1874-3315/20

Send Orders for Reprints to reprints@benthamscience.net

The Open Agriculture Journal

Content list available at: https://openagriculturejournal.com

LETTER

Agriculture 4.0: The Role of Innovative Smart Technologies Towards Sustainable Farm Management

Konstantinos G. Arvanitis[1,*] and Eleni G. Symeonaki[1, 2]

[1] *Department of Natural Resources Management and Agricultural Engineering, Agricultural University of Athens, Athens, Greece*
[2] *Department of Industrial Design and Production Engineering, University of West Attica, Athens (Egaleo), Greece*

Abstract: A number of global issues, including climate change, scarcity of natural resources, demographics and food waste, are placing pressure on the overall sustainability of agricultural systems. For this, a generalized method of whole-farm management approach, based on the potent cross-industry cooperation of stakeholders, infrastructures, technologies and applications will be applied. Indeed, beyond the actual involvement of advanced technologies, the substantial challenge of agriculture towards sustainable growth resides in the competency to enact more sophisticated and effective agricultural processes at lower costs, provide safer and more efficient operating conditions both for the environment and stakeholders (involving farmers, agronomist engineers, policy makers, *etc*.), and finally increase the synergies among them, offering the ability to make decisions even on issues that have ordinarily been outside their areas of expertise. In this context, traditional farm management approaches should undergo fundamental transformations, enabling smart technologies not just for the sake of innovation but to re-engineer the entire value chain so as to preserve sustainability in the agricultural sector. Current advancements in communication technologies, such as Cloud Computing and the Internet of Things, tend to combine with other sophisticated technologies like Computational Intelligence, Robotics, Big Data, *etc*., leading to the fourth stage of revolution in the agricultural sector, known as Agriculture 4.0. The purpose of this study is to specify and evaluate the key technologies and solutions involving ubiquitous computing advancements and conceptual innovations of agricultural production toward Agriculture 4.0, along with their capabilities, effects, and challenges for the benefit of sustainable farm management.

Keywords: Agriculture 4.0, Industry 4.0, Farm management, Smart technologies, Cyber-physical systems, Internet of things, Cloud computing, Sustainability.

Article History	Received: March 04, 2020	Revised: May 13, 2020	Accepted: May 19, 2020

1. INTRODUCTION

To address the challenges of securing adequate food supplies for the constantly increasing world population, agricultural production has to be raised upto 60% during the 21st century [1, 2]. Moreover, due to the escalating pressures on the ecosystem and biodiversity, this aim has to be accomplished, taking into regard the imperative necessity of exploiting natural resources according to the national and international policies related to sustainable growth. In this sense, sophisticated operational farm management, based on quality and quantity coefficients, is considered to be one of the most significant factors for successfully achieving more targeted usage of finite resources and ensure food security, while controlling environmental as well as economical risks in accordance with the objectives for sustainable growth [3, 4].

Farm Management Systems (FMSs) are of fundamental importance for the accomplishment of sophisticated operational farm management as they involve functions for planning, organizing, monitoring, and controlling agricultural operations. However, current FMSs are generally in accordance to specific models [5, 6] and their operations do not exceed the limit of agricultural data monitoring, as well as the delivery of selected control services through standalone applications, which are tightly integrated with each system since they involve closed specifications for commercial infrastructures and address to targeted end-users. This imposes some significant constraints concerning the interoperability of the FMSs as well as the semantic annotation of the numerous heterogeneous agricultural data that need to be handled by them. To improve the performance of these activities in terms of sustainability, FMSs should be competent [7 - 9] to:

(a) Enact efficient and interactive automated agricultural operations (such as cultivation, monitoring, irrigation, *etc*.) in complex environments and farm structures at lower costs.

(b) Provide effective and secure operating conditions both for the environment and agricultural stakeholders (such as farmers, agronomist engineers, policy makers, development

* Address correspondence to this author at the Department of Natural Resources Management and Agricultural Engineering, Agricultural University of Athens, Athens, Greece; E-mail: karvan@aua.gr

cooperation professionals, *etc*.).

(c) Enhance the synergies among all agricultural stakeholders providing them with the ability to make decisions even on matters that are outside their areas of expertise.

These objectives can be achieved altogether by promoting a generalized approach of end-to-end farm management [10], based on the concerted internal and external interaction of technologies as well as farming infrastructures, processes, and applications in a smart digitalized environment, in the context of the cutting-edge trend of Agriculture 4.0 [8, 10 - 12].

2. METHODS

The Agriculture 4.0 concept signifies the fourth industrial revolution in farming (as a major sector of the primary industry) and takes place in concert with the comparable revolution in the entire industrial sector, expressed by the term of "Industry 4.0", as this was originally introduced by the German National Academy of Science and Engineering (acatech), in 2013 [13]. This prominent trend, as reported in the annual meeting of the World Economic Forum (WEF), in 2016 [14], is expected to significantly affect the future development of all industrial sectors [15 - 17] by eradicating the partition among the objects of the physical and virtual world along the entire value chain. To this end, and in accordance with the guidelines for the operative implementation of the Agriculture 4.0, as well as the objectives of sustainable policies, farm management has to be integrated with ubiquitous computing advancements and conceptual innovations of smart technologies with regard to automated processes.

Taking into consideration that the research community has already recognized the high significance of enabling smart technologies in the agricultural sector for the benefit of sustainable growth, in this work the functionality and interoperability of some key smart technologies that are particularly significant for Industry 4.0, as well as their maturity to be integrated into farm management towards the concept of Agriculture 4.0 is presented and critically analyzed. Additionally, some significant challenges are identified and some main conclusions are drawn regarding the integration of potential solutions for the development of responsive and adaptive FMSs, capable of delivering a wide variety of qualitative low-cost services in accordance with the objectives of modern sustainable farming.

3. AGRICULTURE 4.0-DRIVEN SMART TECHNOLOGIES

Existing approaches in the agricultural sector attempt to take benefit of innovative smart technologies that deliver technological solutions at all levels of agricultural production, making it conceivable to develop a self-optimizing end-to-end farm management structure in the context of Agriculture 4.0 that can be easily organized and used by all involved stakeholders. Some key technologies that are particularly significant for Agriculture 4.0, along with their capabilities and effects for the benefit of sustainable farm management, are briefed in the following subsections.

3.1. Agricultural Cyber-Physical Systems (ACPSs)

Cyber-Physical Systems (CPSs) are based on the constant integration of physical components and computational algorithms. Recent advancements in CPSs enable autonomy, usability, scalability, adaptability, resiliency, and security that far exceed the attributes of common embedded systems. Agricultural Cyber-Physical Systems (ACPSs), in particular, address applying to agricultural operations specifically in order to materialize more sophisticated FMSs [18]. ACPSs are capable of constantly monitoring with high efficiency, various fundamental cultivation features (*i.e*. temperature, humidity, soil moisture, plant health, *etc*.) *via* sensory devices, which are spatially deployed over the field usually in wireless networks [19 - 21] and, thus, control agricultural facilities' operations in an automated mode [22, 23].

Since Agriculture 4.0 provides an effective field for the development and application of ACPSs, this technology is considered to be capable of providing an effective way for modifying the workforce performance, for optimizing safety, flexibility, and reliability of the field activities as well as for enforcing the production of higher quality yield at a lower cost [24]. In this way, ACPSs are expected to promote effective precision in farm management concerning both system issues (*i.e*. functionality, efficiency, reliability, *etc*.), as well as end-user requirements (*i.e*., user-friendliness, versatile and powerful graphical user interfaces, communication reliability and robustness, *etc*.).

Some significant issues concerning the deployment of ACPSs with regard to the Agriculture 4.0 for sustainable farm management focus on the following aspects:

- Proper hardware and software design are essential for the adaption to harsh, open field environments in rural areas.
- Since the granularity of information is substantial for precision in farm management, constantly improving the accuracy of sensing operations in terms of cost-effectiveness is quite challenging but necessary at the same time.
- As sensing devices nodes are usually deployed in wireless networks within wide distant rural areas, effective signal and data processing approaches are required so as to achieve the best correlation between cost and accuracy of real-time field sensing.
- Energy autonomy is critical for the effective operation of ACPSs in terms of sustainability, thus, powering ACPs using potent renewable energy sources in the agricultural environment is quite significant.

To this end, it is essential for ACPSs to be robust, flexible, and autonomous for the benefit of sustainable growth. In order to achieve these objectives, the sensing and control loop of ACPSs needs to be further studied by taking into account both the characteristics of agricultural facilities equipment as well as the uncertainties of agricultural environments.

3.2. Cloud Computing

Cloud Computing, often called simply "the cloud", is a technology that was launched in the early to mid-2000s [25] in order to provide hardware, software, and storage computing resources delivered as a service over a private or public network such as the Internet. In particular, Cloud Computing integrates a perfect system, capable of distributing on-demand computing services to the end-users by combining high computing power, storage and network technologies with regard to load balance and re-utilization [25 - 28].

Taking into account that agricultural environments tend to generate voluminous amounts of heterogeneous sensory data which correspond to enormous storage spaces, while additionally, the development of sophisticated smart infrastructures is constantly increasing the demand for more complex intelligent services [7], the performance of such operations in local servers could result into the lack of scalability and inefficiency of FMSs.

Given the fact that Cloud Computing is an Information and Communication Technology (ICT), which offers centralized storage and processing power along with on-demand availability of services, it is considered as deliberate to transpose data processing and storage operations from local infrastructures to distributed Cloud environments for facilitating the management of such extremely large amounts of agricultural data, consequently, improving the time of processing and generating information as well as expanding the capability of providing complex, specialized services for the FMSs [29, 30]. In this sense, incorporating Cloud Computing technology acts for the benefit of sustainable farm management since it negates the need for costly computing resources while facilitating information management and dissemination for efficiently supporting the making of decisions about critical cultivation issues.

3.3. Agricultural Internet of Things (AIoT)

The Internet of Things (IoT) can be semantically defined as a worldwide network of uniquely addressable objects which are interconnected based on standard communication protocols, such as the Internet [31]. Consequently, the Internet serves as a storage and communication infrastructure incorporating virtual object representations that integrate relevant information to the physical objects. In this context, the virtual objects serve as centralized object information hubs, continuously updating and combining data from a wide range of various sources, so as to control any required processes remotely *via* the Internet [31, 32].

According to the guidelines of Industry 4.0 in general and Agriculture 4.0, in particular, physical and virtual objects are interconnected and inter-controlled via intelligent networks established along the entire value chain [33, 34]. Based on this concept, the virtual object structure is tightly linked to the IoT concept, which in the agricultural sector as well as in the industrial one, can be expressed by some specific features, such as heterogeneity, due to a variety of devices, interconnectivity, high scalability, object-related services and at last, dynamic changes since device status can change dynamically at any time [35].

The Agricultural IoT (AIoT) points to a promising framework according to the guidelines of Agriculture 4.0, through which various data related to farms can be acquired, processed, managed, and disseminated as a mechanism through which a diverse series of systems and services can be seamlessly integrated within FMSs [36, 37]. Such systems will be able to:

- successfully handle the constantly increasing diverse real-time data streams;
- handle various, incomplete and, in some cases, contradictory data;
- acquire, correlate and fuse data in real-time;
- dynamically affect network behavior to alter data acquisition, data routing or data recording rules;
- facilitate organized sensing activity through the ability of individual network nodes to reason, operate, and collaborate within a collective framework, recognizing the coexistence of both individual and joint objectives by embracing distributed intelligence and multi-agent approaches.

Consequently, the AIoT is considered to be an indispensable technology for smart farms, while its development in relation to the Future Internet approach offers a basis for a new generation of Farm Management Information Systems, enabling entire smart farms to become active nodes in agricultural value chains.

3.4. Artificial Intelligence (AI) and Machine Learning (ML)

Agriculture faces many challenges as it is characterized by uncertainty in various operations, such as seed sowing, pesticide control, weed management, crop disease infestations, lack of irrigation and drainage facilities, or even lack of storage management. In order to enable efficient risk management, reduce prediction costs on decision making and, subsequently, improve agricultural accuracy and increase productivity, Artificial Intelligence (AI) and Machine Learning (ML) techniques provide intelligent software applications and systems that are capable of performing knowledge work operations involving subtle judgments and unstructured commands [38].

As agricultural environments are characterized by huge amounts of information, several data abstraction levels and various feature selection techniques, such as classification and clustering, are required to obtain the exact content value for heterogeneous data. Data fusion classification techniques, particularly, can be extensively employed on multisensory environments aiming to fuse and aggregate data from multiple distributed heterogeneous sensors (as those deployed in agricultural fields), in order to obtain lower detection error probability and higher reliability [39]. For this purpose, FMSs can employ various AI-based methods, such as Artificial Neural Networks (ANNs), C5.0 classification algorithms, Bayesian fusion and Hidden Markov Model (HMM) methods, whereas in some cases, unsupervised learning may also be applied. Furthermore, clustering, as an exploratory data analysis technique, is widely used for identifying subgroups (clusters) in the data according to the similarity or diversity of data points [40, 41].

In addition, by applying ML techniques, FMSs can evolve into actual AI systems, providing more sophisticated insights and suggestions for any subsequent decisions and actions, ultimately aiming to improve the agricultural production. In this sense, it is expected that the incorporation of ML models in FMSs will expand even more in the near future through the integration of automated data recording, data analysis, ML implementation, and decision-making or support, providing practical tools that come in line with the Agriculture 4.0 guidelines for increasing the production and quality of agricultural goods in terms of sustainability.

3.5. Big Data and Analytics

The recent impetus of the IoT technology, wirelessly interconnecting all kinds of objects and devices, in all stages of the cyber-physical management cycle, is producing large amounts of real-time accessible data about farming processes as well as the entire supply chain. In this regard, operations and transactions are highly significant sources of process-mediated data. Additionally, sensory devices and robots produce non-traditional data such as images, videos, and other kinds of machine-generated data, while social media is also an important source for human-sourced data. As a result, to such large amounts of heterogeneous data, access to explicit information and decision-making capabilities is provided at a level that was not possible before. The key success factor in creating value out of these data is Big Data and Analytics technology.

Big Data is changing the scope and organization of farming as they are being used to provide predictive insights in farming operations, drive real-time operational decisions, and redesign processes [42]. Significant issues, such as efficiency improvement, food security and safety, climate change, and sustainability, are to be addressed by Big Data applications. In this sense, the objectives of Big Data applications extend far beyond farming, but cover the requirements of the entire supply chain related to sensor deployment, benchmarking, predictive modeling and risk management with regard to the Agriculture 4.0 guidelines [43, 44].

3.6. Agricultural Robotic and Autonomous Systems

Robotic and Autonomous Systems are highly complex in general since they consist of various sub-systems, which need to be integrated and properly synchronized to perform tasks perfectly as a whole, and successfully disseminate any required information. This kind of integration is essential for accounting cycle times and time delays, as well as the communication features among all sub-systems [45].

Agricultural Robotic and Autonomous Systems, performing various field tasks, such as sowing, pruning, phenotyping, targeted fertilization, harvesting, and sorting in automated or near-automated modes, are even more complex and sophisticated as they have to operate in unstructured agricultural environments in order to ease the workload on farmers, increase productivity rates, advance soil health and yield quality as well optimize the management of resources [46, 47]. To successfully integrate robotic systems into agricultural processes, the following significant issues need to be addressed:

- Problems, such as the continuously changing conditions and the variability of agricultural production and environment, as well as harsh environmental conditions (*i.e*. dust, vibration, extreme temperature, and humidity), need to be overcome through the development of adequate equipment and intelligent systems so as to achieve successful operation in such environments.
- The costs of robotic systems must be taken into consideration in the FMSs so as to realize the practical usage of various kinds of robots and penetrate more widely into the agricultural sector. In this sense, the costs of robotic systems must be sufficiently lowered to economically justify their usage, since the agricultural products have relatively low value.
- In order for autonomous systems to be suitable for operating unsupervised in open fields, inherent safety and reliability issues have to be overcome, since safeguarding individuals, the environment, the crops, and the machines are all mandatory to this day.

CONCLUSION

FMSs are constantly evolving since the technical background of farms has reached a comparable level currently to that of other industrial sectors and radical changes in farm management can be expected due to the access to big volumes of information and decision-making abilities. Though precision agricultural technologies have been in use for about a decade and normally take the form of yield monitors in cropping systems and robotic milking parlors for dairy, the innovation has accelerated, since the cost of sensors and robotics has fallen. Several innovations driven by the developing usage of data announce a digital revolution in agriculture, expressed as Agriculture 4.0. Agriculture 4.0 technologies refer to production systems that deploy robotics, sensors, and Big Data analytics allowing farmers to manage their farms at detailed spatial and temporal scales. In the IoT, all kinds of devices and smart objects are interconnected and interact with each other through local and global wireless network infrastructures. Advances in robotics permit a greater degree of automation and the decreasing cost of sensor technology allows farmers to monitor factors, *e.g*., soil properties in almost real-time conditions. Accessible and affordable computing power in this condition creates new decision support tools (*e.g*., on-tractor dashboards and mobile applications) for a better management practice while emerging Big Data analytical platforms, *e.g*., cloud computing and ML algorithms, drive AI and support a relevant growth in the volume, velocity, variety, and veracity of data generated in agriculture. Subsequently, agricultural data are quickly providing the main driver not only of revolutions in the outputs and the food chain but also in sustainable farm management.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

Declared none.

REFERENCES

[1] FAO. Climate Smart Agriculture Sourcebook. http://www.fao.org/climate-smart-agriculture-sourcebook/en/ (Accessed February 12, 2020)

[2] Berckmans D. General introduction to precision livestock farming. Anim Front 2017; 7(1): 6-11. [http://dx.doi.org/10.2527/af.2017.0102]

[3] Mulla D, Khosla R. Historical evolution and recent advances in precision farming.Soil-Specific Farming: Precision Agriculture. Boca Raton: CRC Press Taylor & Francis Group 2016; Vol. 1: pp. 1-36.

[4] Leonard EC. Precision agriculture. Encyclopedia of Food Grains. Oxford: Elsevier 2016; Vol. 4: pp. 162-7. [http://dx.doi.org/10.1016/B978-0-12-394437-5.00203-5]

[5] Sørensen CG, Bochtis DD. Conceptual model of fleet management in agriculture. Biosyst Eng 2010; 105(1): 41-50. [http://dx.doi.org/10.1016/j.biosystemseng.2009.09.009]

[6] Rose DC, Sutherland WJ, Barnes AP, *et al.* Integrated farm management for sustainable agriculture: Lessons for knowledge exchange and policy. Land Use Policy 2019; 81: 834-42. [http://dx.doi.org/10.1016/j.landusepol.2018.11.001]

[7] Symeonaki EG, Arvanitis KG, Piromalis DD. Cloud computing for IoT applications in climate-smart agriculture: A review on the trends and challenges toward sustainability. Innovative Approaches and Applications for Sustainable Rural Development, HAICTA 2017. Cham: Springer 2019; Vol. 1: pp. 147-67. [http://dx.doi.org/10.1007/978-3-030-02312-6_9]

[8] Ozdogan B, Gacar A, Aktas H. Digital agriculture practices in the context of Agriculture 4.0. J Econ Finance Account 2017; 4(2): 186-93. [http://dx.doi.org/10.17261/Pressacademia.2017.448]

[9] Deichmann U, Goyal A, Mishra D. Will digital technologies transform agriculture in developing countries? Agric Econ 2016; 47(S1): 21-33. [http://dx.doi.org/10.1111/agec.12300]

[10] Bonneau V, Copigneaux B, Probst L, Pedersen B. Industry 4.0 in agriculture: Focus on IoT aspects. European Commission, Digital Transformation Monitor, 2017 https://ec.europa.eu/growth/tools-databases/dem/monitor/content/industry-40-agriculture-focus-iot-aspects (Accessed February 12, 2020).

[11] De Clercq M, Vats A, Biel A. Agriculture 4.0: The Future of Farming Technology. World Government Summit in Collaboration with Oliver Wyman. https://www.worldgovernmentsummit.org/api/publications/document?id=95df8ac4-e97c-6578-b2f8-ff0000a7ddb6 (Accessed February 12, 2020).

[12] Rose DC, Chilvers J. Agriculture 4.0: Broadening responsible innovation in an era of smart farming. Front Sustainable Food Syst 2018; 2: 1-5. [http://dx.doi.org/10.3389/fsufs.2018.00087]

[13] Kagermann H, Helbig J, Hellinger A, Wahlster W. Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry. Forschungsunion, 2013 http://forschungsunion.de/pdf/industrie_4_0_final_report.pdf (Accessed February 12, 2020).

[14] Chung M, Kim J. The Internet information and technology research directions based on the fourth industrial revolution. KSII Trans Internet Inf Syst 2016; 10(3): 1311-20.

[15] Smit J, Kreutzer S, Moeller C, Carlberg M. Industry 4.0-Study for the ITRE Committee, 2016. http://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf (Accessed February 12, 2020).

[16] Pfeiffer S. The vision of “Industrie 4.0” in the making-A case of future told, tamed, and traded. NanoEthics 2017; 11(1): 107-21. [http://dx.doi.org/10.1007/s11569-016-0280-3] [PMID: 28435474]

[17] Xu LD, Xu EL, Li L. Industry 4.0: State of the art and future trends. Int J Prod Res 2018; 56(8): 2941-62. [http://dx.doi.org/10.1080/00207543.2018.1444806]

[18] An W, Wu D, Ci S, Luo H, Adamchuk V, Xu Z. Agriculture cyber-physical systems. Cyber-Physical Systems; Song, H, S. United States: Elsevier Academic Press 2017; Vol. 1: pp. 399-417. [http://dx.doi.org/10.1016/B978-0-12-803801-7.00025-0]

[19] Piromalis D, Arvanitis K. SensoTube: A scalable hardware design architecture for wireless sensors and actuators networks nodes in the agricultural domain. Sensors (Basel) 2016; 16(8): 1227. [http://dx.doi.org/10.3390/s16081227] [PMID: 27527180]

[20] Li S, Cui J, Li Z. Proceedings of the 4th International Conference on Intelligent Computation Technology and Automation. Shenzhen, China. IEEE 2011; pp. March 28 - 29, 2011; 307-10.

[21] Ojha T, Misra S, Raghuwanshi NS. Wireless Sensor Networks for agriculture: The state-of-the-art in practice and future challenges. Comput Electron Agric 2015; 118: 66-84. [http://dx.doi.org/10.1016/j.compag.2015.08.011]

[22] Fresco R, Ferrari G. Enhancing precision agriculture by Internet of Things and cyber physical systems. Atti Soc Tosc Sci Nat Mem Supplemento 2018; 125: 53-60.

[23] Selmani A, Oubehar H, Outanoute M, *et al.* Agricultural cyber-physical system enabled for remote management of solar-powered precision irrigation. Biosyst Eng 2018; 177: 18-30. [http://dx.doi.org/10.1016/j.biosystemseng.2018.06.007]

[24] Symeonaki E, Arvanitis K, Piromalis D. A context-aware middleware cloud approach for integrating precision farming facilities into the IoT toward Agriculture 4.0. Appl Sci (Basel) 2020; 10(3): 813. [http://dx.doi.org/10.3390/app10030813]

[25] Buyya R, Yeo CS, Venugopal S, Broberg J, Brandic I. Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility. Future Gener Comput Syst 2009; 25(6): 599-616. [http://dx.doi.org/10.1016/j.future.2008.12.001]

[26] Bosse S, Lehmhus D, Lang W, Busse M, Bosse S. Distributed and cloud computing: The big machine.Material-integrated intelligent systems-technology and applications. Germany: Wiley-VCH Verlag GmbH & Co. 2017; Vol. 1: pp. 385-6. [http://dx.doi.org/10.1002/9783527679249.ch17]

[27] Yu J, Yang Z, Zhu S, Xu B, Li S, Zhang M. Electronic and Automation Control Conference (IAEAC). Chongqing, China. IEEE 2018; pp. October 12-14, 2018; 2353-8.

[28] Zhou H, Hu Y, Su J, de Laat C, Zhao Z. CloudsStorm: An application-driven framework to enhance the programmability and controllability of cloud virtual infrastructures. Cloud Computing – CLOUD 2018. Lecture Notes in Computer Science Cham: Springer 2018; 10967: pp. 265-80. [http://dx.doi.org/10.1007/978-3-319-94295-7_18]

[29] Choudhary SK, Jadoun RS, Mandoriya HL. Role of cloud computing technology in agriculture fields. Comput Eng Intell Syst 2016; 7(3): 1-7.

[30] Tan L. Cloud-based decision support and automation for precision agriculture in orchards. IFAC-PapersOnLine, 2016; 49(16): 330-5. https://www.sciencedirect.com/science/article/pii/S240589631631624X (Accessed February 12, 2020).

[31] Botta A, De Donato W, Persico V, Pescapé A. Integration of cloud computing and Internet of Things: A survey. Future Gener Comput Syst 2016; 56: 684-700. [http://dx.doi.org/10.1016/j.future.2015.09.021]

[32] Jeschke S, Brecher C, Meisen T, Özdemir D, Eschert T. Industrial Internet of Things and Cyber Manufacturing Systems.Industrial Internet of Things. Cham: Springer 2017; pp. 3-19. [http://dx.doi.org/10.1007/978-3-319-42559-7_1]

[33] Madushanki A, Halgamuge M, Wirasagoda H, Syed A. Adoption of the Internet of Things (IoT) in agriculture and smart farming towards urban greening: A review. Int J Adv Comput Sci Appl 2019; 10(4): 11-28. [http://dx.doi.org/10.14569/IJACSA.2019.0100402]

[34] Talavera JM, Tobón LE, Gómez JA, *et al.* Review of Iot applications in agro-industrial and environmental fields. Comput Electron Agric 2017; 142: 283-97. [http://dx.doi.org/10.1016/j.compag.2017.09.015]

[35] Lakhwani K, Gianey H, Agarwal N, Gupta S. Proceedings of the Emerging Trends in Expert Applications and Security (ICETEAS 2018). Jaipur, India. Singapore: Springer 2019; pp. February 17-18, 2018; 425-32.

[36] Ma J, Zhou X, Li S, Li Z. In: Connecting agriculture to the Internet of Things through sensor networks, Proceedings of the 2011 International Conference on Internet of things and 4th International Conference on Cyber, Physical and Social Computing, Dalian,. China. 2012; pp. October 19-22, 2011; IEEE; 184-7.

[37] Yan-e D. Proceedings of the 4th International Conference on Intelligent Computation Technology and Automation (ICICTA). Shenzhen, China. IEEE 2011; pp. March 28-29, 2011; 1045-9.

[38] Patrício D, Rieder R. Computer vision and artificial intelligence in precision agriculture for grain crops: A systematic review. Comput Electron Agric 2018; 153: 69-81. [http://dx.doi.org/10.1016/j.compag.2018.08.001]

[39] Castanedo F. A review of data fusion techniques. Scientific World Journal 2013; 2013704504 https://www.hindawi.com/journals/tswj/2013/704 504/ [http://dx.doi.org/10.1155/2013/704504] [PMID: 24288502]

[40] Popa C. Adoption of artificial intelligence in agriculture. Bull Univ Agric Sci Vet Med Cluj-Napoca Agric 2011; 68(1): 284-93.

[41] Dahikar SS, Rode SV. Agricultural crop yield prediction using artificial neural network approach. Int J Innovative Res Electr Electron Instrum Control Eng 2014; 2(1): 683-6.

[42] Ji C, Shao Q, Sun J, *et al.* Device data ingestion for industrial big data platforms with a case study. Sensors (Basel) 2016; 16(3): 279. [http://dx.doi.org/10.3390/s16030279] [PMID: 26927121]

[43] Ip RHL, Ang LM, Seng KP, Broster JC, Pratley JE. Big data and machine learning for crop protection. Comput Electron Agric 2018; 151: 376-83. [http://dx.doi.org/10.1016/j.compag.2018.06.008]

[44] Delgado JA, Short NM, Roberts DP, Vandenberg B. Big data analysis for sustainable agriculture on a geospatial cloud framework. Front Sustainable Food Syst 2019; 3: 54. [http://dx.doi.org/10.3389/fsufs.2019.00054]

[45] Sowjanya KD, Sindhu R, Parijatham M, Srikanth K, Bhargav P. Proceedings of the 2017 International Conference of Electronics, Communication and Aerospace Technology (ICECA). Coimbatore, India. IEEE 2017; pp. April 20-22, 2017; 696-9.

[46] Shamshiri R, Weltzien C, Hameed I, *et al.* Research and development in agricultural robotics: A perspective of digital farming. Int J Agric Biol Eng 2018; 11(4): 1-11. [http://dx.doi.org/10.25165/j.ijabe.20181104.4278]

[47] Reiser D, Sehsah ES, Bumann O, Morhard J, Griepentrog HW. Development of an autonomous electric robot implement for intra-row weeding in vineyards. Agric 2019; 9(1): 18.