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# Navigating the Path to Equitable and Sustainable Digital Agriculture among Small Farmers in Malaysia: A Comprehensive Review

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**Abstract:** The agriculture sector has transformed with the advent of digital agriculture, smart farming and Agriculture 4.0, yet the social science aspects remain underexplored. This article aims to address this gap by conducting a comprehensive review of 17 studies that focus on the social, economic, and institutional dimensions of precision farming, digital agriculture, smart farming and Agriculture 4.0. The objectives are to explore the dynamics between digital agriculture and farm diversity and to identify emerging concerns related to economics, business, institutions, and ethics. Methodologically, the review synthesizes existing literature on socio-cyber-physical-ecological systems, digital agriculture policy processes, the transition from analog to digital agriculture and the global landscape of digital agriculture development. It adopts a multidisciplinary and transdisciplinary approach to provide a holistic understanding of the topic. The outcomes reveal significant implications for policymakers, farmers, and stakeholders in the agriculture sector. Key findings highlight the necessity of addressing social and economic impacts, such as data privacy, security, and accessibility, and the effects of automation on rural employment and community structures. The review emphasizes the importance of developing institutional and governance frameworks to support digital agriculture practices and tailoring policies to promote sustainable and equitable use of digital technologies. It explores how infrastructure, connectivity and local capacities influence the adoption of digital agriculture technologies. The review advocates for further research on the intersection of digital agriculture with broader societal trends, such as climate change, urbanization, and food system transformations, to develop strategies for sustainable and resilient food systems.

**Keywords**: *Digital agriculture; smart farming; agriculture innovation; precision farming; agriculture 4.0; socio-cyber-physical-ecological systems; digital agricultural policy*

## 1. Introduction

Digital agriculture, also known as smart farming or Agriculture 4.0, has been described as the future of agriculture. With the Fourth Industrial Revolution driving innovation across all sectors, it is no surprise that the agricultural industry is also transforming. Digital agriculture incorporates innovative technologies such as precision agriculture, the Internet of Things (IoT), artificial intelligence (AI), and big data analytics to improve crop yields, optimize resource use, and reduce environmental impact. The potential benefits of digital agriculture are vast, including increased food security, economic growth, and sustainability. As such, it has attracted significant attention from researchers, policymakers, and industry leaders (McGrath et al., 2023). In this paper, we present a synthesis of the current state of research in digital agriculture and explore future directions for this rapidly evolving field.

The adoption of digital innovations is increasingly pervasive across various sectors of society. Digitalization encompasses a range of technologies including big data, the Internet of Things (IoT), augmented reality, robotics, sensors, 3D printing, system integration, ubiquitous connectivity, artificial intelligence (AI), machine learning, digital twins, and blockchain (Dayioğlu & Turker, 2021; Chen et al., 2020). In the realms of agriculture and related food, fiber, and bioenergy supply chains and systems, digitalization is anticipated to profoundly alter daily routines and production processes (Smith, 2018). Early indicators of this transformation are already apparent (Di Silvestre et al., 2018; Rotz et al., 2019a). The integration of digital technologies into agricultural production systems, value chains, and food systems has given rise to several concepts, such as Smart Farming (Blok and Gremmen, 2018), Precision Agriculture (Wolf and Buttel, 1996; Eastwood et al., 2017b), Decision Agriculture (Leonard et al., 2017), Digital Agriculture (Shepherd et al., 2018), Agriculture 4.0 (Rose and Chilvers, 2018), and Agriculture Numérique (French) (Numerical Agriculture Bellon Maurel and Huyghe,

2016).

Digitalization in agriculture entails the application of advanced technologies such as sensors, machines, drones, and satellites to monitor animals, soil, water, plants, and human activity both on the farm and throughout the wider value chain and food system (Basso and Antle, 2020). This involves the use of diverse data types, including but not limited to, geolocation, weather conditions, behavioral patterns, phytosanitary statuses, consumption rates, energy usage, pricing, and economic indicators. By leveraging continuous monitoring and extensive big data analytics, this information is processed and interpreted to enable more informed decision-making (Eastwood et al., 2017a). Agricultural digitalization is anticipated to drive the technological enhancement of food systems, value chains, and production methodologies. Furthermore, it is proposed that digitalization can address social issues in farming, such as improving food traceability (Wolfert et al., 2017), enhancing animal welfare standards, particularly in livestock farming, and mitigating the environmental impacts of agricultural practices (Rose and Chilvers, 2018; Busse et al., 2015). The pervasive nature of data in digital agriculture is also expected to facilitate knowledge sharing and learning, as well as enhance the monitoring of crises and controversies within agricultural sectors (Yeates, 2017).

There are significant expectations regarding the ongoing spread and transformative impact of digital technologies, given their extensive adoption in industries such as cropping and viticulture through precision farming over the past two decades (Eastwood et al., 2017a). Despite this, current scientific literature on digital agriculture has primarily focused on the technical aspects of these technologies to enhance agricultural practices and productivity (Rutten et al., 2013; Dick et al., 2019), as well as improving post-farmgate processes like postharvest quality monitoring within logistics and real-time traceability (Rodrigues et al., 2019). Numerous review articles have emerged discussing topics such as precision agriculture, big data analytics, drones, robotics, artificial intelligence, IoT, 3D printing, and the transformative potential these digital technologies hold for agricultural production systems, value chains, and food systems (Mogili and Deepak, 2018; Patrcio and Rieder, 2018; Zhao et al., 2019).

This article offers an overview and thematic organization of social science literature on digital agriculture, showcasing the wide array of perspectives and their complementary nature in understanding digitalization. The article also aims to highlight the potential benefits and drawbacks of digitalization for the sustainable growth of rural regions, food systems, and agriculture. Moreover, it emphasizes the need to foster the reflexivity of those involved in the advancement of digital agriculture are a spectrum of stakeholders, encompassing farmers, researchers, consultants, decision-makers, and academics.

The study aims to address three primary inquiries, namely:

- What are the primary thematic clusters that emerge in social science literature concerning the digitalization of agriculture, as identified through an exploratory review?
- How do the key insights from the reviewed articles connect to these thematic clusters, and do they open up new directions for future research?
- What gaps and opportunities exist for future social science research in the realm of digital agriculture?

To tackle the primary inquiries outlined in this review, the article initially offers a comprehensive outline of the principal thematic clusters evident in social science literature concerning digitalization within agriculture. These clusters encompass precision agriculture and smart farming, digital innovations within food systems, the influence of social and cultural factors on digital agriculture, and the policy and governance implications associated with agricultural digitalization.

Subsequently, the article delves into an analysis of the primary insights extracted from the literature, examining their correlation with these thematic clusters or their potential to instigate fresh lines of inquiry. For instance, the article discusses how precision agriculture can contribute to sustainable food production and rural development, and how social and cultural factors can influence the adoption and impact of digital innovations in agriculture. The article also examines the governance and policy implications of digital agriculture, including issues related to data ownership, privacy, and regulation.

Finally, the article identifies gaps and opportunities for future social science research in the field of digital

agriculture. These include the need for more interdisciplinary research that integrates social, economic, and environmental perspectives, as well as more studies that focus on the experiences and perceptions of farmers and other stakeholders involved in the development and implementation of digital innovations in agriculture. This review article demonstrates the importance of social science perspectives for understanding the potential of digitalization in agriculture and its broader implications for sustainable rural development and food systems. By highlighting the diversity of viewpoints and identifying gaps and opportunities for future research, this article aims to contribute to a more comprehensive and reflexive understanding of digital agriculture and its transformative potential.

## 2. Literature Review

**Digitalization in agriculture's main social science themes:** In this section, we take a closer look at the main social science themes that emerge from the literature on digitalization in agriculture. For our analysis, we utilized the Scopus database to search for articles pertaining to "digital agriculture" and "smart farming" across various journals. We specifically concentrated on journals including the Journal of Rural Studies, the Journal of Peasant Studies, Sociologia Ruralis, Agricultural Systems, NJAS-Wageningen Journal of Life Sciences, Land Use Policy, and the Journal of Agricultural Education and Extension. Additionally, we utilized snowball sampling methods, which involved citing relevant publications that were identified and filtering articles that referenced initial studies on digitalization.

**Table 1: Survey of Thematic Clusters from Social Science Perspectives**

| Thematic cluster | The varying number of reviewed articles with some articles appearing in multiple clusters | The key social science disciplines engaged in this thematic cluster | Theoretical and methodological perspectives employed in this thematic cluster include: | Relevant Articles to the Thematic Cluster |
|---|---|---|---|---|
| Integration, utilization, and adaptation of digital technologies on agricultural farms. | 16 | Economics<br>Sociology<br>Innovation Studies<br>Science and Technology Studies | Adoption and diffusion theory<br>Behavioural psychology<br>Practice theory<br>Assemblage theory<br>Cost and benefit modelling<br>Econometrics<br>Evolutionary economics<br>Innovation systems | Janc et al., 2019<br>Knierim et al, 2019 |
| The impact of digitalization on farmer identity, skills, and agricultural work | 16 | Sociology<br>Social Geography<br>Anthropology | Political economy<br>Practice and identity theory<br>Studies of discourse, power, politics, and social transformation (e.g. Foucault, Bourdieu, Durkheim, Giddens)<br>Actor-network theory<br>Assemblage theory | Vik et al., 2019<br>Lioutas et al., 2019 |

| | | | | |
|---|---|---|---|---|
| | | | Gender studies<br>Ethnography<br>Farming styles<br>Cultural scripts | |
| The intricate dynamics surrounding power dynamics, ownership structures, privacy concerns, and ethical considerations. | 28 | Sociology and political science<br>Philosophy and ethics<br>Science<br>Technology Studies | Political economy<br>Institutional economics Animal ethics<br>Human ethics<br>Responsible Research Innovation<br>Activity theory | Van der Burg et al., 2019<br>Lioutas et al., 2019<br>Jakku et al., 2019<br>Bronson, 2019<br>Wiseman et al., 2019<br>Regan, 2019 |
| Digitalization's impact on agricultural knowledge and innovation systems | 27 | Innovation studies<br>Science and Technology studies<br>Communication Science<br>Economics | Knowledge and Innovation systems<br>Social media analysis<br>Learning theories<br>Evolutionary economics<br>Socio-technical transitions | Fielke et al., 2019<br>Ingram and Gaskell, 2019<br>Relf-Eckstein et al., 2019<br>Rijswijk et al., 2019<br>Eastwood et al., 2019<br>Ayre et al., 2019 |
| Economic and Managerial Dynamics of Digitalized Agricultural Production Systems and Value Chains | 21 | Economics<br>Management Science<br>Sociology | Value chain theories<br>Business Model<br>Risk analysis<br>Institutional economics<br>Service economics | Phillips et al., 2019<br>Rojo Gimeno et al., 2019 |

Following an examination of over 100 social science publications on digital agriculture, we identified five key subject clusters of social scientific literature on the topic. These clusters emerge from a wide range of social science disciplines, including sociology, geography, economics, communication studies, management studies, innovation studies, and humanities fields such as philosophy and ethics. It's essential to emphasize that these themes encourage interdisciplinary dialogues rather than solely contrasting disciplinary viewpoints on digitalization.

Table 1 presents a summary of the thematic clusters, social science disciplines, theoretical perspectives, methodological approaches, and relevant articles associated with each cluster. It is worth mentioning that while this article focuses on digitalization in agriculture, there are also broader discussions on how digitization impacts rural communities that are covered in other works (see, for example, Salemink et al., 2017). Overall, this analysis offers a valuable starting point for understanding the key themes and perspectives that inform social science research on digital agriculture.

**Farming Using Digital Technology:** The first thematic cluster of social science literature on digital agriculture focuses on the use of digital technology in farming. This cluster has a well-established line of inquiry into precision technology adoption, which includes economic and behavioral elements. The research in this area primarily focuses on individual adoption factors, as well as extension and communication interventions to encourage adoption (Barnes et al., 2019). Additionally, the application of advanced farming or intelligent

farming on farms and how it changes agricultural activities has been explored using terms like "tinkering" and "assemblages" (Lowenberg-DeBoer and Erickson, 2019). Post-adoption adaptation has also been studied (Higgins et al., 2017), and this cluster draws from a range of approaches, including modeling approaches of the costs and benefits of precision farming (Schimmelpfennig and Ebel, 2016), quantitative or econometric approaches testing the effects of different variables on adoption (such as farm size and specialization, farmers' ages, education, etc.; see Higgins et al., 2017), and more qualitative work highlighting the situation of both adopters and non-adopters and accounting for less measurable factors (Annosi et al., 2019). Furthermore, some studies have examined the larger networks and innovation systems that form technology and where co-evolution between the technology and larger social and institutional settings takes place beyond the level of the farm (Eastwood et al., 2017).

**Digitalization and its Impact on Farmer Identity, Skillsets, and Work Practices**

This thematic cluster highlights how digitalization affects farmer identity, skills, and work practices. One line of research addresses the practical challenges of human-robot interaction in farming, focusing on ergonomics, health, and safety through systems design (Vasconez et al., 2019). Rural sociology employs a range of theoretical perspectives, including those from Foucault, Latour, Durkheim, Giddens, political economy, and assemblage theory, to explore the sociocultural implications of digitalization. Researchers argue that digitalization is reshaping what it means to be a farmer and shifting agricultural culture from experience-driven to data-driven (Van Hulst et al., 2020). It is also altering farmers' work routines and practices, increasingly dictated by "algorithmic logic" (Miles, 2019). This raises questions about the compatibility of digitalization with practices like agroecology, which necessitate direct farming rather than digitally mediated approaches (Plumecocq et al., 2018). This cluster illuminates how digitalization not only changes the way farmers work but also transforms their identity and the broader culture of agriculture.

**Digitalization of Agricultural Production Processes and Value Networks: Power, Ownership, Privacy, and Ethics**

Critical social science approaches to digitalization in agriculture focus on political economics and political ecologies. This cluster addresses issues such as power dynamics, data ownership, inclusion and exclusion, privacy, and ethics. Through political economics and science and technology studies, researchers examine the impact of digitalization on corporate structures, production systems, supply networks, and their associated institutions, rules, and power balances. This literature seeks to understand how these changes affect various stakeholders and how they respond or resist. It also explores ethical concerns like privacy and data ownership arising from digital technology use (Bronson and Knezevic, 2019; Miles, 2019).

These critical approaches raise concerns about the absence of governmental solutions to address the digital divides and power imbalances resulting from rapid technological advances, which could impede the integration of social concerns (Carolan, 2019; Bronson and Knezevic, 2019). Additionally, researchers highlight threats like cyberattacks that can destabilize digitalized food systems and precision agriculture systems (Trendov et al., 2019). Digital agriculture also impacts animals, for example, through robotic milking systems and technology replacing animal husbandry activities, significantly affecting dairy farming (Bear and Holloway, 2019; Schewe and Stuart, 2015). This has led to ethical debates on animal autonomy and the human-animal connections on farms.

Critical social science approaches to digitalization in agriculture provide a comprehensive framework to understand the complex interactions between digital technologies, society, and the environment. By examining power dynamics, data ownership, inclusion and exclusion, privacy, and ethics, researchers can identify the challenges and opportunities of digitalization in agriculture and develop strategies to mitigate its negative impacts while maximizing its benefits.

**Agricultural Innovation and Digitalization**

Digitalization is revolutionizing agricultural knowledge and innovation systems (AKIS). This thematic cluster explores AKIS from macro, meso, and micro perspectives. Innovation systems studies examine how innovation support mechanisms promote digitalization and transform themselves, for example, by adopting big data analysis (Rotz et al., 2019a). AKIS for digital agriculture is formed by high-tech enterprises, such as drone or satellite makers, service sectors, and multinationals that provide agricultural equipment like self-driving

tractors and automated milking machines (Van Hulst et al., 2020). This literature also investigates how transdisciplinary research might aid integrative solutions that consider technical, moral, social, economic, and commercial concerns (Shepherd et al., 2018).

Some studies examine how learning networks are developed to support innovation in digital agriculture from a meso viewpoint, based on theories of learning and communication. For example, several research studies have focused on how social media and digital platforms facilitate peer learning and local and international knowledge exchange (Kelly et al., 2017). Other research has examined how user-generated data influences policy choices and real-time decision-making, using social media analysis and citizen science methodologies (Cieslik et al., 2018). Further research examines the ongoing processes of how digital decision support systems are becoming more user centered (Leeuwis et al., 2018) and how advisors engage with farmers to link "digital knowledge systems" to "farmer knowledge systems" at the micro-level of knowledge systems (Rose et al., 2018; Lindblom et al., 2017).

**Digitalizing Agricultural Production and Value Networks: Management and Economic Perspectives**
This thematic cluster investigates the economic and managerial dimensions of digitalized agricultural production and value chains. Although substantial research exists on the broader economic and business aspects of digital technology and big data (Jouanjean, 2019), agriculture-specific studies remain relatively limited. Some studies have analyzed the costs and benefits of unmanned aircraft systems and other precision agricultural technologies (Hunt and Daughtry, 2018; Bronson and Knezevic, 2019), while others have explored investment considerations related to the adoption of precision technologies (Rutten et al., 2018). Research on the impact of precision farming on agricultural production has revealed potential disparities between countries (Miles, 2019). Furthermore, digitalized supply chains and big data services and analysis could have economic impacts extending beyond the farm (Smith, 2018).

In developing countries, market information systems have been investigated for their potential to reduce information asymmetries and improve market access (Agyekumhene et al., 2018). In the context of industrialized agriculture, discussions are ongoing about creating information systems to help farmers manage risks, whether climatic or financial (Fraisse et al., 2006). Business models for these services often include innovative insurance schemes tailored for farmers, such as index-based frameworks for climate insurance. However, research on the economic models of digital agriculture remains limited, and existing typologies frequently focus on new direct marketing strategies for farmers and consumers (Bronson, 2018).

Studies on power dynamics in digital agriculture have highlighted the potential drawbacks of vertically integrated systems and innovative business models from political, institutional economic, or value chain perspectives. Under these arrangements, large international firms offer comprehensive "digital package deals" to farmers (Bronson and Knezevic, 2016). As Wolf and Buttel (1996) predicted in the 1990s, these package deals tend to maintain power dynamics favoring agricultural models that rely heavily on chemical inputs. However, innovative business strategies could open new opportunities for transforming value chains. For example, the concept of the "circular economy" seeks ways to convert traditional waste streams into value-added products through on-farm processing (Carolan, 2018b). Additionally, start-ups are introducing platform technologies designed to reduce food waste at the consumer end of urban food systems (Galliano et al., 2017).

## 3. Contributions of the Articles

**Thematic Cluster: Adoption, Usage, and Adaptation of Digital Technologies**
Despite the numerous promises and case studies highlighting the growth of digital technology in agriculture, farmers remain hesitant to adopt these technologies. Two quantitative studies address this knowledge gap. Janc et al. (2019) explore internet usage among Polish farmers, highlighting some foundational requirements for digitalizing their processes. The study reveals a significant "digital gap" in internet access and usage, noting that the social fabric of Polish agriculture may be weakened as digital technology is seen as individualistic and potentially eroding traditional attitudes and institutions associated with shared knowledge acquisition based on family and neighborly ties.

**Thematic Cluster: Effects of Digitization on Farmer Identity, Skills, and Agricultural Labor**
This paper discusses two findings related to the impact of digitization on farmer identity, skills, and agricultural labor. Vik et al. (2019) investigate how automatic milking systems (AMS) in Norwegian dairy farming influence farm labor, farmer skills, and identity. Their study reveals the broader networks and processes shaping this technology and its social and political implications, which affect the performance of robots. They find that milking robots are purchased for quality of life improvements, such as a more flexible workweek, reduced physical effort, and alignment with future dairy farming standards. Policy changes have responded to these fundamental shifts rather than driving them.

**Thematic Cluster: Digitalizing Agricultural Production Systems and Value Chains: Power, Ownership, Privacy, and Ethics**
This article synthesizes research from various industries and supply chains to examine how digital technologies impact power dynamics, data ownership, and privacy issues. Five studies from Europe, North America, and Australia address these themes. Continuing a discussion initiated by Wolf and Buttel (1996) and revisited in recent years, these papers question whether the digitization of agriculture disrupts supply networks or reinforces the dominance of major players. Van der Burg et al. (2019) review the ethics literature in smart agriculture, identifying three key themes: data ownership and accessibility, power distribution, and societal implications. Despite growing academic, policy, and practical interest in the ethics of smart farming and digital agriculture, the authors note a lack of explicit articulation in research and social dialogues regarding the role and significance of digital farms.

**Thematic Cluster: Economics and Management of Digitalized Agricultural Production Systems and Value Chains**
This cluster focuses on two articles related to the economics and management of digitalized agricultural production systems and value chains. Rojo Gimeno et al. (2019) assess the importance of information for precision cattle husbandry, similar to the work of Ayre and Eastwood. They pose a critical question: can more accurate information from digital technologies enhance economic value? The paper proposes a framework for data collection, decision-making, and action that impacts several criteria, illustrating the factors influencing these stages.

## 4. Future Outlook: Emerging and New Research Themes and Questions

This section outlines potential research themes and questions for future social science investigations concerning the economic and ethical aspects of digitization in agriculture. The suggested research themes emerge from the five thematic clusters detailed in Section 2, highlighting their multiple interconnections. Additionally, we propose four new thematic domains to expand the scope of future research endeavors.
Developing Theme Clusters via Study

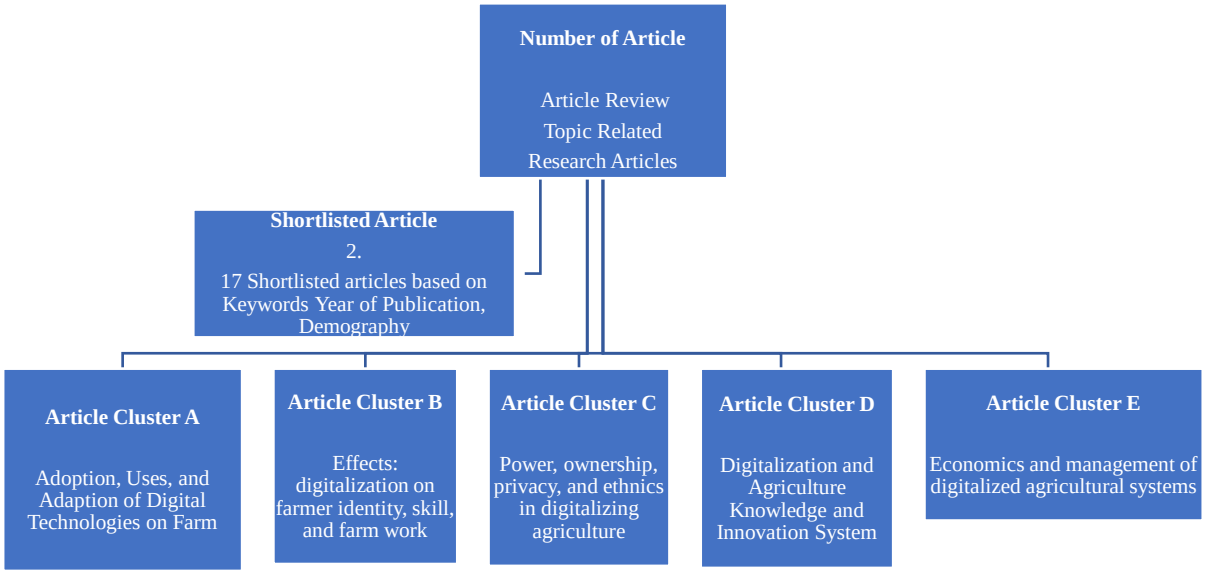
The development of theme clusters is crucial as it allows researchers to identify key themes and topics explored in previous studies. This process provides a deeper understanding of the existing literature and helps identify research gaps that need to be addressed in future studies. This section will describe theme clusters via study and consider them in the context of digital agriculture research.

**Emerging Issues in Digital Technology Uptake, Usage, and Adaptation**
Research on the adoption, usage, and adaptation of digital technologies in agriculture, such as that by Knierim et al. (2019), suggests examining the role of farm types, farming practices, and producer characteristics in digital agricultural technology acceptance and adaptation. Future investigations might consider the following questions:

- Who benefits and who loses with the implementation of digital agricultural technology, and why? How do agricultural actors share advantages and risks?
- How does farm size influence digital agriculture adoption? Does digitization lead to increased farm size and capital concentration, facilitating more standardization and remote monitoring of agricultural practices? How do these factors relate to value chains and food systems?
- How can digital agriculture promote agricultural innovation through feedback, learning, and experimentation? After the widespread implementation of digital agricultural tools, how will farmers

develop and apply experiential knowledge?
- How can humans and animals coevolve with sensors and drones in digital agriculture?

**Figure 1: Themes adopted for this article**




**Farmer Identity, Skills, and Job Concerns**

Studies by Vik et al. (2019) and Lioutas et al. (2019) address various empirical issues regarding the implications of digitalization on farmer identity, skills, and agricultural labor. Further research is needed to understand how digitalization affects farming practices, social media use, and gender relations. Potential research questions include:

- What is the impact of Smart Farming, Digital Agriculture, and Agriculture 4.0 on implicit dichotomies such as "Smart Farming" versus "Dumb Farming" and "Farmer 4.0" versus "Farmer 3.0"?
- How do personas like "YouTubers," "cyborg farmers," "geek farmers," "joystick farmers," and "drone farmers" emerge from the convergence of digital and analog farmer worlds?
- What is the influence of social media on farmer identity and job-related concerns, and how does it impact farming communities and their leaders?
- In what ways do digital technologies impact agricultural work, including their effects on plants and animals? How can plants and animals become "digital agents" and influence human activities?
- How does digitization affect farmer skills, quality, and well-being? What is the process of deskilling/reskilling involved? How do farmers balance digital information with intuition and experience? Can farmers trust machine-generated information?
- How does digitization affect agricultural succession, future investments, and farmer choices?
- How does digitalization impact male and female farmers differently? How does it influence agricultural and rural gender relations?

**Power, Ownership, Privacy, and Ethics in Agricultural Production Systems and Value Networks**

The findings on power, ownership, privacy, and ethics in agricultural production systems and value chains underscore the need for reflection on these issues. Van der Burg et al. (2019) suggest four key study topics based on their review:

- Investigating the societal role of farms, broadening stakeholders' imaginations about smart farming's possible goals, and enhancing their reflection on their relative value.
- Reflecting on the epistemological choices made in data selection, the meaningful connections created between them, and their interpretation (echoing Bronson, 2019).
- Understanding the preconditions for trust among stakeholders involved in smart farming and their

relationships within a data-sharing network (as raised by Jakku et al., 2019; Wiseman et al., 2019).

- How do stakeholders' values differ in the design of digital agriculture (Wolfert et al., 2023)? While digital agriculture should serve public interests, what are the trade-offs with private interests? How are these discussions contextualized within new institutional arrangements like Public-Private Partnerships (PPP) and their implications for social concerns, empowerment, and the privatization of public assets?
- How does digital surveillance affect governance (Van der Burg et al., 2019)?
- How do digital technologies foster resistance? As suggested by Carolan (2018c), how do initiatives like Right to Repair, Farm Hack, and Data Cooperatives respond to Big Data and the Internet of Things? How do grassroots and corporate organizational configurations influence value-chain decision-making?
- How does policy or governance affect trust among actors? How do digital technologies impact power dynamics and information asymmetry (Van der Burg et al., 2019)?
- How might responsible innovation help actors manage the "unknowns" and "unseen" aspects of digital agriculture? Who perceives the risks and uncertainties? How do Responsible Research and Innovation (RRI) processes account for these factors, particularly with "digital game changers" (Brunori et al., 2019)?

**Emerging Issues in Digital Knowledge and Innovation Systems**

In exploring emerging issues within digital knowledge and innovation systems, Rijswijk et al. (2019) propose new terminologies such as "digiware," "Digital Agricultural Innovation Systems," and "digit grasping." These concepts warrant further exploration. Future research in Agricultural Knowledge and Innovation Systems (AKIS) could address:

As "agriculture 4.0" advances with technologies like nanotechnology, gene editing, "omics," and synthetic foods, how do traditional and non-traditional players in the agri-food sector collaborate? How does this collaboration impact cross-sectoral innovation and diverse knowledge? What role do IT companies play in local and global innovation dynamics?

- How does digitalization support agroecology, sustainable intensification, circular agriculture, and vertical farming, and what are its effects on agricultural R&D's experimentation and evaluation of innovative technologies for farmers? Can virtual models, digital twins, and Big Data replace field experimentation?
- How does digitalization influence the development of more general technologies like social media and blockchains, and how does it impact sector-specific dynamics?
- How do new modes of governance, such as interactive digital innovation through Digital Innovation Hubs, Digital Living Labs, Data Cooperatives, Hacker Spaces, open-source innovation, rural Fab-Labs, and Makerspaces, create new digital learning and innovation spaces?
- How do citizen science and social network data transfers influence agricultural innovation? What are their objectives, methods, and impacts on innovation?
- As agricultural researchers and consultants adapt to digital agriculture, how do they acquire, aggregate, curate, interpret, and apply big data?
- How do advisory services manage the processes of analog and digital unlearning, deskilling, learning, and reskilling?
- How do new advisory and research organizational structures and commercial models affect advisor and researcher competencies and training? How do machines innovate?

**Economics and Management of Digitalized Agricultural Production Systems and Value Chains: New Themes and Problems**

In the economics and management of digitalized agricultural production systems and value chains, several new themes and problems require exploration. While Phillips et al. (2019) provide a systematic mapping of new business models, further research is needed to determine their local or global scope and their advantages and disadvantages. Rojo Gimeno et al. (2019) propose several important questions, such as:

- What are the emerging data value-adding and brokering methods employed by various actors, and how do these methods affect the distribution of labor and capital within farms, across farms, and between farms and other supply chain actors?

- How are platform technologies, the Internet of Things, and Artificial Intelligence impacting contracts, trust, and transaction costs among value chain actors?

**An Agenda for Future Research Clusters**

This section proposes potential areas for future research in digital agriculture, building on existing themes. However, there may be overlooked areas that could establish new theme clusters for social science research in this field. One such area is integrating social systems into digital agricultural conceptualizations, such as cyber-physical systems (Wolfert et al., 2017) or "socio-cyber-physical systems" (Lioutas et al., 2019). This area requires conceptual reflection and empirical investigations, potentially benefiting from applying sociotechnical systems research (Carolan, 2017a), assemblage theory (Higgins et al., 2017), or activity systems theory (Lioutas et al., 2019). Concepts like "socio-technological-ecological systems" (McPhearson et al., 2016) and "innovation ecosystems" (Pigford et al., 2018) may also provide useful frameworks (Van der Jagt et al., 2019).

A "sociology of flows" or "tele-coupling" between distant yet interrelated human and natural realms (Hull and Liu, 2018) may also be a significant area of study (Oosterveer, 2015). Researchers could explore how digital agriculture, smart value chains, and food systems create new socio-cyber-physical links and feedback mechanisms. Additionally, they could examine how new methods of farmer-environment information sharing affect field layout and agricultural landscapes.

Moreover, researchers could investigate how digital agriculture systems can connect humans to farming and feedback into human systems, in terms of motorial and cognitive aspects. For example, they could examine how drones and augmented reality affect spatial dimensions, how automation/robots affect tactile and motorial aspects, and how artificial intelligence affects cognitive dimensions.

Digital twins offer a platform for exploring innovative interactions between humans, technology, and the natural environment. Moreover, in line with concepts like the "quantified self" and "digitally enhanced humans," it is important to investigate the extent to which digital technologies can push human boundaries and willingness to integrate with machines. As proposed by HolyLuczaj and Blok (2019), research should also delve into the moral and ethical implications of hybrid entities that combine digital agricultural technology with elements of the natural ecosystem, thereby bridging the traditional divide between naturalness and artificiality.

**Digital Agricultural Transition Pathways**

Although digital technologies are pervasive, their role in sustainability transitions has been understudied. While digital agricultural technologies are suggested to contribute to more sustainable practices (El Bilali and Allahyari, 2018a; Balasundram et al., 2023), their role in transition dynamics remains unclear. Some authors suggest that digital technology could enhance agroecological models (Van Hulst et al., 2020). Empirical questions that arise include:

- What roles do digital technologies play as change agents in agriculture?
- How do they enable actors in the agri-food sector to foster change?
- How do they support alternative 'sustainable niches,' and how do they disrupt or reinforce incumbent 'food regimes'?
- How do digital technologies relate to different agricultural paradigms, such as organic farming, agroecology, bioeconomy, regenerative agriculture, urban agriculture, and vertical farming?

**Digital Agricultural Policy Making**

While there has been some research on agricultural policy and law-making procedures in relation to digital agriculture (Jouanjean, 2019; Soma et al., 2019), there is still much to be explored in this area (Bronson, 2018; Bronson and Knezevic, 2019). The lack of documentation and understanding in this field has been noted in previous work (Sanderson et al., 2018; Trendov et al., 2019). Political science and law could delve deeper into this issue, and empirical questions that could be explored include:

- How can digital agriculture inform real-time policy? What are the implications of data and algorithm-driven agriculture policy? (Jouanjean, 2019)
- How does digitization affect policy audience segmentation, such as small vs. large farms, young farmers, and gender concerns? (Sanderson et al., 2018) How can policymakers address the power

concentration of digital agriculture and mitigate food system cyberattack risks? (Trendov et al., 2019)
- How do policymakers and politicians in the agricultural sector interact with information technology and Agri-tech firms? (Soma et al., 2019)
- In what ways does digital agriculture intersect with the financialization and corporatization of agriculture, and what steps can governments take to alleviate any negative consequences? (Bronson, 2018; Bronson and Knezevic, 2019)

## 5. Conclusion

The findings of this review demonstrate the importance of social science research in digital agriculture, as it provides crucial insights for policy and practice in this field. However, it is important to note that this review only scratches the surface of the many social science topic clusters on digital agriculture and calls for more comprehensive investigations in the future. This article enhances the current understanding of the five thematic clusters by presenting contemporary policies, practices, and institutional setups that have integrated digital agriculture across various sectors and nations. Furthermore, it suggests new avenues for research, such as conceptualizations of social systems in digital agriculture, policy formulation processes, pathways for digitally driven agricultural transitions, and the worldwide landscape of digital agriculture development.

While social science research has provided a variety of complementary viewpoints, there is a need for a greater interdisciplinary and transdisciplinary study to comprehend the institutional frameworks and stakeholder interactions that shape digital innovations and their effects. According to Taebi et al. (2014), interdisciplinary and transdisciplinary approaches can help us better understand the social dynamics of digital agricultural development. Furthermore, Roth et al. (2019) suggest that methodological innovation from analog to digital or social data science is necessary to generate accurate theories of digital societies.

As digital agriculture continues to develop and expand, it is important to address the social, natural, and technological dimensions of this field. This review has highlighted a range of fresh questions that require scientific attention, and interdisciplinary collaboration between social, natural, and technological sciences may help steer digital agricultural development in ways that maximize benefits and minimize risks. By examining and adapting to social dynamics, we can ensure that digital agriculture contributes to sustainable development and inclusive growth.

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