2019) found that younger farmers are more likely to adopt innovations due to a greater adaptive capacity to new technologies. Similarly, regarding the sex at birth variable, Aznar-Sánchez et al. (2020) revealed that being female encourages the adoption of innovative practices since women are more predisposed to collaboration with the farm team and/or other farms and companies of the sector. On the other hand, Thorsøe et al. (2019) found that men are more favorable to the adoption of innovations. Furthermore, many of the studies detected in the current review highlighted that educational background is a significant predictor of innovation adoption (Nastis et al. 2019; Mishra et al. 2018; Sassenrath et al. 2010) as it contributes to increasing self-confidence. In contrast with these findings, Barnes et al. (2019) found no effect on educational status. These conflicting results do not allow to depict a clear picture of the socio-demographic characteristics of the adopter. Therefore, to overcome these limitations of the literature, future research must further investigate whether age, gender, and educational status affect the process of innovation adoption into the farm. This finding could be of significant interest for policymakers to build specific incentives to foster the adoption of innovations in the agricultural sector.

Moreover, as emphasized in our results, few studies have studied the role of contextual factors in affecting sustainable innovation adoption. This is an important shortcoming in the literature as today it is essential for farms to develop open innovation strategies to be effectively competitive in the current, dynamic marketplace. Open innovation can lead to a balance between productivity and sustainability (Chesbrough 2003). Indeed, it has been shown that to facilitate the adoption of sustainable innovative practices, companies must collaborate and integrate their knowledge with external sources (Stefan and Bengtsson 2017). Thus, future research

should consider the importance of cooperation, as a strategic element for farmers' innovation adoption, both within the team and with other farms and organizations operating in the same field of interest, by emphasizing the potential benefits of cooperation and its different avenues.

Furthermore, regarding the types of innovation identified in this systematic literature review, it can be stated that all four agricultural approaches have demonstrated significant importance in terms of reducing environmental impact. For each of these approaches, it has been possible to provide a brief guide on the aspects to consider in order to assist farmers in innovating. These factors include education and information on sustainable approaches, financial support, access to specific resources and technical assistance for each practice, as well as collaboration and knowledge exchange among farmers.

Finally, we underline that it was surprising to note that only 10 articles analyzed innovation in organic agriculture. Organic agriculture has been at the forefront of the agricultural revolution in recent years. It is considered a priority by the European Union, primarily due to the significant impact of the agri-food sector in terms of CO_2 emissions and soil pollution. As a result, its implementation is among the objectives of the European Green Deal, which aims to gradually lead the continent towards climate neutrality. Therefore, it is crucial to promote further research on innovation in organic agriculture in order to effectively address environmental challenges and achieve sustainability goals.

Organic agriculture requires a constant commitment from farmers. It represents what the literature on innovations might define as a "radical innovation" (Dosi 1988): an almost total break with the knowledge networks of the productive paradigm, replaced by completely new and revolutionary techniques (Morgan and Murdoch 2000). The process of transitioning to sustainability requires farmers to set aside much of the knowledge they have acquired in intensive production and acquire new knowledge (Morgan and Murdoch 2000). In this process, the development of open innovation becomes essential. It is not surprising, therefore, that researchers have found that a lack of knowledge is one of the main obstacles to farmers' sustainable conversion (Padel 1994). Hence, it would be interesting to explore whether, in addition to stronger environmental values, there are further differences between farmers who are open to innovation and those who are not, concerning sociodemographic characteristics or teamwork skills, for example. Consequently, it is suggested that prospective studies analyze this topic in greater detail to better define possible differences in the adoption process of sustainable innovations.

Conclusions

The current review provided a twofold result: first, the different factors that have an important role in explaining the adoption of product and process innovations by farmers were detected. Second, the methodological gaps among the available studies were highlighted to provide actionable directions for future studies.

Furthermore, findings confirmed that innovation adoption is influenced by multiple factors of various natures that interact with each other during the adoption process and therefore cannot be considered individually. Subsequently, suggestions were formulated for the implementation of more internally and externally robust studies, resulting from a detailed analysis of existing methodological gaps in the investigated documents.

However, despite the relevance of the results, some limitations of the present SLR need to be highlighted. The first limitation deals with the nature of the review. Indeed, although the procedure is systematic, it must be assumed that, having to replicate this work, another group of researchers may give importance to the details that were overlooked in this SLR. A further limitation of this study lies in choosing to use only scientific articles and excluding all other documents (such as books and gray literature). Additionally, it is possible that valuable studies were published on platforms other than Scopus and Web of Science, despite their recognized value and dissemination in the international scientific community. Potentially interesting research may also not have been filtered as it might not have carried the specific search key terms in the text. In addition, the current review included only research performed in developed countries totally overlooking insights from developing nations. However, it should be remembered that these are characteristics of most

SLRs and depend, as Paul and Criado (2020) pointed out, on the subjective component intrinsic to the literature review process. Finally, the nature of the studies analyzed did not allow a thorough investigation of the interactions among the various factors influencing the innovation process. In this study we simply investigate which variables influence farmers' choices; nevertheless, it would be greatly valuable to investigate the relations among factors in further studies. In addition, future research might use different theoretical models and methodologies or might investigate one specific agricultural sector (or compare results across sectors), where farmers are more/less prone to innovations.

Despite these limitations, theoretical, methodological, and practical implications can be drawn from the work. From a theoretical point of view, these findings try to overcome the existing gaps of the literature, which is rather fragmented and incomplete especially regarding the organic farming sector, by providing a complete set of determinants useful to create a general picture of the factors affecting farmers' innovations adoption. Relatedly, it is important to note that, as Greenhalgh et al. (2004) pointed out, many factors may simultaneously intervene in affecting farmers' behavior; therefore, both socio-demographic, psychological, and contextual factors need to be considered complementary to each other. Current findings could indeed be a useful guideline for scholars who intend to approach new research in the domain of farmers' innovation adoption behavior. Notwithstanding, however, there are several alternative robust theoretical models available. At the methodological level, the current SLR provides several practical insights on possible patterns scholars can follow to perform new empirical studies with higher levels of internal and external validity.

Finally, policymakers can take several actions to promote the adoption of sustainable practices. This includes investing in agricultural education to provide targeted training programs that raise awareness, develop technical skills, and enhance understanding of the challenges and opportunities associated with sustainable practices. It is also crucial to provide farmers with adequate technical support by establishing mechanisms that grant access to specialized consultants and industry professionals. Financial incentives, such as grants and tax incentives, can help reduce costs and barriers related to the adoption of sustainable practices. Moreover, policymakers should encourage knowledge sharing and collaboration among farmers to facilitate mutual learning and the dissemination of practical information. Implementing awareness and outreach policies through communication campaigns and promoting successful models of sustainable agriculture can increase awareness among farmers and the general public about the benefits of sustainable practices in addressing environmental and social challenges.

At a practical level, current results provide insights contributing to the ongoing policy debate on the most effective measures to foster sustainable innovation adoption among farmers in developed countries. Truly understanding the factors influencing farmer decision-making would allow for the development of more appropriate and effective agri-environmental policies, as policy interventions based on incomplete information may be insufficient to reduce the negative environmental externalities of agriculture. This may be the case with European CAP, which, relying primarily on traditional policy instruments that do not deepen farmer decision-making understanding, has had a mixed record in achieving environmental goals (Eurostat 2018). Therefore, excluding some factors can lead to unrealistic ex-ante policy assessments. Current outcomes could help policy institutions to better target specific interventions to farmers' individual characteristics and farms' needs to promote a wider diffusion of sustainable innovations and thus achieve the United Nations Sustainable Development Goals 2030 (FAO 2016).

Appendix

Table 4 Reviewed studies

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Bianchi et al. (2022)	*Animal*	Italy	53	Investigate which factors can influence the investment in precision livestock farming	Structured questionnaires	GLM procedure	Age (younger)	Complexity, cost due to the implementation of the innovation, and adaptation/reinvention
Finger and Möhring (2022)	*Ecological economics*	Switzerland	1073	Explore the relation between farmers adoption of pesticide-free production and their perception of the positive effects on the environment	Online-survey	OLS regression	Environmental attitude	/
Ploll et al. (2022)	*Sustainability*	Germany and UK	28	Investigate farmers' perceptions driving the diffusion of beneficial soil microbes	In-depth qualitative interviews	Qualitative description of data collected	Compatibility and environmental attitude	Complexity, perceived relative advantage of implementing the innovation, and cost due to the implementation of the innovation
Verburg et al. (2022)	*Agricultural systems*	The Netherlands	23	Analyze what factors may determine the very different diffusion of organic dairy farming	Semi-structured interviews	Qualitative description of data collected	Economic incentives and advice support	Clear regulation, cost due to the implementation of the innovation, absorptive capacity for new knowledge, and perception of better market positioning

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Jack et al. (2022)	*Preventive veterinary medicine*	UK	400	Determine the influence of socio-psychological factors on the adoption of anthelmintic resistance mitigation practices	Telephone questionnaire	Structural equation modeling (SEM)	Subjective norms towards innovation, age (younger), education (more educated)	Risk perception
Payen et al. (2022)	*Environmental Science & Policy*	France	400	Understand drivers that might influence winegrowers to adopt sustainable practices	Structured questionnaire	Binary logistic model	Age, company size, number of workers, being certified organic, and attitude towards innovation	/
Feliciano (2022)	*Scottish Geographical Journal*	UK	7	Investigate the implementation of sustainable practices by horticultural farmers, and the motivations and enablers for adoption	Semi-structured interviews	Qualitative description of data collected	Efficiency and cost reduction, regulations, market demand, and environmental and social consciousness	/
Laurett et al. (2021)	*Journal of Rural Studies*	USA	23	Identify the variables measuring the sustainable development in agriculture, its antecedents and barriers	Mixed approach	Qualitative description of data collected	Engagement with sustainability, concern about future generations, and environmental motivators	Lack of information and knowledge and lack of planning and support
Pépin et al. (2021)	*Agricultural Systems*	France	165	Investigate the extent to which structural factors that can influence organic conversion	Online-survey	Factor analysis of mixed data (FAMD)	Organic certification and company size (smaller)	/

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Gütschow et al. (2021)	*Regional Environmental Change*	Germany	10	Identify key farmer barriers to the introduction of diversified crop rotations and their relative weights	Face-to-face interview	Qualitative description of data collected	Compatibility with business strategy and previous knowledge	High initial costs and limited resource availability
Creissen et al. (2021)	*Pest Management Science*	UK	225	Investigate factors that drive farmers towards a sustainable approach to pest management	National data set	Ordered regression model	Large company size, group memberships, and previous knowledge	Level of familiarity with innovation
Bakker et al. (2021)	*Ecological Economics*	Netherlands	7500	Understand the intention of farmers to reduce pesticide use	Structured questionnaires	Structural equation modeling	Positive attitude towards innovation, high perceived behavioral control, and injunctive standards	High-risk aversion
Bonke and Musshoff (2020)	*Agronomy for Sustainable Development*	Germany	172	Determine German farmer's intention to adopt mixed cropping	Structured questionnaires	Partial least squares structural equation modeling	Positive attitude towards environment and subjective norms	Risk of not being able to place the innovation on the market, change in work routine, and low perceived behavioral control
Bechini et al. (2020)	*Journal of Cleaner Production*	Italy	92	Investigate the adoption of sustainable crop management practices in Italian dairy farms	Mixed approach	Factor analysis	Positive attitude towards the environment, previous knowledge about innovation, and company size	High initial costs, low economic incentives, and low perceived behavioral control

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Aznar-Sánchez et al. (2020)	*Agronomy*	Spain	10	Identification of the factors that condition the adoption of sustainable practices in the management of agricultural land.	Mixed approach	Delphi method and factor analysis	Continuous information, large company size, awareness about innovation, economic incentives, social pressure, and gender (female)	Lack of adequate knowledge on sustainable agriculture, complexity of innovation, initial costs, and risk aversion
Vecchio et al. (2020)	*Land Use Policy*	Italy	174	Deepening the process of adoption of technologies related to precision agriculture	Structured questionnaires	Two step cluster analysis	High levels of education, continuous information, pro-environmental attitude, and positive attitude towards innovation	Complexity of innovation and management of technology and machinery and initial costs
Ghadge et al. (2020)	*Production Planning and Control*	UK	55	Understanding the key barriers influencing the implementation of sustainability in the artisanal cheese supply chain	Structured questionnaires	Fuzzy analytical hierarchy process	Economic incentives, awareness of sustainability, supportive social networks, clear regulation, and planned long-term management	Initial costs, market product cost, company size, unawareness of government regulations, and lack of consensus regarding the concept of sustainability
Groth-Joynt et al. (2020)	*Australasian Journal of Environmental Management*	Australia	2000	Exploring how farmers' professional identity influences the adoption of sustainable innovations	Face-to-face interview	Logistic regression	Hobbies and non-farmers prefer the biodiversity and amenity values associated with their properties	Part-time and full-time focus similarly on farming as a business

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Tóth et al. (2020)	*Agronomy*	Hungary	151	Investigating which constructs influence innovation decision-making in the Hungarian food sector	Structured questionnaires	Structural equation modeling	Positive attitude and subjective norms towards innovation, pro-environmental attitude, and relative advantage	Low perceived behavioral control on innovation
Mills et al. (2020)	*Agroecology and Sustainable Food Systems*	Denmark, Hungary, Italy, Poland, Spain	5	Presenting specific barriers and opportunities for the adoption of soil carbon management practices	Mixed approach	Qualitative description of data collected	Economic incentives, clear regulation, planned long-term management, supportive social networks, relative advantage, and compatibility	Complexity of innovation and management of technology and machinery, lack of adequate knowledge on sustainable agriculture, and poor advice support
Nastis et al. (2019)	*Sustainability*	Greece	82	Determining the factors influencing farmers' risk management decisions	Face-to-face interview	Multinomial probit regression	Positive attitude towards innovation, planned long-term management, high levels of education, large company size, and higher age	High-risk aversion
De Steur et al. (2019)	*Business Strategy and the Environment*	Italy	64	Understand the adoption of sustainability practices in Italian wine SMEs	Structured questionnaires	Hierarchical cluster analysis	Positive attitude towards the environment and get a product with added value	Lack of information about sustainability practices, additional consulting costs, and additional marketing costs

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Caffaro et al. (2019)	*Sustainable Development*	Italy	199	Investigate the role of the information environment and socio-psychological variables in the adoption of agri-environmental innovations	Structured questionnaires	Path analysis	Participate in farmer associations, attend training courses, and high perceived behavioral control on innovation adoption	Low propensity for continuing education and low level of education
Barnes et al. (2019)	*Land use policy*	Belgium, Germany, Greece, The Netherlands and UK	971	Understanding the internal and external determinants of the adoption of precision farming technologies	Face-to-face interview	Multinomial logit	Large company size, high income, younger age, supportive social networks, continuous information, pro-innovation attitude, and economic incentives	Lack of adequate knowledge of sustainable agriculture and negative perceived profitability
García-Cortijo et al. (2019)	*J. Rural Stud*	Spain	771	Identifying the determinants of sustainable innovation in the agri-food industry	National database	Box-Cox regression model	Large company size, older companies, high income, where the company is located, and clear regulation	Lack of adequate knowledge
Caffaro and Cavallo (2019)	*Agriculture*	Italy	310	Exploring drivers for the adoption of smart farming technologies	Mixed approach	Logit regression	Relative advantage, receptive context for change, and farm size	Low levels of education, working on-farm alone, and low absorptive capacity for new knowledge

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Thorsøe et al. (2019)	*Land use policy*	Denmark	5207	Exploring the drivers, the opportunities and barriers to implement sustainable soil resource management practices	Mixed approach	Qualitative description of data collected	Gender (man), adequate knowledge of machinery, large company size, and planned long-term management	Poor advice support, change of work routine, and complexity of innovation and management of technology and machinery
Kernecker et al. (2019)	*Precision Agriculture*	France, Germany, Greece, The Netherlands, Spain and UK	287	Exploring what motivates farmers from different cropping systems to adopt SFT and what factors support their adoption	Structured questionnaires	Qualitative content analysis	Pro-environmental attitude, large company size, experience years, and awareness of the importance of innovation	Lack of adequate knowledge on sustainable agriculture and complexity of innovation and management of technology and machinery
Mishra et al. (2018)	*Environmental management*	USA	230	Investigate the factors influencing the intensity of adoption of precision farming instruments	Face-to-face interview	Negative binomial regression model	High levels of education and Participating in supportive program	Lack of adequate knowledge on sustainable agriculture and complexity of innovation and management of technology and machinery
Bijttebier et al. (2018)	*Land use policy*	Belgium, The Netherlands, Germany, and Italy	8	Analyze farmers' decisions about applying soil conservation practices	Structured questionnaires	Non-parametric Mann-Whitney *U* test	Ability to operate with appropriate machinery, technical knowledge, and experience in the field	Lack of appropriate technology, lack of expertise, and unsuitable soil

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Siepmann and Nicholas (2018)	*Sustainability*	Germany	8	Investigating winegrowers' motivations and obstacles to practical conversion to organic farming	Structured questionnaires	Qualitative description of data collected	Pro-environmental attitude and Supportive social networks	Skeptical attitudes towards social networks, doubting the environmental benefits of organic practices, and initial costs
Mase et al. (2017)	*Climate Risk Management*	USA	5000	Investigate the adoption of climate change adaptation strategies.	National database	OLS regression	Farmers' perceptions of risk, attitudes towards innovation, and adaptation attitudes	Low awareness of the causes of their practices on the environment
Long et al. (2016)	*Journal of Cleaner Production*	The Netherlands, France, Switzerland, and Italy.	26	Identify the main socio-economic barriers inhibiting the adoption and diffusion of technological innovations in Europe	Face-to-face interview	Qualitative description of data collected	Planned long-term management, pro-environmental attitude, and relative advantage	Lack of knowledge of, and access to capital/investment; demonstrating positive impact of the innovation; unsympathetic regulatory landscape; and high costs
Trujillo-Barrera et al. (2016)	*European Review of Agricultural Economics*	The Netherlands	164	Understanding producers' motives for adopting sustainable practices	Face-to-face interview	Logit regression	Expected economic rewards and risk tolerance	Risk perception
Rochecouste et al. (2015)	*Agricultural Systems*	Australia	31	Understanding the drivers of Australian farmers in adopting conservation agriculture practices	Face-to-face interview	Qualitative description of data collected	Economic incentives and supportive social networks and awareness of the importance of innovation	Poor advice support and change of work routine

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Greiner (2015)	*Agricultural Systems*	Australia	224	Study readiness to adopt conservation practices	Face-to-face interview	Principal components analysis	Maximize company profit and earn a high income	Unclear understanding of the impact of grazing practices on biodiversity
Schulz et al. (2014)	*Journal of Agricultural Economics*	Germany	128	Assessing Farmers' Willingness to Accept "Greening"	Discrete choice experiment	Discrete choice experiments-BLM	Ability to predict results and be a full-time farmer	High costs and change of work routine
Hellerstein et al. (2013)	*European Review of Agricultural Economics*	USA	68	Measuring farmers' preferences for perceived risks to implementing sustainable practices	Lottery	OLS regression	Risk tolerance	High-risk aversion
Arbuckle et al. (2013)	*Environment and Behavior*	USA	1276	Understanding farmer perspectives on climate change adaptation and mitigation	National database	Structural equation model	Pro-environmental attitude and trust in institutional actors	Perceived risks
Aubert et al. (2012)	*Decision support systems*	USA	438	Study factors influencing farmers' adoption of precision agriculture technology	Structured questionnaires	Partial least squares	Predisposition to innovativeness, high level of education, ease of use, compatibility, and relative advantage	Complexity of innovation and management of technology and machinery
Knutson et al. (2011)	*Renewable Agriculture and Food Systems*	USA	42	Investigate what barriers producers perceive in using sustainable practices to mitigate droughts	Face-to-face interview	Qualitative description of data collected	Planned long-term management and economic incentives and supportive social networks	High-risk aversion and high costs

Table 4 (continued)

	Journal	Country of the study	Sample size	Aim	Data collection	Main empirical methodology	Main results	
							Drivers	**Barriers**
Greiner and Gregg (2011)	*Land Use Policy*	Australia	224	Study readiness to adopt conservation practices	Face-to-face interview	Principal components analysis	Pro-environmental attitudes and financial, technical, and policy support	Resource constraints, uncertainty, and lack of industry coordination
Sassenrath et al. (2010)	*Journal of Sustainable Agriculture*	USA	13	Determining successful strategies to meet future challenges to sustainable agriculture	Structured questionnaires	Qualitative description of data collected	Economic return and pro-environmental attitude	Lack of adequate knowledge of sustainable agriculture
Wauters et al. (2010)	*Land use policy*	Belgium	160	Determine the factors that influence the adoption of soil conservation practices	Structured questionnaires	Linear regression model	Positive attitude to innovation, intention towards innovation, and subjective norms	Low perceived behavioral control

Table 5 Factors influencing farmers and their references

Factors	References
Absorptive capacity for new knowledge	Verburg et al. (2022), Caffaro and Cavallo (2019), Aubert et al. (2012)
Adaptation/Reinvention	Bianchi et al. (2022), Thorsøe et al. (2019), Bijttebier et al. (2018), Mase et al. (2017), Rochecouste et al. (2015), Creissen et al. (2021), Bonke and Musshoff (2020), Schulz et al. (2014)
Advice support	Verburg et al. (2022), Laurett et al. (2021), Thorsøe et al. (2019), Rochecouste et al. (2015), Arbuckle et al. (2013), Greiner and Gregg (2011)
Age	Bianchi et al. (2022), Jack et al. (2022), Payen et al. (2022), Nastis et al. (2019), Barnes et al. (2019)
Attitude towards innovation	Payen et al. (2022), Bakker et al. (2021), Bakker et al. (2021), Bonke and Musshoff (2020), Tóth et al. (2020), Nastis et al. (2019), Mase et al. (2017), Aubert et al. (2012), Wauters et al. (2010)
Awareness of the importance of innovation	Creissen et al. (2021), Aznar-Sánchez et al. (2020), Ghadge et al. (2020), Kernecker et al. (2019), Mishra et al. (2018), Mase et al. (2017), Long et al. (2016), Rochecouste et al. (2015), Greiner (2015)
Clear regulation	Verburg et al. (2022), Feliciano (2022), Ghadge et al. (2020), Mills et al. (2020), García-Cortijo et al. (2019)
Company size	Payen et al. (2022), Pépin et al. (2021), Creissen et al. (2021), Bechini et al. (2020), Aznar-Sánchez et al. (2020), Ghadge et al. (2020), Nastis et al. (2019), Barnes et al. (2019), García-Cortijo et al. (2019), Caffaro and Cavallo (2019), Thorsøe et al. (2019), Kernecker et al. (2019)
Compatibility	Ploll et al. (2022), Gütschow et al. (2021), Mills et al. (2020), Aubert et al. (2012)
Complexity	Bianchi et al. (2022), Ploll et al. (2022), Aznar-Sánchez et al. (2020), Vecchio et al. (2020), Mills et al. (2020), Thorsøe et al. (2019), Kernecker et al. (2019), Mishra et al. (2018)
Continuous updating	Laurett et al. (2021), Aznar-Sánchez et al. (2020), Vecchio et al. (2020), Caffaro et al. (2019), Barnes et al. (2019)
Cost due to implementation of the innovation	Bianchi et al. (2022), Ploll et al. (2022), Verburg et al. (2022), Gütschow et al. (2021), Bechini et al. (2020), Ghadge et al. (2020), De Steur et al. (2019), Long et al. (2016), Schulz et al. (2014), Knutson et al. (2011)
Economic incentives	Bechini et al. (2020), Aznar-Sánchez et al. (2020), Ghadge et al. (2020), Mills et al. (2020), Long et al. (2016), Rochecouste et al. (2015), Knutson et al. (2011), Greiner and Gregg (2011)
Education	Jack et al. (2022), Vecchio et al. (2020), Nastis et al. (2019), Caffaro et al. (2019), Caffaro and Cavallo (2019), Thorsøe et al. (2019), Mishra et al. (2018), Aubert et al. (2012)
Environmental attitude	Finger and Möhring (2022), Ploll et al. (2022), Feliciano (2022), Laurett et al. (2021), Bechini et al. (2020), Vecchio et al. (2020), Ghadge et al. (2020), Tóth et al. (2020), De Steur et al. (2019), Barnes et al. (2019), Kernecker et al. (2019), Bijttebier et al. (2018), Long et al. (2016), Arbuckle et al. (2013), Greiner and Gregg (2011)
Gender	Aznar-Sánchez et al. (2020), Thorsøe et al. (2019)
Knowledge of sustainable agriculture	Gütschow et al. (2021), Creissen et al. (2021), Bechini et al. (2020), Aznar-Sánchez et al. (2020), Mills et al. (2020), De Steur et al. (2019), Barnes et al. (2019), García-Cortijo et al. (2019), Kernecker et al. (2019), Sassenrath et al. (2010)
Network Structure	Ghadge et al. (2020), Mills et al. (2020), Caffaro et al. (2019), Barnes et al. (2019), Caffaro and Cavallo (2019), Mishra et al. (2018), Knutson et al. (2011), Greiner and Gregg (2011)
Organic certification	Payen et al. (2022), Pépin et al. (2021)
Perceived behavioral control on innovation	Bakker et al. (2021), Bechini et al. (2020), Tóth et al. (2020), Caffaro et al. (2019), Schulz et al. (2014), Wauters et al. (2010)

Table 5 (continued)

Factors	References
Perceived relative advantage	Ploll et al. (2022), Verburg et al. (2022), Feliciano (2022), Bonke and Musshoff (2020), Tóth et al. (2020), Mills et al. (2020), Caffaro and Cavallo (2019), Long et al. (2016), Trujillo-Barrera et al. (2016), Greiner (2015), Aubert et al. (2012), Sassenrath et al. (2010)
Planned long-term management	Ghadge et al. (2020), Mills et al. (2020), Nastis et al. (2019), Thorsøe et al. (2019), Long et al. (2016), Knutson et al. (2011)
Readiness to cooperate	Creissen et al. (2021)
Risk attitude	Jack et al. (2022), Bakker et al. (2021), Bonke and Musshoff (2020), Nastis et al. (2019), Mase et al. (2017), Trujillo-Barrera et al. (2016), Hellerstein et al. (2013), Arbuckle et al. (2013), Knutson et al. (2011)
Subjective norms towards innovation	Jack et al. (2022), Bonke and Musshoff (2020), Aznar-Sánchez et al. (2020), Tóth et al. (2020), Wauters et al. (2010)
Time employment	Groth-Joynt et al. (2020), Schulz et al. (2014)
Working conditions (e.g., morphological, and structural)	García-Cortijo et al. (2019)

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Declarations

Conflict of interest The authors declare no competing interests.

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