

Digital Technologies in Agriculture: Developments and Perspectives

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Abstract

Purpose – It is widely considered how the world of agriculture has been changing in recent years in relation to recent technological innovation developments. Technological and communicational innovations that, in an increasingly connected world, have changed all sectors of the economy and agriculture is no exception. **Design/methodology/approach** – This article aims to highlight what are the relevant aspects of digital technologies used by agriculture framed in the industry 4.0 paradigm through a research that analyses the most diffused technologies in order to highlight common patterns and technological overlaps. These show how the domains under analysis are directly connected and describe the most important technologies able to drive digital transformation processes in the agricultural sector.

Findings and Originality/value – The outputs of our empirical research highlight: a dictionary of Precision Agricultural Technologies includes 324 terms; a graph, describing the most cited technologies composing the dictionary and the connections between themselves; a representation of main technological clusters which describes the overlap between Industry 4.0 and Precision Agriculture.

Keywords: precision agriculture, Industry 4.0, digital transformation, text mining, enabling technologies.

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Introduction

The fundamental role of technologies in the innovation process of companies all over the world, regardless of the commercial sector they belong to, is sublimated by the wave of the Industry 4.0 paradigm which aims to integrate digital technologies into business processes by developing new business models (Chiarini et al., 2020). This new innovative concept is based on the advanced digitization of factories, the Internet and future-oriented technologies that bring intelligence into devices, machines and systems (Lasi, et al., 2014). Also in the agri-food sector, the evolution of innovation technologies is playing a key role for companies in strengthening their production processes and organizational structures through automation, monitoring and information technology (Foglia and Reina, 2006; Kamariotou, et al., 2019; Zhang and Kovacs, 2012). Technological innovation has therefore become necessary over time for the development of companies that grow in size and structure, with new paths oriented towards the integration of the most advanced technologies in the cultivation processes (Zhang et al., 2002). From these premises we can highlight the two main challenges that modern agriculture must face in the next future: the need to increase production and reduce environmental impacts. The digital technologies behind precision agriculture are the resources to be exploited to tackle these two sustainability issues, optimizing the entire production system of companies taking into account environmental and economic constraints (Zheng et al., 2021). In this article we try to shed light on the

nature and application of the technological tools at the basis of the paradigms of Industry 4.0 and Precision Agriculture. We analyse connections and overlaps between these two paradigms, in order to create a dictionary that identifies the most innovative technologies applied in agriculture, with the aim of helping to make this topic clearer by illustrating existing digital technologies and promoting managerial practices in the current agri-food landscape.

Framing Precision Agriculture

Precision Agriculture (also called Precision Farming) has developed since the end of the twentieth century with the aim of promoting agricultural management which, based mainly on digital technologies, allows to improve production processes and increase profitability, minimizing environmental damage and preserving the quality standards of agricultural products. It is precisely digital technologies that open the door to the possibility of making agricultural production processes precise taking into account the actual crop needs and the biochemical and physical characteristics of the soil. The concept of Precision Agriculture emerged in the United States in the nineties, where the House of Representatives (1997) defines it as an application of technologies, principles and strategies to monitor and optimize agricultural production processes in order to manage agricultural production in relation to the real needs of the plot. Over time, there has been an evolution of the various provisions of the PA that have slowly allowed to establish the constitutive elements of the concept and its fields of application in order to intercept, among other things, the PA as a management tool alongside with concepts of economic and environmental sustainability. Table 1 shows the main definitions based on a careful selection of the existing literature. Starting from a literature review carried out on the Scopus database (see Table 1) focused on the analysis of definitions of the concept of Precision Agriculture, it emerged that technology was the first central element of Precision Agriculture. However, over the years the attention of the scientific community has also focused on other elements, such as: General Benefits, Sustainability and Applications. This development path can be detailed in Table 1, thanks to which it is possible to understand how the definitions of Precision agriculture have been enriched over time with new and more complex contents until reaching the definition of management strategy. Pierce and Nowak (1999) highlight the central position of Technology and the Generated Benefits as the two key elements of Precision Agriculture. Then we arrive with the definition of Zhang, et al., (2002) to strengthen these two distinctive elements, recognized in literature. Kirchmann and Thorvaldsson (2000), also stressed on the technologies and completed the definition with the introduction of the Sustainability concept. Bongiovanni (2004) instead, emphasizes the environmental theme by defining Precision Agriculture as an application that can help manage harvest production inputs in an environmentally friendly way. In a study of the European Union (Schrijver et al., 2016) entitled Precision Agriculture and the future of farming in Europe, the PA definition introduce the concept of digital techniques and optimization of production processes; which brings out the concept of field application. Finally, in 2019, the International Society of Precision Agriculture (ISPA) adopted an univocal definition that connects all the definitions given above and frames the PA as a management tool.

Table no. 1. Literature review, definitions and technologies of Precision Agriculture

<u>AUTHOR</u>	<u>DEFINITION</u>	<u>TITLE AND JOURNAL</u>	<u>YEAR</u>	<u>DISTINCTIVE ELEMENTS</u>
F.J.Pierce, P. Nowak	Precision agriculture is the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality. Precision agriculture is technology enabled.	Aspects of Precision Agriculture- Advances in Agronomy vol. 67, pp. 1-85	1999	Technology Generated Benefits
H. Kirchmann, G. Thorvaldsson	Precision agriculture is a discipline that aims to increase efficiency in the management of agriculture. It is the development of new technologies,	Challenging targets for future agriculture - European Journal of Agronomy 12, pp. 145–161	2000	Technology Generated Benefits

<u>AUTHOR</u>	<u>DEFINITION</u>	<u>TITLE AND JOURNAL</u>	<u>YEAR</u>	<u>DISTINCTIVE ELEMENTS</u>
	modification of old ones and integration of monitoring and computing at farm level to achieve a particular goal.			
N.Zhang, M.Wang, N.Wang	PA is conceptualized by a system approach to re-organize the total system of agriculture towards a low-input, high-efficiency, sustainable agriculture.	Precision Agriculture- a worldwide overview Computer and Electronics in agriculture, 36, pp. 13-132	2002	Technology Generated Benefits Sustainability
R. Bongiovanni, J.Lowenberg-Deboer	Precision Agriculture (PA) can help in managing crop production inputs in an environmentally friendly way.	Precision Agriculture and Sustainability Precision Agriculture, Vol.5, pp.359-387,	2004	Generated Benefits Sustainability
A. McBratney, B. Whelan, T. Ancev	One generic definition could be “that kind of agriculture that increases the number of (correct) decisions per unit area of land per unit time with associated net benefits”.	Future directions of Precision Agriculture - Precision Agriculture, 6, pp. 7-23 Springer Science Business Medis Inc.	2005	Generated Benefits
Y. S. Tey, M. Brindal	Precision agriculture is a production system that involves crop management according to field variability and site-specific conditions. Precision agricultural technologies are those technologies which, either used singly or in combination, as the means to realize precision agriculture.	Factors influencing the adoption of precision agricultural technologies: a review for policy implications, Precision Agriculture, Vol.13, pp 713-730	2012	Technology
E. Pierpaoli, G. Carli, E. Pignatti, M. Canavari	Precision Agriculture is a fairly new concept of farm management developed in the mid-1980s. PA bases its applicability on the use of technologies to detect and decide what is “right”.	Drivers of Precision Agriculture Technologies Adoption: A Literature Review, Procedia Technology, Vol.8, pp.61-69	2013	Technology
R. Schrijver, K.Poppe, C. Daheim	Precision agriculture (PA) or precision farming, is a modern farming management concept using digital techniques to monitor and optimize agricultural production processes.	Precision Agriculture and the future of farming in Europe-Scientific Foresight Study	2016	Digital techniques
International Society of Precision Agriculture (ISPA)	Precision Agriculture is a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production	International society of precision agriculture (ISPA). https://www.ispag.org	2019	Management Strategy

Methodology

The work focuses on the creation of a dictionary which identifies the most innovative technologies that are applied in Precision Agriculture by investigating the overlaps with Industry 4.0 technologies to create clusters and to analyse the connections between them. The dictionary aims to analyse the technologies related to the Precision Agriculture domain and to identify those belonging also to the Industry 4.0 paradigm. Concretely, the dictionary is a list of Precision Agriculture technologies that were identified by analysing papers retrieved from the international database. First of all, the twenty-five most cited scientific papers were identified by using the query “precision agriculture”, among those published on Scopus between 2002 and 2017. These 25 papers were analysed manually in order to identify the technologies mentioned in them and belonging to the Precision Agriculture domain. This list composed of 137 technologies was used to feed the next research steps how described in Figure 1 flowchart.

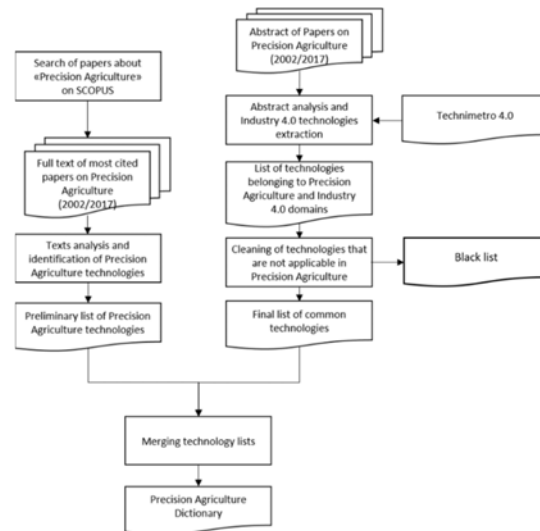


Figure no. 1. Process to create precision agriculture dictionary

However, this list of technologies was not considered exhaustive because of the limited number of analysed sources, which however provided the basic information to build the background of the analysis. Moreover, according to the goal of the research to investigate the connections between Industry 4.0 and Precision Agriculture domain, it was necessary to include Industry 4.0-based knowledge into the process. To address the above-mentioned limitations and given the proximity of the founding concepts of Industry 4.0 and Precision Agriculture, the Technimetro® was used to expand the list of technologies at the base of the dictionary. Technimetro® (Chiarello, et al., 2018) is a dictionary that contains more than 1500 technologies belonging to the Industry 4.0 paradigm and was created by selecting the Industry 4.0 technologies found in manuals, technical documents and scientific publications on Scopus. The relationships between these technologies were studied through a text mining activity to describe possible clusters and to understand how technologies are linked one-another. Therefore, the Technimetro® was used to understand if the Industry 4.0 domain contains Precision Agriculture technologies so to analyse the overlaps between the two sectors. To answer this question, all abstracts of the publications on Precision Agriculture (published on SCOPUS from 2002 to 2017 for a total number of 4320 papers) were analysed using the software “R Studio”. In this way, technologies belonging to the Technimetro® that were also mentioned in the Precision Agriculture publications could be identified. Such analysis allowed to identify more than 1000 technologies belonging to the Technimetro® which were cited in the abstracts. Moreover, among the technologies extracted through the Technimetro® only those cited at least three times were selected to be part of the final list so to avoid casual citations of technologies that do not belong to the Precision Agriculture field. The remaining technologies were checked again to manually eliminate not applicable terms, which were stored in a blacklist. Technologies were removed with the help of control groups. Finally, the new list of technologies

obtained, was compared to the list of technologies identified at the beginning with the analysis of twenty-five papers for removing duplicates and creating the Precision Agriculture dictionary.

Results and discussion

This study confirmed the relationship between Industry 4.0 and Precision Agriculture domains and allowed to create a list of over 1000 technologies referring to the Precision Agriculture domain, by expanding the list generated thanks to the analysis of the 25 most cited papers on Precision Agriculture. This analysis shows how the intersection between the technologies belonging to Industry 4.0 and Precision Agriculture is very broad and makes the two concepts very close from a technological point of view. The dictionary of Precision Agricultural Technologies includes 324 terms. Thanks to a graph, the most cited technologies and the connections between them allowed to identify at least 6 technology clusters. The graph in Figure 2 shows the structure of the dictionary containing the technologies related to Precision Agriculture and the relationships between the technologies that compose it. This representation allows to deepen the connections between the different clusters and technologies. The connections are represented by the lines that join the different nodes (which represent Precision Agriculture technologies) of the graph. The size of the nodes varies proportionally to the number of papers they are cited in, instead their position depends on the number of connections between the different technologies: the most connected ones acquire a more central position into the graph and vice versa. Table 2 shows the technologies present in the six different clusters.

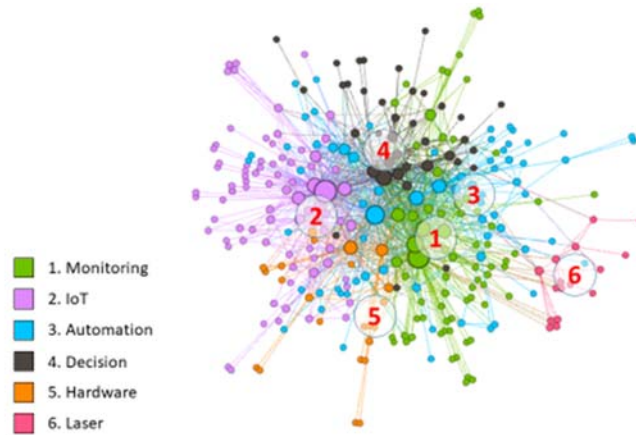


Figure no. 2. Graphical representation of precision agriculture dictionary

Table no. 2. Clusters in the Precision Agriculture dictionary

#	CLUSTER	TECHNOLOGIES
1	Monitoring	GPS, GIS, Data processing, GSM, Satellite, Ultrasound, Lidar, Broadband, Cellular, ...
2	IoT	Wireless sensor network, Internet of things, RFID, Bluetooth, Zigbee, Wi-fi, Micro-controller, Arduino, ...
3	Automation	Autonomous vehicle, Mobile Robot, Unmanned aerial vehicle, Agricultural robot, Computer vision, Data management, ...
4	Decision	Artificial intelligence, Data mining, Expert systems, Forecasting, Machine learning, Semantic web, Smart grid, ...
5	Hardware	Embedded system, Cyber-physical system, Manure spreader, Raspberry pi, CMOS, FPGA, ...
6	Laser	Laser, Laser transmitter, Laser receiver, Laser surveying, Optical fiber, Photonic sensor, ...

Monitoring systems

Monitoring systems represent a very important research topic in the panorama of studies focused on innovation in the agri-food sector. The growth of data generated by the entire agricultural supply chain represents an opportunity for companies to adopt new business models more suited to changes in the context in which they operate. The monitoring activity it includes activities that take place in many aspects of agriculture, in particular, thanks to the high-resolution satellite images is used for analysis of the soil and crop conditions (e.g. crop growth, yield and stress) in order to make the interventions of the farmers prompt and effective (Stafford, 2000; Warren and Metternicht 2005; Zhang and Kovacs, 2012). In recent years, thanks to the evolution of Internet technologies, significant opportunities of monitoring have also been obtained thanks to the use of mobile devices, which can contribute to the development of agriculture, businesses and rural areas by supporting the traceability of production, trade, services and products (Li, et al., 2010; Szilagy and Herdon, 2006).

Internet of Things (IoT)

The term Internet of Things (IoT) refers to a new technological paradigm in which many objects or “things”, such as wireless sensors network, microcontroller and other tools, interact with each other for the purpose of extract information that helps companies to undertake innovation paths (Farooq et al., 2015, Lee and Lee, 2015) and, as the term “Internet” implies, networking capability is the other core features of the IoT devices (Tzounis, et al., 2017). These technologies offer significant opportunities that can contribute to the innovation of many industrial sectors, acquiring an ever-greater centrality in business dynamics (Xu, et al., 2014; Vermesan and Friess, 2015). The exponential increase in the adoption of the technologies for the Internet of Things (IoT) has also reached the agri-food sector, increasing the interest in research and innovation towards the development of reliable, verifiable and transparent traceability systems (Caro, et al., 2018) and as Brewster, et al., (2017) argues, IoT technologies could contribute to food security and the reduction of agricultural and food waste, using sensors, RFID, actuators, drones, navigation systems, cloud-based data services and analyses that offer a variety of decision support tools (Al-Fuqaha, et al., 2015; Kumari, et al., 2015; Tzounis, et al., 2017). In particular, sensors are used by farmers in the field to measure environmental parameters such as temperature and humidity and these data can be used to make production more efficient (Sethi and Sarangi, 2017). Another major application of IoT technologies in agriculture occurs in production within greenhouses. In this case, information on humidity, soil, temperature is often collected in real time and subsequently sent to servers for analysis (Zhao, et al., 2010).

Automation management

The automated management of farms represents one of the most fascinating challenges in the panorama of current Industry 4.0 technologies applied to precision agriculture. Among the technologies used in the automation field, the expert and intelligent systems based on artificial vision algorithms are becoming successful drivers in the management of agricultural business processes and automation technology based on computerized vision is increasingly used to increase productivity and efficiency (Foglia and Reina, 2006). The rapid evolution of artificial intelligence has provided many suggestions for improving the efficiency of agricultural production in automation and a more correct and effective management of resources (Vazquez-Arellano, et al., 2016). Machine vision technology provides numerous tips and insights to support agricultural decisions and practices thanks to the evolution of techniques such as GPU (Graphics Processing Unit) and DBN (Deep Belief Networks) (Li, et al., 2019; Mochida, et al., 2019).

Decision Support Systems in the agri-food sector

Among the technologies supporting decision-making processes in the agri-food sector, the importance of Decision Support Systems must be underlined. The DSS concept emerged in the literature around the 1970s, when computer-based software was studied for the first time in order to solve problems by analyzing semi-structured and unstructured data (Anthony, 1965; Gorry and Scott Morton, 1971; Simon, 1965). In the following years, due to their flexible nature, the DSS have made significant

contributions to face today's challenges to make agriculture more productive and sustainable at the same time (Mysiak et al., 2005). In literature, several authors attest the effectiveness of these tools, just remember the application of DSS in the analysis of food safety and quality (Wijtzes, et. al, 1998); on the compaction of agricultural soils (Canillas & Salokhe, 2002); minimization of waste in wine production (Musee, et. al, 2005) and support for logistics managers in identifying the most effective solution to implement in their activities (Kamariotou, et. al, 2019). Furthermore, through the DSS tool, solutions can be implemented in the agricultural context aimed at optimizing processes which may include the identification of a correct timing for the sowing phase and a better use of water resources that can be framed in the paradigm of environmental and economic sustainability (Trogo, et al., 2015).

Hardware and Laser

These clusters could be integrated in the previous ones, but their importance and their specificity in terms of application allow them to emerge among other technologies. Laser measurement systems represent one of the most used technologies in Precision Agriculture, and there are several applications of these tools in agricultural systems. Research shows that an effective application of these technologies is found with reference to soil levelling processes, with improvements in crop activities, increasing the efficiency and precision of the processes, the yield and the quality of the products (Li, et al., 1999; Zheng, et al., 2007). With laser information collection systems, new hardware technologies have come to the storage of input data and production monitoring. In this regard, it has been found that it is possible to design an accurate system using hardware and open systems to record the Open source hardware (OSH) (Mesas-Carrascosa, 2015).

How shared knowledge and understanding facilitate development paths identification

To date, the evolution of digital techniques in the framing logic of innovation technology inherent in the Industry 4.0 paradigm has made many steps forward. The agricultural sector and investors seem to have welcomed the PA market with great interest, although the margins for improvement still seem to be great in order to exploit its full potential. In this sense, the use of the dictionary could be very interesting for companies operating in the agricultural sector. The possible applications of the dictionary are manifold and mainly refer to the field of text mining for business intelligence purposes or to support policy makers in the evaluation of projects and proposals. The application of the dictionary would allow to know more easily and faster whether a given company adopts the technologies of PA or whether it uses any PA Paradigm related to ICT technologies to visualize the development path. The growing diffusion of digital technology techniques in a context of Precision Agriculture aimed at marginalizing the costs and the pervasiveness of the industry 4.0 paradigm in the agricultural context may favour innovative processes in the primary sector and face new challenges deriving from the current socio-economic context.

Conclusion

The study, therefore, confirms the relationship that exists between Industry 4.0 and Precision Agriculture and can be useful in various aspects, both on a theoretical and practical level. From a theoretical point of view, the dictionary offers the possibility to identify how some domains of Industry 4.0 overlap and can be used in the agricultural context. From a practical point of view, the analysis of the technologies that emerged from the study of the literature offers the opportunity to better understand how they are applied in the agricultural sector. Overall, the study intends to suggest how to overcome the gap between farmers and the application of innovative technologies. Future works will explore, with qualitative studies based on the use of Case Studies and in-depth interviews, the effects of digital innovations in the agricultural sector and verify if, and what extent, the conditions for their application exist.

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