The 4.0 revolution in agriculture: a multi-perspective definition

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Abstract: In the early 2010s, a new revolution in agriculture has been triggered by the introduction of digital technologies, such as cheap and improved sensors and actuators, low cost micro-processors, high bandwidth cellular communication, Cloud based ICT systems and Big Data analytics. As a result, a new phase in the agricultural evolution started: the so-called Agriculture 4.0. Since the novelty of the notion and the little attention demonstrated by the literature, a holistic definition of Agriculture 4.0 is not present yet. Indeed, different authors take different perspectives from which the Agriculture 4.0 concept is studied and explained: Precision Farming Evolution perspective, Industry 4.0 in agriculture perspective, Digital Technologies perspective, Informed Decision-Making perspective, Beyond the Farm Boundaries perspective and Ultimate Goal perspective. In the last years, different authors attempted to define the Agriculture 4.0 concept, anyway lacking in completeness: the analysis presented shows that Agriculture 4.0 cannot be fully appreciated and understood without taking a multi-perspective approach. Therefore, a systematic literature review has been performed with the objective to provide a clear and holistic definition of Agriculture 4.0 and the related boundaries.

Keywords: Agriculture 4.0, Smart Farming, Digital Agriculture, Literature Review.

1.Introduction

Nowadays, a new revolution in the agricultural field is in place: the so-called Agriculture 4.0. This is actually the last step of a revolutions' set characterizing the primary sector during the years (Guild and Danaher, 2014; CEMA, 2017). The European Agricultural Machinery Association named CEMA divides the evolution experienced in agriculture until the current period into three phases.

In the early 20th century, agriculture was a labour-intensive system with low productivity (Luu and Nguyen, 2017), able to feed the population, but requiring a vast number of small farms and a third of the population to be active in the primary agricultural production process (CEMA, 2017).

"The Green Revolution" is the phase of farming, began in the late 1950s, when new agronomic management practices (like supplemental nitrogen), new chemicals (like synthetic pesticides and fertilizers) and more efficient machines thanks to combustion engines (Zambon *et al.*, 2019) allowed to take advantage of relatively cheap inputs, thus dramatically increasing yield potential and growing returns to scale at all levels (CEMA, 2017).

"Precision Farming", or "Precision Agriculture", started once military GPS-signals were made available for public use in the mid-1990s (Osservatorio Smart AgriFood, 2017). Thus, Precision Farming entails solutions for automatic steering solutions, sensing and control for variable rate applications, telematics to monitor the vehicle fleet and data management through farming software. In this way, Precision Farming improves the accuracy of the operations, managing in-field variations rather than treating fields as a whole, managing animals rather than herds (CEMA, 2017). The intention is to apply the right amount of input at the right location and at the right time, to enhance production and improve quality, while protecting the environment (Awasthi and Reddy, 2013; Wachowiak *et al.*, 2017; Fresco and Ferrari, 2018).

In the early 2010s, a new evolution in the agricultural field has been triggered by the introduction of digital technologies (Bronson and Knezevic, 2016), such as cheap and improved sensors and actuators, low cost micro-processors, high bandwidth cellular communication, Cloud based ICT systems and Big Data analytics (Gacar, Aktas and Ozdogan, 2017). These technologies led to two new phenomena. On the one hand, the emergence of agricultural eco-systems, with platforms combining data from several sources, both sensors or equipment, in the field/farm or external sources (FAO, 2017), allows the farmer to monitor his/her operations from a dashboard with real-time (or near real-time) information and to make decisions based on quantified hypotheses to increase the result (Janssen *et al.*, 2017; Shepherd *et al.*, 2018). On the other hand, the cooperation across different players in the agricultural and food value chain is possible: digital data are the glue that unites the eco-system participants to provide value to the food supply chain (Verdouw *et al.*, 2016; Bilali and Allahyari, 2018). As a result, a new phase in the agricultural evolution started: the so-called Agriculture 4.0.

According to Wolfert, *et al.* (2014), Agriculture 4.0 has the potential to increase the global food production and therefore to feed the growing population, which is expected to reach 9 billion people in 2050 (Wolfert, Goense and Sorensen, 2014; Esmeijer *et al.*, 2015; Sharma and Parhi, 2017). Indeed, digital technologies, applied in the agricultural domain, increase the productivity of farming operations, as experienced by Monsanto (Guild and Danaher, 2014; Carolan, 2017). At the same time, the evolution towards the Agriculture 4.0 is good not only for farmers, but also for the sustainable development of the primary sector (Zambon *et al.*, 2019).

Despite the relevance of the topic, few authors studied the topic in scientific literature (Zambon *et al.*, 2019). Since the novelty of the concept and the little attention demonstrated by the literature, a univocally recognized definition of Agriculture 4.0 is not present yet.

The objective of this paper is to provide a clear and holistic definition of Agriculture 4.0 and the related boundaries.

RQ. What is Agriculture 4.0?

2.Methodology

To answer the research question, the literature has been investigated by using "Agriculture 4.0" as keyword on the Scopus scientific database. Due to the poor results found, additional keywords were introduced. In particular, the analysis has been structured by identifying a cluster of keywords referring to the 4.0 revolution (i.e. Digital, Smart, Intelligent and 4.0) and a cluster of keywords referring to the agricultural domain (i.e. agriculture and farming). By combining keywords coming from the two clusters, about 1000 scientific articles have been found on Scopus.

To filter the large pool of papers, inclusion criteria have been applied: 1) articles published in English language; 2) articles published after the 2010 (year of the emergence of the 4.0 revolution); 3) articles referring to the subject area of "Agricultural and Biological science", "Computer science", "Environmental science", "Social science", "Engineering", "Business Management", "Decision science" (Scopus filters). A careful abstract reading of the remaining papers allowed to take a further filter, eliminating from the research those technical articles mainly related to the study of specific applications. In the research, only papers available for students of the Politecnico di Milano were selected. Finally, only 54 articles related to the concept of Agriculture 4.0 were read.

Since the novelty of the topic, non-scientific papers coming from the grey literature were included in the analysis: 24 non-scientific articles cited by the 54 available scientific papers were selected, following a waterfall approach.

The detailed reading of these articles allowed to identify 21 authors attempting to define the Agriculture 4.0 concept. In the following section, the result of the literature review is reported.

3.Literature review

In literature, there are different terms frequently used to refer to Agriculture 4.0, such as "Smart Agriculture", "Intelligent Agriculture" and "Digital Farming", or "Digital Agriculture" (CEMA, 2017), as well as different standpoints from which the Agriculture 4.0 concept is studied and explained.

A set of authors refer to Agriculture 4.0 as an evolution of the Precision Farming concept (Zambon *et al.*, 2019). Indeed, unlike Precision Farming, which is just taking in-field variability into account, Agriculture 4.0 goes beyond (CEMA, 2018; Himesh *et al.*, 2018; Huh and Kim, 2018), by basing management tasks not only on location, but also on context awareness (Wolfert, Goense and Sorensen, 2014).

In parallel, other authors explain the Agriculture 4.0 concept as an application of methods of Industry 4.0 in the agricultural field (Andritoiu, Bazavan, Besnea, Roibu, & Bizdoaca, 2018; Huh & Kim, 2018; Zambon, Cecchini, Egidi, Saporito, & Colantoni, 2019; Braun, Colangelo, & Steckel, 2018; CEMA, 2017; Perez-bedmar, 2018; Gacar, Aktas, & Ozdogan, 2017):

> "Similarly to the concept of Industry 4.0, the transformation process in Agriculture 4.0, aimed at increasing competitiveness, is also implemented through the use of modern information technology" (Piwowar, 2018).

Based on the definition by Piwowar (2018), the foundation of the current agricultural phase is in smart and digital technologies, which consist of sensors, actuators, digital brains and communication technologies (CEMA, 2017; Gacar, Aktas and Ozdogan, 2017).

The use of digital technologies allows "to harness the vast amount of data available from the field, equipment sensors and other third party sources" (Jayaraman *et al.*, 2014). More in detail, the data generated by the farming operations along all farm processes can be managed by digital technologies, that allow (largely) automated data transmission, processing and analysis (CEMA, 2017). Therefore, Agriculture 4.0 makes use of Precision Farming technologies and takes resources for intelligent data management, enabling the concept of Cyber-Physical System (CPS) in agriculture:

> "Technology is now capable of automating cyber-physical systems by networking between different machines. This is what we call Agriculture 4.0" (Weltzien, 2016).

> "Smart Farming is a development that emphasizes the use of information and communication technology in the cyber-physical farm management cycle" (Wolfert *et al.*, 2017).

The Cyber-Physical System, defined as "transformative technologies for managing interconnected systems between its physical assets and computational capabilities" (Lee, Bagheri and Kao, 2015), is the theoretical foundation that allows to integrate previously separated data silos (in-field generated) (Fresco and Ferrari, 2018), with the aim to support the creation of knowledge (Esmeijer *et al.*, 2015). In literature, authors highlight different intelligent data management potentialities:

> "The Digital Agriculture, also known as information-based agriculture model, places the processes of providing processing and interpreting digital data based on the agricultural production and management systems" (Zhang, 2011).

According to Zhang (2011), the integration of data silos allows to move from data to information, thanks to the interpretation of signals coming from the agricultural process. An additional step is then added by the CEMA (2018) definition:

> "Digital Farming is the evolution in agriculture and agricultural engineering from Precision Farming to connected, knowledge-based farm production systems" (CEMA, 2018).

Based on this definition, the farmer could takes a step forward in the understanding of the surrounding environment, creating knowledge based on the information available. However, the intelligent data management allows even more:

> "The mechanisms that depart mostly from current common agricultural practices stem from […] analytics services that integrate previously separated data silos and that are both holistic (integrating different aspects of farm management), prescriptive and predictive in their support to strategic management decisions and daily operations" (Esmeijer *et al.*, 2015).

The knowledge generated from data silos integration is therefore used to boost the decision-making process of farmers, making it more fact- and math-based and less intuition-based (McCown, 2002). Formally:

> "A digital agricultural system is a database that includes not only various kinds of data relevant to agriculture, ranging from soil conditions to market assessment, but also optimal decision functions that help make best decisions in a series of agricultural production and marketing processes" (Shen, Basist and Howard, 2010).

As clearly stated by Shen, et al. (2010), the focus could be the farm enterprise, but not only:

> "Digital Agriculture refers to the use of detailed digital information to guide decisions along the agricultural value chain" (Shepherd *et al.*, 2018).

As shown in the latter definition, the generated knowledge stemming from the use of smart technologies that collect, integrate and analyse automatically data can be employed at different levels in the food value chain. Indeed, on one side, the knowledge can be used internally to the farm context, by networking different machines (Weltzien, 2016), or, even more, to optimize the cyber-physical farm management cycle (Wolfert *et al.*, 2017). On the other side, Digital Agriculture, under different data governance and business models, has the potential to enable collaboration and trust within the value chain, both upstream and downstream, providing to farmers information on or links to suppliers, buyers, logistics providers, etc. (Miller, Saroja and Chris Linder, 2013).

> "The smart farming approach implies that farm management tasks and upstream interactions in the supply chain are informed by collected data, enhanced by context and situation awareness, and triggered by real-time events" (Eastwood *et al.*, 2017).

Thus, Agriculture 4.0 has the power to enable the integrated internal and external networking of farming operations (CEMA, 2017; Zambon *et al.*, 2019).

Whereas the authors studied since so far have focused on what, how and where to apply the technologies 4.0 in agriculture, few others define Agriculture 4.0 in relation to its ultimate goal, thus focusing on the why:

> "Scientists and policymakers are increasingly looking to smart farming as a technological solution to address societal concerns around farming, including provenance and food traceability, animal welfare in livestock industries, and the environmental impact of different farming practices" (Eastwood *et al.*, 2017).

> "The development of Agriculture 4.0 is good not only for farms but also for sustainable development" (Zambon *et al.*, 2019).

> "Digital Agriculture means the using of computer and communication technologies to increase profitability and sustainability in agriculture" (Gacar, Aktas and Ozdogan, 2017).

This last definition has to be read with the awareness that sustainability, in agriculture, relates to the capacity of an agro-ecosystem to predictably maintain production through time, therefore, under a given set of both environmental, economic and socially acceptable circumstances (Luu and Nguyen, 2017; Pigford, Hickey and Klerkx, 2018).

4.Findings

By analysing the definitions available in literature, an increasing trend in the number authors attempting to explain the Agriculture 4.0 concept can be appreciated.

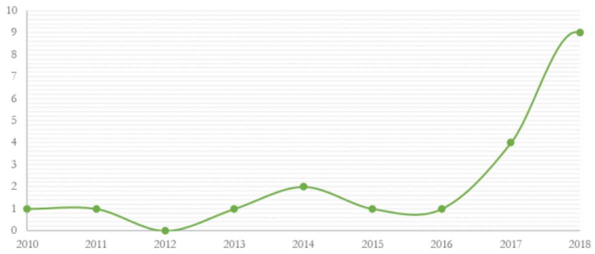

Figure 1: number of publications on the Agriculture 4.0 definition per year

Based on the literature review, it can be noticed that different authors take different standpoints from which the Agriculture 4.0 concept is studied and explained: 1) Precision Farming Evolution perspective (PFE) interprets the Agriculture 4.0 as the step forward Precision Farming in the historical evolution characterizing the primary sector; 2) Industry 4.0 in agriculture perspective (I4.0) interprets the Agriculture 4.0 as the 4.0 revolution characterizing the industrial sector applied in the agricultural domain; 3) Digital Technologies perspective (DT) interprets the Agriculture 4.0 as the digitalization of the agricultural sector; 4) Informed Decision-Making perspective (IDM) interprets the Agriculture 4.0 as the capability of boosting the farmer's decision-making process, extending from simple context awareness, to automated decisions (Cyber-Physical System) thanks to the integration of data silos; 5) Beyond the Farm Boundaries perspective (BFB) interprets the Agriculture 4.0 as the glue linking actors in the food value chain; 6) Ultimate Goal perspective (UG) interprets the Agriculture 4.0 by analysing its main objectives.

In the following, the definitions of Agriculture 4.0 available in literature are classified according to the perspectives just identified:

	Agriculture 4.0 perspectives					
Author	PFE	I4.0	DT	IDM	BFB	UG
Shen, *et al.* (2010)				X		
Zhang, (2011)				X		
Miller, *et al.* (2013)					X	
Jayaraman, *et al.* (2014)			X			
Wolfert, *et al.* (2014)	X					
Esmeijer, *et al.* (2015)				X		
Weltzien, (2016)				X		
Eastwood, *et al.* (2017)				X	X	X
Gacar, *et al.* (2017)		X	X			X
CEMA, (2017)			X		X	
Wolfert, *et al.* (2017)			X	X		
Braun, *et al.* (2018)		X				
Perez-bedmar, (2018)		X	X			
Fresco, *et al.* (2018)				X		
Piwowar, (2018)		X	X			
Himesh, *et al.* (2018)	X			X	X	
CEMA, (2018)	X			X		
Shepherd, *et al.* (2018)				X	X	
Andritoiu, *et al.* (2018)		X				
Huh, *et al.* (2018)	X	X				
Zambon, *et al.* (2019)	X	X	X		X	X

Table 1: different perspectives assumed by authors when defining the Agriculture 4.0 concept

Moreover, by studying the definitions, the largest part of authors recognizes the capability of the Agriculture 4.0 to boost the farmer's decision-making process. On the contrary, few authors focused on the ultimate goal of the fourth revolution in agriculture.

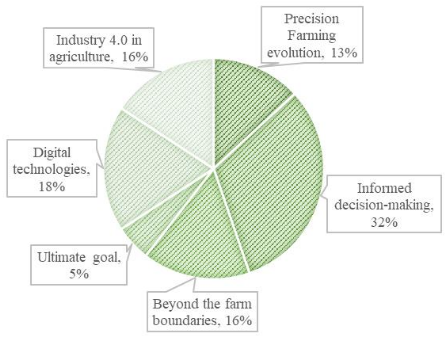

Figure 2: percentage of authors per each Agriculture 4.0 perspective (graph based on the 21 papers listed in Table 1)

Finally, Table 2 highlights that a comprehensive definition of Agriculture 4.0 is missing: indeed, no more than three perspectives are managed by a single author until 2019. Only recently, Zambon, *et al.* (2019) have reported in their work almost all the perspectives identified. However, the Agriculture 4.0 concept is addressed by Zambon, et al. (2019) in a quite fragmented way and a comprehensive definition is not provided.

Being all the previously mentioned viewpoints on Agriculture 4.0 never linked to each other, the topic can be comprehensively defined as follows:

"Agriculture 4.0 is the evolution of Precision Farming, realized through the automated collection, integration and analysis of previously separated data silos coming from the field, equipment sensors and other third-party sources, enabled by the use of smart and digital technologies of Industry 4.0, making in this way possible the generation of knowledge, to support the farmer in the decision-making process in the farm enterprise and when dealing with different players in the agricultural and food value chain, therefore breaking the boundaries of the single farm enterprise. The final aim is to enhance profitability and economic-environmental-social sustainability of agriculture."

In the picture below, multiple perspectives emerging from the Agriculture 4.0 definition are reported.

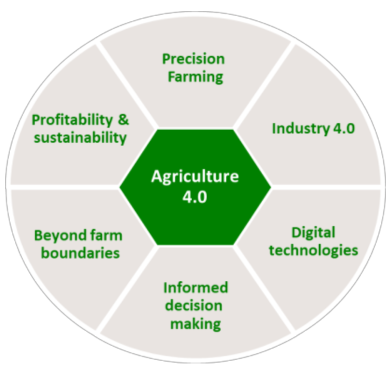

Figure 3: multiple perspectives of Agriculture 4.0

5.Perspectives of the definition

In the following, an explanation of the reason why the different standalone perspectives are part of the Agriculture 4.0 definition is provided.

5.1 Precision Farming

Precision Farming is intended as the deployment, in both fields and stables, of precision technologies, such as Wireless Sensor Network, Global Positioning System (GPS), airborne multispectral and hyperspectral imagery (Adinarayana et al., 2012; Awasthi and Reddy, 2013; Yang et al., 2013), to apply the right amount of input, at the right location and at the right time (Bellon Maurel and Huyghe, 2017), so to enhance production and improve quality (Awasthi and Reddy, 2013; Wachowiak et al., 2017; Fresco and Ferrari, 2018). In the 4.0 era, Precision Farming techniques evolve thanks to the introduction of new technologies (improved sensors and actuators, cloud-based ICT systems and Big Data), that make managerial decisions based not only on in-field variability, but also on context awareness. This is the reason why many authors consider Agriculture 4.0 as an evolution of Precision Farming.

5.2 Industry 4.0

Industry 4.0 is the vision of future production, in which, leveraging on an array of digital technologies (Bonneau and Copigneaux, 2017), the entities of the working environment are linked each other in a continuous and effortless way (Braun, Colangelo and Steckel, 2018). The result is that devices constantly communicate with each other, thus achieving a high level of coordination: in this context, problems can be solved independently by entities and products become intelligent, containing all the information needed to autonomously dispatch throughout the production plant (Kiel et al., 2016). Being Agriculture 4.0 structurally similar to the concept of Industry 4.0 (CEMA, 2017), many authors define the transformation process in agriculture in parallel with similar evolutions in the industrial world.

5.3 Digital technologies

Nowadays, through the Internet of Things (IoT), it is possible to easily collect data from the field, from the surrounding environment and from the market (e.g. crop yield, temperature, pests and diseases, seeding cost, etc.) (Taechatanasat and Armstrong, 2014). Moreover, the deployment of robots and Unmanned Aerial Vehicles (UAV) further increases the amount of data automatically collected from the farm's operations (Primicerio et al., 2012; Tzounis et al., 2017; Andritoiu et al., 2018). The plenty of data silos, integrated and stored through innovative technologies as the Cloud (Kaloxylos et al., 2012; Botta et al., 2016), can be analysed through Big Data analytics to extract hidden information (Gacar, Aktas and Ozdogan, 2017). Therefore, smart and digital technologies, enabling the collection, integration and analysis of data silos (Jayaraman et al., 2014), unlock new prospects for the farmer, becoming the foundation of the current agricultural phase (Piwowar, 2018).

5.4 Informed decision-making

Farmers make decisions based on their personal goals, their subjective beliefs about the environment and the envisioned tasks (McCown, 2005). Being farmers' beliefs traditionally heavily weighted by their own experience, the result is that farmers' behaviour is typically driven by intuition and rarely they rely on aided analytic decision-making (Öhlmér, 2001). By collecting, integrating and analysing vast amount of data with Decision Support Systems (DSS) (Taechatanasat and Armstrong, 2014), Agriculture 4.0 makes the farmer's decisions more fact- and math-based and less intuition-based (McCown, 2002). In addition, Agriculture 4.0 gives the chance to automate decisions (Braun, Colangelo and Steckel, 2018) thanks to the Cyber-Physical System concept, i.e. smart devices connected to the internet that control the farm system (Wolfert et al., 2017). Being the decision-making process of the farmer impacted by the new revolution in agriculture, many authors define Agriculture 4.0 leveraging on the informed decisions concept.

5.5 Beyond farm boundaries

Traditionally, actors such as suppliers of seeds, pesticides and nutrients, veterinarians, advisors for strategic decision-making, machine vendors, financial service providers, inspection and customers, were not integrated in the farm processes (Esmeijer et al., 2015). The opportunities offered by Agriculture 4.0 allows the farmer to connect with the different players of the food chain to exchange useful data (Maksimović, Vujović and Omanović-Mikličanin, 2015) and services (Wolfert, Goense and Sorensen, 2014). For instance, while harvesting, the farmer can better coordinate with transportation and transformation companies (Jagtap, Rahimifard and Kingdom, 2017), or the Original Equipment Manufacturer can offer monitoring and maintenance services based on machines generated data (Esmeijer et al., 2015; Liu, 2017; Deans, Ros-Tonen and Derkyi, 2018; Singh et al., 2018), or an agronomist can offer treatment insights remotely (Rodriguez de la Concepcion, Stefanelli and Trinchero, 2014). Being the coordination and the service exchange among actors one of the main results of the fourth agricultural revolution, many authors define Agriculture 4.0 in relation to the chance for the farmer to go beyond the farm boundaries.

5.6 Profitability and sustainability

The new tools available in the 4.0 era allow to pursue the ultimate goal of Agriculture 4.0, defined by different authors as the increase of profitability and economic-environmental-social sustainability of farming (Eastwood et al., 2017; Gacar, Aktas and Ozdogan, 2017; Zambon et al., 2019). For example, integrating data silos, the farmer has the opportunity to further reduce inputs, automate processes and increase yields (Sonka, 2016; Himesh et al., 2018). In addition, the farmer can flexibly choose business partners and access effective services in a more efficient way (Wolfert et al., 2017). For these reasons, many authors define Agriculture 4.0 in relation to its ultimate goal.

6.Conclusions

The objective of the paper is to provide a clear and holistic definition of Agriculture 4.0 and the related boundaries. Indeed, during the years, different authors attempted to define the Agriculture 4.0 notion, anyway lacking in completeness.

The analysis presented shows that Agriculture 4.0 cannot be fully appreciated and understood without taking a multi-perspective approach. Therefore, the proposed definition has the merit to link the thought of different authors into a unique sentence, providing in this way a comprehensive definition of the topic. In addition, differently from the past, the definition explains the fourth agricultural revolution as based on the integration of data coming from different sources (both internal and external to the farm), which have never been included before.

However, the limit of the definition provided is to not clarify how the profitability and economic-environmental-social sustainability of agriculture can be enhanced thanks to Agriculture 4.0: the definition simply presents different perspectives, without explaining the mechanisms and dynamics underlying Agriculture 4.0 to reach its ultimate goal. This means that a more in-depth analysis is needed to understand what Agriculture 4.0 is.

Finally, the definition is a first attempt to make clarity around the discussed topic, with the aim to stimulate future researches.

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