STI POLICY AND MANAGEMENT

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Digital Transformation in The Agriculture Sector: Exploring The Shifting Role of Extension Workers

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ARTICLE INFO

Article History:
Received : 10 October 2022
Revised : 9 December 2022
Accepted : 9 December 2022
Available online : 15 December 2022

Authorship Contribution:
The main author is Chris Sugihono herein after as co-authors

Keywords:
Transformation,
digital technology,
digital platform,
agricultural extension workers

ABSTRACT

The world's digitalisation will continue. The exponentially increasing use of digital technology has disrupted various industries, including agriculture. This paper examines how digital technologies are transforming the agricultural sector and investigates the changing roles of agricultural extension workers in the digital era. This paper incorporated qualitative data (online observation) gathered via the World Wide Web via an unobtrusive observation technique and data from a literature review. The findings revealed that digital technology is altering the agricultural sector in two ways: the food system and the agricultural knowledge and innovation system. This paper tries to demonstrate how digitalisation has changed the role of agricultural extension workers. The extension worker's role is renewed to adjust to the digital ecosystem, such as informant, consultant, advisor, facilitator, mediator, and promoter. In addition, extension workers' roles as content creators and influencers, gatekeepers, big data analysts, artificial intelligence, and gamify creators will be expanded in the new field. Meanwhile, in response to these two major challenges, this research provides managerial implications for extension institutions and individual agricultural extension workers in Indonesia responding to the digital era.

I. INTRODUCTION

Agriculture is an important sector for Indonesia, contributing around 12.6% of the country's GDP, employing almost a third (29.96%) of the Indonesian labour force, and is dominated (93%) by smallholder farmers. This sector makes the country depend on the agricultural sector during the COVID-19 pandemic. While another sector decreased, agriculture recorded a growth of 1.37% (BPS, 2022). Millions of Indonesians (275 million people) depend on the agricultural sector to supply their food consumption with diverse preferences as the middle-class economy grows. To supply these demands, it is important to maintain and improve agricultural businesses' productivity, competitiveness, and sustainability.

Indeed, the agricultural sector still copes with recurring problems. Farmers have a low bargaining position and face difficulties accessing

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DOI: 10.14203/STIPM.2022.350

markets and price information (Anggraini et al., 2020), low production efficiency (Rachmawati, 2021), and unattainable to technology and financing for inclusive capitalisation (Fitriani, 2018). Furthermore, there is still information asymmetry between farmers and other agricultural value chain actors, resulting in a need for more transparency and effective communication to generate high productivity and prevent food loss due to untraceable supply chains (Goh, 2022).

Simultaneously, the world is becoming increasingly digitalised. The emergence of the COVID-19 pandemic, whether we like it or not, has encouraged and accelerated the process of digitalisation in all areas of life. Technological development has accelerated with the growth of the internet in recent years. 73,7% of internet users were reported in the global digital report (https://www.hootsuite.com/resources/digital-trends). Users of mobile connections (mobile phone/smartphone/tablet) reached 125.6% of Indonesia's total population. This means that one person has more than one device. Moreover, rapid digital technology advances in digital devices, automation, artificial intelligence, and machine learning exist. These innovative technologies lead to what researchers call the 'fourth agricultural revolution', or 'Agriculture 4.0'. This revolution is shaping the agriculture of the future, characterised by high-tech, radical, and potentially game-changing (Klerkx & Rose, 2020).

Agriculture 4.0 has disruptive and transformative properties. The adoption of innovative technologies can affect how food is produced, processed, traded, and consumed (Klerkx & Rose, 2020). The most frequently cited impacts of digitisation in agriculture tend to refer to precision agriculture technologies that are promoted as highly efficient, capable of reducing input costs while increasing yields, inclusiveness, transparency, and business sustainability (Eastwood et al., 2019; Ayoub Shaikh et al., 2022). Furthermore, with innovative technologies such as IoT, AI, blockchain, augmented reality, remote sensing, and distributed computing, farmers can access inputs, markets, finance, and decision-making services for good farming practices. Innovative technologies are predicted to enable new business models to help increase farm yields and profitability efficiently and effectively (Goh, 2022).

This condition is also a new challenge for agricultural extension and how to respond to societal changes. Some researchers call it a digital society, a society characterised by digitised and connected social life, with computers and algorithms mediating many daily activities. Digital technology has become part of everyday life. Things once considered science fiction is now taken for granted, such as smartphones, global information networks, and virtual reality. Society has become increasingly dependent on technology and digital infrastructure. The structure of this new society is quite abstract and difficult to understand (Dufva & Dufva, 2019). It is time for agriculture extension to change one of its old paradigms, namely the transfer of information and technology. Knowledge and extension workers no longer dominate knowledge, and information can increase democratisation and change the relationship between extension workers and farmers to be more equal and inclusive.

Over the past century, agricultural extension has become integral to agricultural development. The extension became an instrument of government policy starting in the 1970s as an effort to deal with the world food crisis through the main food production increase program (Benson & Jafry, 2013), through Green Revolution efforts to expand new practices, varieties, knowledge, and techniques in anticipation of Malthus' prediction of famine due to unbalanced population growth and food production growth (Cook et al., 2021). Until now, the extension still plays a central role in agricultural development in Indonesia.

The advent of digital technology has changed the way people communicate, work, learn and interact. The results of the Ministry of Communication and Informatics' survey (Kominfo, 2020) report that WhatsApp is the most widely used social media (98.9%), then Facebook (89.8%) and YouTube (87.8%). This affects the sources of information obtained by the community, most of which (76%) come from social media. Even 55.2% said they trusted social media information, especially WhatsApp. The digital

era, where people's actions are often mediated by digital ICT, has forced the agricultural extension system to adjust. Digital-based ICT does not create social order, but unconsciously, when people adopt a technology, the characteristics, system, and order will indirectly change. Some countries are responding to digitalisation by expanding the role of extension workers, not just transferring technology as has been done. Some of the new roles of extension workers that have emerged in the digital era require a new type of skill, namely digital literacy.

Thus, this study aims to answer two questions: (1) To what extent are digital technologies transforming the agricultural sector? and (2) What should agricultural extension agencies do to remain relevant in the digital era? In the literature, these have been extensively investigated to review the topic of agriculture and digitalisation. Discern the changes taking place, widely reported, and extensively explored in the literature used online observations. This paper starts by giving an overview of the types of technologies that can transform the agricultural sector. Additionally, it also outlines the forms and landscapes of transformation as digitalisation develops in agriculture. From those discussions, the shifting role of agricultural extension needs to be anticipated. Finally, it considers the implications for extension organisations and agricultural extension personnel.

II. METHODOLOGY

The data were collected using two methods: literature review and online observation with an unobtrusive observation technique on digital platform sites in the Indonesian agricultural sector. The literature review reviewed all major digital transformation and agricultural extension studies to integrate or synthesize evidence related to the research questions. The literature review was sourced from Scopus and Google Scholar databases.

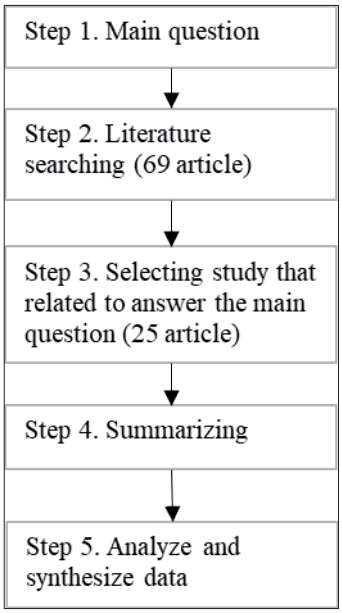

Fig. 1. The flow diagram of the literature review

Intending to identify studies that are suitable for achieving the key objectives of this research, ~~we~~ the researchers search in the literature database Scopus using the string "agriculture" AND "digital transformation" AND "digital technology" OR "digital farming" OR "mobile phone" OR "internet" OR "internet of things" OR "blockchain" OR "Artificial intelligence" OR "Drone". Sixty-nine articles were found, and then the relevant articles were selected to referee answer research questions. Then, it was sorted into 25 articles related to the research topic. These articles were summarised and categorised, synthesised, and analysed. Accomplished research objective focused on the local Indonesian context, the articles were searched, which has related to research questions on Google Scholar.

The data from Online observation were collected from May to June 2022 on eleven websites related to this topic. The selection of these websites was determined purposively based on the Compasslist report with the title Indonesia agritech report. From there, several start-ups whose company valuations have increased exponentially were tabulated. Searching by Google search engine regarding start-ups business practices was attained through their official website. Then, the content analysis was

conducted regarding business services, products, and business models. The validity of the websites was tested by the URL Checker (https://www.emailveritas.com/url-checker) using advanced artificial intelligence (AI) and machine learning techniques to detect fraudulent websites and quickly determine if they are legitimate.

Online observation is a research method widely used in the digital era through online observation on sites related to the research topic; in this case, sites linked to digital platforms in the agricultural sector. The technique used is unobtrusive observation. An unobtrusive researcher is a bystander collecting data without interacting. The researcher can collect data by downloading relevant materials for further analysis. In this form of observation, the researchers do not make posts, ask questions, respond, or involve themselves in interactions with the community on the online site. Considering that the public can access all the data collected in this study, the researchers are aware that there will be no privacy of individuals or institutions that will be disturbed by this research (Salmons, 2021).

This research finds the proper context as a novelty where digital transformation needs to be addressed by changing the role of agricultural extension workers, especially in developing countries.

III. RESULTS AND DISCUSSION

A. Digital Technology as an Entrance to Digital Transformation

Digital technology refers to using digital-based information and communication technologies to collect, store, analyse and share information, providing essential technical support for innovation in various fields. In the agricultural sector, digital technologies are disruptive because they replace old technologies while making old ways of working irrelevant and modifying the attributes that users value (Christensen, 2013). Unexpectedly, Nieto Cubero et al. (2021) entitle it to a radical technology because of its ability to generate new market infrastructures and produce discontinuities at the macro and micro levels.

Humans have limited capacity to process complex agricultural big data, so they need the help of tools that facilitate analysis in making useful decisions. Based on observation, six categories of digital technologies are the entry points for digital transformation in agricultural practices: mobile phones, internet-connected to various electronic devices, the internet of things (IoT), artificial intelligence (AI), drones, and blockchain (Table 1).

First, mobile phones are an early-generation digital technology, wireless handheld device that allows users to make and receive calls and send text messages. Mobile phones operate on cellular networks, consisting of cell sites scattered throughout cities, the countryside, and even mountainous areas. If the user happens to be in an area with no signal from any cell site belonging to the cellular network provider to which they subscribe, calls cannot be made or received at that location (Aker & Ksoll, 2016).

Second, the internet is a globally connected network system that facilitates worldwide communication and access to data resources through an enormous collection of private, public, business, academic, and government networks. In the agricultural sector, the internet allows the exchange and sharing of knowledge about market situations, climate predictions, and government programs. Therefore, thanks to the internet, a farmer can acquire and expand knowledge, contact other actors, promote his products and services, order the necessary means of production, and carry out administrative tasks (Emeana et al., 2020).

Third, the internet of things (IoT) is one of the most revolutionary technologies, as all objects connected to the web will be enabled to share and process data through their sensors and communication devices autonomously. The basic concept is that the interaction between physical components using a specific scheme will be connected to the Internet. IoT devices provide helpful information about various physical parameters to improve cultivation practices in an agricultural environment. The goal is to identify how the information collected can be used smartly. Farmers can use smartphones and

Table 1.
Digital technology and its role in the agriculture sector

No	Digital technology	Capacity/ability	Roles in agriculture	Source
1	Mobile phone	Voice and text communication	Facilitate communication between actors regarding prices, markets, production facilities, cultivation consulting, and climate information	(Aker & Ksoll, 2016; (Khan et al., 2020); Beza et al., 2018)
2	Internet (connected to a laptop or smartphone)	Voice communication, text, images, video, social media, browsing, digital platforms (e-commerce, e-learning)	Facilitate access to information and communication of farmers globally, increase human resource capacity online, business networks, markets, economic transactions, and financing	(Emeana et al., 2020); (Zheng et al., 2022); Subejo et al., 2019)
3	Internet of Things (IoT): Wireless Sensor Networks (WSNs), cloud computing, big data analytics, embedded systems, communication protocols	Capture, process, filter, and store data locally and in the cloud to develop a user-friendly interface and other utilities as needed.	Capture, process, filter, and store data locally and in the cloud to develop a user-friendly interface and other utilities as needed.	(Boursianis et al., 2022); Hsu et al., 2020)
4	Artificial Intelligence (AI) and Machine learning	Observing, learning, reasoning, and offering approximate solutions for complex functions.	Assist decision-making in precision agriculture cultivation	(Ayoub Shaikh et al., 2022); Elbeltagi et al., 2022)
5	Drone (Unmanned Aerial Vehicles)	Create high-resolution aerial imagery and perform AI-commanded actions	Supporting precision agriculture, detecting and mapping pests, diseases, and weeds, irrigating, fertilising, and spraying pesticides.	(Rejeb et al., 2022); Tsouros et al., 2019)
6	Blockchain	Combining cryptography and distributed computing to provide an algorithm for exchanging values securely.	Providing data flow security into agricultural business models, assisting in product traceability, and developing financial technology (fintech).	(Ferrández-Pastor et al., 2022; Patel et al., 2022)

tablet devices to access real-time agricultural data (soil and crop conditions, irrigation, fertilisation, weeds, or climate). As a result, farmers can act and intervene when necessary, based on valid data, rather than relying on their traditional intuition (Boursianis et al., 2022).

Fourth, artificial intelligence (AI) has revolutionised information technology and shaped the way of life. AI is a system with the ability to act intelligently, interpret external data correctly, and use this purpose to carry out specific tasks with flexible configurations, even capable of reproducing human behaviour with cognitive, social, and emotional intelligence (Di Vaio et al., 2020). Due to its flexibility and robustness, AI is also being applied in agriculture. It is reported that AI applications can act as a rapid decision-making tool during climate change with high accuracy and low statistical error (Elbeltagi et al., 2022).

Fifth, drones, known as unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UAS), are remote-controlled aircraft with many advantages over other remote sensing technologies. Drones can provide high-resolution images and videos on cloudy days. In agriculture, drones integrated with computing technology and onboard sensors can support agricultural management (e.g., mapping, monitoring, irrigation, crop diagnosis), crop growth monitoring yield estimation, drought stress assessment, and weed, pest, and disease detection. Based on environmental data, drones can simultaneously spray the right amount of water and pesticides.

Finally, blockchain is a decentralised, replicable, distributed ledger technology that underlies many additional innovations and is secure, traceable, cost-effective, transparent, and fast. Some researchers use blockchain technology in the agricultural sector for supply chain digitisation and traceability, linking it with Radio Frequency Identification or RFID devices (Ferrández-Pastor et al., 2022). Since blockchain is a technology that relies on algorithmic blocks, containing transaction information, connected and validated in chronological order and forming a chain that has permanent, immutable, transparent, and tamper-proof records, it is also widely used in the field of agricultural finance (Patel et al., 2022).

Digital technology can produce two types of disruptive innovations, namely digital farming and smart farming, also known as precision farming.

First, digital agriculture is the application of digital technologies along the agricultural value chain. Digital tools can be embodied in agricultural machinery (e.g., precision farming technologies using sensors, data analytics, and variable rate technologies) or intangible, e.g., extension applications, farm management software, and digital platforms that connect farmers to the value chain (Daum et al., 2022).

Second, smart agriculture or precision agriculture is defined as the application of modern information and communication technologies (IoT, GPS, big data) to improve the productivity and quality of agricultural products (De Clercq et al., 2018). IoT technology can manage temperature, light, and soil moisture data in a central control system by applying Artificial Intelligence (AI) algorithms to help farmers manage crop production systems (Wolfert et al., 2017). Smart agriculture provides practical solutions to several complex problems such as soil fertility, crop quality, pest and disease incidence, precision fertilisation and irrigation, and various agronomic data recording.

B. Digital Transformation in Agriculture

The development of digital technology has resulted in digital transformation in the agricultural sector. There is no universal definition of digital transformation in academic circles. According to Peng & Tao (2022), digital transformation is a change in the core business model and creates a new business model due to the use of digital technology. Digital transformation is synonymous with the transformation of business practices characterised by business model innovation, value creation, and new economic forms.

The digital transformation of agriculture has gone beyond the use of tools and software, as it impacts the knowledge and skills of its users, both main actors (farmers), business actors, and other supporting actors, such as extension workers, researchers, and consumers. Information fusion plays a vital role in digital extension transformation. The aspect of information fusion is the integration of various heterogeneous information sources. Information fusion improves the estimation and prediction of circumstances based on the combination process of data or information (Steinberg & Bowman, 2001). In agricultural extension, information fusion helps predict information-seeking behaviour. The development of internet users in the search for agricultural innovations needs to be studied further through the Internet of Behaviours.

Internet of Behaviours (IoB) is the aggregation and analysis of data based on user behaviour and preferences. IoB links the digital world and human behaviour, characteristics, goals, and interactions and provides the desired

adjustment or exchange between the quality of experience (QoE) and quality of service (QoS). IoB can observe human behaviour, adjust itself, and influence human decisions implicitly and explicitly (Moghaddam et al., 2022). The development of IoB initiated the research and development of personal digital twin and cognitive digital twin (De Kerckhove & Saracco, 2021; Javaid et al., 2021; Stary, 2021). Extension IoB activities can have implications for creating knowledge as a service software (De Kerckhove & Saracco, 2021) in agricultural extension.

The digital transformation of agriculture can be detected in the emergence of digital platforms. A digital platform is a platform that functions as a standardised digital interface by utilising digital technology to facilitate interactions between various parties (Chen et al., 2022). Appertain to digital platforms as a way to develop information technology infrastructure, and they include social media, mobile computing, and e-commerce platforms (Ahmed et al., 2022). Digital platforms sometimes utilise location data and previous usage information to predict behaviour. It thus goes beyond the traditional market mechanism of one-way interaction to make it more interactive. Digital platforms have three main characteristics: technology-mediated, enabling interaction between groups of users, and allowing groups of users to perform specified tasks (Ratten, 2022).

Based on online observations, digital platforms have penetrated the agricultural sector not only to change the old business model into a new one but also to overcome the problems of farmers that have not been facilitated. These problems include five aspects, namely access to information (related to good agricultural practices/ GAP, prices, pests and diseases, climate), access to financing and farm insurance, access to quality production inputs (such as seeds, fertilisers, and pesticides), market access, and access to mechanisation and precision farming technology services. The platform's presence consolidates the prerequisites for agricultural development as formulated by Mosher, that there are five basic conditions and facilitating conditions. The basic conditions include markets, technology, means of production, production stimulation, and smooth and continuous transportation. The facilitating conditions consist of education (extension), financing, "*gotong royong" (*cooperation), improvement and expansion of agricultural land, and agricultural development planning (Mosher, 1965).

Departing from these problems, digital platforms have emerged to change two major systems: the food system and the agricultural knowledge and innovation system. The transformation of the food system is marked by the emergence of digital marketplaces, traceable supply chain systems, fintech-based financing (peer-to-peer lending), and mechanisation and precision agriculture platforms. The transformation of agricultural knowledge and innovation systems is characterised by new forms of agricultural information services, new sources of knowledge, and new actors in agricultural innovation. This paper only provides the broad perspective design to enable future transformative processes. Meanwhile, further research and implementation are needed to explore Indonesia evolving digital extension.

Transformation of the Food System

The food system starts from upstream, on a farm, off-farm, and distribution chain. The upstream aspect is the stage before planting in the field, including plant and livestock breeding, biotechnology, seed/seedling production, and farmland history. The on-farm element is the second stage of the agricultural production chain carried out on the land. The off-farm element refers to the process chain of agricultural products developed off-farm, covering post-harvest, processing, and storage. The last stage is distribution, where food products are transported for consumption by the public.

The transformation of the food system due to the use of digital technology is characterised by the development of new business models, namely the digital marketplace model, the financial technology (fintech)-based peer-to-peer financing model with crowdfunding pattern, the supply chain traceable network model, and the precision farming model (Table 2). Each of these business models is starting to displace the old business model. The transformation seeks to provide an

end-to-end solution to agricultural problems by cutting agricultural products' supply and demand information gap and traceability.

Table 2. The changing landscape of food systems due to digitisation in the agriculture sector

No	Area of change	Description of changes
1	Market	Facilitating farmers and buyers (off-takers), and consumers break the long marketing chain.
2	Agricultural finance	Provision of financial services through the intermediation of creditors (lenders) with farmers (borrowers) peer-to-peer (P2P) lending with low-interest rates to increase agricultural productivity or profitability
3	Supply chain	Manage supply chain to increase profitability through certification and traceability
4	Farming practices and mechanisation services	Producing precision agricultural technology to increase productivity and yield quality based on Internet of Things (IoT) solutions, providing crop maintenance services (fertilisation & IPM) using drones

The first change is the commodity market. Up to a point, the market is defined as a physical meeting place between sellers and buyers. The length of the marketing chain from farmers to consumers is often the cause of the high disparity in prices received by farmers and prices that consumers must pay. Many actors are involved in the marketing chain of agricultural products. As an initial bridge, agribusiness terminals and sub-terminals (STA) facilitate transactions and the formation of commodity prices. With the emergence of digital platforms such as "Sayurbox" (https://www.sayurbox.com/), The farm-to-table concept allows consumers to buy fresh vegetables and fruits directly from farmers, and vice versa, allowing farmers to gain direct access to urban consumers.

Similarly, the platform "TaniHub" (https://foodsolutions.tanihub.com/) provides market solutions and farmer support applications that help simplify agricultural supply chains, increase farmer income, and stabilise product prices. These solutions address the challenges of not having up-to-date marketing or pricing information, as well as food supply and demand mismatches.

From a network theory perspective, the emergence of "hubs" is a consequence of the length of the agri-food chain, which consists of many actors who directly and/or indirectly operate along the journey of a product, from the initial stage of production to the final stage of use. Direct actors work directly along the supply chain, from upstream to downstream, from farmers, traders, retailers, and consumers. Indirect actors support the smooth running of the supply chain, such as providers of seeds, seedlings, fertilisers, agricultural machinery, and pesticides. The role of digital "hubs" is replacing the classic "hubs" that used to be played by agribusiness terminals and sub-terminals. The ability of digital "hubs" to aggregate small suppliers and create a single point of transaction for consumers brings about changes for more efficient business processes. In addition, digital technology makes commercial transactions easier, faster, and cheaper than ever before. The application of communication technology, which can share data, also supports fulfilling certain food needs (Sgroi & Marino, 2022).

The second change is in the aspect of agricultural financing. Hitherto, farmers have had difficulty accessing financing for farm capital. As a result, farmers have fallen into debt with intermediary traders and perpetuated the *Ijon* system. Bank credit has had difficulty penetrating because the risk of agricultural credit is relatively high, and the procedures are quite strict and cannot be fulfilled by farmers. The emergence of digital-based financing platforms offers credit access and facilitates debtors' role in crowdfunding. Such as the "TaniFund" and "Crowde" platforms (https://crowde.co/) attempt to create a service ecosystem for farmers by providing access to financing (sharia contract/ *murabahah*/buying and selling) and supply of production facilities or high-quality inputs such as seeds, fertilisers, and pesticides and access to markets at prices that are transparent to farmers. They work with off-takers to buy farmers' produce.

Digital agricultural finance platforms with crowdfunding patterns are emerging to enable professionals or financiers in urban areas to lend to farmers in rural areas. Besides being attractive due to higher returns and interest rates. There are also philanthropic reasons to help farmers succeed. The loan pattern is usually made at the start of the growing season and repaid a few months later. Short-cycle crops that generate strong returns are ideal such as chilli peppers, vegetables, and corn.

The third change is the supply chain system. Supply chain here is a term related to traceability in food production, as traceability is associated with recording the flow of food products. In the complexity of the supply chain, there is potential for deliberate fraud, i.e., by substituting ingredients or failing to meet quality or microbiological safety standards leading to food adulteration. Hitherto, the supply chain of food products has been exceedingly difficult to trace its origin. Digital platforms are emerging to address consumer concerns about quality and halal food products. Traceability, transparency, and integrity of food products have become global issues that agricultural producers need to attain. Transparency is the openness of where food is produced, processed, and transported. Integrity relates to food safety, authenticity, and quality of food products. Start-up companies in Indonesia widely use blockchain technology to build digital platforms that make food products easily traceable in the supply chain. Currently, consumers, especially for export products, want food products that are clear where they come from, are grown on land with clear certification, the production process (organic or not), and are monitored in real-time at every step along the value chain by different parties. Platforms such as "TaniSupply" or "Koltiva" (https://www.koltiva.com/) offer digital solutions that enable supply chain traceability.

The fourth change is precision agriculture and mechanisation. Precision agriculture is a digital-based smart farming technology to increase efficiency, effectiveness, productivity, and profitability. This technology is also a solution to anticipate the reduction of agricultural labour. Platforms such as "Habibi Garden" (www.habibigarden.com) offer integrated precision farming devices that promise efficiency in automatic irrigation systems, plant watering, and fertilisation decisions based on actual sensor data, plant growth can be monitored and controlled via Smartphone. Likewise, the E-fishery platform (https://efishery.com/en/) provides auto feeders for fish and shrimp. This allows farmers to schedule feedings using a smartphone. The device has an Internet of Things (IoT)-based sensor to know when the fish or shrimp are full, so it stops dispensing feed. The "Aria" platform (https://www.hiaria.id/) offers drone services at a low cost of service per hectare so that it can be affordable, considering that small farmers are unlikely to buy drones because they are expensive.

By providing integrated services, digital platforms are also working with pesticide companies to provide chemicals for agriculture. Here, a new profession emerged: drone pilots, individuals who can operate drones for agricultural activities (mapping, spraying fertilisers and pesticides, and observation). Advanced technologies such as sensors, artificial intelligence, and robotics are increasingly being promoted to increase food production and efficiency by minimising resource use (Rotz et al., 2019).

Transformation of Agricultural Knowledge and Innovation System

Agricultural knowledge and innovation systems (AKIS) are a network of research, education, extension, and support subsystems that aim to provide agricultural knowledge and innovations to farmers (Rijswijk et al., 2019). The observation shows that the development of digitalisation in the agricultural sector offers opportunities for inexperienced players to enter the AKIS, providing new services through digital technology facilities.

The areas of research, education, and extension, dominated by the public/government, have begun to adjust to the role of the private sector and farmers through social learning. The fluidity of knowledge providers' public and private roles in digital agriculture continues to move towards a more data-driven and open

innovation model. The development of social media technology, such as Facebook, YouTube, Instagram, TikTok, and WhatsApp, as well as a network of websites, has become a centre for the dissemination and interaction of new knowledge. Three areas are transforming, namely the area of information services, information sources, and innovation producers (Table 3).

The first change is in the realm of information services. Hitherto, agricultural information has been provided by the state through the organisation of agricultural counselling. The development of digital technology and public demand for speed and accuracy of services has led to new online service provisions business models such as the cultivation information website "Paktani Digital" (https://paktanidigital.com/) and the agricultural consultation application "Dokter Tania" (https://www.neurafarm.com/), the information service "integrated cropping calendar" (http://katam.info/), and "cyber extension" (http://cybex.pertanian.go.id/). Some of these platforms are one-way, but some are two-way, for example, the "Dokter Tania" consultation platform. This change has caused the spatial role of extension workers in some aspects, such as in consultation services, to be replaced by digital devices.

The second change is in the source of knowledge. In the Agricultural Knowledge and Information System (AKIS), knowledge is the domain of research, education, and extension institutions. Along with the development of digital technology, a concept called Crowdsourcing emerged. This idea was first coined in 2006 by J. Howe, editor of Wired magazine. Crowdsourcing is a new way of working and exchanging digitally mediated information (Nevo & Kotlarsky, 2020). Crowdsourcing allows farmers, farmer groups, and even agricultural companies to exchange ideas, information, experiences, and knowledge in a virtual community. This situation leads to connections among actors in the agricultural system. The result is increased social interaction between key actors and businesses mediated by digital technology online. Social interaction can be an essential element of social learning.

Social learning theory was introduced by Albert Bandura, who stated that the learning process could occur by observing, storing information (retention), and imitating (reproducing). Finally, farmers are motivated to imitate other farmers' behaviour, attitudes, and emotional reactions (Bandura & Walters, 1977). For this farmer, the virtual interaction space is not limited to spatial or temporal dimensions, allowing him to meet other farmers in areas he has never known. Virtual space provides both a place for introduction and a space for existence and collaboration. Hitherto, the social learning process has been facilitated by extension workers through physical group meetings. Meanwhile, nowadays, learning is mediated by digital

Table 3. The changing landscape of agricultural knowledge and innovation systems due to digitalisation

No	Areas of change	Description of changes	New business model
1	Information services	The emergence of digital platforms that provide information to farmers on prices, harvest planning, climate, and potential pest & disease attacks online and in real-time	Digital platforms: Apps and websites on agronomy, market information (prices), farm management tools
2	Source of knowledge	The development of a virtual community of farmers facilitated by social media platforms that enable knowledge exchange	Crowdsourcing
3	Innovation actors	The emergence of active participation of farmers as non-scientists in scientific research and being able to produce new products (seeds, fertilisers, pesticides, agricultural machinery) and disseminate them through the internet.	Citizen science

platforms such as WhatsApp groups (WAG), YouTube, Instagram (Suratini et al., 2021), and Facebook groups (Aulifia et al., 2016). The extension worker is no longer the authority on knowledge, as group members have the same position. Only members with strong social capital and social ties gain the trust of other members (Fielke et al., 2020).

The development of digital technology and crowdsourcing has led to a potentially bleak future for the extension profession. As Yuval Noah Harari predicted, as digital technology gets smarter, more and more professions will be eliminated from the job market. The idea of a profession for life becomes obsolete. Only the idea of lifelong learning will remain relevant (Harari, 2017). This means that if extension workers want to survive in the digital era, there is no other choice except to continue learning to adapt to the dynamics of the times and upgrade their capacity with new skills, new literacy, and a new mindset.

The third change occurs in the realm of innovation actors. The presence of digital technology has intensified citizen science. The term citizen science developed in the mid-1990s. Some researchers refer to it as amateur science or "popular science" or some say community science is used to designate non-professionals involved in science without the aim of producing new scientific knowledge (Ebitu et al., 2021). Citizen science gives rise to the active participation of non-scientists (laypeople/amateurs/volunteers) in scientific research activities, including data collection, interpretation, and analysis.

In recent years, there have been farmers who can breed and produce many superior varieties of rice, and there are also those who produce hybrid corn seeds on the island of Java (Antons et al., 2020). In addition, in the digital market, there are many sales of superior plant seeds from farmer research and farmer-produced agricultural machinery, pesticides, and fertilisers made by farmers. These changes need to be anticipated and responded to by public research institutions to determine the positioning of the research domain.

C. The Shifting Role of Agricultural Extension Workers

The digital agriculture ecosystem through the start-up model in Indonesia is experiencing rapid growth. According to the Compass List Indonesia Agritech Report 2020 (www.compasslist.com), the valuation of agricultural start-up companies is increasing exponentially. The digitalisation of agriculture in the private sector can be seen in agricultural companies and the birth of the digital agricultural start-up trend, as well as the Internet of Things system for cultivation, monitoring, harvesting, distribution, marketing, and extension. There are potential agri-start-ups, for instance, Chilibeli, Kedai Sayur, eFishery, TaniGroup, EdenFarm, Tunas Farm, Habibie Garden, 8villages, Aruna, Jala, MSMB, Eragano, iGrow, Limakilo, Biotech, Crowde, Inagi, Magalarva, and Warung Pintar. The agri-start-ups received funding from East Ventures, Salim Group, UMG Idealab Indonesia, Alpha JWC Ventures, Mandiri Capital Indonesia, Telkomsel, Sinar Mas Digital Ventures, Triputra Group, Hatch, 500 Startups, and Brinc (Tang & Putera, 2020).

In the case of community, like it or not, these digital agriculture actors are helping to advance many aspects of traditional agriculture and are making important contributions to the transformation. The agriculture sector needs from production, supply chain, market access, and transactions to financing solutions. Stakeholders in the agriculture sector must be aware of and ready for the changes brought about by digital transformation.

The Indonesian government tried to respond to the dynamics of technological development at the global level by launching an advanced, independent, and modern agriculture program. One of the breakthroughs made by publishing Presidential Regulation (Perpres No 35/2022) concerning Strengthening the Function of Agricultural Extension includes strengthening working relationships, institutions, human resource capacity, extension materials, utilisation of information and communication technology (ICT), and infrastructure facilities.

An extension is still expected to play a central role in guarding and mitigating social

changes in society to ensure that all farmers are kept at the pace of change. Not only Indonesia but from our literature review were founded that several countries are responding to digitalisation by expanding the role of extension workers, not just transferring technology as has been done so far. Some of the new roles of extension workers have emerged in the digital era (Table 4).

Based on Table 4, digitalisation has shifted some of the roles of agricultural extension workers to follow the needs of a digital society. The use of smartphones has changed the way extension workers practice and interact with farmers. The informant role, which used to be done physically and is limited, is now starting to be done through multichannel.

Table 4.
The shifting role of extension workers in the era of digital society

The role of extension agents	Descriptions	Source
Informant	Providing information, recommendations, and hybrid knowledge	(Rose et al., 2018)
Consultant	Serving consultation via video call	(Zournazis & Marlow, 2015)
Advisor	Accompanying farmers' learning in understanding the nature of digital data and its interpretation	(Klerkx, 2021).
Facilitator	Facilitating virtual meetings	(Klerkx, 2021).
Mediator	Intermediating farmers, advanced software, and farming system actors	(Bryant et al., 2010)
Promotor	Promoting and encouraging farmer involvement in the use of digital platforms	(Eastwood et al., 2019)
Content creator dan influencer	Creating content on social media, posting statuses for influence, interaction, engagement, and celebrity roles	(Klerkx, 2020)
Translator	Translating knowledge at the interface of technology and agricultural management	(Eastwood et al., 2019)
Sense maker	Helping farmers explore the meaning and added value of digital tools and technologies	(Eastwood et al., 2019)
Expert users	As an expert user of a particular digital platform	(Eastwood et al., 2019); (Hughes et al., 2021) (Kummer et al., 2021)
Data analyst	Analysing the database of farmers who access web-based extension sites and combining hybrid knowledge	(Rose et al., 2018); (Juniarti et al., 2022)
Artificial intelligence scientist	Internet of behaviour analysis represents actual conditions, analyses historical activities, and simulates future behaviour.	(Verdouw et al., 2021)
Decision maker based on socio-cyber-physical system	Decision-making and making rules (policy) based on a data-driven socio-cyber-physical system	(Rijswijk et al., 2021)
Software developer	Creating an agricultural extension recommendation system based on semantic web knowledge representation: ontology, web services, software agents; user personalisation; and knowledge-based system.	(Pryima et al., 2020); (Jahanshiri & Walker, 2015)
Gamify creator	Designing and creating an agricultural extension with a gamification approach that prioritises playfulness	(Klerkx, 2021)

According to Rose et al. (2018), the role of extension workers in delivering information has evolved into delivering hybrid knowledge, which farmers still need to obtain in cyberspace. The next differentiator is that extension workers also play a role in analysing big data. The abundance of data and information in cyberspace is a wonderful opportunity for extension workers to develop themselves and produce and process the information farmers need. This analytic capability characterises the knowledge produced by extension workers compared to that produced by farmers.

The same applies to the role of consultant. In the past, extension workers only provided face-to-face consultations, but now, in addition to face-to-face meetings, they also receive consultation services in the form of video calls (Zournazis & Marlow, 2015). In the Netherlands, in playing the role of advisor, extension workers assist farmers in understanding the nature of digital data and its interpretation.

Extension workers have started to reduce the intensity of face-to-face meetings and play the role of facilitator in virtual meetings. This pattern is considered more efficient and minimises costs. To influence farmers to be interested in new practices, extension workers also play the role of content creators by posting statuses or interesting things on social media, interacting, building engagement, and increasing the number of followers (Klerkx, 2021).

In New Zealand, Eastwood et al. (2019) reported that extension workers proactively lead farmer engagement with software in dairy farming. They act as promoters, promote, and encourage farmer involvement in using digital platforms. Then, they also act as a sense maker, helping farmers increase added value using digital devices and acting as a translator, translating digital language into the farmer's language.

Bryant et al. (2010) also reported the role of extension workers as mediators, bridging the interests of farmers with stakeholders. For example, in mediation with financing institutions, extension workers need to understand the procedures and risks of farm credit as well as fintech, e-wallet, and digital-based licensing procedures (Klerkx, 2022). This mediation is increasingly facilitated by digital technology.

IV. PRACTICAL IMPLICATIONS

The digital age, where people's actions are often mediated by technology, has forced agricultural extension systems in some countries to adjust. Technology does not create social order, but unconsciously, when people adopt a technology, the characteristics, system, and order will indirectly change. The adjustment is not just about organising extensions in cyberspace, such as developing Cybex websites, virtual meetings, and online technical guidance, but focusing on physical spaces that are increasingly digital. Thus, digitalisation supports clients and partners who are moving their operations in the context of digital agriculture. This has the consequence of the need to build new capacities, in this case, we borrow the term popularised by Professor Robert Duncan (1976), namely ambidexterity in terms of extension organisations and terms of human resources (agricultural extension workers).

For extension organisations, it is important to maintain the tension between the potential benefits of digital transformation and its potential negative impacts. Extension organisations must be able to explore and adapt to the evolving waves of transformation while exploiting the potential and resources available to ensure that no farmer is left behind. In contrast, the relationship between digital transformation and farmer welfare is not always linear. Technology always has ambivalence. It can improve the efficiency and effectiveness of processes, enhance collective action, and democratise knowledge. On the other hand, technology always leaves behind those who do not meet the standard requirements due to knowledge and skills gaps. In this case, small and marginalised farmers will find it difficult to follow the trends of Agriculture 4.0.

Extension organisations must be able to ensure that extension services reach all social layers. Exploration efforts are realised through the development of innovation in every line of extension (organisational innovation, service innovation, infrastructure innovation, human resource management innovation, and financing

innovation) to respond to and accompany the pace of digital transformation, which is quite disruptive and so fast. Without innovation, extension organisations will lose their relevance. Extension organisations will only become administrative agents of government projects.

From the exploitation aspect, it is necessary to improve the structure to be more agile to quickly adapt to potential opportunities and threats due to digitalisation. Current extension organisations have a large, highly hierarchical, bureaucratic structure, from the central to the village level, with work instructions that seem top-down. This situation makes it quite challenging to respond to environmental changes. Therefore, the organisation needs to think about how to make the bureaucratic structure simpler, its resources (both human, financial, and facilities) have high flexibility to be shifted and focused on action.

For individual agricultural extension workers, amid challenging situations full of uncertainty and complexity, it is necessary to foster three new things: a new mindset, new literacy, and new soft skills. First, the new mindset in question is a growth mindset (Dweck, 2006), namely the belief in being willing and able to change for the better. This must be pursued because most agricultural extension workers are generation X and baby boomers who resist change.

Secondly, new literacy or digital literacy is the ability of agricultural extension workers to operate digital technology to support agricultural development. Digital literacy must be fostered and cultivated to communicate with the digital society. Most of the current extension workers are digital immigrants, somewhat stuttering in technology, As a consequence, all extension agriculture actor endeavour to adapt the digitalisation.

Finally, there are new soft skills. Today's extension workers are mostly concerned with technical perspectives but do not think enough about dealing with farmers as multifaceted human beings. The new soft skills in question are the ability to collaborate, communicate, complex problem-solving that is not only technical but also non-technical, understand the digital ecosystem, and have creative and critical thinking. As mentioned above, digital transformation produces progressive and regressive tensions. Extension workers must be able to bridge the digital divide, especially farmers who are identified as powerless. Hence, they are not uprooted and separated from the new generation of farmers, commonly called millennials (Setiawan et al., 2020).

Synthesising relevant literature to the research objectives, the literature review, and online observation related to digital transformation and agricultural extension have several implications. The broad themes with a practical impact are Indonesian agriculture's digital technology transformation system. Additionally, few socio-agriculture scholars in Indonesia are involved in the global trend, particularly in Agriculture Knowledge and Innovation System, within Web 2.0 and Web 3.0. era. The majority of the implication of the research area applies to those development actors:

a) Government
   - Act as preliminary studies for policy instruments in the development agenda of digitalisation extension agriculture.
   - Support the research referee in implementing strategic planning in the Ministry of Agriculture, specifically agricultural extension based on information and communication technology and improve the quality of agricultural and human resources.

b) Research and Academic Institutions
   - Propose the priority research agenda in the agriculture advisory system based on web 2.0 and web 3.0 development.
   - Collaborate the research work among multi-discipline expertise in social science, computer science, and government research agency.
   - Identify the real phenomenon of transformation digitalisation in research work.
   - Observe the main problem and case in Indonesia's agriculture human resources.

c) Private Sector
   - Evaluate the mobile application, digital, and smart farming technology to know and fulfil the needs of end users.

- Enlarge the adoption innovation of digitalisation agriculture based on the user's database and the characteristic of the adopter.

V. LIMITATION

This study, nevertheless, has several limitations that can be corrected in further research. First, the websites we have observed are very limited; they may present ideal business services and do not reflect existing facts. This situation needs to be clarified. Second, this research focuses on one actor, namely agricultural extension workers. Digital transformation in the agricultural sector involves many actors: farmers, the private sector, and the government. Third, this study did not investigate virtual networks that farmers may have, such as social media, which can also be considered an increasingly important source of information.

Based on these limitations, the suggestion for further research is to explore the role of other actors involved in digital transformation in both the food and knowledge systems. How do other actors in the farmer network, such as extension workers, and traders, see the different network configurations? These issues may also be included in future studies. Second, the business models identified here need to be verified. These studies could use a more systematic empirical observation approach to how the user experience can be explored. For example, whether the involvement of farmers in using digital technology can increase productivity and farmer income. Third, it would be interesting to examine to what extent agricultural extension workers' digital literacy levels. Thus, the extension worker has a sufficient digital literacy level to adapt and adjust work patterns in the digital era? What are the challenges and obstacles experienced in carrying out extension work?

VI. CONCLUSION

Disruptive digital technology has transformed the agricultural sector through changes in the food system and agricultural innovation knowledge systems. This change has a duality; on the one hand, it benefits farmers by increasing production and supply chain efficiency. On the other hand, it creates a digital divide and commercialises and commodifies agricultural information data. Extension institutions and individual agricultural extension workers must overcome and sustain these two tensions through repositioning and changing roles. Extension workers act as content creators, influencers, gatekeepers, translators, sense makers, expert users, big data analysts, artificial intelligence and digital twin data scientists, decision-makers, software developers, and gamify creators.

Digitisation is not just equipping extension organisations with ICT tools; more than that, a new mindset, new literacy, and new soft skills must be built. Given that this study is exploratory and has a limited sample size of observations, the business models identified here need to be verified in future research. These studies could use a more systematic approach to empirical observation.

ACKNOWLEDGEMENT

The authors would like to thank the reviewer for the constructive feedback.

Appendix 1. Selected studies that answer research questions about digital transformation in the agricultural sector

No	Research question	Study
1	To what extent are digital technologies transforming the agricultural sector?	Aker & Ksoll, 2016
		Ayoub Shaikh et al., 2022
		Beza et al., 2018
		Boursianis et al., 2022
		De Clercq et al., 2018
		Emeana et al., 2020
		Ferrández-Pastor et al., 2022
		Hsu et al., 2020
		Khan et al., 2020
		Patel et al., 2022
		Rejeb et al., 2022
		Rose et al., 2018
		Subejo et al., 2019
		Tsouros et al., 2019
		Wolfert et al., 2017
		Zheng et al., 2022
		Zournazis & Marlow, 2015
2	What should agricultural extension agencies do to remain relevant in the digital era?	Bryant et al., 2010
		Eastwood et al., 2019
		Hughes et al., 2021
		Jahanshiri & Walker, 2015
		Juniarti et al., 2022
		Klerkx, 2020
		Klerkx, 2021.
		Kummer et al., 2021
		Pryima et al., 2020;
		Rijswijk et al., 2021
		Rose et al., 2018;
		Verdouw et al., 2021

Appendix 2. List of websites

No	Organisation	Focus	Data	Web address
1	PT Sayurbox	e-grocery platforms	Qualitative	https://www.sayurbox.com
2	PT Tanihub Indonesia	Bridging farmers with the market	Qualitative	https://foodsolutions.tanihub.com/
3	PT Crowde Membangun Bangsa	Agricultural funding ecosystem	Qualitative	https://crowde.co/
4	PT Koltiva	Tailoring IT solutions and agri-tech services	Qualitative	https://www.koltiva.com/
5	PT Habibi Digital Nusantara	Agricultural technology	Qualitative	www.habibigarden.com
6	PT Multidaya Teknologi Nusantara	Aquaculture ecosystem by offering an end-to-end platform that provides access to feed, financing, and market to fish and shrimp farmers	Qualitative	https://efishery.com/en/
7	Aria Agriculture Indonesia	Service of logistics and precision farming	Qualitative	https://www.hiaria.id/
8	Paktani digital	Connecting farmers with various other stakeholders in one digital application device.	Qualitative	https://paktanidigital.com/
9	PT Neura Cipta Nusantara	Precision agriculture	Qualitative	https://www.neurafarm.com/
10	Ministry of Agriculture	Spatial and tabular information about cropping calendar, season predictions, etc.	Qualitative	http://katam.info/
11	Ministry of Agriculture	The web-based information system provides an exchange of agricultural information through the cyber area	Qualitative	http://cybex.pertanian.go.id/
12	Compasslist	Information about innovative technology start-ups	Quantitative	www.compasslist.com
13	Hootsuite	Global digital reports such as internet user, social media user	Quantitative	https://www.hootsuite.com/resources/digital-trends

REFERENCES

Ahmed, A., Bhatti, S. H., Gölgeci, I., & Arslan, A. (2022). Digital platform capability and organisational agility of emerging market manufacturing SMEs: The mediating role of intellectual capital and the moderating role of environmental dynamism. *Technological Forecasting and Social Change*, *177*, 121513.

Aker, J. C., & Ksoll, C. (2016a). Can mobile phones improve agricultural outcomes? Evidence from a randomized experiment in Niger. *Food Policy*, *60*, 44–51. https://doi.org/https://doi.org/10.1016/j.foodpol.2015.03.006

Aker, J. C., & Ksoll, C. (2016b). Can mobile phones improve agricultural outcomes? Evidence from a randomized experiment in Niger. *Food Policy*, *60*, 44–51. https://doi.org/https://doi.org/10.1016/j.foodpol.2015.03.006

Anggraini, N., Sutarni, S., Fatih, C., Zaini, M., Analianasari, A., & Humaidi, E. (2020). Digital marketing produk pertanian di Desa Sukawaringin Kecamatan Bangunrejo Kabupaten Lampung Tengah [Digital marketing of agricultural products in Sukawaringin village, Bangunrejo, Lampung Tengah]. *Jurnal Pengabdian Nasional*, *1*(1).

Antons, C., Winarto, Y. T., & Prihandiani, A. F. (2020). Farmer-plant-breeders and the law on Java, Indonesia. *Critical Asian Studies*, *52*(4), 589–609.

Aulifia, A., Subejo, S., & Harsoyo, H. (2017). Persepsi anggota grup facebook "Komunitas Hidroponik Jogja (Hi-Jo)" terhadap pengembangan hidroponik [Perception group members of "Komunitas Hidroponik Jogja (Hi-Jo)" toward

hydroponic development]. *Agro Ekonomi*, *27*(2), 165. https://doi.org/10.22146/jae.22691

Ayoub Shaikh, T., Rasool, T., & Rasheed Lone, F. (2022). Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming. *Computers and Electronics in Agriculture*, *198*, 107119. https://doi.org/https://doi.org/10.1016/j.compag.2022.107119

Bandura, A., & Walters, R. H. (1977). *Social learning theory* (Vol. 1). Englewood cliffs Prentice Hall.

Benson, A., & Jafry, T. (2013). The state of agricultural extension: an overview and new caveats for the future. *The Journal of Agricultural Education and Extension*, *19*(4), 381–393. https://doi.org/10.1080/1389224X.2013.808502

Beza, E., Reidsma, P., Poortvliet, P. M., Belay, M. M., Bijen, B. S., & Kooistra, L. (2018). Exploring farmers' intentions to adopt mobile Short Message Service (SMS) for citizen science in agriculture. *Computers and Electronics in Agriculture*, *151*, 295–310. https://doi.org/https://doi.org/10.1016/j.compag.2018.06.015

Boursianis, A. D., Papadopoulou, M. S., Diamantoulakis, P., Liopa-Tsakalidi, A., Barouchas, P., Salahas, G., Karagiannidis, G., Wan, S., & Goudos, S. K. (2022). Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: a comprehensive review. *Internet of Things*, *18*, 100187.

BPS (Badan Pusat Statistik-Central Bureau of Statistics). (2022). *Berita resmi statistik: pertumbuhan ekonomi produk domestik bruto [official news statistics: gross domestic product economic growth]*.Apaka

Bryant, J. R., Ogle, G., Marshall, P. R., Glassey, C. B., Lancaster, J. A. S., Garcia, S. C., & Holmes, C. W. (2010). Description and evaluation of the Farmax Dairy Pro decision support model. *New Zealand Journal of Agricultural Research*, *53*(1), 13–28.

Chen, L., Tong, T. W., Tang, S., & Han, N. (2022). Governance and design of digital platforms: a review and future research directions on a meta-organisation. *Journal of Management,* 48(1). https://doi.org/10.1177/01492063211045023

Christensen, C. M. (2013). The innovator's dilemma: when new technologies cause great firms to fail. *Harvard Business Review Press*.

Cook, B. R., Satizábal, P., & Curnow, J. (2021). Humanising agricultural extension: A review. *World Development*, *140*, 105337. https://doi.org/https://doi.org/10.1016/j.worlddev.2020.105337

Daum, T., Adegbola, P. Y., Adegbola, C., Daudu, C., Issa, F., Kamau, G., Kergna, A. O., Mose, L., Ndirpaya, Y., Fatunbi, O., Zossou, R., Kirui, O., & Birner, R. (2022). Mechanization, digitalisation, and rural youth - Stakeholder perceptions on three mega-topics for agricultural transformation in four African countries. *Global Food Security*, *32*, 100616. https://doi.org/https://doi.org/10.1016/j.gfs.2022.100616

De Clercq, M., Vats, A., & Biel, A. (2018). Agriculture 4.0: The future of farming technology. *Proceedings of the World Government Summit, Dubai, UAE*, 11–13.

De Kerckhove, D., & Saracco, R. (2021). *The Future of digital twins*. Digital Reality, an IEEE Future Directions.

Di Vaio, A., Palladino, R., Hassan, R., & Escobar, O. (2020). Artificial intelligence and business models in the sustainable development goals perspective: A systematic literature review. *Journal of Business Research*, *121*, 283–314.

Dufva, T., & Dufva, M. (2019). Grasping the future of the digital society. *Futures*, *107*, 17–28. https://doi.org/https://doi.org/10.1016/j.futures.2018.11.001

Duncan, R. B. (1976). The ambidextrous organisation: Designing dual structures for innovation. *The Management of Organisation*, *1*(1), 167–188.

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.

Eastwood, C., Ayre, M., Nettle, R., & Rue, B. (2019). Making sense in the cloud: Farm advisory services in a smart farming future. *NJAS - Wageningen Journal of Life Sciences*, *90–91*(December 2018), 100298. https://doi.org/10.1016/j.njas.2019.04.004

Ebitu, L., Avery, H., Mourad, K. A., & Enyetu, J. (2021). Citizen science for sustainable agriculture – A systematic literature review. *Land Use Policy*, *103*, 105326. https://doi.org/https://doi.org/10.1016/j.landusepol.2021.105326

Elbeltagi, A., Kushwaha, N. L., Srivastava, A., & Zoof, A. T. (2022). Chapter 5 - Artificial intelligent-based water and soil management. In R. C. Poonia, V. Singh, & S. R. Nayak (Eds.), *Deep learning for sustainable agriculture* (pp. 129–142). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-323-85214-2.00008-2

Emeana, E. M., Trenchard, L., & Dehnen-Schmutz, K. (2020). The revolution of mobile phone-enabled services for agricultural development (m-Agri services) in Africa: The challenges

for sustainability. *Sustainability (Switzerland)*, *12*(2). https://doi.org/10.3390/su12020485

Ferrández-Pastor, F.-J., Mora-Pascual, J., & Díaz-Lajara, D. (2022). Agricultural traceability model based on IoT and blockchain: Application in industrial hemp production. *Journal of Industrial Information Integration*, *29*, 100381. https://doi.org/https://doi.org/10.1016/j.jii.2022.100381

Fielke, S., Taylor, B., & Jakku, E. (2020). Digitalisation of agricultural knowledge and advice networks: A state-of-the-art review. *Agricultural Systems*, *180*(August 2019), 102763. https://doi.org/10.1016/j.agsy.2019.102763

Fitriani, H. (2018). Kontribusi fintech dalam meningkatkan keuangan inklusif pada pertanian (Studi analisis melalui pendekatan keuangan syariah dengan situs *peer to peer lending* pada pertanian di Indonesia [Fintech's contribution in increasing inclusive finance on agriculture]. *El-Barka: Journal of Islamic Economics and Business*, *1*(1), 1–26.

Goh, L. (2022). How AgriTech is transforming traditional agriculture in emerging markets. *Breakthrough: The Promise of Frontier Technologies for Sustainable Development*, 125.

Harari, Y. N. (2017). Reboot for the AI revolution. *Nature*, *550*(7676), 324–327.

Hsu, T.-C., Yang, H., Chung, Y.-C., & Hsu, C.-H. (2020). A creative IoT agriculture platform for cloud fog computing. *Sustainable Computing: Informatics and Systems*, *28*, 100285. https://doi.org/https://doi.org/10.1016/j.suscom.2018.10.006

Hughes, D., Kehs, A., & McClosey, P. (2021). PlantVillage Nuru: smallholder farmers in Kenya see income boosts with their personal artificial intelligence assistant. In A. Elbehri & R. Chestnov (Eds.), *Artificial intelligence for agriculture* (pp. 34–40). FAO and ITU. https://doi.org/10.4060/cb7142en

Jahanshiri, E., & Walker, S. (2015). Agricultural knowledge-based systems at the age of semantic technologies. *International Journal of Knowledge Engineering-IACSIT*, *1*(1), 64–67. https://doi.org/10.7763/IJKE.2015.V1.11

Javaid, M., Haleem, A., Singh, R. P., Rab, S., & Suman, R. (2021). Internet of behaviours (IoB) and its role in customer services. *Sensors International*, *2*, 100122. https://doi.org/10.1016/J.SINTL.2021.100122

Juniarti, H. A., Sari, Y., Salim, I., & Wulandari, N. T. (2022). Analisis time series adopsi pengguna Desa Apps berdasarkan dataset dan prediksi adopter menggunakan model ARIMA [Time series analysis of Desa Apps User adoption based on dataset and adopter predictions using the ARIMA Model]. *Seminar Nasional Hasil Penelitian Sosial Ekonomi Pertanian*.

Khan, N. A., Qijie, G., Sertse, S. F., Nabi, M. N., & Khan, P. (2020). Farmers' use of mobile phone-based farm advisory services in Punjab, Pakistan. *Information Development*, *36*(3), 390–402.

Klerkx, L. (2020). Advisory services and transformation, plurality and disruption of agriculture and food systems: towards a new research agenda for agricultural education and extension studies. *Journal of Agricultural Education and Extension*, *26*(2), 131–140. https://doi.org/10.1080/1389224X.2020.1738046

Klerkx, L. (2021). Digital and virtual spaces as sites of extension and advisory services research: social media, gaming, and digitally integrated and augmented advice. *Journal of Agricultural Education and Extension*, *27*(3), 277–286. https://doi.org/10.1080/1389224X.2021.1934998

Klerkx, L. (2022). Advisory support and learning on non-technical aspects of farming: a key topic for extension and education research. *The Journal of Agricultural Education and Extension*, *28*(3), 251–253. https://doi.org/10.1080/1389224X.2022.2073112

Klerkx, L., & Rose, D. (2020). Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways? *Global Food Security*, *24*, 100347.

Kominfo (Kementerian Komunikasi dan Informatika-Ministry of Communication and Informatics). (2020). Status literasi digital indonesia 2020: Hasil survei di 34 provinsi [Indonesia's digital literacy status 2020: survey results in 34 provinces]. 90.

Kummer, B., Karan, R., & Rupavathara, S. (2021). Plantix - your crop doctor: every month around one million smallholder farmers use the Plantix app to grow healthier crops. In A. Elbehri & R. Chestnov (Eds.), *Artificial Intelligence for Agriculture* (pp. 19–28). FAO and ITU. https://doi.org/10.4060/cb7142en

Moghaddam, M. T., Muccini, H., Dugdale, J., & Kjaergaard, M. B. (2022). Designing internet of behaviors systems. *2022 IEEE 19th International Conference on Software Architecture (ICSA)*.

Mosher, A. T. (1965). Getting agriculture moving. Essentials for development and modernization. *Getting Agriculture Moving. Essentials for Development and Modernization.*

Nevo, D., & Kotlarsky, J. (2020). Crowdsourcing as a strategic IS sourcing phenomenon: Critical review and insights for future research. *The Journal of Strategic Information Systems*, *29*(4), 101593. https://doi.org/https://doi.org/10.1016/j.jsis.2020.101593

Nieto Cubero, J., Gbadegeshin, S. A., & Consolación, C. (2021). Commercialization of disruptive innovations: Literature review and proposal for a process framework. *International Journal of Innovation Studies*, *5*(3), 127–144. https://doi.org/https://doi.org/10.1016/j.ijis.2021.07.001

Patel, R., Migliavacca, M., & Oriani, M. E. (2022). Blockchain in banking and finance: A bibliometric review. *Research in International Business and Finance*, *62*, 101718. https://doi.org/https://doi.org/10.1016/j.ribaf.2022.101718

Peng, Y., & Tao, C. (2022). Can digital transformation promote enterprise performance? —From the perspective of public policy and innovation. *Journal of Innovation & Knowledge*, *7*(3), 100198. https://doi.org/https://doi.org/10.1016/j.jik.2022.100198

Pryima, S. M., Strokan, O. V., Rogushina, J. V., Gladun, A. Y., Lubko, D. V., & Malkina, V. M. (2020). Ontological analysis of outcomes of non-formal and informal learning for agro-advisory system AdvisOnt. *International Conference on Technologies and Innovation*, 3–17. https://bunker2.zlibcdn.com/dtoken/09307aa2729ea51c872931e1b3912be4/Technologies and Innovation 6th International Conference%2C CITI 2020%2C Guayaquil%2C Ecuador%2C November 30 – December 3%2C 2020%2C... %28Rafael Valencia-García%2C Gema Alcaraz-Marmol et

Rachmawati, R. R. (2021). Smart farming 4.0 untuk mewujudkan pertanian indonesia maju, mandiri, dan modern [Smart farming 4.0 to build advanced, independent, and modern Indonesian agriculture]. *Forum Penelitian Agro Ekonomi*, *38*(2), 137. https://doi.org/10.21082/fae.v38n2.2020.137-154

Ratten, V. (2022). Digital platforms and transformational entrepreneurship during the COVID-19 crisis. *International Journal of Information Management*, 102534. https://doi.org/https://doi.org/10.1016/j.ijinfomgt.2022.102534

Rejeb, A., Abdollahi, A., Rejeb, K., & Treiblmaier, H. (2022). Drones in agriculture: A review and bibliometric analysis. *Computers and Electronics in Agriculture*, *198*, 107017. https://doi.org/https://doi.org/10.1016/j.compag.2022.107017

Rijswijk, K., Klerkx, L., Bacco, M., Bartolini, F., Bulten, E., Debruyne, L., Dessein, J., Scotti, I., & Brunori, G. (2021). Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilisation. *Journal of Rural Studies*, *85*, 79–90. https://doi.org/10.1016/J.JRURSTUD.2021.05.003

Rijswijk, K., Klerkx, L., & Turner, J. A. (2019). Digitalisation in the New Zealand agricultural knowledge and innovation system: Initial understandings and emerging organisational responses to digital agriculture. *NJAS - Wageningen Journal of Life Sciences*, *90–91*(November), 100313. https://doi.org/10.1016/j.njas.2019.100313

Rose, D. C., Morris, C., Lobley, M., Winter, M., Sutherland, W. J., & Dicks, L. V. (2018). Exploring the spatialities of technological and user re-scripting: the case of decision support tools in UK agriculture. *Geoforum*, *89*, 11–18.

Rotz, S., Gravely, E., Mosby, I., Duncan, E., Finnis, E., Horgan, M., LeBlanc, J., Martin, R., Neufeld, H. T., Nixon, A., Pant, L., Shalla, V., & Fraser, E. (2019). Automated pastures and the digital divide: How agricultural technologies are shaping labour and rural communities. *Journal of Rural Studies*, *68*, 112–122. https://doi.org/https://doi.org/10.1016/j.jrurstud.2019.01.023

Salmons, J. E. (2021). *Doing qualitative research online* (2nd ed.). Sage.

Setiawan, I., Rasiska, S., & Supyandi, D. (2020). Korban "tuhan-tuhan" digital: garapan masa depan penyuluhan pembangunan 4.0 [digital victims "Gods": future form of development extension 4.0]. *Indonesian Journal of Socio Economics*, *1*(2), 115–128.

Sgroi, F., & Marino, G. (2022). Environmental and digital innovation in food: The role of digital food hubs in the creation of sustainable local agri-food systems. *Science of the Total Environment*, *810*, 152257. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.152257

Stary, C. (2021). Digital twin generation: Re-conceptualizing agent systems for behavior-centered cyber-physical system development. *Sensors*, *21*, 1096. https://doi.org/10.3390/s21041096

Steinberg, A., & Bowman, C. (2001). *Revisions to the JDL data fusion model*. https://doi.org/10.1201/9781420038545.ch2sum

Subejo, Untari, D., Wati, R., & Mewasdinta, G. (2019). Modernization of agriculture and use of information and communication technologies by farmers in coastal Yogyakarta. *Indonesia Journal of Geography*, *51*(3), 332–345. https://doi.org/http://dx.doi.org/10.22146/ijg.41706

Suratini, S., Muljono, P., & Wibowo, C. T. (2021). Pemanfaatan media sosial untuk mendukung kegiatan penyuluhan pertanian di kKabupaten Minahasa Provinsi Sulawesi Utara [Utilization of social media to support agricultural extension activities in Minahasa Regency, North Sulawesi Province]. *Jurnal Penyuluhan*, *17*(1), 12–24.

Tang, B., & Putera, P. A. W. (2020). *Indonesia Agritech Report 2020, a CompassList Research Publication*. https://www.compasslist.com/CompassList_Indonesia_Agritech_Report_2020.pdf

Tsouros, D. C., Bibi, S., & Sarigiannidis, P. G. (2019). A review on UAV-based applications for precision agriculture. *Information*, *10*(11), 349.

Verdouw, C., Tekinerdogan, B., Beulens, A., & Wolfert, S. (2021). Digital twins in smart farming. *Agricultural Systems*, *189*, 103046. https://doi.org/https://doi.org/10.1016/j.agsy.2020.103046

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big data in smart farming–a review. *Agricultural Systems*, *153*, 69–80.

Zheng, Y., Zhu, T., & Jia, W. (2022). Does Internet use promote the adoption of agricultural technology? Evidence from 1 449 farm households in 14 Chinese provinces. *Journal of Integrative Agriculture*, *21*(1), 282–292. https://doi.org/https://doi.org/10.1016/S2095-3119(21)63750-4

Zournazis, H. E., & Marlow, A. H. (2015). The use of video conferencing to develop a community of practice for preceptors located in rural and non traditional placement settings: An evaluation study. *Nurse Education in Practice*, *15*(2), 119–125.