Unlocking the Potential of Agriculture 4.0: A Comparative Study on Italian Farms' Technological Evolution, Business Demands, and Perceived Benefits

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Abstract: This paper aims to investigate the state-of-the-art of Agri 4.0 adoption in Italian agricultural companies and to understand variations in business needs, technologies implemented, and benefits perceived. The study utilizes a descriptive approach with longitudinal features, examining 543 Italian agricultural companies through a survey and comparing the responses of 168 sub-samples in common with a similar survey launched two years prior. The results show that Italian agricultural companies still have limited awareness of Agri 4.0 technologies, with company size (in terms of hectares and revenues) influencing technology adoption. Knowledge and adoption of Agri 4.0 technologies increase over a two-year interval. Companies are primarily seeking Agri 4.0 solutions to improve environmental sustainability and product quality, and the perceived benefits are related to the number of Agri 4.0 technologies used. The paper acknowledges some limitations, such as the limited number of subjects involved in the longitudinal study and the focus on a limited geographical area (Italy) and suggests incorporating additional Agri 4.0 technologies in future surveys to gain further insights into Agri 4.0 development. This study provides one of the first attempts to assess variations in Agri 4.0 implementation concerning technology adoption, business need expressed by farmers, and the alteration of benefits, filling a gap in the literature of longitudinal studies investigating the development of the Agri 4.0 paradigm in a specific agricultural context.

Keywords: Agriculture 4.0, Smart Farming, Survey, Longitudinal Study

I. INTRODUCTION

In near future the world will face some major challenges, such as (1) climate change: with major effects of agriculture and earth arable surface, (2) freshwater shortage due to overall utilisation increase (also in agriculture), (3) demographic changes, with less people in rural areas and ageing workforce [1], and (4) geopolitical instability with subsequent potential fluctuations of process for fundamental agricultural inputs. A fundamental help in addressing these challenges comes from the so-called Agriculture 4.0 (Agri 4.0). [2]

Agri 4.0 encompasses various scientific domains, with some directly focused on land cultivation (such as water control, crop cultivation, harvesting, etc.), while others extend into different disciplines like engineering, economics, and management [3]. The development of Agri 4.0 is driven by advancements in information and communication technology (ICT) and the need to enhance agricultural productivity for food safety and environmental concerns. Agri 4.0 is a derivative of the broader concept of Industry 4.0, which aims to integrate technologies like Internet of Things (IoT), artificial intelligence, and cloud computing to automate cyber-physical tasks in agriculture, enabling better planning and control of agricultural systems. In fact, there are many other areas where the 4.0 paradigm is being applied, such as logistics processes [4]. This concept aligns with the adoption of digital technologies to support manufacturing processes in Industry 4.0 paradigm [5].

According to literature, the motivation behind agricultural progress lies in reducing input costs and increasing productivity. However, sustainability should not be disregarded, as it has emerged as a crucial aspect across various human activities. Hence, one of the objectives of Agri 4.0 is to minimize the environmental impact of agricultural practices, even though this research showcases interesting highlights related to this specific aspect. Implementing Agri 4.0 solutions offers farms the potential to achieve specific goals and benefits. Thus, while the existing literature has explored this concept, providing specific instances of classifying the potential advantages, and investigating in the enabling digital technologies, there is a lack of comprehensive study that primarily focuses on understanding the awareness and adoption of digital solutions in agriculture. Furthermore, scientific research has not made significant contributions in terms of examining the business needs that lie behind the willingness among farmers to invest in such technologies, along with the overall impact of their implementation, both in a broader sense and specifically within the context of the Italian market. Moreover, the present article empirical research methods, proposes a further point of view (lacking in the relevant literature), presenting a longitudinal analysis of such factors, leading to a gap in the generation of scientific findings based on practical insights from those directly involved in agricultural practices.

In an attempt to fill the above-mentioned literature gaps, the following research questions have been formulated:

RQ1: What is the state-of-of the-art of Agri 4.0 adoption in the Italian farms?

RQ2: Which business needs bring farmers to invest in Agri 4.0 and which benefits perceived?

RQ3: What are the main Agri 4.0 evolutions regarding technologies implemented, business needs and perceived benefits?

The article is structured as follows: Section 2 describes the research methodology used, that is followed by Section 3 in which results on three main thematic analysis have been discussed. Thereafter, Section 4 discusses the main findings and present the proposal for future research agenda.

II. RESEARCH METHODOLOGY

A. *Research design*

This research has two primary objectives focused on the implementation of Agri 4.0 (A4.0) in the agricultural sector of Italy. Firstly, it seeks to assess the current state of A4.0 adoption in Italy, emphasizing technological advancements related to core enabling technologies [6], identifying business motivations driving farmers to invest in these technologies, and analysing the benefits resulting from their implementation [7]. Secondly, the study aims to evaluate the evolution of A4.0 in the Italian agricultural sector by comparing responses from a sub-sample of two surveys, as depicted in Figure 1.

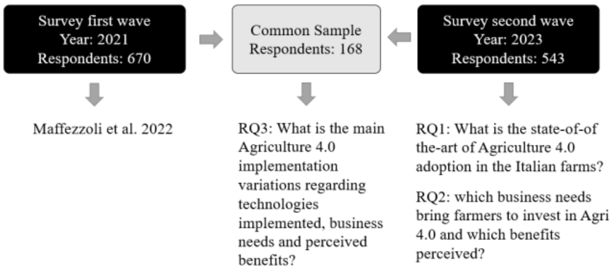

Figure 1 Research design

To achieve the first objective, the researchers analysed survey results conducted between the end of 2022 and February 2023. For the second objective, they employed a longitudinal study design, comparing responses from a sub-sample that participated in both the current survey and a previous survey conducted in 2021. Longitudinal studies, commonly used in medical and social sciences, observe the changes in a phenomenon over time within a specific sample. The survey design used in this research follows a similar approach to a previous study conducted in 2021, as discussed by Maffezzoli et al. [8]. During the research we have employed a two-wave fixed panel design with a two-year interval between the surveys. The data collection process and management were consistent for both surveys. This methodology has been utilized in other scientific literature [9], such as the study by Zheng et al. [10], which also employed a longitudinal design with similar characteristics.

The survey was conducted online using the web survey mode as it was deemed cost-effective and feasible in terms of time and resources. Utilizing web surveys eliminated the need for manual data transfer and minimized interviewer biases [11]. The researchers chose "Qualtrics" as the web survey tool, which provides an open platform for designing, launching, and collecting online surveys. The tool also facilitated mail recording and tracking to monitor response statuses, while the questionnaire served as the primary data collection tool. Each farm's reference person completed and archived the questionnaire. Data collection occurred between the end of 2022 and the first two months of 2023, with regular reminder mailings every two weeks and follow-up telephone calls to ensure respondent participation. The questionnaire consisted of four sections: the first section gathered basic information about the company and the respondent, the second section focused on the extent of the company's existing A4.0 enabling technology knowledge, and the third section explored business needs and benefits achieved.

B. Sample description and data collection

Sample description is shown from two perspectives. First, the complete 2023 sample (S1), then the common subsample (S2). In order to show the data concisely, we have represented in each table both the full sample data and the sub-sample in common.

Table 1 shows the company size by cluster. Due to the absence of a dedicated classification for farm size in the primary sector, a decision was made to create five tailored clusters. This approach was chosen to avoid confusion caused by using traditional criteria associated with manufacturing businesses, as there is significant variation in turnover across different sectors, and it is the same presented in first wave survey (Maffezzoli et al., 2022).

Table 1 Revenue cluster distribution (total & common sample)

Revenue Cluster	**Nr. of farms – S1**	**(%) S1**	**Nr. of farms – S2**	**(%) S2**
A. < EUR 30,000	*107*	*20*	*32*	*19*
B. between EUR 30,000 and 100,000	*148*	*27*	*52*	*31*
C. between EUR 100,000 and 250,000	*100*	*18*	*31*	*18*
D. between EUR 250,000 and 500,000	*59*	*11*	*20*	*12*
E. > EUR 500,000	*129*	*24*	*33*	*20*
Total	**543**	**100**	**168**	**100**

In the table, it is important to highlight that the majority of the sample, accounting for 65% (slightly higher in comm sub-sample with 68%), falls below a turnover of EUR 250,000. Conversely, the remaining 35% (32% in sub-sample) surpass this threshold, with 24% (20% in sub-sample) of them having a turnover exceeding half a million euros.

Due to the unique characteristics of the sector being examined, and in order to conduct a more comprehensive analysis, an extra indicator of sample company size was employed (Table 2), namely, the number of cultivated hectares. However, it is worth noting that there is no definitive classification for the categories to be considered in this case.

Table 2 Land size distribution (total & common sample)

Hectares Cluster	**Nr. of farms S1**	**(%) S1**	**Nr. of farms S2**	**(%) S2**
A. < 10	*139*	*26*	*49*	*29*
B. between 10 and 20	*75*	*14*	*35*	*21*
D. between 20 and 50	*111*	*20*	*32*	*19*
E. > 50	*218*	*40*	*52*	*31*
Total	**543**	**100**	**168**	**100**

In this case sub-sample is slightly smaller compared to the total sample, 69% of farms are below 50 hectares while it is 60% in total sample.

III. RESULTS

A. Agri 4.0 Technology adoption.

The initial finding of the analysis focuses on examining the current level of knowledge of Agri 4.0 solutions among the survey's participants (S1). Figure 2 provides a summary of the results. To gauge the awareness, a 4-point scale was utilized, ranging from low to high familiarity with the solutions. These levels include: (a) *Unknown*, which means lack of familiarity, indicating no awareness of the existence of the solutions; (b) *Known but do not use*, that means limited familiarity, implying having heard of the solutions to a small extent; (c) *Used in the past, not anymore*, meaning the respondent has a theoretical familiarity, indicating a good understanding of the solution; and (d) *In use*, or in other words there is practical familiarity, signifying knowledge of the solutions and practical examples in the field.

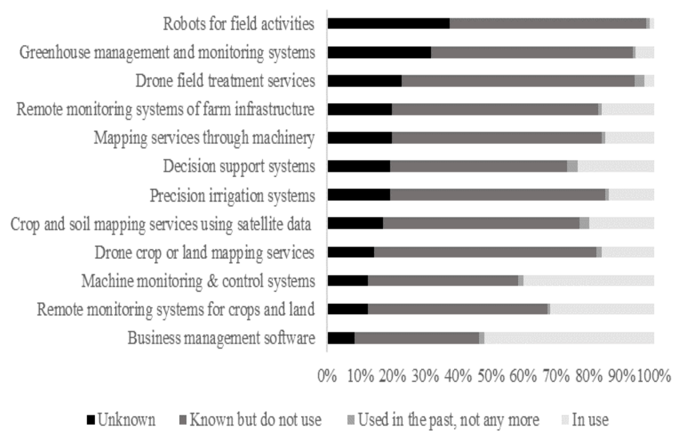

Figure 2 Agri 4.0 solutions awareness level.

The data reveals varying levels of adoption and awareness among the surveyed participants for different Agri 4.0 solutions. Overall, it is evident that certain solutions have gained higher traction and acceptance compared to others, hereby some of the highlights of the analysis depicted in Figure 2.

First of all, it is important to point out that approximately 52% of respondents reported using *business management software*, indicating a substantial adoption rate. However, 38% were aware of this solution but had not yet incorporated it into their operations.

Remote monitoring systems for crops and land, which demonstrated relatively high levels of awareness (55%) and adoption (32%), indicating a considerable interest in leveraging technology for monitoring and managing crops and land remotely.

Similar to remote monitoring systems, *machine monitoring and control systems* exhibited notable awareness (46%) and adoption (40%) rates, implying their perceived value in optimizing farm machinery operations.

Drone-based mapping services for crops and land showed significant awareness (68%), indicating a widespread recognition of their potential benefits. However, adoption levels were relatively lower (16%), possibly due to various factors such as cost, regulatory challenges, or limited integration capabilities.

Precision irrigation systems (enabled by digital technologies) demonstrated relatively high level of awareness (66%), indicating the recognition of their potential in optimizing water usage. However, adoption levels were reported at 14%, suggesting potential barriers to implementation.

Similar to precision irrigation systems, *decision support systems* were familiar to 54% of the respondents, while adoption levels were reported at 23%. This indicates a moderate uptake, potentially due to the complexity of integrating such systems into existing agricultural practices.

The use of *drones for field treatment services* exhibited relatively lower adoption levels (3%) despite a significant awareness rate (71%). Suggesting that practical challenges hinder their widespread use. At last, we find that *robots for field activities* demonstrated the lowest adoption rate (1%) among the surveyed solutions, despite a relatively high awareness level (60%). Practical limitations, cost factors, or technological challenges might contribute to this low adoption rate.

B. *Agricultural Business needs and benefits perceived.*

Combining the information about business needs and perceived benefits in a single paragraph provides a clear and concise overview of the relationship between the two. The identified needs directly align with the perceived benefits and how addressing those needs with specific Agri 4.0 solutions mentioned above can lead to positive outcomes.

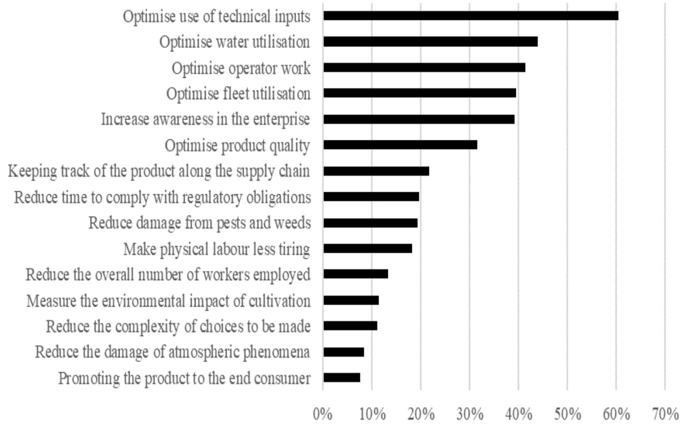

Figure 3 Business Needs expressed.

Figure 3 presents the farmers identified business needs, along with the corresponding percentages indicating their relative importance. The key findings reveal a diverse range of priorities requiring attention and optimization. At the top of the list, optimizing the use of technical inputs emerged as the highest priority, emphasizing the significance of efficiently utilizing resources such as fertilizers, pesticides, and machinery. Other important areas include optimizing operator work, fleet utilization, and water utilization. These factors highlight the importance of streamlining tasks, leveraging technology, and implementing sustainable irrigation practices to enhance operational efficiency and conserve valuable resources. The findings also emphasize the importance of reducing complexity in decision-making processes, promoting consumer engagement, optimizing supply chain management, and increasing awareness of enterprise operations.

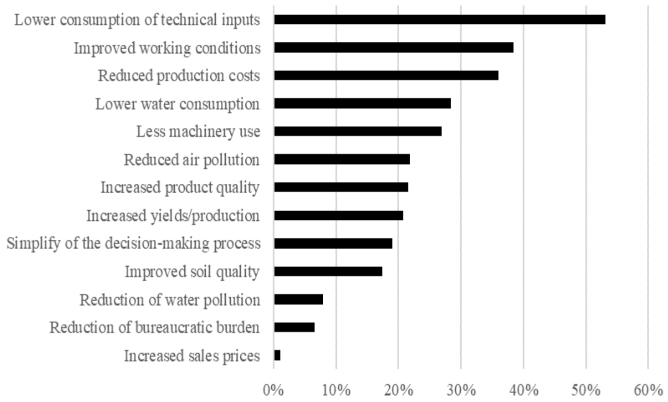

Figure 4 Benefits perceived.

Figure 4 presents the perceived benefits of adopting Agri 4.0 solutions. It showcases the benefits in descending order. At the top, with 53%, is the lower consumption of technical inputs, highlighting the desire to reduce resource dependency [12]. Improved working conditions follow closely at 38%, emphasizing the importance placed on enhancing the welfare of agricultural workers. Reduced production costs rank third at 36%, indicating that Agri 4.0 is meeting the expectation of cost savings. Resource efficiency is recognized through lower water consumption (28%) and reduced machinery use (27%), showing strong connection with business needs expressed. It is important to highlight that reduction of water pollution (8%) and reduction of bureaucratic burden (7%) are perceived as relatively minor benefits. Last but not least, increased sales prices are viewed as the least significant, with only 1% of farmers perceiving it as a positive outcome.

C. *Variations in technologies implemented, business needs and benefits.*

As previously depicted, the sub-sample of common companies is constituted of 168 farms. But, in the analysis that will be shortly presented, only the "utilizer" sample has been analysed. The first notable result is the increase in users within the sample, from 114 in the first survey to 121 in the second, a growth of 6.1%.

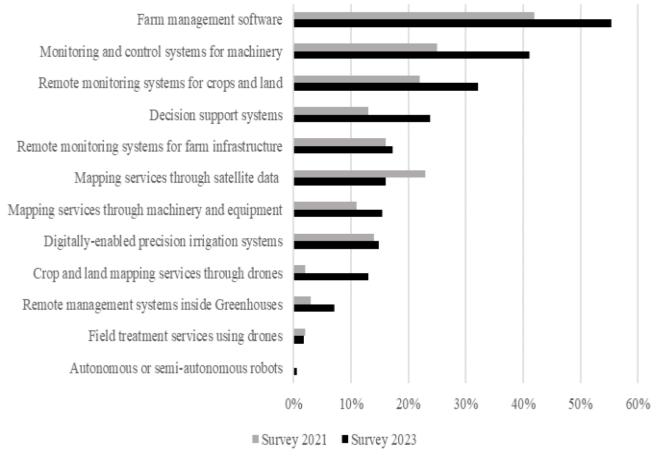

Figure 5 Agri 4.0 solutions utilization comparison

Monitoring and control systems for machinery exhibits the largest positive delta of 16%. The significant increase suggests a growing interest in implementing monitoring and control systems to enhance the efficiency and productivity of agricultural machinery [13]. Decision support systems also show a large positive delta of 11%. It indicates a significant increase in adoption and interest in decision support systems, which provide valuable insights and recommendations for agricultural decision-making [14]. With a positive delta of 10%, there has been an increase in the utilization of remote monitoring systems for crop and land monitoring. This technology allows farmers to remotely monitor and assess the condition of their crops and land [15], leading to more informed decision-making. Also farm management software shows a positive delta of 13%. On the other hand, the only negative delta is observed in mapping services through satellite data, which shows a negative delta of -7%. Taking a closer look at the graph, we can see that it could be due to alternative mapping services, such as Drone mapping, which is gaining traction within the sample.

Table 3 Business Needs Comparison

Business Needs	(%) 2023	(%) 2021	(%) Delta
Optimise use of technical inputs	*66*	*56*	*10*
Optimise water use	*49*	*38*	*11*
Optimise operator work	*40*	*30*	*10*
Increase awareness of what is happening in the business	*39*	*31*	*8*
Optimise fleet utilisation	*35*	*35*	*0*
Optimise product quality	*27*	*27*	*0*
Keeping track of the product along the supply chain	*25*	*41*	*-16*

Reduce pest and weed damage	*21*	*19*	*2*
Reduce the time required to fulfil regulatory obligations	*20*	*20*	*0*
Make physical labour less tiring	*18*	*20*	*-2*
Reduce the overall number of workers employed	*12*	*16*	*-4*
Reduce the complexity of the choices to be made	*10*	*20*	*-10*
Reducing the damage of atmospheric phenomena	*9*	*9*	*0*
Measure the environmental impact of cultivation	*9*	*34*	*-25*
Promoting the product to the end consumer	*7*	*27*	*-20*

Positive and negative deltas reflect the changing priorities and focus areas within the surveyed companies. Table 3 shows that, while there is an increasing emphasis on optimizing technical inputs (such as technical inputs and water usage) and operator work. Although, it shows that there has been a decline in the importance given to measuring environmental impact and promoting products directly to consumers. It would be interesting to study the reasons for this and possibly the correlation with main external factors.

Table 4 Benefits Perceived Comparison

Benefits	**(%) 2023**	**(%) 2021**	**(%) Delta**
Lower consumption of technical inputs	*54*	*39*	*15*
Improved working conditions	*43*	*20*	*23*
Reduced production costs	*38*	*23*	*15*
Lower water consumption	*30*	*35*	*-5*
Less machinery use	*25*	*22*	*3*
Increased product quality	*24*	*34*	*-10*
Reduction in air pollution	*21*	*22*	*-1*
Simplify the decision-making process	*17*	*18*	*-1*
Increased yields/production	*17*	*22*	*-5*
Improved soil quality	*13*	*31*	*-18*
Reduction of water pollution	*12*	*27*	*-15*
Reduction of bureaucratic burden	*7*	*13*	*-6*
Increased sales prices	*2*	*2*	*0*

Table 4 highlights the evolving perception of benefits achieved, with some benefits showing significant positive deltas and others experiencing negative deltas. Table 4 highlights the fact that higher perceived benefits are efficiency related, even though larger delta (23%) is related to improving working conditions (physical fatigue). On the other hand, larger negative delta belongs to soil quality and water pollution (-18% and -15%, respectively), reflecting an interesting reduction in environmental attention.

Business needs expressed and perceived benefits show an interesting relationship. Farms articulate their specific requirements, such as reducing production costs, optimizing resource utilization, and increase awareness of farm operations. Correspondingly, perceived benefits encompass lower input consumption, lower machinery utilization, and enhanced working conditions. The alignment between farm needs and perceived benefits indicates the industry's adaptability to changing market dynamics, technological advancements, and sustainability considerations. Understanding this relationship is fundamental in developing targeted agricultural solutions that address the evolving demands of farms, leading to sustainable and efficient farming practices.

IV. Discussion and Conclusion

This paper presents analysis and provides valuable insights into the adoption and awareness levels of various Agri 4.0 solutions. It highlights the varying degrees of acceptance and utilization across different technologies. Understanding the adoption patterns, but also needs that bring farmers to invest in 4.0 solutions and related perceived benefits can assist policymakers, researchers, and industry stakeholders in identifying barriers and devising strategies to facilitate the wider integration of Agri 4.0 solutions in the agricultural sector, thereby unlocking the potential benefits of enhanced productivity, efficiency, and sustainability in farming practices. The results of the study demonstrate varying levels of adoption and awareness of Agri 4.0 technologies among farmers. Certain solutions, such as business management software and remote monitoring systems, have gained higher traction and acceptance compared to others. We identified a diverse range of business needs expressed by farmers, focusing on resource optimization, operational efficiency, and awareness of farm operations.

Another significant result of this study is that the perceived benefits of adopting Agri 4.0 solutions align closely with these needs, emphasizing lower consumption of technical inputs, improved working conditions, and reduced production costs. However, there were variations in the perceived benefits over time, with a decline in the importance given to environmental impact and consumer engagement. Regarding technologies implemented, the study revealed changing priorities within the surveyed companies. Monitoring and control systems for machinery and decision support systems experienced significant increases in adoption, indicating a growing interest in efficiency and decision-making processes.

Nonetheless this study presents some limitations. Although the focus of the study was precisely on the comparison of technology utilisation and the 'needs vs. benefits' nexus, a key part related to the obstacles encountered by user companies towards 4.0 technologies is absent. Second, the study primarily presents descriptive statistics. Statistical tests, such as chi-square tests or regression analysis, could provide insights into the significance of the observed differences and associations. The absence of statistical analysis limits the strength of the conclusions that can be drawn from the findings. For this reason, the focus of the research team following this preliminary study, will be precisely to strengthen the results with the appropriate analyses.

Last but not least, further investigation will deepen contextual information about the specific agricultural settings or regions where the study was conducted, because the adoption and awareness of Agri 4.0 technologies can be influenced by various factors, such as socio-economic conditions, infrastructure availability, or regulatory frameworks. Without understanding the context, it is challenging to fully interpret and generalize the findings.

Overall, this study underscores the importance of aligning Agri 4.0 solutions with farmers' specific needs and priorities. Understanding the relationship between business needs and perceived benefits is crucial for developing targeted agricultural solutions that address evolving demands and promote sustainable and efficient farming practices.

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