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Agriculture 4.0: a terminological introduction

Agricultura 4.0: uma introdução terminológica

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ABSTRACT - This paper presents a terminological delimitation of Agriculture 4.0 by analyzing relevant articles on the state of the art in this field. The fundamentals of Agriculture 4.0, which include the application of the Internet of Things, big data, artificial intelligence, cloud computing, and connectivity, is presented. In conclusion, it can be stated that Agriculture 4.0 is an inevitable and irreversible trend in modern agriculture.

Key words: Digital Agriculture. Smart Farming. Terminology.

RESUMO - Este paper pretende apresentar uma delimitação terminológica para a Agricultura 4.0 por meio da análise de artigos no estado da arte que abordam esta temática. Os fundamentos da Agricultura 4.0 que podem ser elencados como a Internet of Things, Conectividade e Computação em Núvem, Big Data e Inteligência Artificial e uma breve introdução à cada um deles é realizada. Como conclusão pode-se declarar que a Agricultura 4.0 é uma tendência irrefreável e sem volta no mundo agrícola moderno.

Palavras-chave: Agricultura Digital. Fazendas Inteligentes. Terminologia.

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INTRODUCTION

The technical term Agriculture 4.0 originated as an analogy to the term Industry 4.0, which was coined by the Ministry of Education and Research of the German government in a final report of the Working Group (WG) officially instituted to develop guidelines for the German industry in the context of integrating it into a "smart, networked world." In this world, the manufacturing environment includes vertical networking, end-to-end engineering, and horizontal integration across the entire value network of increasingly smart products and systems, which are set to usher in the fourth stage of industrialization––"Industrie 4.0" (KAGERMANN; WAHLSTER; HELBID, 2013).

In general, the First Industrial Revolution was based on mechanical technology, starting in 1780. There was the Second Industrial Revolution (1870), with a focus on electrical technology; then, in mid-1969, electronic technology began to emerge, leading to information technology (IT) operated by computers. Subsequently, the Third Industrial Revolution occurred, culminating in automation technologies.

The Fourth Industrial Revolution is based on the evolution of the Third Revolution. It can be defined as the fusion of the physical, digital, and biological worlds through intensive and extensive use, since the 2000s, of systems and processes based on the Internet of Things (IoT), synthetic biology, and cyber-physical systems (smart grids, autonomous vehicles, industrial control systems, robotics systems, automatic pilots avionics, and medical monitoring) (BRAZIL-MDIC 2017). All of these elements are interconnected by physical or wireless networks; the cloud may or may not be utilized; big data is used; and artificial intelligence (AI) algorithms perform the decision making in whole or in part.

Utilizing the concept of Industry 4.0, Agriculture 4.0 can also be divided into revolutions, as Zhai *et al.* (2020), described, with the First Agricultural Revolution in 10,000 BC, in which the power came from man or animals and the tools were simple. After just over 82 centuries, the Second Agricultural Revolution emerged in the 19 th century, with the adoption of mechanical power from tractors powered by combustion engines and the use of agrochemicals. In the last quarter of the 20th century and the beginning of the 21 st century, computers became widespread. The development of agricultural robots began, in addition to precision hegemonic farming, thus leading to the Third Agricultural Revolution, the evolution of which paved the way to the Fourth Agricultural Revolution with the use of IoT, cloud computing, AI, generation and use of Big Data, and systems development by cyber-physicists. In this revolution, the systems and devices are intelligent and have relative autonomy for decision making, and are all connected ubiquitously.

There is no consensus on the exact moment in history when the Fourth Agricultural Revolution, commonly called Agriculture 4.0, began. This date is still diffuse, as when you are at the foot of a great mountain, you cannot see it at all. What is certain is that Agriculture 4.0 has taken shape based on the gradual development of its fundamental tripod: IoT, AI, and ubiquitous connectivity linked to cloud computing. These technologies and processes have their roots long before Agriculture 4.0, beginning even in the Third Industrial Revolution, permeating the Third Agricultural Revolution, and culminating in the Fourth Agricultural Revolution. As an initial estimate, it could be located between 2013 and 2018—with the formalization of the term Industry 4.0 (KAGERMANN; WAHLSTER; HELBID, 2013) in 2013 and the beginning of the frequent appearance of the term Agriculture 4.0 in scientific research indices such as ScienceDirect (ELSEVIER, 2020) in 2018.

Other terms are currently blended with the concept of Ag. 4.0, the most widespread of which is digital agriculture, which is a simplified term that can be defined as the fusion between precision agriculture and information and communication technology (ICT). According to Shena *et al*. (2010), the concept of digital agriculture involves the expansion of the concept of precision farming that emphasizes production procedures not only by obtaining relevant data and their treatment but also through optimal decision functions to improve agricultural processes through AI technologies.

Another technical term that is not as widespread is smart farming, which refers to a revolutionary paradigm shift that has emerged as an optimization of the binomial agricultural management/increased efficiency of agroecosystems through intelligent technologies, such as connected agricultural machinery, sensor networks, IoT, automated systems, robots, and drones. All of these technologies utilize cloud computing-enabled optimization of planning, thus increasing efficiency and decision-making capacity, saving time and resources, improving food quality, decreasing the environmental footprint, and increasing food safety (LIOUTAS; CHARATSARI, 2020a).

All of these terms are interconnected, and, in the literature, researchers often refer to two or more terms in the same paper, not worrying about the delimitation between them. This is a recurrent phenomenon in new areas of knowledge; just as there is difficulty establishing an exact date for its appearance, the terminology at the beginning of formalization is also diffuse, as was the case with precision farming 30 years ago. Such observations are common in situations where the research community's intellect-scientific-social process swells rapidly.

In this context, Klerkx *et al.* (2019), refer to this process as the digitalization of agriculture; it is a socio-technical process that comprises the agricultural application of IoT, Big Data, augmented reality, robotics, sensors, 3D printing, system integration, ubiquitous connectivity, AI, machine learning (ML), digital twins, and blockchain, among other emerging technologies. According to the authors, the digitalization of agriculture implies managing on-farm and off-farm tasks that focus on different types of data using sensors, machines, drones, and satellites to monitor, control, and act on the soil, water, animals, and humans. With this data, the past is interpreted and the future can be predicted, leading to significantly faster and more accurate decision making through constant monitoring or access to specific data.

Regarding the terminology, we intend to contribute to a possible delimitation by surveilling the current literature. The scientific finder ScienceDirect (ELSEVIER, 2020) was used for an advanced search on September 15, 2020, using the following keywords: Agriculture 4.0 (Ag.4.0), Digital Agriculture (Di.Ag.), and smart farming (S.F.). A total of 146,968 articles were found for Ag.4.0, 93.383 for Di.Ag. and 6,949 for S.F. A relevance filter was employed with several other keywords, such as big data, robotics, digital maps, IoT, automation, precision farming, remote sensing, unmanned aerial vehicle, ML, deep learning, AI, cloud computing, and connectivity; abstracts were obtained from the first 100 articles listed by the finder for each term.

From this sampling, considering the switching of terms and reading the contents of the abstracts, we determined the proportions of articles that effectively discuss the "philosophy" of work referring to the definition defined for S.F. (LIOUTAS; CHARATSARI, 2020a), Di.Ag. (SHENA; BASIST; HOWARD, 2010) and Ag.4.0 (ZHAI *et al*., 2020). As regards Ag.4.0, 19% of the articles refer strictly to the theme's core; for Di.Ag., this number is 12%; and for S.F., 73%. Based on a gross extrapolation according to the population of articles, we have an estimate of 27,923 articles for Ag.4.0; 11,205 for Di.Ag.; and for 5,073 articles S.F.

In other words, in terms of quantity, it is more productive to search for Agriculture 4.0; in terms of quality, it may be more interesting to search for S. F.. The term digital agriculture undergoes an interesting phenomenon in the 100 abstracts read; there is an evident "migration" by precision farming researchers to the term digital agriculture, although many of these papers do not have a "merger" with ICT, nor do they make use of AI. However, almost all use IoT or geotechnologies.

As a reinforcement for these numbers, when the same search was performed in the Scielo finder (SCIELO, 2020), 564 articles were found for Ag.4.0, 91 articles were found for Di.Ag., and 7 articles were found for S. F.. For the purpose of comparison, a search using the same method on ScienceDirect but with the terms "Industry 4.0" and "Smart Cities" yielded 215,262 and 57,839 articles, respectively. Regarding the proportion of articles within the core of the theme, considering the first 100 within a relevance filter, 89% are directly related to the theme for "Industry 4.0," whereas for "Smart Cities," this number is 91%. This fact indicates that the scientific communities that are concerned with industries and cities have already defined their terminology. This should serve as a motivation for the agricultural research community to do the same.

LITERATURE REVIEW

Agriculture 4.0

According to Klerkx and Rose (2020), Agriculture 4.0 already comprises operational technologies such as robotics, nanotechnology, protein synthesis, cell agriculture, genetic editing technology, AI, blockchain, and ML, which have had pervasive and profound effects on the production systems of food and the future of agriculture. The authors warned that attention is needed regarding the inclusion and exclusion of technologies concerning the direction of sustainable agriculture and innovation-oriented food systems; they argued that responsible innovation processes are critical for anticipating the potential impacts of Agriculture 4.0, primarily considering inclusive processes.

Rose *et al*. (2021), reported that the Agriculture 4.0 narrative has been predominant in terms of productivity improvement and environmental protection, and this fact has generated significant positive and negative social effects, thus clearly indicating that there must be a greater inclusion of people in agricultural innovation systems that must be guided by responsible principles within a vision of social sustainability.

Lajoie-O'Malley *et al*. (2020), reported that the use of digital technologies in agriculture substantially affects the delivery of services by ecosystems within the supply of food in which they are inserted. Braun, Colangelo, and Steckel (2018) presented reasons within an analysis of heuristic processes wherein the stochastic environmental conditions in terms of the division of labor in agricultural production show that innovations in the management of supply chains not the only provide the means to solve the inherent problems of agricultural production in the Farming 4.0 model but also provide the basis for new forms of work and business.

The sustainability of agri-food product supply chains has been analyzed by Saetta and Calderelli (2020), who identified interventions to improve supply chain management and logistics processes from a 4.0 perspective. Lezoche *et al*. (2020), performed an extensive literature review describing hundreds of new technologies available for agri-food supply chains within the Agriculture 4.0 philosophy. In the same vein, Miranda *et al*. (2019), described how S3 (sensing, smart, and sustainable) technologies have led to the development of a systematic process for creating new products in the agri-food 4.0 chains.

The use of big data for the sustainable management of supply chains for bioenergy production was analyzed by Belaud *et al*. (2019), who claimed that the use of Big Data in conjunction with Industry 4.0 technologies can revolutionize agricultural waste management. Annosi *et al*. (2019), evaluated technologies 4.0 in the context of smart agriculture within the context of the benefits that these technologies can bring to small and medium-sized agricultural enterprises, with the main benefit being an aid to farmers in decision making.

Torky and Hassanein (2020) presented blockchain integrated with IoT to implement agricultural data analysis systems by developing a smart P2P system capable of verifying, securing, monitoring, and analyzing information for precision farming applications.

Digital Agriculture

Rotz *et al*. (2019), claim that the digital revolution is underway in agriculture, increasing production and efficiency and reducing the use of resources. Simultaneously, this raises critical social issues, such as rising land and automation costs, the development of a high-/low-skill fork in the labor market, and problems with data control. Bronson (2019) extended these concerns using a responsible innovation structure that considers the ethical and social dimensions, mostly with respect to big data, for decision making. He recommended a responsible digital transition.

Lioutas and Charatsari (2020b) state that big data represents a new productive factor in agriculture that generates new realities by adding an extra dimension-the “cyber” dimension-in agricultural systems, which has created a new and complex cyber–physical–social system. However, understanding of the sustainability of this new system is still rudimentary. Lajoie-O’Malley *et al*. (2020), conducted a study on policy documents regarding digital agriculture and concluded that international players in agriculture imagine food systems’ future with these technologies prioritizing production maximization.

Fielke, Taylor, and Jakku (2020), when evaluating the digitization of agriculture, identified three key conclusions: 1) the connectivity between humans and technologies in agricultural knowledge, advice networks, and value chains, will continue to increase; 2) the transparency of agricultural informational practices and interactions between this system’s actors will be driven by increasing connectivity; and 3) there are challenges that balance the priorities of various agricultural stakeholders in the digitization of agricultural innovation systems.

Smart Farming

Knierim *et al*. (2019), stated that politicians and experts assume that smart farming technologies have a strong potential to improve the economic performance of farmers and that they will contribute to more sustainable agriculture. Yoon, Lim and Park (2020) studied the factors that affect the adoption of smart farm technologies in Korea and identified the main factors acting in this context, which are as follows: the level of complexity, the compatibility of technology, the degree of innovation, knowledge of IT, the characteristics of CEOs, financial costs, human vulnerability, lack of skills to operate the systems, competitive pressure, government support, and the move to a digital environment.

Segundo Pivoto *et al*. (2018), stated that the concept of smart farming involves the incorporation of IT and communication technologies within machines, sensors, and equipment for use in agricultural production systems. In this context, the authors identified the main limiting factor for the evolution of smart farming in Brazil as the integration of various systems on the market; another critical factor is the education, skills, and competencies of farmers to understand and handle these tools.

Grieve *et al*. (2019), stated that smart agri-robotic solutions can overcome the current challenges posed by threats to world food security, challenges such as population growth, aging of the agricultural population, meat consumption trends, climate change, and abiotic and biotic stresses. Moreover, these technologies should solve problems in the horticultural or viticulture sectors as well as global broadacre crops.

Eastwook *et al*. (2019), claimed that smart farming technologies’ increased use of data presents farmers with an opportunity to better understand their agroecosystems, thereby increasing production and profits with sustainability and animal welfare. The authors studied agricultural consultants' capacity to manage a vast dataset. The conclusions reached are that smart farming technologies have disruptive potential for agricultural management, requiring more significant input from consultants to facilitate an optimal adaptation of the system. Jakku *et al*. (2019), explored the techno-social factors that influence the development of smart farming and Big Data applications. The analysis showed that the primary concern of farmers is in the procedures regarding the transparency and distribution of their data and who benefits from them through access to agricultural data made available by the systems.

Lytos *et al*. (2020), stated that recent advances in ICT have generated the ability to collect, process, and analyze data from different sources while materializing the concept of smart agriculture. These advances refer to not only the quantity but also the variety and speed of collection of this data, and the concept of big data is the key to understanding future trends in agriculture.

FUNDAMENTALS OF AGRICULTURE 4.0

Internet of Things

Because of its great potential for utilization in diverse applications and the excellent future propsects, the term IoT has been widely studied by researchers and companies, focusing on the ability to connect not only individuals but also devices in an internet network. IoT is an extension of the current Internet that allows it to control devices remotely and even use them as service providers.

Allowing the connection between different devices to the same network enhances the emergence of new applications, increasingly personalized according to the requirement. However, the devices can communicate with each other, and this requires the standardization of some of them. It is also important that smart devices can connected to the Internet.

The role of IoT devices is to map the environment and collect information about the desired parameters. With technological advances, sensors have evolved into increasingly specific and accurate applications. Wireless sensor networks (WSNs) are used on a large scale in industrial areas, but in recent years, agriculture has also found ways to use WSNs to monitor the various information sources available in the environment.

As did several other researchers, Dagar, Som and Khatri (2018) and Maheswari *et al*. (2019), used sensors to measure physical quantities and parameters such as the soil moisture, ambient temperature, luminosity, amount of a particular nutrient in fertigation solutions, color of objects, fruit maturation point, detection of pests and diseases, machine speed, and georeferencing of coordinates.

The actuators, in turn, are responsible for receiving the response from the processors and transforming it into some change in the conditions of the system, as in the case of the study by Kamath, Balachandra and Prabhu (2019). They used an irrigation system as an actuator to control irrigation in crops, with a controller and temperature sensors.

Big Data

All the information used for the practice of intelligent agriculture is derived from the connection of several systems that operate in real time from the use of IoT, cloud computing, AI, and big data, among other technologies that connect all stages of the productive process from gathering information related to culture as well as data on suppliers, final consumers, and customers (LI; NIU, 2020).

Big data is one of the pillars of digital agriculture, as it enables the practical collection, analysis, and dissemination of data; thus, producers can increase productivity at rates never observed since the mechanization process (POSADAS; GILBERT, 2020). As the volume of data collected is large, complex, and heterogeneous, traditional computational tools cannot perform the processing and management of information, and complex algorithms are required to assist in data analysis (RAUTENBERG; CARMO, 2019).

Big data is based on six characteristics: the volume, as a large volume of data is generated every minute through different means and technologies; the speed, which allows data to be generated with agility and to be accessed in real time to optimize tasks; the variety, as data are collected from different technologies and must have the ability to be processed together; the veracity, referring to the integrity and accuracy of the data so that there is no storage of uncertain information; the variability, which allows the understanding and treatment of data to eliminate specific events that do not reflect the pattern of long-term behavior; and the value, which is a highly relevant characteristic, because rich, accurate, and reliable information are necessary for decision making (AKNTAR, 2018).

The leading technology associated with big data is data mining, whose function is to perform data processing in search of anomalies, patterns, and correlations to predict reliable results and trends that can support new actions to increase income, reduce costs, and improve the production chain process (LI; NIU, 2020).

Mining facilitates the understanding of the behavior of the data, as data mining can be used together with ML algorithms to build models that perform the task of prediction, association, or grouping of the data. Then, through established standards, the results are presented, and the best path to be followed is defined (FERNANDES; CHIAVEGATTO FILHO, 2019).

Coble *et al*. (2018), studied the challenges and opportunities of big data in agriculture and pointed out that this technology enables critical information analysis at all stages of the production chain. For example, the authors cite the opportunity to predict the production and selection of suitable crops for a given region, using big data and ML, through algorithms that identify the input and output relationships in the selection of a culture based on productivity, soil type, climate, and natural phenomena.

Cevallos, Valencia and Romero (2020) integrated a big data model on the IoT to determine how this technology could contribute to the management of organic banana production in the province of El Oro in Ecuador. The authors concluded that the implementation of digital agriculture in this region provided specific answers to existing problems and satisfied the needs of producers to practice management aimed at developing sustainable practices.

To characterize the effects of local and environmental variables on the population density of Mediterranean fruit flies in citrus groves, Krasnov *et al*. (2019), used the platform of the company Agritask (Israel) to follow the growth cycle, in addition to improving and ensuring safe production in the citrus crop. The platform monitored the crop by analyzing data from different sources so that big data could be applied. The authors stated that this technology afforded model predictions that enabled the efficient management of fruit flies in the region.

As aforedescribed, big data is already a reality; the ability to extract information from these data and convert them into strategic possibilities to optimize assertive decision making to increase productivity, decrease costs, and reduce impacts on the environment will cause the agricultural properties of the future to increase the monitoring and automation of each stage of the production process.

Connectivity and Cloud Computing

The concepts of connectivity and cloud computing are interconnected in the context of Agriculture 4.0, as the digitization of agriculture implies that the elements operating within a farm must be connected through extensive and intelligent networks and without disruption to enable cloud computing systems to join in evaluating, diagnosing, and deciding on actions and interventions in the field (FIELKE; TAYLOR; JAKKU, 2020).

According to Armbrust *et al*. (2010), cloud computing is a concept defined as the availability of computational applications accessible through the Internet, through remotely hosted hardware and software. Ruschel *et al*. (2010) conceptualized cloud computing as “the idea of using, anywhere and regardless of platform, the most varied types of applications over the internet with the same ease of having them installed.”

Cloud computing has a virtual hard drive function, enabling the storage of files on the network for access and modifications from another device. This concept has aroused great interest in the academic and business environments, representing opportunities for research, productivity gains, cost reduction, and emission of pollutants (HEIDEKER; KAMIENSKI, 2015).

According to Cooper (2015), Industry 4.0 depends on a hosting center, where the storage, data sharing, and information of factory processes become more practical, requirements that are achieved by cloud computing. Cloud computing allows users to have remote access to their data, applications, and other resources with ease, at any time, as long as they have access to the Internet.

Artificial Intelligence

Artificial intelligence refers to the possibility of providing inanimate artificial machines and systems with cognitive and conditioning learning abilities, similar to those of humans (KAPLAN; HAENLEIN, 2019).

Talaviya *et al*. (2020), reviewed the use of AI in agriculture with various applications and results, noting that in systems where AI was applied, crop production, monitoring, processing, and commercialization were improved in real time. The authors reported on several advanced computer systems designed to detect diseases, determine yield and quality, and enable automatic irrigation and spraying, thus reducing the workload of farmers, and the use of various sensors and robots, most of which are integrated into drones that perform mapping processes, some equipped with actuators that enable functions such as irrigation actions.

CONCLUSION

1. In the agricultural world, Agriculture 4.0 is an inevitable trend from which there is no return. A parallel can be made with the current connectivity of people through personal smartphones;

2. The penetration of communication and information technologies in the psycho-social structure of people, cities, and industries enabled by smartphones, IoT, and AI ocurred gradually and has immense potential to be identified and exploited because of the ease of operation and cost reduction. Therefore, as systems steadily improved, their use by people and industries became widespread resulting in the dependency on the increasing functionalities of these systems. The use and access, as well as the evolution, continued to progress such that we can state that humanity currently exists in an almost symbiotic synergy with digital technology;

3. Agriculture 4.0 is essentially the digitalization of socio-technical phenomena associated with agroecosystems (ALBIERO, 2018), analogous to what occurred in urban and industrial systems. Albiero (2019) stated that robotics is similar to a wave to be surfed that can take us to the beach. From this perspective, the beach/coast/continent is Agriculture 4.0.

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