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Focus Group on Artificial Intelligence (AI) and Internet of Things (IoT) for Digital Agriculture

(FG-AI4A)

FG-AI4A WG-Roadmap

Standardization gaps and roadmap for AI and IoT in digital agriculture

Working Group: Mapping and Analyzing AI and IoT standards related Activities in Digital Agriculture

FG-AI4A Publication

Standardization gaps and roadmap for AI and IoT in digital agriculture

Summary

This Technical Report analyses and identifies standardization gaps related to AI and IoT in digital agriculture and develop a future standardization roadmap, taking into consideration the activities currently undertaken by other ITU groups, various standards developing organizations (SDOs) and forums.

Keywords

AI; IoT; Digital Agriculture; Gap analysis; Standardization roadmap.

Note

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Acknowledgement

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It is based on the contributions of various authors who participated in the Focus Group activities. Mr Gyu Myoung Lee (Korea (Republic of)) and Mr Laura-Sophia Von Hirschhausen (Fraunhofer HHI, Germany) served as the main Editors of this Technical Report, supported by Mr Lizhang Xu (Jiangsu University, China) and Ms Namrata Singh (Telecommunication Engineering Centre, Department of Telecommunications, Ministry of Communications, India). Ms Mythili Menon (FG-AI4A Advisor) and Ms Chiara Co (FG-AI4A Assistant) served as the FG-AI4A Secretariat.

Change Log

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1. Scope

This Technical Report identifies feasible AI and IoT technologies for digital agriculture while providing an analysis of standardization gaps related to AI and IoT in digital agriculture.

The main objectives of the roadmap are to:

- avoid duplication of standardization efforts within the domain of digital agriculture
- gain insights into the various technologies utilized in digital agriculture
- optimize collaboration and synergies among stakeholders in the digital agriculture sector, and
- underscores areas where progress is being made (i.e., trends) and where it is needed (i.e., gaps).

This Technical Report offers an overview of standardization activities related to AI (and complementary technologies) for digitalization of agriculture.

2. References

[ITU-T Y.4000] Recommendation ITU-T Y.4000 (2012), *Overview of the Internet of things*

[ITU-T M.3080] Recommendation ITU-T M.3080 (2021), *Framework of artificial intelligence enhanced telecom operation and management (AITOM)*

[ITU-T L.1504] Recommendation ITU-T L.1504 (2016), *ICT and adaptation of agriculture to the effects of climate change*

[ITU-T Y.4450] Recommendation ITU-T Y.4450, *Overview of Smart Farming based on networks*

[ITU-T Y.3172] Recommendation ITU-T Y.3172 (2019), *Architectural framework for machine learning in future networks including IMT-2020*

[ITU-T Y.4100] Recommendation ITU-T Y.4100 (2014), *Common requirements of the Internet of things*

[Y Suppl. 76: ITU-T Y.4000-series] Supplement 76 to ITU-T Y.4000, *Use cases of Internet of things-based smart agriculture*

3. Terms and Definitions

Artificial Intelligence (AI) [ITU-T M.3080]: Computerized system that uses cognition to understand information and solve problems.
NOTE 1 – ISO/IEC 2382-28 defines AI as "an interdisciplinary field, usually regarded as a branch of computer science, dealing with models and systems for the performance of functions generally associated with human intelligence, such as reasoning and learning".
NOTE 2 – In computer science AI research is defined as the study of "intelligent agents": any device that perceives its environment and takes actions to achieve its goals.
NOTE 3 – This includes pattern recognition, the application of machine learning and related techniques.
NOTE 4 – Artificial-intelligence is the whole idea and concept of machines being able to carry out tasks in a way that mimics human intelligence and would be considered "smart".

Climate-smart agriculture (CSA) [ITU-T L.1504]: CSA is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change.

Machine Learning (ML) [ITU-T Y.3172]: processes that enables computational systems to understand data and gain knowledge from it without necessarily being explicitly programmed.

Internet of Things (IoT) [ITU-T Y.2060]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

Smart livestock farming [ITU-T Y.4450]: A convergence service which applies information and communication technologies (ICTs) to livestock value chains, with the potential to deliver more productive and sustainable production. NOTE 1 – By integrating processes of smart farming, management information systems, stockbreeding automation and robotics, smart livestock farming helps decision-making for more effective and efficient exploitation, operations and management of livestock value chains. NOTE 2 – Examples of products from domesticated animals (excluding pets) are meat, eggs, milk, honey, fur, leather and wool.

4. Abbreviations and Acronyms

This Technical Report uses the following abbreviations and acronyms:

AI	Artificial Intelligence
FAO	Food and Agriculture Organization
ICT	Information and communication technology
IoT	Internet of Things
ISO	International Organization for Standardization
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
ML	Machine Learning
SDO	Standards Development Organization
SLF	Smart livestock farming
UN	United Nations
WG	Working Group

5. Introduction

FG-AI4A established six working groups for pre-standardization activities in line with the agreed Terms of Reference. Among them, WG-Roadmap aims to develop a roadmap for future standardization related to AI and IoT in digital agriculture as follows:

The Working Group for Mapping and Analysing AI and IoT standards related Activities in Digital Agriculture (WG-Roadmap) is dedicated to mapping, analysing and identify the standardization gaps related to AI and IoT in agriculture and develop a future standardization roadmap, taking into consideration the activities currently undertaken by other ITU groups, various SDOs and forums. The activities include an accurate mapping of existing standards relevant to digital agriculture and an analysis of the standardization requirements needed for the existing solutions in the market to address challenges identified in WG-AS. It will also factor in the results of WG-DAM to develop its gap analysis.

There is a growing need for comprehensive guidelines that blend scientific knowledge, technological advancements, expert insights, and practical experience. These guidelines play a crucial role in promoting interoperability, aiding regulatory efforts, and facilitating capacity building. Standards Developing Organizations (SDOs) are instrumental in developing and disseminating such guidelines, operating at both national and international levels through organizations like the ITU, ISO, IEC, ETSI, and ANSI.

While official standards endorsed by Standard Development Organizations (SDOs) are essential, complementary guidelines can also be developed and implemented by UN agencies like UNESCO. This dynamic landscape of standardization involves numerous stakeholders focusing on diverse topics. Therefore, ongoing collaboration among these stakeholders is vital to prevent redundant efforts and identify areas where standardization is lacking but necessary.

The International Telecommunication Union (ITU) functions as the specialized United Nations agency for information and communication technologies (ICTs) and is the sole international SDO within the UN system. The ITU's primary standardization efforts are conducted through its Telecommunication Standardization Sector (ITU-T). As part of ITU-T, Focus Groups play a crucial role by convening internal and external experts to aid in the preliminary standardization of particular ICT applications and emerging technologies. The Focus Group on "Artificial Intelligence (AI) and Internet of Things (IoT) for Digital Agriculture" (FG-AI4A) was established by ITU-T Study Group 20 on Internet of things (IoT) and smart cities and communities (SC&C) to explore digital technologies to enhance the administration of farming operations and secure food stability. The activities of Focus Group on "Artificial Intelligence (AI) and Internet of Things (IoT) for Digital Agriculture" (FG-AI4A), are coordinated closely with the Food and Agriculture Organization of the United Nations (FAO)/

In order to streamline efforts and enhance collaboration between the standardization and digital agriculture sectors, the FG-AI4A has created a Working Group dedicated to mapping AI and IoT activities within agriculture (WG-Roadmap). This group's objective is to conduct a comprehensive review of historical, ongoing, and planned standardization initiatives in this field, with a specific focus on Standard Development Organizations (SDOs) and United Nations (UN) bodies. By analyzing these activities, this technical report aims to highlight emerging standardization trends and identify areas where additional efforts are needed to guide future standardization endeavors effectively.

The report provides an overview of the methods employed for gathering and analyzing the standards and activities database. Curation involved comprehensive research of literature and online sources, supplemented by a survey administered by FG-AI4A. The analysis of standards involved conducting overviews of the standardization database, focusing on trend and gap analysis discussed in Chapter 8.

This report presents the outcomes of these methods, showcasing a database comprising 43 standard contributions, followed by an exploration of the primary trends and gaps identified. An examination of the results reveals that ongoing standardization activities primarily focus on establishing frameworks for smart farming technologies, with a strong emphasis on integrating IoT and data analytics to enhance crop and livestock management efficiency. The guidelines outlined in the database prioritize the development of data models, service requirements, and architectures tailored for smart greenhouses, livestock farming, and agricultural education. These efforts aim to bolster productivity and sustainability in agriculture through technology-driven and data-centric approaches. Notably, AI and IoT emerge as significant trends in digital agriculture, each playing a pivotal role in advancing the industry. However, the relative prominence of AI and IoT varies depending on the specific applications and the developmental stage within different agricultural sectors.

- AI is often applied for tasks such as crop monitoring, yield prediction, disease detection, and precision agriculture. ML algorithms are necessary when large datasets shall be analysed, which enables better decision-making for farmer. Furthermore, AI is used when resource utilization is optimised, when processes are automated, and overall enhance the efficacy of farm operations.

- IoT systems are involved when sensor networks and connected devices are used, or when real-time data is collected. Prominently smart sensors and IoT devices are employed over soil monitoring, weather forecasting, and livestock tracking. Following IoT contributed to the development of smart farming practices, enabling remote monitoring and management of agricultural processes.

In summary, AI is often applied for data analysis and decision-making, while IoT focused on real--time data collection though interconnected devices.

The analysis revealed that numerous gaps in current standards are being actively tackled through the development of use cases and technical reports under FG-AI4A. As technology and standardization evolve, this standards database and associated activities will require ongoing updates, leveraging the new partnerships forged within the UN and SDO communities.

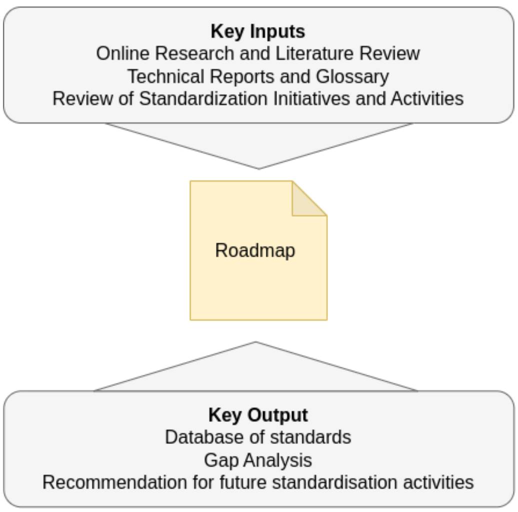

Figure 2 – Key inputs and outputs of the roadmap

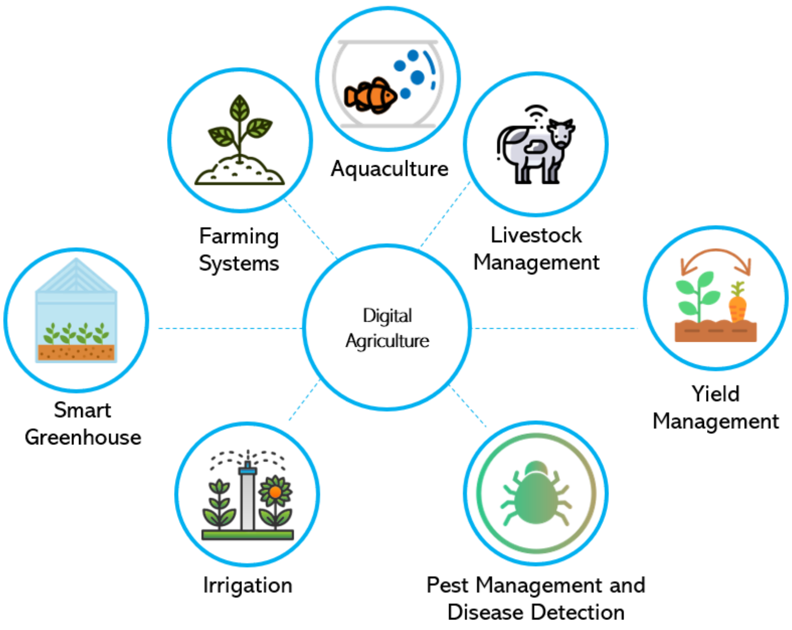

Figure 3 – Application Areas for Digital Agriculture

For the purpose of this report, seven application areas were identified:

- *Farming systems:* This refers systems in which natural resources are managed so that potential yield and the stock of natural resources do not decline over time. [b-Sciencedirect]

- *Smart Greenhouse:* This would refer to a microclimate using sensors and software to detect greenhouse gas emissions, measuring soil moisture, solar radiation, humidity and air temperature, making it possible to remotely control parameters in a timely manner. [b-FAO-1]

- *Irrigation:* This refers to the artificial application of water for the purpose of agriculture

- *Aquaculture:* Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. [b-FAO-2]

- *Yield management:* The largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. [b-FAO-1] Yield management in agriculture involves utilizing data regarding crop production, market dynamics, consumer preferences, and environmental variables to make strategic choices regarding production quantities, harvest timing, sales locations, and pricing strategies.

- *Livestock management:* Livestock encompasses domesticated animals utilized for the production of milk, eggs, meat, and various by-products. Essential to livestock management is the provision of proper care and nutrition to the animals, along with effective management practices aimed at generating profit. [b-Engineering]

- *Pest Management and Disease Detection:* Pest and disease management involves employing a combination of preventive and corrective strategies to mitigate or thwart the adverse impacts of pests on humans and the environment. The primary objective is to attain desired results while minimizing expenses and potential risks to both people and the ecosystem. [b-Agriculture]

6. Methods

As depicted in Figure 2, the roadmap contains information obtained through three distinct methods. Initially, a thorough examination of existing literature and online resources offered a comprehensive view of the standardization framework within this field. Technical reports and a glossary provided foundational knowledge, while a survey administered by the established connections between use cases and the standardization environment.

For the analysis, this report focuses on the standards (rather than activities). These standards were collected and analysed using an Excel datasheet and are depicted in Table 1. Short descriptions to the standards are found in Table 2.

Table 1 contain the list of relevant standards related to digital agriculture and application of technologies for agriculture in general. The gap analysis was developed from Tables 1 using the Fraunhofer Large-Language Model FHGenie, which is based on the GPT-4 model.

7. AI and IoT technologies for Digital Agriculture

Through the review, previous work of the focus group and survey of over 60 standards could be identified in Table 1 and categorized based on the application areas in Figure 3. These came from SDOs including ITU, ISO, IEC and IEEE. For this roadmap standards relating to artificial intelligence and internet of things for agriculture, and standards on artificial intelligence and internet of things were included if they were observed to have a pertinent link to their application agriculture.

Table 1 – Standards-based Outcomes and Reports from SDOs and other Relevant Entities

Acronym	**SDO and linked subgroup/committee**	**Application Areas**	**Technology**	**Status**
ITU-T L.1505, *Information and communication technology and adaptation of the fisheries sector to the effects of climate change*	ITU-T SG5	Aquaculture and Smart greenhouse	Non-specific	Approved in 2017
ITU-T L.1504, *ICT and adaptation of agriculture to the effects of climate change*	ITU-T SG5	Farming systems and Smart greenhouse	Non-specific	Approved in 2016
ITU-T Y.4450, *Overview of Smart Farming based on networks.*	ITU-T SG20	Farming systems	IoT	Approved in 2015
ITU-T Y.4466, *Framework of smart greenhouse service.*	ITU-T SG20	Smart greenhouse	IoT	Approved in 2020
ITU-T Y.4482, *Requirements and framework for smart livestock farming based on the Internet of Things.*	ITU-T SG20	livestock, management, irrigation	IoT	Approved 2022
ITU-T Y.4218, *IoT and ICT requirements for deployment of smart services in rural communities*	ITU-T SG20	Farming systems	IoT	Approved in 2023
ITU-T Y.SFPP, *Reference framework for the smart farmland production platform*	ITU-T SG20	Farming systems and Yield management	IoT	under study
ITU-T Y.IoT-soil, *Requirements of IoT-based soil environmental protection and remediation*	ITU-T SG20	Farming systems	IoT	under study
ITU-T Y.Sup.SmartAqua-usecases, ITU-T Y.4000-series - Use cases of IoT-based smart aquaculture	ITU-T SG20	Aquaculture	IoT	under study
ITU-T Y.DM-SLF, *Conceptual data model of smart livestock Farming service.*	ITU-T SG 20	livestock, farming	IoT, Big data	under study
ITU-T Y.4495, Requirements and a reference model of data for smart greenhouse service	ITU-T SG20	Smart greenhouse	Big data	Approved in 2023

ITU-T Y.Suppl.76 to ITU-T Y.4000-series, *Usecases of IoT based Smart Agriculture.*	ITU-T SG 20	livestock, farming systems, irrigation	IoT	Published in 2023
ITU-T Y.4606, *Requirements and functional model of data management system for smart greenhouse service*	ITU-T SG20	Farming systems	IoT	Published in 2023
ITU-T Q.5028, *Data management interfaces for intelligent edge computing-based smart agriculture service*	ITU-T SG11	Yield management	Edge computing	Published in 2023
ITU-T Q.IEC-DTINF, *Data management interfaces in digital twin smart aquaculture system with intelligent edge computing*	ITU-T SG11	Aquaculture	Edge computing	under study
ITU-T Q.IEC-FWINF, Data management interfaces for intelligent edge computing-based flowing-water smart aquaculture system	ITU-T SG11	Aquaculture	Edge computing	under study
ITU-T Y.IMT2020-qos-req-sa, *Quality of service assurance requirements and framework for smart agriculture supported by IMT-2020 and beyond*	ITU-T SG13	Farming systems	Non-specific	under study
ITU-T Y.2248, *Service model for Entry-level Smart Farm*	ITU-T SG13	Farming systems	Non-specific	Approved in 2023
ITU-T Y.2244, *Service model for a cultivation plan service at the pre-production stage.*	ITU-T SG 13	Yield management	IoT	Approved 2019
ITU-T Y.2243, *A service model for risk mitigation service based on networks*	ITU-T SG13	Farming systems	Non-specific	Approved in 2019
ITU-T Y.2245, *Service model of the agriculture information-based convergence service.*	ITU-T SG 13	Farming systems	IoT	Approved in 2020
ITU-T Y.2246, *Smart farming education service based on u-leaning environment.*	ITU-T SG 13	Farming systems	Non-specific	Approved 2021
ITU-T Ymlip, *A Service model of risk mitigation on livestock pandemic based on networks.*	ITU-T SG 13	Livestock management	IoT	under study
ITU-T Y.esm, *Service model for Entry-level Smart Farm.*	ITU-T SG 13	Farming systems	IoT, AI	under study
ITU-T Y.ous, *Overview of Unmanned Smart Farm based on networks.*	ITU-T SG 13	Farming systems	IoT	under study

ITU-T F.DLIM-AHFS, *Requirements of the distributed ledger incentive model for agricultural human factor services*	ITU-T SG16	Farming system	DLT	under study
ITU-T F.FIISReqs, *Requirements and functional architecture for machine-vision-based farm intelligent inspection system*	ITU-T SG16	Farming system	AI	under study
FG-AI4NDM-COM - *AI for communications: Towards natural disaster management*	ITU/WMO//UNEP FG-AI4NDM	Pest Detection & Disease Detection	AI	Published in 2023
E-Agriculture Strategy Guide	ITU and FAO	Farming systems	IoT, AI	published 2016
Digital Tools in USAID Agricultural Programming Toolkit	Government's Global Hunger & Food Security Initiative	Farming systems	IoT, AI	published 2018
E-Agriculture in Action	ITU and FAO	Farming systems	IoT, AI, big data	published 2017
E-Agriculture in Action: Blockchain for Agriculture	ITU and FAO	Farming systems	IoT, AI, big data	published 2019
E-Agriculture in Action: Drones for Agriculture	ITU and FAO	Farming systems	IoT, AI, big data	published 2018
E-Agriculture in Action: Artificial Intelligence for Agriculture	ITU and FAO	Farming systems	IoT, AI, big data	published 2021
E-Agriculture in Action: Big Data for Agriculture	ITU and FAO	Farming systems	IoT, AI, big data	published 2019
ETSI TS 103 410-6: Extension to SAREF; Part 6: *Smart Agriculture and Food Chain Domain*	ETSI	Farming systems, livestock management, yield management	Internet of Things	Published 2019
Strategic Advisory Group Report on Smart Farming (SAG SF)	ISO	Farming systems, livestock management	IoT, AI, big data	published 2022
IEEE P2418.3 - *Framework of Distributed Ledger Technology (DLT) Use in Agriculture*	IEEE	Yield management	DLT	Published 2019

IEEE P2992 - *Recommended Practice for Data Expression, Exchange, and Processing in Smart Agriculture*	IEEE	Farming systems, Yield Management	Big data	Published 20211
ISO 16119-1:2013 - *Agricultural and forestry machinery Environmental requirements for sprayers Part 1: General*	ISO/TC 23/SC 6	Farming management	Non-specific	Reviewed in 2018
ISO/DIS 16122-1 *Agricultural and forestry machinery* *Inspection of sprayers in use* *Part 1: General*	ISO/TC 23/SC 6	Farming management	Non-specific	under development
ISO 8026:2009 - *Agricultural irrigation equipment Sprayers General requirements and test methods*	ISO/TC 23/SC 18	Irrigation	Non-specific	Reviewed in 2020
ISO 9635-1:2014 - *Agricultural irrigation equipment* *Irrigation valves* *Part 1: General requirements*	ISO/TC 23/SC 18	Irrigation	Non-specific	Reviewed in 2020
ISO 5231:2022 - *Extended farm management information systems data interface (EFDI)* *Concept and guidelines*	ISO/TC 23/SC 19	Farming systems	Non-specific	Published in 2022
ISO 10975:2023 - *Agricultural machinery and tractors* *Auto-guidance systems for operator-controlled tractors and self-propelled machines* *Safety requirements*	ISO/TC 23/SC 19	Farming systems, yield management	Non-specific	Published in 2023
ISO 11783-1:2017 - *Tractors and machinery for agriculture and forestry* *Serial control and communications data network* *Part 1: General standard for mobile data communication*	ISO/TC 23/SC 19	Yield Management	Non-specific	Reviewed in 2023
ISO 4254-6:2020 -*Agricultural machinery* *Safety* *Part 6: Sprayers and liquid fertilizer distributors*	ISO/TC 23/SC 3	Yield Management	Non-specific	Published in 2020
ISO 4444:2022 - *Agricultural sprayers* *Recording of spray drift parameters*	ISO/TC 23/SC 6	Yield Management	Non-specific	Published in 2022
ISO 20966:2007 *Automatic milking installations*	ISO/TC 23	Livestock management	Non-specific	Reviewed in 2023

Requirements and testing				
ISO/IEC DIS 5259 *Artificial intelligence* *Data quality for analytics and machine learning (ML)* *Part 1: Overview, terminology, and examples*	ISO/IEC JTC 1/SC 42	General	IoT, AI, big data	under development
ISO/IEC TR 5469:2024 *Artificial intelligence* *Functional safety and AI systems*	ISO/IEC JTC 1/SC 42	General	AI	under development
ISO/IEC TS 8200 *Information technology* *Artificial intelligence* *Controllability of automated artificial intelligence systems*	ISO/IEC JTC 1/SC 42	General	AI	under development
ISO/IEC AWI TS 17847 *Information technology* *Artificial intelligence* *Verification and validation analysis of AI systems*	ISO/IEC JTC 1/SC 42	General	AI	under development
ISO/IEC TR 17903 *Information technology* *Artificial intelligence* *Overview of machine learning computing devices*	ISO/IEC JTC 1/SC 42	General	AI	ongoing
ISO/IEC CD TR 20226 *Information technology* *Artificial intelligence* *Environmental sustainability aspects of AI systems*	ISO/IEC JTC 1/SC 42	General	AI	under development
ISO/IEC AWI TR 21221 *Information technology – Artificial intelligence – Beneficial AI systems*	ISO/IEC JTC 1/SC 42	General	AI	under development
ISO/IEC TR 24030:2024 *Information technology* *Artificial intelligence (AI)* *Use cases*	ISO/IEC JTC 1/SC 42	General	AI	Published in 2024
ISO/IEC AWI TR 42103 *Information technology*	ISO/IEC JTC 1/SC 42	General	AI	under development

Artificial intelligence *Overview of synthetic data in the context of AI systems*				
ISO/IEC 23894:2023 *Information technology* *Artificial intelligence* *Guidance on risk management*	ISO/IEC JTC 1/SC 42	General	AI	Published in 2023
ISO/IEC TR 24027:2021 *Information technology* *Artificial intelligence (AI)* *Bias in AI systems and AI aided decision making*	ISO/IEC JTC 1/SC 42	General	AI	Published in 2021
ISO/IEC 21823-4:2022 *Internet of things (IoT)* *Interoperability for IoT systems* *Part 4: Syntactic interoperability*	ISO/IEC JTC 1/SC 41	General	IoT, digital twin	Published in 2023
ISO/IEC TR 22417:2017 *Information technology* *Internet of things (IoT) use cases*	ISO/IEC JTC 1/SC 41	General	IoT, digital twin	Published in 2017
PWI TR JTC1-SC41-11(AWI) *Digital Twin - Correspondence measurement of digital twins*	ISO/IEC JTC 1/SC 41	General	IoT, digital twin	Completed in 2022
PWI TR JTC1-SC41-12 (AWI) *Internet of Things (IoT) – Environmental and ecological effects, risks, and considerations of underwater acoustic signalling*	ISO/IEC JTC 1/SC 41	General	IoT, digital twin	Completed in 2022

8. Trend- and Gap-Analysis

Through an analysis of existing standards in Table 1, several recurring themes could be found and are described in line with this roadmap.

Agricultural value chain: The standards in Table 1 a broad spectrum of agricultural processes, including smart farming, smart greenhouses, smart livestock farming, risk mitigation, and entry-level smart farms. This indicates a trend toward creating a fully integrated, technology-driven agricultural ecosystem. This specificity in applications indicates a trend towards addressing unique agricultural challenges through tailored IoT and AI solutions.

Data and AI: Many standards in Table 1, such as those focusing on data models for smart greenhouses and smart livestock farming, highlight the importance of data accumulation, management, and utilization. This suggests a strong trend toward leveraging big data and AI technologies to enhance agricultural productivity and sustainability. The use of AI for yield forecasting, pest and disease management, and even weather prediction in Table 1 showcases a trend towards predictive analytics in agriculture. This approach aims at anticipatory management strategies to improve outcomes and mitigate risks.

Sustainability and Efficiency: Several standards aim at improving sustainability and efficiency in agriculture, addressing global challenges like climate change and food security. Initiatives like Gaia-X and International Data Spaces (IDS) are geared towards creating a more secure, sovereign, and interoperable data exchange framework, which is crucial for sustainable and efficient agricultural practices.

Emerging Technologies: The standards in Table 1 reflect an increasing adoption of emerging technologies such as IoT, drones, blockchain, and digital twins. These technologies are recognized for their potential to revolutionize agriculture by improving data collection, analysis, and decision-making processes. With references to deep learning, IoT, and digital twins in Table 1, there is a clear trend towards leveraging cutting-edge technologies. These technologies are being applied in innovative ways to enhance agricultural productivity, sustainability, and decision-making processes.

Interoperability: There's a clear movement towards ensuring interoperability among different systems and promoting open digital ecosystems depicted in Table. This is evident from the focus on standards that facilitate data sharing, security, and the creation of federated data infrastructures.

Through an analysis of existing standards from Table 1, the gaps in the following areas are found and are described in line with the goal of this roadmap.

- **Uniformity in Data Standards:** Despite efforts shown in Table 1, there seems to be a need for more unified and universally accepted data standards. This would facilitate easier data sharing and interoperability between different systems and countries, enhancing global agricultural collaboration.
- **Global Standards and Interoperability:** Despite the development of specific use cases and standards, there is an apparent gap in global standards that facilitate interoperability across different regions and agricultural systems. Enhanced global collaboration could foster more widespread adoption and technology transfer.
- **Accessibility:** Many of the existing standards in Table 1 focus on advanced approaches requiring significant technological infrastructure and expertise in their implementation. There is a gap in making these technologies more accessible and affordable to smallholder farmers and in developing countries where such resources are scarce.
- **Ethics, Privacy and Security:** As AI and IoT technologies as depicted in Table 1 become more integrated into agriculture, there's a growing need for comprehensive standards addressing the ethical use of these technologies, data privacy, and protection.

- **Integration with Traditional Agricultural Practises:** There is a gap in the existing standards that specifically address the integration of high-tech solutions with traditional farming practices. Bridging this gap could facilitate smoother transitions and adoption rates among traditional farmers.
- **Environmental Impact and Biodiversity:** While technological advancements shown across the spectrum of standards are aimed at increasing efficiency and productivity, there is a lesser focus on their impact on biodiversity and ecosystems. Bridging this gap requires more research and guidelines on environmentally friendly technologies.
- **Climate Adaption and Resilience:** While sustainability is a focus, specific standards for enhancing climate adaptation and resilience in agricultural practices seem less emphasized in Table 1. Developing standards that address climate change impacts more directly could be beneficial. Although some technologies in Table 1 aim at resource management, there's a broader need for standards and technologies specifically designed to enhance resilience to climate change, helping farmers adapt to changing conditions and extreme weather events.

The landscape of standardization in IoT and AI within agriculture is rapidly evolving, with a strong focus on integrating emerging technologies, enhancing data utilization, and promoting sustainability. Collaboration between standardization bodies, governments, and the private sector will be crucial in addressing these gaps and ensuring that the benefits of technological advancements are accessible to all agricultural stakeholders. From Figure 4 and Figure 5, it is feasible to observe how the main technological and agricultural themes correspond quantitatively to several standards. The detailed exploration of specific use cases and regulatory developments highlights significant trends in the adoption of IoT and AI in agriculture, focusing on precision, sustainability, and innovation. However, addressing the identified gaps, especially in terms of global standardization, accessibility, and environmental sustainability, will be crucial to fully leverage these technologies for the benefit of the global agricultural sector. Integrating these technologies with traditional farming practices and ensuring they are accessible to all farmers worldwide will enhance food security, sustainability, and resilience against climate change.

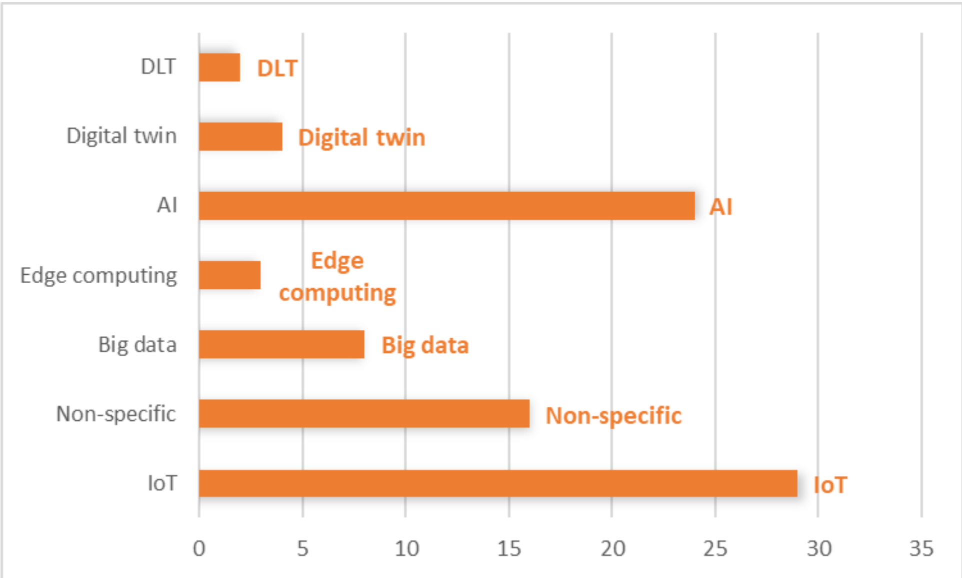

Figure 4 –Overview of standards linked to the use of different types of technologies for digital agriculture

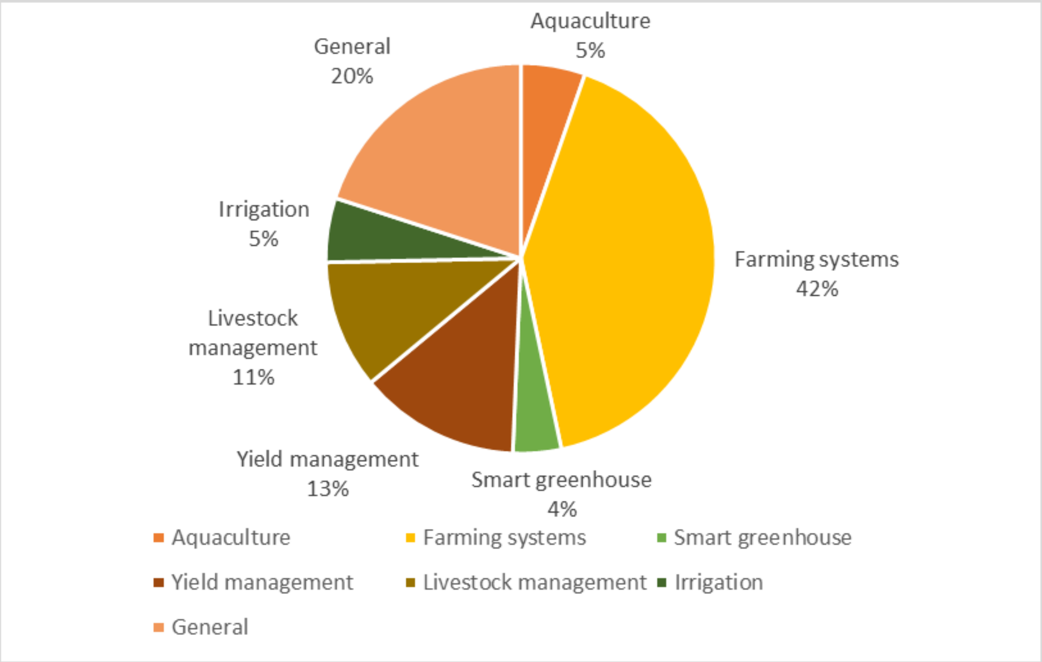

Figure 5 –Overview of standards linked various agricultural themes

9. Outlook

The landscape of standardization in IoT and AI within agriculture is rapidly evolving, marked by an increasing emphasis on integrating emerging technologies, enhancing data utilization, and promoting sustainability. The analysis underscores a concerted movement towards a comprehensive, technology-driven agricultural ecosystem that leverages big data and AI to enhance productivity and sustainability. With initiatives aimed at fostering sustainability and efficiency, alongside the adoption of cutting-edge technologies like IoT, drones, blockchain, and digital twins, the future points towards an agriculture sector that is highly data-driven, interconnected, and sustainable.

The focus on interoperability and the promotion of open digital ecosystems indicates a forward-looking approach to agricultural technology development, one that underscores the importance of seamless integration across various platforms and systems. The evolving standardization landscape is thus characterized by dynamic innovation, with a strong foundation in emerging ICTs that are set to revolutionize agricultural practices.

10. Conclusion

Addressing the gaps identified through this analysis is imperative for harnessing the full potential of digital agriculture technologies. The need for more unified data standards, global standards facilitating interoperability, and measures to enhance accessibility underscores the necessity for a collaborative approach in the standardization process. Bridging these gaps will not only facilitate global agricultural collaboration but also ensure that technological advancements are accessible and beneficial to all stakeholders within the agricultural sector.

Moreover, comprehensive standards addressing the ethical use of AI and IoT technologies, data privacy, and environmental sustainability are essential to ensure that technological advancements contribute positively to the sector. Integrating these technologies with traditional farming practices, enhancing climate adaptation and resilience, and ensuring their accessibility to farmers worldwide are crucial steps towards achieving food security, sustainability, and resilience against climate change.

In essence, the roadmap towards standardization in digital agriculture outlines a path characterized by innovation, collaboration, and a commitment to sustainability. It calls for ongoing efforts from standardization bodies, governments, and the private sector to ensure that the benefits of IoT and AI technologies are fully realized and equitably distributed across the global agricultural landscape.

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