Unbundling the information needs of new-generation agricultural companies

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Abstract

Over the past decades, the interest in Precision Agriculture (PA) has increased in most developed countries. The adoption of new technologies in agriculture is complex. PA improves efficiency, product quality, the rational use of chemicals and biological resources, and the preservation of the environment. Because of the need to invest in technology for sustainability and profitability, the sector becomes increasingly data driven. However, this data becomes valuable and strategic only if effectively managed.
This study, through a critical literature review on selected topics, sheds light on PA's information potential for farms' managerial processes. It investigates the impact of PA on profitability, the features of farmers' decision making, and the specificities of Decision Support Systems for agribusinesses. Given the sector characteristics, the discussion of findings leads to the identification of aspects that should be carefully considered when designing an information system for new-generation agricultural companies. Considering the limited amount of previous research on the decision-making process in farming and the challenges posed by the use of technology, the authors believe that this study could assist researchers, practitioners, and farmers interested in increasing their knowledge of the issue.

Keywords: Agritech, Precision agriculture, Decision support systems, Integrated information management, Farm management extension.

1. Introduction

The last decades have witnessed significant concerns regarding the environmental sustainability of intensive Agriculture. Soil and water are no

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longer considered inexhaustible or plentiful resources and therefore must be used efficiently. Meanwhile, global farming has changed significantly over the last twenty years as the world moved towards digital and mobile platforms and new technologies emerged. Agriculture is increasingly becoming a data-driven sector due to sensors in the field, on animals and soil, GPS tractors, variable rate applications and earth observation satellites, which transmit real-time data. This technological shift promises increasing yields, better crops quality and improved efficiency by avoiding the misuse of resources and contributing to the safeguard of the environment (Yost *et al.*, 2017). The term that identifies this technological approach to agriculture is Agritech. The use cases of Agritech covers the entire agriculture value-added chain from Biotech techniques to Precision Agriculture till Blockchain for agricultural logistics[1].

Looking at the Italian agriculture sector, similarly to what is happening worldwide, we assist at incremental attention to Agritech investments (CREA, 2021). Italy is the fifth largest country in Europe and the ninth in the world for exports of agricultural products (CREA, 2021; Gianneschi, 2021). Italian Agrifood sector represents a well-known example of Made in Italy characterized by excellence in quality, food safety, innovation, sustainability, biodiversity, and respect for tradition (Raponi, 2017; CREA, 2021; Gianneschi, 2021). Agricultural companies' interest in technological advancement is mainly due to the need to improve farming production efficiency and enhance the uniqueness of Italian products. We are not assisting to a simple technological change. Moving to Agritech implies a broader innovation process. New-generation agricultural companies look to combine progress with tradition and technological advancements with craftsmanship. If, on the one hand, Agritech investments make field operations less physically demanding, on the other, technology-driven agricultural processes require farmers to rethink their approach to farm management. Farmers are asked to increase their knowledge on previously unexplored critical areas, such as investment evaluation, data-driven analysis, strategic planning, and control. This means a profound cultural change for farmers, which finds concrete realization in the evolution of their competencies to encompass farm management extension. In particular, *farm management extension* deals with the development of data management capabilities and

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[1] In this paper we specifically discuss the managerial implications of Precision Agriculture. Issues related to Biothec and Blochchain technologies adoption are out of the aim of this study.

strategic management skills for improved decision-making in the use of resources (Cisternas *et al.*, 2020).

The remainder of the publication is organized as follows: Section 2 illustrates the study aim and motivation. The selected research methodology is presented in Section 3, whereas its results are shown in Section 4. A concluding discussion about the main critical points of the literature review and the identification of crucial aspects for developing agribusiness Decision Support Systems together with future work suggestions, is given in Section 5.

2. Motivation and aim of the study

Precision Agriculture (PA) can be defined as a modern approach to farming that relies on information and communication technology (ICT) to support technical activity and farmers' decision-making (Cisternas *et al.*, 2020). PA's operations rely on the cyclical observation and acquisition of data, allowed by a set of devices and sensors, followed by the interpretation and evaluation of the information acquired, to implement a system of operational-strategic decisions. Its purpose is to explore, among the possible solutions, the most suitable for any agricultural production by promoting the ability to impose inputs on the system and obtain the desired outputs, controlled through the production capacity of the entire system (Kopishynska *et al.*, 2020). PA covers yield mapping through GIS, fertilization through variable-rate technologies, weather observation by metrological stations, drones' yield monitoring, and various sensors (Cisternas *et al.*, 2020). ICT includes hardware and software devices that process the data captured by the machines, providing the necessary information for the decision making processes. Specifically, ICT allows identifying, locating, quantifying, and recording every agricultural unit's spatial and temporal variability, making farmers perform a specific agronomic intervention on each land with greater precision (Aubert *et al.*, 2012). Among PA's potential advantages is cost reduction, which is possible by employing resources only when and where required by matching soil composition and crops needs or through water resource management (Mintert *et al.*, 2016). Besides improving resources efficiency, these new practices lower fertilizers, herbicides, and pesticide uses and therefore are perceived as strategical for environmental preservation. The massive use of ICT in agriculture is also expected to improve technical-productive, economic, and ecological decision-making. Data provided by PA should also decrease the excessive subjectivity of farmers' operative and strategical decisions, usually taken on hypothetical reasoning rather than actual data.

The entire history of agricultural development suggests that adopting innovative technologies is always crucial in enhancing sustainable productions (Fountas *et al.*, 2004; Lee *et al.*, 2021). However, although technologies have been available for decades, their implementation in agriculture is developing slowly (Higgins *et al.*, 2017; McConnell, 2019; Pathak *et al.*, 2019). Research shows that technological transfer in the agricultural sector is not straightforward (Pathak *et al.*, 2019). Farmers' decision to implement new technologies is multifaceted; they are usually captivated by these new techniques, but, at the same time, they are highly sceptical about the worthiness of the investment (Kernecker *et al.*, 2020). Users' ability to perform PA procedures and the confidence in their daily use usually increase when a new mindset is created through hands-on experiences with software, coupled with instructor-guided and self-directed instruction (Kitchen *et al.*, 2002; Cisternas *et al.*, 2020). Even when PA is sufficiently diffused, there is evidence that the managerial exploitation of PA's data is still not at the hype of supporting the critical decision-making process of agricultural companies (Tantalaki *et al.*, 2019). Decision Support Systems, which are software used to manage the information generated by PA devices and aimed at assisting farmers' decision-making, are often far from user-friendly (Liu *et al.*, 2021). They do not fit in a comprehensive performance management system, so they tend to be limited to operative in-site decisions rather than being broadly exploitable strategically (Kopishynska *et al.*, 2020).

Looking at Italy, although PA has been technologically available for over twenty years, it is still struggling to take off. Among the main factors that slow down its large-scale adoption lies the evidence that, while the costs of investing in PA are known, companies cannot reasonably determine the economic profitability of these technologies (Vecchio *et al.*, 2020). We find similar findings at the European level. Agricultural companies, especially small and medium-sized, still do not own specific information technology systems and sufficient expertise to extend the use of PA over operations boundaries (Loures *et al.*, 2020; Kopishynska *et al.*, 2020). Much still has to be done to exploit the information potential of PA's operational data and connect them to financial performance measurement within an integrated system that supports the entire decision-making process of farmers.

Given the above, our study aims to shed light on PA's information potential for farms' managerial processes. Through a critical literature review on selected topics, we investigate the impact of PA on profitability, the features of farmers' decision-making, and the specificities of Decision Support Systems for agribusinesses. The discussion of findings leads us to identify some aspects that, in our opinion, should be carefully considered when designing the information system of new-generation agricultural companies. Evidence shows that the decision-making process of Agritech companies has been only partially explored in the literature (Ndemewah *et al.*, 2019). For this reason, we believe that our study could enrich context-related literature (Gatti, Chiucchi, 2017), being helpful for researchers, practitioners, and farmers interested the increase their knowledge of the issue. The value-added of our literature review is that it systematises contributions from several research fields such as agricultural techniques, performance management, information systems design. These investigation areas influence how new-generation agribusinesses operate in the field and manage their performance through brand-new data. Former research has proved the benefits of relying on a contingency approach when defining new management information systems (Ali *et al.*, 2022). Previous findings have revealed that contingent factors play a fundamental role in designing and implementing new organizational tools. Specifically, the effectiveness of innovation is dependent on a fit or match between the level of technology, environmental unpredictability, the organization size, structure, managerial attitude and its current information system. In this sense, our work provides an overview of the contingent factors that must be considered to design and develop an integrated management information system for Agritech companies.

To develop the study, and therefore to guide our literature review, we have defined the following research questions:

Q.1: How does PA modify agribusiness profitability?

Q.2: What are small and medium-sized agricultural companies' decision-making and performance management features?

Q.3: How do DSS improve the decision-making process of companies investing in PA?

The following section describes the methodology followed in selecting the literature we have reviewed.

3. Methodology

Previous contributions discussed in this paper were selected using a scoping study approach (Tranfield *et al.*, 2003; Arksey, O'Malley, 2005). Scoping studies have been developed within the medical sciences to confine the bias and increase the rigour of narrative literature reviews but have been particularly valuable within management research (Tranfield *et al.*, 2003; Speziale, Kloviené, 2014; Lauzier *et al.*, 2020). A scoping study is a systematic literature review that rapidly maps the fundamental concepts supporting a research subject and the available primary sources and types of evidence. Relying on a scoping study helps us detail the findings and range of the high number of research conducted on the topic, thereby providing an instrument for analyzing and summarising them clearly and logically. Although scoping studies are less structured than systematic reviews and do not offer statistically testable results as meta-analysis, they provide greater conceptual clarity and decrease traditional researchers' implicit biases.

The strategy we used to identify the evidence was the same for the three questions and relies on search engines (Google, Google Scholar, Science Direct and Emerald Journals Database). To guide the analysis, we first identified a set of terms that could characterize the investigation subject. Arksey and O'Malley (2005) stressed that the more the researcher becomes familiar with the argument investigated, the more search terms will be redefined to deepen the searches. «The process is not linear but iterative, requiring researchers to engage with each stage in a reflexive way and, where necessary, repeat steps to ensure that the literature is covered in a comprehensive way» (Arksey, O'Malley, 2005, p. 22). The search strategy has concentrated on the following ar-eas: "Precision Agriculture" AND "financial performance", "Precision Agriculture2 AND "information management", "agriculture business" AND "performance management", "Precision Agriculture" AND "Decision Support Systems".

Designing an information system for decision-making implies conducting a deep analysis of all relevant elements (e.g., data, information, entry agents, information needs, source of information, users) and their interconnections, and then reviewing all the steps in the analysis spectrum. Once we have illustrated the findings of our literature review, we will discuss them, suggesting the critical aspects that should be considered in the design of a DSS for agribusinesses.

4. Literature review

The literature review is organized into three sections according to the research questions previously identified. Subsection 4.1 presents previous studies investigating how PA modifies agribusiness profitability and generates new information potential. Research on decision-making and performance measurement in farming is illustrated in subsection 4.2. Lastly, subsection 4.3 deals with studies carried how on DSS for agribusinesses.

4.1. PA influence on farm's profitability and information potential

Assessing the profitability of PA is a critical factor for farmers to invest in innovation. Several studies have provided evidence of PA's impact on farms' financial performance, from the simplest forms (assisted driving, automatic driving) to the most advanced ones (production mapping, variable dosing systems, sensors for physiological analysis) (Timmermann *et al.*, 2003; Knight *et al.*, 2009; Robertson *et al.*, 2007; Paustian *et al.*, 2017). New technologies can affect farms' performance through operating costs, overhead costs, and changes in yields. Diakosavvas *et al.* (2016) found PA investments worthwhile in 68% of cases. Several factors influence the profitability of these innovations, for instance, the extent of spatial variability of soil conditions, the size of a field, and the uncertainty about output and input prices.

Moreover, the effect on profitability varies according to the adopted technology. In some cases, PA reduces operating costs and raise allocated overhead (by substituting labour and working capital for fixed assets), or it could increase working capital investments through increased use of resources (if mapping signals a need) but, at the same time, it could increase the yields as well; or do the reverse (Schimmelpfennig, 2016). So an appraisal of the accounting effects of each potentially adaptable technology is needed if farmers want to assess the opportunity to invest in PA consciously.

Fixed asset investments

Moving to PA means acquiring special equipment or additional components (tangible assets), operating software (intangible assets), services such as the provision of maps for variable rate technologies, and related installation expenses. It also requires time and effort to learn how to use and maintain these new tools (Finco *et al.*, 2021). Additionally, investing in a defined technology usually binds future companies' operational and strategic decisions. The increase in fixed assets raises the company's accrued costs, modifies short-term profitability, and shapes the future (Schimmelpfennig, 2016; Finco *et al.*, 2021). For goods with highly specialized content, subject to a robust technical evolution, the leading cause of depreciation is obsolescence, which prevails over their decline in value caused by physical wear and tear. PA investments fall entirely within this category since technical progress in this area is extreme, and the speed at which more efficient factors are available on the market is very high (Knight *et al.*, 2009). As a result, the economic life of these factors is reduced and the depreciation suffered is elevated. If use is discontinued, the limited resale potential of these investments makes them sunk costs. There might even be additional costs to uninstall or terminate the use of precision technology (Schimmelpfennig, 2016). Outsourcing to a custom service provider is a possible option that generates costs in any case. All these factors increase the financial risks of PA adoption. For these reasons, usually, farmers require a higher expected return to investing in PA (Schimmelpfennig and Ebel, 2016).

Working capital and labour related investments

If, on the one hand, PA requires consistent investment in fixed assets, on the other, financial efforts are counterbalanced by variable cost reduction. These systems reduce the machinery's usage cost thanks to the faster execution of the operations and greater efficiency of mechanical processes. Farm performance benefits from savings in seeds, water, fertilizers, fuels, lubricants, maintenance costs, and insurance (Lindblom *et al.*, 2017; Finco *et al.*, 2021). Variable cost savings depend on the type and amount of technology adopted and the regularity or irregularity of agricultural plots and crop features (Gualand, 2015). The study of Frascarelli (2016) on maize cultivation, for example, shows that the transition from manual to automatic driving has generated savings on the side of working capital for 29,37 euro/ha. In this respect, the benefits of the PA is, therefore, twofold. Besides better financial results, PA promotes sustainable agriculture and environmental defence (Buckwell, 2014; Mipaaf, 2015; Pisante, 2016). In terms of productivity and ecological sustainability, the highest benefits are obtained by mapping productions through GPS technology, satellite data, drones, and site sensors. By matching the output gained through PA processes with soil characteristics (in terms of nutrients), weather conditions, and forecasts, it is possible to define future strategies for optimizing production factors, lowering the use of chemicals and reducing any differences in production observed (Pisante, 2016).

A significant change is also on the side of human resources in terms of costs, know-how and professionalism. Automatic processes and technology-driven operations cause a reduction in the use of low value-added labour while requiring an increase of expertise and professionalization within the company or making farms increasingly rely on the consultancy sector (Lazzari *et al.*, 2015; Frascarelli, 2016). The decrease in overlaps with assisted and automatic driving, other than having a positive effect on the use of direct factors, implies at the same time a reduction of human resources' working time, increasing labour productivity and its quality (Buckwell, 2014). This second aspect is often overlooked. Assisted and automatic driving improves the work performance compared to manual driving, reducing errors to less than 5 cm while eliminating overlaps due to the untimely closure or the lack of partialization of working areas. According to Tamagnone *et al.* (2003), in Western Po Valley, the waste traced back to error varies between 13% and 22%, depending on the fields' size and geometry. PA could decrease these wastes from overlaps by up to 1-2%, depending on the size and shape of the fields (Kopishynska *et al.*, 2019), with the undeniable benefit of increasing farming financial and environmental sustainability.

Crops quality, yields, and revenues

Although most of PA's advantages relate to input efficiency and better management of production costs, its adoption undeniably impacts revenues. PA improve yields both directly and indirectly. The uniform distribution of seeds, fertilizers and agro pharmaceuticals, without overlaps and fallacies, leads to improved crop development. Indirect effects arise from farmers' increased knowledge of soil and crop conditions, allowing timelier and evidence-based decisions (Frascarelli, 2016). Humidity sensors, as an example, allow to carry out irrigation interventions at the most appropriate times, instead of when the crop is withering, or at regular time slots, as traditional agriculture routines (Finco *et al.*, 2021). This prevents water waste and improves products quality (Bellvert *et al.*, 2021).

Due to the many complex factors, profitability cannot be demonstrated in all cases and under all scenarios. A critical aspect that affects the cost-opportunity assessment of PA is farm size (Diakosavvas *et al.*, 2016). Frank *et al.* (2008) have investigated this issue evaluating the adoption of PA across the EU, where the average field size varies significantly. Empirical evidence demonstrates that auto-guidance systems become profitable when implemented on 100 to 300 ha fields (Frank *et al.*, 2008; Diakosavvas *et al.*, 2016). Meyer-Aurich *et al.* (2010) findings show that the gross economic advantage of site-specific management of nitrogen fertilizer in Germany ranges between 10€/ha and 25€/ha, depending on the type of sensor used and size of the field. In their study, the authors concluded that the crop extension is relevant to determining the cut off threshold to obtain financial benefits. Field size had to exceed 250 ha regarding nitrogen fertilizer management through soil sensors. It is a mixed picture: other studies in Denmark have shown no appreciable economic benefit from using variable rate technology for fertilizer application (Oleson *et al.*, 2004).

It has been stressed that low benefits have been reported by studies that had concentrated on PA adoption in areas where crop management is already highly optimized (European Commission, 2014). Where crop management is sub-optimal, modern technology is rarely in use. In these areas, benefits from PA may be substantial.

PA' information potential

PA increases the variety of information available for decision making (Cisternas *et al.*, 2020). The combination of GPS systems and sensors on the tractors allows differentiating between setting-up, transport and work in the field. Gps systems also provide time-driven operational indicators. Measuring the time-stamp difference from the first point to the last point in the crop area defines the amount of time spent on a task. The cost accounting system could handle this data to derive time-driven efficiency measures (Tantalaky *et al.*, 2019). As an example, operational times or operational rates for each machinery or tractor, for controlling purposes, could be calculated (Auernhammer, 2001). Brand new technical measures provided by PA devices improve cost accounting procedures, especially regarding overhead allocation (Schimmelpfennig, 2018).

Regarding profitability analysis, Gps technology is adequate to find out low/high yield regions. Studies have proved that yields correlations are high between years, so taking decisions on Gps based information allows forecasting the expected profitability of a selected agricultural area (Jurshik *et al.* 1998; Steinmayr, 1999). Considering that yield is a dominant factor in calculating gross margins, areas with low long-term gross margins may be set aside or used alternatively to improve farm efficiency. Data provided may also increase the materiality of differential analyses for leased land, especially when comparing land financial returns with loans rates.

PA data also fosters environmental accounting (Andrade *et al.*, 2022). Considering the heterogeneity of agricultural environments in terms of soil type, slope, nutrient levels, and moisture content, production optimization and agroecosystems conservations can benefit from technological development. The expansion of agricultural and urban areas has already led to the conversion of 43% of the Earth's land (Barnosky *et al.*, 2011) and is currently the primary cause of habitat loss and biodiversity decline (Laurance *et al.*, 2014). In many countries, nutrient pollution problems have forced policy proposals, like extensification premiums, intensification levies, and perhaps even input levies, which demand detailed and auditable records on farm level for all farms concerned (Robertson *et al.*, 2007). In this sense, PA information becomes valuable to measure the sustainability of modern agriculture, assuming a strategic role for a broad set of users: farmers, private contractors, cooperatives, public government, and the social community (Andrade *et al.*, 2022). Although the term environmental sustainability has been often associated with PA, only a few studies have investigated the benefits of PA on Sustainability through environmental indexes (Schimmelpfennig, 2019; Andrade *et al.* 2022), suggesting that much still have to be done on this front.

4.2. Decision-making and performance management in small and medium-sized agricultural companies

The economic performance of the agriculture sector has been deeply explored by Microeconomic theory. The topic has been faced up mainly as an efficiency problem. According to these studies, farms' technical and economic efficiency depends primarily on socio-economic, technological and operational variables, precisely, production process complexity, crop specialization, farm size, farmers' household age and education (Puig-Junoy and Argiles, 2004; Musemwa *et al.*, 2013).

Beyond these, Rougoor *et al.* (1998) have identified management ability as a factor shaping farm efficiency. Farm management is the practice of controlling and optimizing the performance of on-farm operations under certain environmental and economic conditions (Puig-Junoy and Argiles, 2004). The literature suggests that using accounting information to plan, implement, and manage on-farm processes improves the decision-making process and, consequently, increases farm performance in terms of operational and financial results (Puig-Junoy, Argiles, 2004; Luening, 1989; Poppe, 1991). However, farm management is complex and typically shaped by internal and external factors. The complex interaction among three specific factors usually determines farm efficiency (Puig-Junoy and Argiles, 2004). The first one is the farmer's practical ability to manage investments. This ability can result from personal attitude, previous education, formal practices, and procedures adopted in its decision-making process. The second factor is represented by working effectively on-site through technical and biological activities. The third factor is the institutional, physical, and economic environment influencing the farm's operations.

On the side of Financial and Management Accounting (MA) studies, state of the art on farms management and related decision-making process has been described as a black box given the little research that has generated an incomplete knowledge on the subject (Harling, Quail, 1990; Ndemewah *et al.*, 2019, Kopishynska *et al.*, 2020). Luening (1989) stresses that even though accounting data has never been so popular among farmers, it plays a strategic role, especially as a diagnostic tool for identifying the strengths and weaknesses of agricultural companies. However, empirical evidence still reports low use of accounting information by farmers (Poppe, 1991; Puig-Junoy and Argilès, 2004; Ndemewah *et al.*, 2019; Kopishynska *et al.*, 2020). Agriculture is probably one of the most conservative industries. Structured decision-making adoption and MA diffusion are low, informatization is fragmented, especially in countries still striving to reach post-industrialism (Kopishynska *et al.*, 2020). On average, in Europe, each farm manages 16.1 hectares of Utilized Agricultural Area (UAA). Over the years, however, the agriculture sector has experienced profound changes (Eurostat, 2018). The total number of farms has decreased, while the average size of each farm has grown up. Even if the farm dimension increases considerably and the complexity of processes raises dramatically, the householder still wants to maintain complete control over the company (Kopishynska *et al.*, 2020). However, if, on the one hand, the farmer has a deep knowledge of on-site technical and biological operations, on the other, he usually lacks a professional understanding of leading, managing, and controlling the increased complexity of his company. Looking specifically at MA, Ndemewah *et al.* (2019) stress that its practice in agriculture is subject to information problems and shaped by influencing factors such as familism, government policies, market competition and seasonal climate change. Carroll and Halabi (2015) highlight the low usage paradox in the sector: although needed, farmers tend not to use MA in their farms. Farmers seem to be less interested in using MA tools than they are in the operation of farm equipment and cropping practices (Harling and Quail, 1990; Kudryashova *et al.*, 2020). A few farmers apply simple MA techniques such as budgeting when making decisions (Öhlmér *et al.*, 1998; Ojua, 2017). Farm management and farmers' decision-making processes are relatively intuitive and based on the farmer's unique personal experience and site-specific circumstances (Fountas *et al.*, 2006; Silva and Malaquias, 2020). Farm householders use their social network and experience to evaluate financial decisions (Öhlmér *et al.*, 1998). They measure the opportunity of investments mainly in terms of non-financial indicators (yields, resource efficiency, working time). There is also evidence that farmers perceive financial information as hard to understand or un-useful due to the dependency on uncontrollable environmental variables (Poppe, 1991). In Italy, the low interest of farmers toward concepts and measures of financial performance is probably linked to the juridical and fiscal position of farmers. Except for those who run an agricultural company as a partnership or a public company, farmers pay direct taxes on cadastral land return rather than actual income. This is a reason that could explain the poor attention toward proper cost accounting and performance management information systems.

Similarly to what has been evidenced by the literature on small and medium enterprises, even agricultural companies in the form of a partnership or public companies report low use of accounting information (Silva and Malaquias, 2020). According to Quinn (2011), the lack of appropriate technological resources and adequate training among personnel are often one explanation for the absence of MA. The absence of a formal and reliable MA system results in a management approach based on personal judgment. On the other hand, there is evidence that successful farmers are more interested in business management than their less successful colleagues (Harling and Quail, 1990; Trip *et al.*, 2002; Oyewo, 2021). The study of Wilson *et al.* (2001), for example, provides experimental proof that, in eastern England, farm dimension, farmers' education and managerial experience increase their need for better information to assist their decision-making process. This information-seeking attitude, which belongs to a minority group of farmers, leads them to integrate their knowledge with other sources such as scientific knowledge, consultant guidelines, periodicals and other sources. Wilson *et al.* (2001) also found that continuous search for better information was positively associated with a higher level of technical efficiency.

Given the availability of technology and internet-based devices for farming processes, data is no longer the primary constraint for progress in modern agriculture. The challenge today is rather how to exploit the potential of these data.

4.3. Decision Support Systems for new-generation agribusinesses

A DSS is a software system that analyses vast volumes of unstructured data and accumulates information to help solve specific problems and increase decision-making effectiveness (Power, 2002; Aubert *et al.*, 2012; Korte *et al.*, 2013; Rossi *et al.*, 2014; Lindblom *et al.*, 2017; Zhai *et al.*, 2020). A DSS illustrates the probability of various outcomes resulting from multiple options and suggests to its user the preferred path to the optimal decision. The software is usually composed of four primary systems: Data Management, Model Management, Knowledge-based, and User Interface subsystem (Turban *et al.*, 2005). The Data Management module elaborates the data employed to make decisions in the Knowledge-based subsystem. The Model Management unit includes a variety of models that assist decision-makers in developing their reasoning. However, the knowledge-based component is the system's core since it manages the problem-solving process to generate the final solution. The User Interface has an instrumental role that encourages interaction between the user and the software to obtain information.

DSSs have been introduced in agriculture as an indispensable tool to complete Agritech investments. Specifically, they perform the following activities (Zhai *et al.*, 2020):

- gathering, managing, and combining several types of information required for selected cultivation;
- examining and interpreting data;
- employ the analysis to suggest the most suitable course of action.

Agribusiness DSS (ADSS) can provide farmers information on plant growth or plant disease risk to set up treatments according to their actual needs (Rossi *et al.*, 2014). Intenet-based devices, variable rate technologies, sensors, and meteorological station are limited to daily farm operations if not supported by an effective DSS that guide farmers in strategically exploiting data provided by these devices. Previous research has investigated the variety of ADSS developed and adopted worldwide. These studies cover ADSS for yield management and irrigation according to soil characteristics, crops needs and climatic conditions (Bochtis *et al.*, 2012; Czimber, Galos, 2016, Udias *et al.*, 2018). Looking at Italian Agritech, the diffusion of PA and ADSS has been lower than in Europe (Fenu, Mallocci, 2020). Since PA adoption intensifies DSS implementation, the limited spread of Agritech in Italy slows down the adoption of ADSS (Fenu, Mallocci, 2020). Research shows that automatic driven machines and sensors are employed on only 2% of the utilized agricultural land and almost exclusively in Northern Italy (Scuderi *et al.*, 2022). The adoption of digital farming systems, assisted by ICT, is attested between 1 and 4-5%, in contrast to 40-70% of China, Israel, and the USA (Trivelli *et al.*, 2019). Internet-based technologies in the cereal, fruit and vegetable, and wine sectors are growing very slowly, despite the developments made due to the COVID-19 pandemic (Scuderi *et al.*, 2022).

The fact that ADSS are less used than expected is an issue not limited to the Italian context (Kopishinska *et al.*, 2020; Zhai *et al.*, 2020). Barriers to adoption cover mainly technical problems related to new types of equipment, difficulties in accessing software, lack of compatibility between new tools, and adaptability of new procedures to institutionalized farm routines (Robertson *et al.*, 2007 Kopishinska *et al.*, 2020; Zhai *et al.*, 2020). Besides these problems, research reveals farmers' concerns about service providers' potential mismanagement of agricultural data, troubles in managing the number of records (Zhai *et al.*, 2020), poor software user-friendliness (Jellason *et al.*, 2021), high costs of investment required (Cosby *et al.*, 2016) and incapacity to measure the financial profitability of innovations (Lee *et al.* 2021). Producers of PA devices often offer, together with the asset sold, a system that records and processes data produced by their equipment and web portals where farmers can access additional services. However, farmers usually own machinery of several brands. The fact that data comes out from different sources and requires diversified elaboration protocols forces farmers to use a variety of web portals and software to process and use them. Frequently farmers need to transfer data from one system to another manually. ADSS models rarely provide financial feedback on resource efficiency and are never connected, if existing, to the company's MA system (Kopishinska *et al.* 2020). It has been noted that during the first 15 years of PA's history, research was targeted to make electronics and software components progress, while the agronomic analysis, as well as information processing and decision-making support, were left behind (Zhai *et al.*, 2020). This aspect may have played a role in the low diffusion of ADSS (Fountas *et al.*, 2004).

Zhai *et al.* (2020) provide a comprehensive review of thirteen ADDSs. The authors not only analyze specific purposes ADSS but also score their quality according to a set of parameters selected from the Software Quality Requirements Evaluation (SQuarRE), including accessibility, interoperability, scalability, and functionality completeness. Their findings provide evidence that all the thirteen ADSS investigated presents several limitations for PA management, and therefore, a considerable number of improvements can be made. The authors (Zhai *et al.*, 2020, p. 12) summarise the main challenges as the following: "(i) simplifying graphical user inter-faces to improve accessibility and usability; (ii) enriching functionalities to provide more adequate decision supports during the whole life cycle of Agriculture 4.0; (iii) adapting to uncertainty and dynamic factors to provide accurate decision supports; iv) considering replanning mechanisms to strengthen the robustness of ADSS; (v) adopting knowledge from experienced experts in case of adjusting inappropriate decision supports; (vi) enabling prediction and forecast to prepare farmers for future decision-making activities; and (vii) performing analysis on historical information to enhance the quality of decision supports".

Often, the success or failure of an ADSS adoption depends on the direct involvement of the end-users in the information system development process. Several authors have stressed the need for a user-centred approach for DSS design (Cerf *et al.*, 2012; Matthews *et al.*, 2008; Thorburn *et al.*, 2011; Van Meensel *et al.*, 2012). According to this approach, to be effective, a DSS should be conceived, designed, and implemented based on the users' needs and the context of use, rather than pushing the users to change by accommodating their behaviour in the ICT architecture constraints.

5. Discussion and conclusions

The findings of our literature review provide a multifaceted picture. Previous research has shown the need and opportunity to evolve traditional agriculture toward more sustainable production models driven by technology. Generally speaking, there is evidence that PA positively affects farms' profitability in terms of increased resource efficiency and quantity/quality improvements in yields. However, empirical results prove also that the measure of financial advantages related to PA adoption is conditioned by several factors, first of all, farm size. Therefore, future investigation on this front is needed to guide farmers in appraising PA's investments.

On the side of managerial processes, findings reveal that farmers' decision-making process still relies on site-specific circumstances, personal experience, and social networks. Farmers usually are inclined to use technology for technical processes but less willing to base their decision-making on data provided by these systems. Even accounting information for financial performance monitoring is low, confirmed by the modest adoption of formalized MA systems within the sector, especially in small and medium-sized companies.

These findings describe a kind of paradox. On the one hand, we have the fast development of PA devices, while on the other, research highlights that farmers' attitude to use the information potential of these new devices is low and impeded by their limited technological knowledge. A way to overcome this apparent contradiction could be to rely on ICT to support the transition from traditional to modern agriculture by helping farmers become familiar with the information provided by PA devices and exploit their usefulness.

Although several ADSSs already exist on the market, empirical research has recognized some pitfalls that suggest a profound reflection on the features these systems shall possess to reduce implementation problems and increase usability among farmers. It has been noted that current ADSS usually do not include accounting information modules. Given the value of this information for modern farming, a better reflection on its inclusion is expected. On this side, making the ADSS able to investigate the financial implications of technical operations may guide the education process of farmers toward managerial professionalization. The integration among different databases such as internal production systems, external information systems (satellite GPS, GIS data, metrology data, etc.), management and financial accounting systems would allow farm management extension, increasing farmers' ability to take action on different decisional areas. The investigation object may well be a single device, an activity, a field, or a management zone according to the user's need at one point in time. Moreover, the system's drill down analytic capability would allow data aggregation and disaggregation, giving the DSS high flexibility.

The adoption of PA forces farmers to change their customized routines. Traditionally, farmers consider all fields as one farm (Kopishinska *et al.*, 2020). They usually buy devices, fertilizers, and other resources for the entire economy, regardless of crop uniqueness, leading to suboptimal results. According to system data analytics, PA requires organizing the fields in several smaller management zones, fields characteristics (distinct zones have physical characteristics and productivity conditions), topographical data, humidity, fertilizer needs, etc. These areas are part of a field that reflects a relatively homogeneous combination of factors of profitability limitation. This information, converted in financial terms, means that each management zone, with specific operational attributes and related costs and revenue, may be considered profit centres within the MA system. Data provided by PA infrastructure would then allow performing cost allocation on real-time operational data rather than on an assumption base. Since operational performance may be considered a leading indicator of financial performance, monitoring operational data allows predicting and acting on future economic outcomes. The rationale behind integrating different databases is that where a variable exists that directly influences another, the system must integrate data from various sources to highlight their interlink (Edersheim, Vanderbosch, 1991; Porter, 1985; Shank, Govidarajan, 1993). Specifically, data provided by the MA system is fundamental to complete farmers' knowledge on financial cause and effects implications of production processes. The system should then be able to investigate each source of variability in companies' performance: physical conditions, production activities, costs and financial returns.

Our literature review shows that, although several ADSS exist on the market, a significant challenge for developing an integrated agribusiness DSS is better addressing users' demands. Turning the development process of an ADSS *on the user's head* involves beginning with the decision maker's requirements and working back to the data necessary to quantify relevant model outputs. At the moment, it seems that much still has to be done on this front. For example, most users need whole-farm models that consider interactions among multiple crops and livestock. Most of ADSS, however, lacks these features. They represent only single crops and can only simulate inter-cropping or crop-livestock interactions. This limit is probably because these systems are primarily developed in industrialized nations, where large scale commodity crops prevail. Software developers prefer single crop modelling because they are more manageable; its development requires less computational resources and is driven by a smaller set of data than models of crop rotations, inter-crops or crop-livestock systems. When put at work, the system does not account for the complexity of everyday operations, and, in the long run, it is unable to measure effectively support strategical decision making. These shortcomings need to be addressed if we want that DSS devices act as drivers for sustainable agriculture in general and PA specifically.

In our opinion, the poor user-friendliness attributed to ADSS is a two-faced problem. The responsibility for that is not only on software developers' side; it is also an issue related to farmers' knowledge deficit.

Therefore, special consideration should be paid to make users' involvement in the ADSS development a tool to educate them on the proper use of technology and accounting information. Evidence shows that technological innovation can become a driver for farmers' professionalization if its introduction is seen as a complex shared process of co-learning and negotiation, in which social learning practices are promoted (Kitchen *et al.*, 2002). The learning perspective is strengthened when participatory approaches and involvement strategies are implemented, especially at the early stage of the DSS development process (Leeuwis, 2004). This method simplifies most new practices' implementation process but does not limit itself to a technical question of user-friendliness. This methodological approach provides the ground on which trust and stronger relations between the actors involved (farmers, consultants and developers) are created, and farmers' managerial professionalization is achieved (Lindblom *et al.*, 2017).

The value-added of our literature review is that it encompasses several research fields such as agricultural techniques, performance management, information systems design. These investigation areas influence how new-generation agribusinesses operate in the field and manage their performance through brand-new data. However, our findings are affected by some limitations. The searching strategy was guided by selecting terms that may have limited the quality and number of studies discussed in this paper and consequently conditioned the appropriateness and correctness of our discussion. Additionally, our study focuses on a multisector research topic. When dealing with the impact of PA on profitability and related information needs for farm management, the area under investigation is broad, and the literature review requires relying on diversified sector-related sources. Most of the studies we have discussed come from economics, agricultural, agricultural engineering, and computer science journals. Consequently, our reasoning may have been affected by an incomplete ability to assess the quality and value of the reviewed studies. On the other side, though, given the little previous research on the topic, focusing only on Business Administration related journals would have excessively restricted the investigation and the consequent analysis.

Having considered that investigating managerial implications of technological shifts in agriculture is a topic that has received little attention so far, further research into farms' management and decision-making would enrich context-related research. Specifically, qualitative research that explores the longitudinal process of PA and ADSS adoption in farm-ing using case study methodology would improve research and practitioners' understanding of factors that facilitate or resist technological change in agribusiness. We suggest that relying on an inter-sector research team would overcome problems related to such a multifaced research topic. The value of this kind of study will enrich knowledge and contribute to the theorizing of appropriate sector-based information systems.

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