BRILL WAGENINGEN ACADEMIC

INTERNATIONAL JOURNAL ON FOOD SYSTEM DYNAMICS 16 (2025) 1–12

International Journal on FOOD SYSTEM DYNAMICS
brill.com/fsd

Barriers and drivers of digital agriculture adoption: Insights from Italian farming stakeholders

Rocco Addorisio[1], *Nicola Casolani*[2], *Giulia Maesano*[1], *Silvia Coderoni*[2], *Maria Angela Perito*[2], *Michele Mattetti*[1], and *Maurizio Canavari*[1]

[1]Department of Agricultural and Food Sciences, University of Bologna, Bologna, Italy
[2]Department of Bioscience and Agro-Food and Environmental Technology, University of Teramo, Teramo, Italy
rocco.addorisio2@unibo.it; ncasolani@unite.it; giulia.maesano2@unibo.it; scoderoni@unite.it; maperito@unite.it; michele.mattetti@unibo.it; maurizio.canavari@unibo.it

Received August 2024 | Accepted December 2024 | Available online February 2025

Abstract

Digital agriculture technologies represent a solution for improving productivity levels and environmental sustainability, thanks to data with great potential. Therefore, understanding the mechanisms of adoption and diffusion of digital farming technologies is crucial. Notably multiple factors are responsible for farmers' technology adoption rate. The objective of this paper is to analyze the barriers to technology adoption and drivers of diffusion for a group of Italian stakeholders by using qualitative research methods. Results identify many barriers to technology adoption and point out that cooperation between stakeholders, along with collaborative efforts through technical support and training activities are key strategies.

Keywords

digital farming technologies – stakeholders – farming supply chain – technology adoption – decision-making process

1 Introduction

Global agriculture needs to increase overall productivity to meet the demand for food, feed and fibers in the coming years while also targeting environmental challenges (Finger et al., 2019; Navarro et al., 2020). In this context, the European Commission developed the Green Deal Farm to Fork strategy, aimed at transforming European agri-food sector towards a sustainable food system (World Economic Forum, 2022). Transition to alternative food systems is crucial for addressing agricultural challenges, and technology, diversification and organic farming have been identified as the key alternative systems attributes (Reidsma et al., 2023).

This complex issue can only be resolved by addressing the twin transition, ecological and digital, while improving productivity levels and environmental sustainability (Bauer et al., 2021).

As regards the digital transition, an interesting avenue is related to a large amount of information, with great potential, that modern technologies (e.g., such as Canbus/Isobus protocols, Remote Sensing, IoT, etc.) generate and that the entire sector must accurately and effectively manage (European Commission, 2020; Lytos et al., 2020; Medici et al., 2021). Digital agriculture can be seen as an extension of precision agriculture (Sponchioni et al., 2019) as it does not refer to a specific application, but the collection, integration and analysis of data from different sources is considered. Agriculture 4.0 or smart agriculture consists of technologies combining sensors, information systems, enhanced machinery, and informed management to

Published with license by Koninklijke Brill BV | DOI:10.18461/IJFSD.V16I1O1
 | ISSN: 1869-6945 (online)

optimize production by accounting for variabilities and uncertainties within agricultural systems (Mammarella et al., 2022). The rise of these technologies and the potential disruptive impact of digital agriculture make it particularly important to understand the mechanisms of adoption and diffusion of digital farming technologies (Barbosa Júnior et al., 2024; Shang et al., 2021).

The existing literature clearly shows the complexity and dynamic nature of the adoption process of new technologies (Montes De Oca Munguia et al., 2021). Indeed, multiple factors involved in the decision-making process have been identified as responsible for the technology adoption rate by farmers (Dibbern et al., 2024; Drewry et al., 2019; Fragomeli et al., 2024; Gemtou et al., 2024; Osrof et al., 2023; Verbeke et al., 2024).

According to recent studies, in Italy, the agricultural technology adoption process is still at an early stage (Osservatorio Smart Agrifood, 2023). Several points of misalignment between supply and demand have been found in the Italian smart farming market, with the result being that the services offered do not fully meet the real needs of farms (Osservatorio Smart Agrifood, 2023). Among these misalignments, most Italian farms do not take advantage of data because they lack the necessary equipment and technology to collect and process it. In addition, few Italian farms produce data by using it in a sectoral and non-interoperable way. Thus, increasing the use of digital agricultural technologies could be crucial in tackling modern agriculture challenges (Lee et al., 2021). However, the knowledge of factors affecting farmers' decision-making process is still incomplete.

Although the literature has studied the mechanisms of innovation diffusion for several years, there seems to be no convergence in the theories and models that attempt to explain the phenomenon. Some authors underscore the specificity of theories in modelling different aspects of the technology adoption process (Dissanayake et al., 2022; Osrof et al., 2023), and others raise doubts about the generalist capacity of theories in representing different technologies and practices (Montes De Oca Munguia et al., 2021). In particular, Montes De Oca Munguia and Llewellyn (2020) identified a lack of clarity regarding the analytical methods and the choice of explanatory variables to model adoption. Shang et al. (2021) state that the mechanisms of adoption and diffusion of digital farming technologies must be understood at both farm and system levels, paying attention to system interactions alongside individual characteristics in determining technology diffusion.

Several examples of categorising determinants of digital agricultural technologies have been provided in the literature (Dibbern et al., 2024; Fragomeli et al., 2024; Gemtou et al., 2024; Kakkavou et al., 2024; Osrof et al., 2023; Shang et al., 2021; Troiano et al., 2023).

However, not many studies have focused on farmers' knowledge of digital solutions and their levels of adoption (Maffezzoli et al., 2022). In addition, most of the studies on the adoption of innovative agricultural practices and technologies have generally covered the farm-level dimension, whereas the recent literature on the topic calls for a more holistic approach, considered critical in implementing the sustainable transition and demonstrating technology's real impact (Barrett and Rose, 2022; Djekic et al., 2021; Pedersen et al., 2024; Vinod Chandra et al., 2024; Zaharia et al., 2021). McGrath et al. (2023) argued that such an approach could be realised through needs analysis and co-design initiatives, although they found little emphasis in the literature. Indeed, Monteiro Moretti et al. (2023) focused on the actors' perceptions of precision agriculture innovations system and their role in influencing their diffusion, finding that the actors' different and contrasting perceptions of technologies hinder the adoption and diffusion process.

Similarly, other authors highlighted the importance of considering stakeholders' perceptions and engaging them in the development and scaling up of a resilient innovation framework to effectively deploy technologies on farms (Knierim et al., 2019; Reimer et al., 2023; Sun et al., 2024; Vecchio et al., 2022). Finally, stakeholders' involvement and coordination in the agricultural transition process could positively affect the adoption decision-making process, having a cumulative effect on it (Pedersen et al., 2024).

Overall, the ability of farmers to adopt digital solutions and the further integration of the collected data in their current working setting is influenced by different components, such as farm and operators' characteristics, interactions with peers and institutions, technology attributes and attitudinal aspects (Osrof et al., 2023; Shang et al., 2021). Specifically, the category of interactions includes technical support as an adoption factor, when the implementation of smart agricultural technologies requires hard skills that are difficult to obtain, depending on farmers and technology characteristics (Pedersen et al., 2024).

In particular, advisors play a role in linking established and new actors in the innovation system, bridging the gap between developers and users (Kernecker et al., 2020). Less prevalent, but no less valuable, seems to be the role of human-centered design as a process-based approach to resolving the contrast between available tools and the low levels of adoption and inclusiveness of agricultural technologies (Müller et al., 2024). Therefore, the crucial role of systemic factors in the adoption of agricultural innovations is evident, reflecting many studies that have highlighted the importance of farmers' access to extension services, such as education and training (Gemtou et al., 2024; Knierim et al., 2019).

Furthermore, the study of the risks and benefits of agricultural data sharing is emerging in the landscape of digital agriculture adoption, identifying the promotion of collaboration across the agri-value chain as the main driver and concerns about data privacy and security among the main barriers to data sharing (Jakku et al., 2019; Sullivan et al., 2024). Based on evidence from the literature, categories of individual, technological, social, and economic factors that influence technology adoption can depict the overall decision-making process (Dibbern et al., 2024; Dissanayake et al., 2022). In the decision-making process context, three main gaps remain in the literature: (1) the divergence within the technology adoption explanatory factors (de Oca Munguia and Llewellyn, 2020); (2) an assessment of the role of system interactions on individual behaviour (Gemtou et al., 2024; Shang et al., 2021); (3) stakeholders' perceptions of the challenges and opportunities in the digital farming system (Monteiro Moretti et al., 2023).

This paper describes an exploratory study on stakeholders' needs and demands for digital technologies along the Italian food supply chain and the barriers hindering the diffusion of system innovations. Therefore, our research will integrate earlier studies on digital agriculture adoption by including stakeholders' perceptions of the process. The general objective of our study was to provide qualitative empirical evidence on the barriers to the adoption of digital agricultural technologies and the drivers of its diffusion. Special attention is given to specific needs and demands that could be useful in designing tailored pathways for implementing the digital transition, such as the role of interactions along the food supply chain.

The primary contribution of this research lies in its technology-neutral perspective, offering a comprehensive examination of the adoption process. This approach stands in contrast to previous investigations, which typically focus on the adoption of a specific technological innovation or tool.

2 Materials and Methods

In this study, an exploratory approach was used to investigate the phenomenon. Based on a rational inductive process, starting from observing individual cases, the study aimed to derive a general rule through a process of abstraction (Molteni and Troilo, 2007). The investigation was based on two alternative and complementary qualitative research methods, focus groups and interviews, that have been previously used to investigate stakeholders' decision-making process in the agri-food sector (Galabuzi et al., 2021; Marcu et al., 2015; Osei et al., 2021; Sabbagh and Gutierrez, 2023).

Two Focus Groups (FGs) were planned to discuss stakeholders' demands and barriers related to the use of tools for tracing farming activities at the field level. At the same time, in-depth interviews were designed and carried out to deepen the understanding of those demands and barriers from the perspective of key informants. A FG is a discussion led by a moderator in a unstructured and natural manner with a small group of participants (Malhotra et al., 2013) intended to generate creative discussion by promoting interactions within the group. This method was chosen as it is a useful tool for gathering qualitative information to answer specific research questions (Bloor et al., 2001) and allows for capturing opinions, motivations, decisions, and priorities about a particular area of interest.

In-depth interviews consist of a conversation where people talk with each other and interact. Usually and predominantly, a researcher poses questions and the participant answers (Knott et al., 2022). In this case, interviews were used as a combined research method with focus group providing a space for extended conversations that allowed for more insightful results (Monteiro Moretti et al., 2023; Osei et al., 2021). We used semi-structured interviews as the most common type, based on a topic guide informed by the focus group outcomes.

Table 1 provides the list of the respondent categories along with the type and number of interviews. The two FGs were conducted with 14 participants in total, ranging from farmers' associations to farm entrepreneurs and machine and service providers. Participants were selected to represent different interest groups, including public and private sector representatives. One FG was held in February 2023 in Bologna (Emilia-Romagna Region, Italy) with 6 participants, and a second was held on September 2023 in Catania (Sicily Region, Italy) with 8 participants. Along with the FG meetings, 14 semi-structured interviews were administered among a wider range of stakeholders from different tiers of the food supply chain to focus on their needs regarding digital technologies' adoption and to discern the heterogeneity of the adoption's barriers. Overall, the stakeholder group interviewed consisted of farmers, machinery, service and technology providers, representatives of cooperatives and certification bodies.

The suitable selection of participants followed a purposive sampling approach, which is generally considered the most useful method for interview-based research since the number of interviews to be conducted is too small to achieve representativeness (Knott et al., 2022). The number of interviewees was defined according to the concept of saturation (Knott et al., 2022), and 27 key informants from the Italian farming supply chain, which plays a crucial role within the Italian agricultural sector, were recruited.

TABLE 1 Summary of the interviewees' characteristics

	Focus groups	Interviews
Farmers	5	1
Machine providers	2	1
Input providers	1	
Associations	3	
Service and tech providers	2	3
Consultants		4
Processors		1
Certifiers		2
Policy makers		2
TOTAL	**13**	**14**

SOURCE: AUTHORS' ELABORATION

Specifically, the participants were selected based on evidence from the literature (extrinsic motivation) and the objectives of the project (intrinsic motivation) which aligned with the same inclusion criteria: the interviewee plays a role within the supply chain and has an interest in the innovation system under investigation. The topics for the discussion were aimed at understanding: i) data needs for each actor along the supply chain; ii) the major barriers to digital technologies adoption and ii) the major benefits of digital technologies.

The semi-structured interviews focused on general perceptions of digital farming technologies, barriers and drivers to their adoption and the needs of digital farming technologies for managing field activities, resulting in a total of seven open-ended questions. In both, FGs and interviews, stakeholders were informed about the study's objectives. The data collection sessions took place from February to October 2023. The FGs lasted approximately 1 hour and 30 minutes, while the interviews lasted about 1 hour each.

To obtain a subjective interpretation validated within the research group, the transcriptions of the interview texts and FGs were analysed through latent content analysis, a systematic and objective research method that produces valuable inferences from verbal, visual and written data, aiming at describing and quantifying a specific phenomenon (Downe-Wamboldt, 1992). Specifically, the process of analysis involved: decontextualization, identifying meaning units; recontextualization, including content and excluding dross; categorization, identifying homogeneous groups; data reduction, clarifying information, and data interpretation, finding the underlying meaning (Bengtsson, 2016).

As shown in Figure 1, the analysis was performed through the following stages, adapted from Bengtsson (2016):

Decontextualization. The participants' statements, classified into individual units of meaning, constitute the unit of analysis which thematizes the phenomenon under investigation to facilitate its analysis and interpretation.

Recontextualization. According to the previous phase, individual statements are contextualised in the relative units of sense, enabling the exclusion of any information that does not contribute to answering the research questions.

Categorization. Categorization is based on the study's theoretical assumptions and consists of dividing the units of meaning into categories of information that help to make the results explicit.

Data reduction. Interviews produced a huge number of statements, pertaining to ten units of sense, which in turn were reduced to eliminate redundancy and assigned to the four main categories.

Data interpretation. Data categorisation allows the information collected to be categorised systematically facilitating a clearer and more objective thematization of the contents. Meanwhile with data interpretation, an attempt is made to provide a general explanation of the phenomenon, based on the research hypothesis.

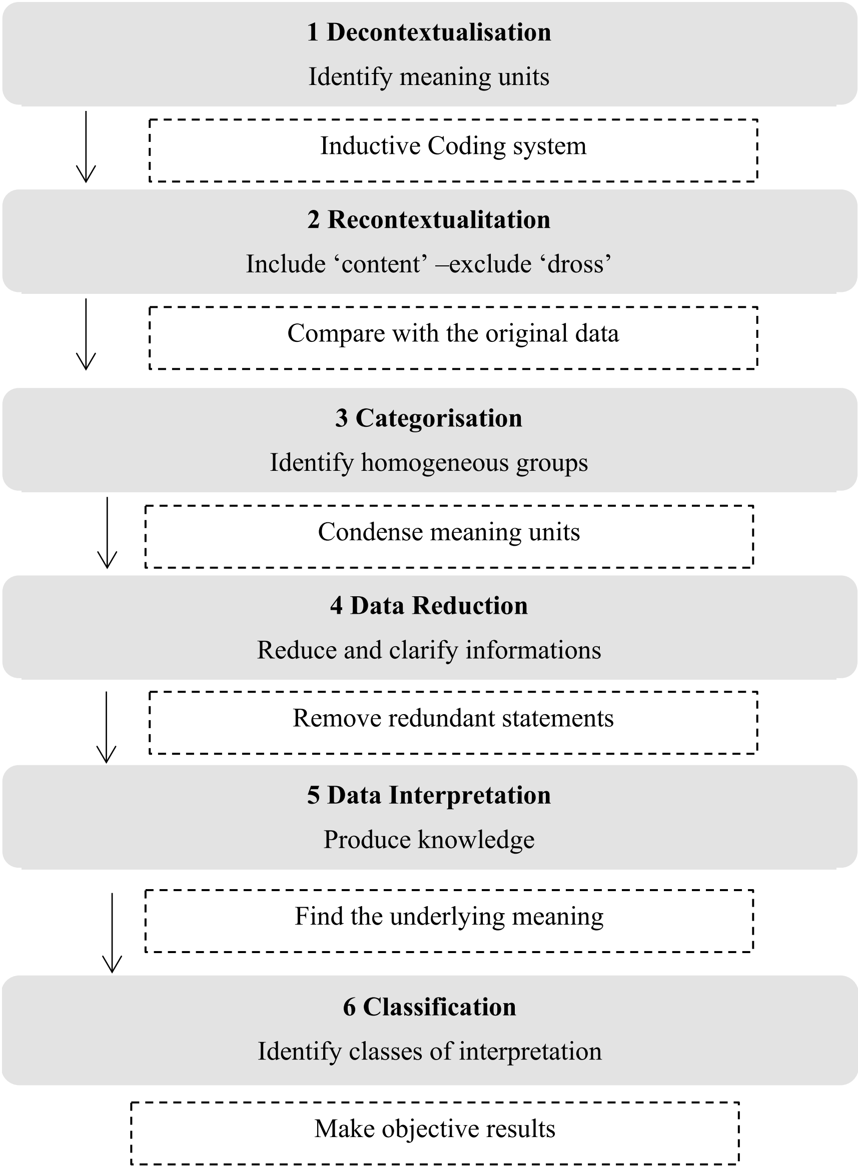

FIGURE 1
Overview of data analysis process
SOURCE: ADAPTED FROM BENGTSSON, 2016

Classification. Classes of data interpretation were identified to promote the objectivity and comparability of the results of the study, as well as to maximise their evidence.

3 Results

Data analysis is summarised in Table 2 and identifies three major themes: the data requirements to improve the management of the farming activities, the characteristics of the innovation adoption process, and the benefits related to the technologies' adoption, which are composed of different units of sense that can be interpreted as opportunities, challenges or actions regarding the adoption and diffusion of Agriculture 4.0.

TABLE 2 Summary of categories

Categories	Units of sense	
Data requirements	1	Data availability
	2	Demands
	3	Data management
	4	Data security and property
Adoption determinants	5	Adoption drivers
	6	Adoption barriers
Adoption benefits	7	Economics benefits
	8	Environmental benefits
	9	Social benefits
	10	Relations with supply chain

SOURCE: AUTHORS' ELABORATION

3.1 *Data requirements*

Data requirements encompass four different units of sense that have been reported by participants: data availability, demands, data management and data security and property.

Data availability and demands, respectively, refer to the current availability and usefulness of data for farm management, from whatever source they originate. Overall, participants stated that although farm data availability is mostly appropriate for management needs, there are few requirements for additional data emerging. Indeed, stakeholders reported a lack of fully exploited data potential due to their inability to use technologies and lack of awareness regarding their usefulness. Specifically, interviewees reported seven additional requests for activities to be tracked. They focused on: soil mapping; predictive data for crop protection and nutrition and water management; inputs saving and crop yields to analyse farm efficiency; predictive machine maintenance (only one participant); traceability of farming activities to report to public bodies; and carbon credits evaluation as an indicator of environmental performance (only one participant).

Data management encompasses anything related exclusively to farmer data use. Certainly, the element to which stakeholders placed the most importance was the complexity in managing and processing data rather than collecting it. Indeed, they frequently showed interest in having specific tools to fulfil priority needs rather than equipment, i.e. Decision Support Systems (DSS). In most cases, data integration from different sources such as machine sensors, remote sensing, field observations, and data interoperability between different protocols were the attributes of complexity more emphasized. Indeed, farmers in our sample claim the need for further technical support and training programs to overcome challenges in technologies complexity. Furthermore, Italian stakeholders mostly raised concerns about the effectiveness of the national public incentives for technology purchases, arguing that linking subsidies for conventional equipment to the adoption of digital technologies, often leads to dysfunctional adoption. Thus, the outlined condition would exacerbate farmers' constraints in effectively integrating new technologies into their existing work setting, while reinforcing the previously mentioned needs.

Finally, *data security and ownership* were investigated with respect to the perceived risk of manipulations as well as attention to digital rights and intellectual property. Overall, participants perceived a general low risk of misappropriation of sensitive data in collection and management process, evaluating it more as an opportunity to improve farm operability through sharing data rather than as a threat. They clearly perceived the importance of sharing data to improve farm operability exhibiting a good level of confidence toward service and technology providers even though they claim the ownership of the data.

3.2 *Innovation adoption process*

Certainly, the adoption process was the primary issue, receiving great attention from all the participants. It refers to the determinants of the adoption and diffusion of digital farming technologies and includes two further units of sense: barriers and drivers of adoption, listed in Table 3. Participants focused more on the barriers to adoption rather than the drivers of diffusion, identifying many factors that may hinder the adoption of a technology, preventing both purchase and use of a specific equipment.

The main barriers affecting technology adoption that emerged were: the lack of innovativeness intended as attitude and trust toward innovations; cultural barriers, such as traditional habits and beliefs that prevent change; the lack of awareness of technology benefits and usefulness; farm size and farm system meaning specialization and crops profitability, influencing the investment capacity especially compared to high technology costs; the lack of technical support in collecting and interpreting data; the lack of technical expertise at different levels of the supply chain and farm location in terms of bio-physical conditions.

Concerning the diffusion drivers, it strongly emerged that the trigger for the use of digital technologies in agriculture is the ability to improve the economic performance of farms by reducing operational costs. However, some participants highlighted the importance of improving environmental performance, particularly for areas with resource constraints. They also pointed out the pivotal role of the interactions among actors in increasing competitiveness through aggregation, spreading information and building trust in the digital farming system. In addition, political and societal pressure to control the compliance of agricultural activities, as well as market demand for products' reliability, emerged as drivers for technology adoption.

TABLE 3 Determinants of digital agriculture adoption according to Italian stakeholders (full list)

Barriers	Drivers
1 Lack of attitude and trust toward innovations	1. Contractors' availability
2 Cultural barriers	2. Technical support
3 Lack of awareness of technology benefits and usefulness	3. Training
4 Lack of information availability	4. Availability of information on technology
5 Lack of extension service availability	5. Laws and regulations
6 Farm succession (turnover)	6. Political and societal pressure
7 Farm size	7. Economic performance improvement
8 Farm location/region (bio-physical conditions)	8. Environmental performance improvement
9 Risk management attitude	9. Interactions to increase Knowledge, confidence and competitiveness
10 Type of cropping system	
11 Education level	
12 Lack of technology competence at different levels	
13 Barrier from farm subsidies	
14 Farm system (specialization and crops profitability)	
15 Low investment capacity	
16 Lack of technical support	

SOURCE: AUTHORS' ELABORATION

3.3 *Adoption benefits*

This theme includes the benefits according to the triple bottom line (that is, people, planet, and profit) principles (Norman and MacDonald, 2004), as well as benefits from any aspect that contributes to improving relationships with stakeholders in the supply chain.

Among the adoption benefits reported by participants, the economic advantages were judged to be the most important, even though a lack of strategical economic analysis was found. Indeed, participants mainly reported a stand-alone use of technology aimed at reducing operational costs, without exploiting the potential of temporal analysis and planning. This is strictly in line with the demands and difficulties in managing the technological complexity that have been raised, pointing to the need for increased adoption intensity from embodied-knowledge technologies towards information-intensive ones.

On the contrary, the social advantages related to the safety and working conditions appeared poorly understood, having been reported as risk reduction and increased organisational capacity in a few cases. Environmental advantages were mentioned, especially by linking them to economic benefits and the ability to manage soil fertility and climate change risk.

Finally, the capacity to implement supply chain relations was well valued through aggregation initiatives that are able to moderate business risk and increase the competitiveness and investment capacity of farms, contributing to a greater readiness to innovate. The interviewees also referred to the benefits for administrative compliance and activities traceability to improve reliability and competitiveness operating in specific supply chain.

4 Discussion

Our research contributes to the study of factors involved in farmers' decision-making process in adopting digital farming technologies. The objective was to explore the perceptions of Italian stakeholders along the farming supply chain to provide a systemic overview of the process capturing interactions within the system. Our findings show several barriers and drivers for adoption and diffusion of digital technologies in crop production and provide useful insights into farmers' needs and solutions to encourage farm digital transition. Stakeholders from our sample stated that Italian farmers are not able to fully exploit their current technology endowment and integrate it into their actual work-setting, because they are not aware of technology's usefulness and benefits.

In addition, due to their lack of expertise, Italian farmers are reported to be overwhelmed by the complexity of technology, especially in managing and processing data, and require enhanced technical support and training.

These findings are aligned with the recent literature that highlights the importance of farmers' access to the extension services (Gemtou et al., 2024), confirming the crucial role of the systemic approach that, through interactions along the supply chain, support stakeholders' integration, generating positive effects on the decision-making process (Pedersen et al., 2024).

In addition, the negative impact of the fragmented market development of agricultural technologies on their integration complexity, suggests the need for more effective and focused incentives. Stakeholders interviewed depicted a situation with a low level of maturity and knowledge of technology among Italian farmers, aligning with previous literature (Maffezzoli et al., 2022), and highlighting the endogenous role of awareness in the adoption process (Vecchio et al., 2020).

Consistent with previous findings (Kolady et al., 2021; Miller et al., 2019) that found that the adoption rate of embodied-knowledge precision farming technologies is higher than information-intensive ones, they underscored the necessity for knowing specific tools to fulfil high-priority needs and increase adoption intensity. Therefore, it is clear that in order to lead Italian agriculture towards the digital transition process effectively, it is essential to target the involvement of all stakeholders to create effective technological solutions that meet farmers' demands (McGrath et al., 2023). Stakeholders' evidence regarding factors affecting farm technology adoption is largely consistent with the extended field literature (Dibbern et al., 2024; Fragomeli et al., 2024; Gemtou et al., 2024; Osrof et al., 2023; Shang et al., 2021; Troiano et al., 2023), in fact they identified structural, individual and systemic factors at the core of the decision-making process.

Particularly, respondents align with the recent literature in underlining the leading role of behavioral factors and individual perception, which affect the propensity to adopt innovations (Kakkavou et al., 2024; Vecchio et al., 2022, 2020). On the contrary, with regard to the agricultural data sharing, Italian stakeholders interviewed mostly perceive the relative benefits of collaboration within the supply chain rather than the privacy and security risks as reported in the literature (Sullivan et al., 2024). In our interpretation, this misalignment could be ascribed to the observed lack of technological awareness and adoption intensity.

Participants in the study point out the lack of expertise in the supply chain and their necessity to access more effective technical support and training activities to develop awareness of the usefulness and benefits of technology. This concept relates to the systemic approach reported in recent literature (Masi et al., 2022; Monteiro Moretti et al., 2023) which states that interactions among actors (especially meso-actors) can spread awareness, information and knowledge within the innovation system by contributing to overcoming barriers. The majority of stakeholders interviewed highlighted the role of economic and environmental benefits in adopting digital farming technologies (Osrof et al., 2023; Shang et al., 2021; Troiano et al., 2023) and only in a few cases benefits from relations within the supply chain were perceived.

Nevertheless, most of the emerged factors hindering the adoption, such as farm systems, lack of technical support and lack of technical expertise at different levels, can be overcome by fostering the interactions with peers and institutions and through stakeholders' participation (Gemtou et al., 2024; Pedersen et al., 2024). Therefore, these findings demonstrate that the role of relationships in the supply chain is rather underestimated and suggest delving into individual factors and determining how to overcome them through system interactions.

Indeed, the literature focused on the influence of social relations on adoption, suggesting this approach as a strategy to overcome hurdles and improve innovations (Busse et al., 2014; Monteiro Moretti et al., 2023).

Given the limitations of the study stemming from its explorative and qualitative nature and its limited scope, a more in-depth analysis that incorporates different geographical locations, farm systems, and supply chain actors is needed to explore system perceptions accurately and obtain generalisable results. Qualitative methods are an effective tool for investigating complex or emerging topics in depth (Coderoni et al., 2021). However, they have certain limitations that need to be handled carefully. For example, Focus Groups have limitations regarding groups' representativeness (Gibbs, 1997) and the influence of individuals' traits (Gibbs, 1997; Smithson, 2000), such as secrecy or tendency to prevaricate, on the progression of the discussion. In this regard, an expert moderator helped manage these limitations.

On the other hand, semi-structured interviews allow individual opinions to emerge freely without external affectation, but they have limited applicability, due to their time-consuming (Barriball and While, 1994). Therefore, the results might suffer from methodological biases. Nevertheless, they did not prevent transparent findings which were validated within the project team. In addition, it might be useful in creating a meaningful cognitive framework to replicate the study using a quantitative methodology to measure the effect of the identified barriers on digital technology adoption intention.

5 Conclusion

Digital agriculture represents a strategic tool to address challenges of modern agriculture. Despite this, its adoption remains relatively low and confined to embodied-knowledge technologies that fail to meet farmers' specific needs. Our research contributes to understanding the factors influencing farmers' decision-making process in adopting digital farming technologies. The objective was to explore the perceptions of Italian stakeholders across the farming supply chain to provide a systemic overview of the process and capture interactions within the system (Pedersen et al., 2024). Our findings highlight several barriers and drivers to the adoption and diffusion of technologies in crop production, offering valuable insights into farmers' needs and solutions to accelerate the agricultural digital transition.

Stakeholders in our sample indicated that Italian farmers are unable to fully exploit their current technological endowment and integrate it into their work setting due to a lack of awareness of the technologies' usefulness and benefits. Additionally, farmers' lack of expertise leaves them overwhelmed by the complexity of technology, especially in managing and processing data, which makes greater technical support and training essential. These findings align with recent literature that emphasizes the importance of farmers' access to extension services (Gemtou et al., 2024), confirming that a crucial precondition for embracing digital transformation is to perceive this process from a perspective of interaction along the supply chain, supporting stakeholders integration to generate positive effects on decision-making process.

Therefore, we believe promoting cooperation and participation might emerge as a key strategy. Collaborative efforts have the potential to prioritize farmers' needs within the marketplace while fostering and facilitating behavioural change. The agricultural sector could effectively embrace digital transformation by tackling these identified challenges through strategic policies and collaborative training programs, ensuring sustainable growth and resilience in the face of evolving technological demands.

Furthermore, the profitability of farms will increasingly depend on their ability to collect and use the large amounts of data generated. It is worth noting that there is still a lack of clarity among stakeholders regarding how to exploit these opportunities and increase the adoption intensity. Indeed, the study results suggest a need for targeted policy interventions and comprehensive training programmes to increase awareness and knowledge about the benefits associated with the adoption of digital technologies. Thus, it is essential to invest in both technologies and skills, as well as in training and developing understanding of the opportunities of digital transformation.

In conclusion, this study demonstrates that the role of relationships in the supply chain is rather underestimated and suggests delving into individual factors and figuring out how to overcome them through system interactions. Future research should focus on the economic assessment of technologies across different farm systems, to highlight the benefits of adopting digital technologies. Additionally, it should evaluate the experiences of those who have already adopted these technologies to guide the decision-making of potential new adopters.

Acknowledgements

This research was financed by the Italian Ministry of University and Research under Grant No. 2020SCNF4L. G. M. received funding from the European Union NextGenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D. D. 1032 17/06/2022, CN00000022) within the Agritech National Research Center. This paper reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

References

Barbosa Júnior, M. R., De Almeida Moreira, B. R., Dos Santos Carreira, V., De Brito Filho, A. L., Trentin, C., Pereira de Souza, F. L., Tedesco, D., Setiyono, T., Flores, J. P., Ampatzidis, Y., Da Silva, R. P., Shiratsuchi, L. S. (2024). Precision agriculture in the United States: A comprehensive meta-review inspiring further research, innovation, and adoption. *Computers and Electronics in Agriculture*, **221**: 108993.

Barrett, H., Rose, D. C. (2022). Perceptions of the Fourth Agricultural Revolution: What's In, What's Out, and What Consequences are Anticipated? *Sociologia Ruralis*, **62** (2): 162–189.

Barriball, K. L., While, A. (1994). Collecting data using a semi-structured interview: a discussion paper. *Journal of Advanced Nursing-Institutional Subscription*, **19** (2): 328–335.

Bauer, P., Stevens, B., Hazeleger, W. (2021). A digital twin of Earth for the green transition. *Nature Climate Change*, **11** (2): 80–83.

Bengtsson, M. (2016). How to plan and perform a qualitative study using content analysis. *NursingPlus Open*, **2**: 8–14.

Bloor, M., Frankland, J., Thomas, M., Robson, K. (2001). *Focus Groups in Social Research*. London, SAGE Publications Ltd.

Busse, M., Doernberg, A., Siebert, R., Kuntosch, A., Schwerdtner, W., König, B., Bokelmann, W. (2014). Innovation mechanisms in German precision farming. *Precision Agriculture*, **15** (4): 403–426.

Coderoni, S., Helming, J., Pérez-Soba, M., Sckokai, P., Varacca, A. (2021). Key policy questions for ex-ante impact assessment of European agricultural and rural policies. *Environmental Research Letters*, **16** (9): 094044.

Dibbern, T., Romani, L. A. S., Massruhá, S. M. F. S. (2024). Main drivers and barriers to the adoption of Digital Agriculture technologies. *Smart Agricultural Technology*, **8**: 100459.

Dissanayake, C. A. K., Jayathilake, W., Wickramasuriya, H. V. A., Dissanayake, U., Kopiyawattage, K. P. P., Wasala, W. M. C. B. (2022). Theories and Models of Technology Adoption in Agricultural Sector. *Human Behavior and Emerging Technologies*, **2022**: 1–15.

Djekic, I., Batlle-Bayer, L., Bala, A., Fullana-i-Palmer, P., Jambrak, A. R. (2021). Role of the Food Supply Chain Stakeholders in Achieving UN SDGs. *Sustainability*, **13** (16): 9095.

Downe-Wamboldt, B. (1992). Content analysis: Method, applications, and issues. *Health Care for Women International*, **13** (3): 313–321.

Drewry, J. L., Shutske, J. M., Trechter, D., Luck, B. D., Pitman, L. (2019). Assessment of digital technology adoption and access barriers among crop, dairy and livestock producers in Wisconsin. *Computers and Electronics in Agriculture*, **165**: 104960.

European Commission (2020). A farm to fork strategy for a fair, healthy and environmentally-friendly food system. Communication 381 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0381 (accessed on June 30, 2024).

Finger, R., Swinton, S. M., El Benni, N., Walter, A. (2019). Precision Farming at the Nexus of Agricultural Production and the Environment. *Annual Review of Resource Economics*, **11** (1): 313–335.

Fragomeli, R., Annunziata, A., Punzo, G. (2024). Promoting the Transition towards Agriculture 4.0: A Systematic Literature Review on Drivers and Barriers. *Sustainability*, **16** (6): 2425.

Galabuzi, C., Agaba, H., Eilu, G. (2021). Farmers' Perceptions, Socio-economic and Political Stakes: What Inspires the Integration of Prunus africana On-Farms in Central Uganda? *Small-scale Forestry*, **20** (3): 371–389.

Gemtou, M., Kakkavou, K., Anastasiou, E., Fountas, S., Pedersen, S. M., Isakhanyan, G., Erekalo, K. T., Pazos-Vidal, S. (2024). Farmers' Transition to Climate-Smart Agriculture: A Systematic Review of the Decision-Making Factors Affecting Adoption. *Sustainability*, **16** (7): 2828.

Gibbs, A. (1997). Focus Groups. *Social Research Update*, **19**.

Jakku, E., Taylor, B., Fleming, A., Mason, C., Fielke, S., Sounness, C., Thorburn, P. (2019). "If they don't tell us what they do with it, why would we trust them?" Trust, transparency and benefit-sharing in Smart Farming. *NJAS: Wageningen Journal of Life Sciences*, **90–91** (1): 1–13.

Kakkavou, K., Gemtou, M., Fountas, S. (2024). Drivers and barriers to the adoption of precision irrigation technologies in olive and cotton farming – Lessons from Messenia and Thessaly regions in Greece. *Smart Agricultural Technology*, **7**: 100401.

Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., Borges, F. (2020). Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe. *Precision Agriculture*, **21** (1): 34–50.

Knierim, A., Kernecker, M., Erdle, K., Kraus, T., Borges, F., Wurbs, A. (2019). Smart farming technology innovations – Insights and reflections from the German Smart-AKIS hub. *NJAS – Wageningen Journal of Life Sciences*, **90–91**: 100314.

Knott, E., Rao, A. H., Summers, K., Teeger, C. (2022). Interviews in the social sciences. *Nature Reviews Methods Primers*, **2** (1): 1–15.

Kolady, D. E., Van der Sluis, E., Uddin, M. M., Deutz, A. P. (2021). Determinants of adoption and adoption intensity of precision agriculture technologies: evidence from South Dakota. *Precision Agriculture*, **22** (3): 689–710.

Lee, C.-L., Strong, R., Dooley, K. E. (2021). Analyzing Precision Agriculture Adoption across the Globe: A Systematic Review of Scholarship from 1999–2020. *Sustainability*, **13** (18): 10295.

Lytos, A., Lagkas, T., Sarigiannidis, P., Zervakis, M., Livanos, G. (2020). Towards smart farming: Systems, frameworks and exploitation of multiple sources. *Computer Networks*, **172**: 107147.

Maffezzoli, F. A., Ardolino, M., Bacchetti, A. (2022). The Impact of the 4.0 Paradigm in the Italian Agricultural Sector: A Descriptive Survey. *Applied Sciences*, **12** (18): 9215.

Malhotra, N. K., Birks, D. F., Willis, P. A. (2013). *Essential of marketing research*. Harlow, Pearson Education.

Mammarella, M., Comba, L., Biglia, A., Dabbene, F., Gay, P. (2022). Cooperation of unmanned systems for agricultural applications: A theoretical framework. *Biosystems Engineering*, **223**: 61–80.

Marcu, A., Gaspar, R., Rutsaert, P., Seibt, B., Fletcher, D., Verbeke, W., Barnett, J. (2015). Analogies, metaphors, and wondering about the future: Lay sense-making around synthetic meat. *Public Understanding of Science*, **24** (5): 547–562.

Masi, M., De Rosa, M., Vecchio, Y., Bartoli, L., Adinolfi, F. (2022). The long way to innovation adoption: insights from precision agriculture. *Agricultural and Food Economics*, **10** (1): 27.

McGrath, K., Brown, C., Regan, Á., Russell, T. (2023). Investigating narratives and trends in digital agriculture: A scoping study of social and behavioural science studies. *Agricultural Systems*, **207**: 103616.

Medici, M., Pedersen, S. M., Canavari, M., Anken, T., Stamatelopoulos, P., Tsiropoulos, Z., Zotos, A., Tohidloo, G. (2021). A web-tool for calculating the economic performance of precision agriculture technology. *Computers and Electronics in Agriculture*, **181**: 105930.

Miller, N. J., Griffin, T. W., Ciampitti, I. A., Sharda, A. (2019). Farm adoption of embodied knowledge and information intensive precision agriculture technology bundles. *Precision Agriculture*, **20** (2): 348–361.

Molteni, L., Troilo, G. (2007). *Ricerche di marketing*. Milano, McGraw-Hill.

Monteiro Moretti, D., Baum, C. M., Ehlers, M.-H., Finger, R., Bröring, S. (2023). Exploring actors' perceptions of the precision agriculture innovation system – A Group Concept Mapping approach in Germany and Switzerland. *Technological Forecasting and Social Change*, **189**: 122270.

Montes De Oca Munguia, O., Llewellyn, R. (2020). The Adopters versus the Technology: Which Matters More when Predicting or Explaining Adoption? *Applied Economic Perspectives and Policy*, **42** (1): 80–91.

Montes De Oca Munguia, O., Pannell, D. J., Llewellyn, R. (2021). Understanding the Adoption of Innovations in Agriculture: A Review of Selected Conceptual Models. *Agronomy*, **11** (1): 139.

Müller, A., Steinke, J., Dorado, H., Keller, S., Jiménez, D., Ortiz-Crespo, B., Schumann, C. (2024). Challenges and opportunities for human-centered design in CGIAR. *Agricultural Systems*, **219**: 104005.

Navarro, E., Costa, N., Pereira, A. (2020). A Systematic Review of IoT Solutions for Smart Farming. *Sensors*, **20** (15): 4231.

Norman, W., MacDonald, C. (2004). Getting to the Bottom of "Triple Bottom Line." *Business Ethics Quarterly*, **14** (2): 243–262.

Osei, R. K., Medici, M., Hingley, M., Canavari, M. (2021). Exploring opportunities and challenges to the adoption of blockchain technology in the fresh produce value chain. *AIMS Agriculture and Food*, **6** (2): 560–577.

Osrof, H. Y., Tan, C. L., Angappa, G., Yeo, S. F., Tan, K. H. (2023). Adoption of smart farming technologies in field operations: A systematic review and future research agenda. *Technology in Society*, **75**: 102400.

Osservatorio Smart AgriFood (2023). Il mercato dell'Agricoltura 4.0 in Italia. Politecnico di Milano. Available at: https://www.osservatori.net/it/prodotti/formato/report/report-il-mercato-agricoltura-40-italia (accessed on February 01, 2024).

Pedersen, S. M., Erekalo, K. T., Christensen, T., Denver, S., Gemtou, M., Fountas, S., Isakhanyan, G., Rosemarin, A., Ekane, N., Puggaard, L., Nertinger, M., Brinks, H., Puško, D., Adrián, J. B. (2024). Drivers and barriers to climate-smart agricultural practices and technologies adoption: Insights from stakeholders of five European food supply chains. *Smart Agricultural Technology*, **8**: 100478.

Reidsma, P., Accatino, F., Appel, F., Gavrilescu, C., Krupin, V., Manevska Tasevska, G., Meuwissen, M. P. M., Peneva, M., Severini, S., Soriano, B., Urquhart, J., Zawalińska, K., Zinnanti, C., Paas, W. (2023). Alternative systems and strategies to improve future sustainability and resilience of farming systems across Europe: from adaptation to transformation. *Land Use Policy*, **134**: 106881.

Reimer, A., Doll, J. E., Boring, T. J., Zimnicki, T. (2023). Scaling up conservation agriculture: An exploration of challenges and opportunities through a stakeholder engagement process. *Journal of Environmental Quality*, **52** (3): 465–475.

Sabbagh, M., Gutierrez, L. (2023). Farmers' acceptance of a micro-irrigation system: A focus group study. *Bio-based and Applied Economics*, **12** (3): 221–242.

Shang, L., Heckelei, T., Gerullis, M. K., Börner, J., Rasch, S. (2021). Adoption and diffusion of digital farming technologies – integrating farm-level evidence and system interaction. *Agricultural Systems*, **190**: 103074.

Smithson, J. (2000). Using and analysing focus groups: Limitations and possibilities. *International Journal of Social Research Methodology*, **3** (2): 103–119.

Sponchioni, G., Vezzoni, M., Bacchetti, A., Pavesi, M., Renga, F. (2019). The 4.0 revolution in agriculture: A multi-perspective definition. *Proceedings of the Summer School Francesco Turco*, **1**: 143–149.

Sullivan, C. S., Gemtou, M., Anastasiou, E., Fountas, S. (2024). Building trust: A systematic review of the drivers and barriers of agricultural data sharing. *Smart Agricultural Technology*, **8**: 100477.

Sun, Y., Miao, Y., Xie, Z., Wu, R. (2024). Drivers and barriers to digital transformation in agriculture: An evolutionary game analysis based on the experience of China. *Agricultural Systems*, **221**: 104136.

Troiano, S., Carzedda, M., Marangon, F. (2023). Better richer than environmentally friendly? Describing preferences toward and factors affecting precision agriculture adoption in Italy. *Agricultural and Food Economics*, **11** (1): 16.

Vecchio, Y., De Rosa, M., Adinolfi, F., Bartoli, L., Masi, M. (2020). Adoption of precision farming tools: A context-related analysis. *Land Use Policy*, **94**: 104481.

Vecchio, Y., Di Pasquale, J., Del Giudice, T., Pauselli, G., Masi, M., Adinolfi, F. (2022). Precision farming: what do Italian farmers really think? An application of the Q methodology. *Agricultural Systems*, **201**: 103466.

Verbeke, W., Diallo, M. A., Dooremalen, C. van, Schoonman, M., Williams, J. H., Van Espen, M., D'Haese, M., Graaf, D. C. de (2024). European beekeepers' interest in digital monitoring technology adoption for improved beehive management. *Computers and Electronics in Agriculture*, **227**: 109556.

Vinod Chandra, S. s., Anand Hareendran, S., Ghassan Faisal, A. (2024). Precision farming for sustainability: An agricultural intelligence model. *Computers and Electronics in Agriculture*, **226**: 109386.

World Economic Forum (2022). Transforming Food Systems with Farmers: A Pathway for the EU. World Economic Forum. Available at: https://www.weforum.org/publications/transforming-food-systems-with-farmers-a-pathway-for-the-eu/ (accessed on February 01, 2024).

Zaharia, A., Diaconeasa, M.-C., Maehle, N., Szolnoki, G., Capitello, R. (2021). Developing Sustainable Food Systems in Europe: National Policies and Stakeholder Perspectives in a Four-Country Analysis. *International Journal of Environmental Research and Public Health*, **18** (14): 7701.