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INFLUENCING FACTORS OF FARMER'S DIGITALIZATION READINESS IN SURAKARTA: AN INTERPRETIVE STRUCTURAL MODELING APPROACH

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ABSTRACT

This study investigates the digitalization readiness of urban horticultural farmers in Surakarta, Indonesia, by identifying key influencing factors and formulating strategic interventions to support inclusive digital transformation. A qualitative research design was employed, integrating Interpretive Structural Modeling (ISM) and MICMAC analysis to explore systemic relationships among readiness factors. Data were collected

through interviews, focus group discussions, and document analysis involving 20 key informants, including farmers, agricultural extension agents, and local government officials. The analysis identifies five principal factors shaping farmers' digital readiness: agricultural technology availability, digital literacy, training and capacity building, institutional support, and government involvement. Among these factors, government involvement functions as the dominant driving force within the hierarchical system of digital readiness. Based on the structural relationships identified, the study proposes four strategic interventions: strengthening local digital agriculture policies and incentive mechanisms; implementing context-specific training programs to address psychological and technical barriers to adoption; empowering farmer groups as innovation intermediaries; and integrating digital literacy initiatives with accessible agricultural technology platforms and supporting infrastructure. This study contributes an integrative analytical framework by combining the Technology Readiness Index (TRI), the Technology-Organization-Environment (TOE) model, and ISM-MICMAC analysis. The novelty lies in linking macro-level readiness indicators with micro-level systemic interactions to generate a comprehensive and actionable roadmap for urban agribusiness digitalization. The findings provide evidence-based guidance for policymakers and practitioners to promote inclusive, scalable, and sustainable digital transformation in urban agriculture.

KEYWORDS: Agricultural Innovation, Digital Readiness, Interpretive Structural Modeling (ISM).

1. INTRODUCTION

The rapid evolution of digital technology has significantly redefined the agricultural landscape worldwide, fostering a transition from traditional farming to data-driven and interconnected systems. Smart farming technologies, such as the Internet of Things (IoT), artificial intelligence (AI), remote sensing, and big data analytics, have emerged as key enablers of precision agriculture, allowing for enhanced productivity, real-time monitoring, and resource optimization across the value chain (Dibbern et al., 2024; Fragomeli et al., 2024; Misra et al., 2022). In both developed and developing economies, digital agriculture is being promoted as a strategic response to climate challenges, labor constraints, and food security concerns. Indonesia has initiated several programs to mainstream digital tools in agriculture, including the Agriculture War Room and Millennial Farmer initiatives. Nevertheless, the country's digital transformation trajectory remains uneven, with smallholder horticultural farmers facing persistent barriers such as limited Information and Communication Technology (ICT) infrastructure, low digital literacy, and minimal institutional support (Fuentes-Peñailillo et al., 2024; Gumbi et al., 2023).

Despite an expanding body of literature on agricultural digitalization, research on farmer readiness, especially within urban or peri-urban contexts, remains scarce. Most existing studies focus on rural regions or large-scale commodity crops, overlooking the unique vulnerabilities of small-scale urban farmers who often operate on fragmented land with constrained access to digital services (Larasati, 2024; Srinivasan & Yadav, 2024). Surakarta, a mid-sized urban city in Central Java, presents a compelling case for localized study due to its coexistence of pressures of urbanization and persistent horticultural activity in districts like Banjarsari and Laweyan. However, the extent to which farmers in this setting are psychologically, institutionally, and technologically prepared for digital adoption remains unclear. Furthermore, studies rarely integrate behavioral and systemic frameworks, such as the Technology Readiness Index (TRI) and Technology-Organization-Environment (TOE) to explore both individual and structural dimensions of readiness (Giua et al., 2022; Kumar & Sharma, 2025; Risqi Arifia, 2024). This study addresses that research gap by systematically identifying and structuring the key factors that shape horticultural farmers' digital readiness in Surakarta through Interpretive Structural Modeling (ISM) and MICMAC analysis.

Beyond technological and institutional factors, the socio-cultural characteristics of Surakarta also shape farmers' readiness for digital transformation. Surakarta is widely recognized for its strong communal culture, characterized by gotong royong (mutual cooperation), neighborhood associations, and collective decision-making within farmer groups. These social norms influence how innovations are discussed, evaluated, and adopted at the community level. In many cases, farmers rely on peer recommendations and group consensus before experimenting with new technologies. Consequently, digital adoption is not purely an individual decision but a socially embedded process influenced by trust, collective learning, and local leadership. Understanding this cultural dimension is therefore essential for designing digital agriculture programs that align with the social dynamics of urban farming communities in Surakarta.

2. LITERATURE REVIEW

The integration of information and communication technology (ICT) throughout the agricultural value chain, encompassing production, distribution and marketing, is referred to as agricultural digitalization. The objective is to enhance efficiency, productivity and sustainability in the agricultural sector (Johan et al., 2024; Yang et al., 2025). The implementation of the Internet of Things (IoT), artificial intelligence (AI), big data and digital platforms is pivotal in supporting precision agriculture practices and in responding to global challenges, including climate change and market dynamics (Bhat & Huang, 2021). In Indonesia, however, the process of agricultural digitalization is a complex journey that faces significant challenges. These include disparities in digital infrastructure in rural areas, low digital literacy among farmers, and weak regulations governing digital transformation (Alahmad et al., 2023; Gumbi et al., 2023).

It is imperative to acknowledge the pivotal elements inherent in the implementation of digitalization, encompassing the domains of smart farming through the utilization of sensors and IoT devices, the realm of agricultural e-commerce, the management paradigm enabled by big data, and the employment of mobile applications for the provision of extension services, market intelligence, and access to financing (Balyan et al., 2024; Dibbern et al., 2024). The success of technology adoption is influenced by various factors, including farmer characteristics, supportive conditions such as the availability of extension services and digital platforms, and the active involvement of the government and

stakeholders in developing policies, infrastructure, and innovative business models (Khanna, 2021).

Surakarta, commonly known as Solo, is a city in Central Java Province, Indonesia, where the study was conducted. Its precise geographical location is defined by the coordinates 7°32' and 7°38' south latitude, and 110°45' and 110°52' east longitude. The area under consideration is approximately 44.04 km², and the average altitude is 95 meters above sea level. Administratively, Surakarta is divided into five districts: The following areas are included in the study: Banjarsari, Jebres, Laweyan, Serengan and Pasarkliwon. Despite being classified as a city with strong urban characteristics, several areas in the Banjarsari, Laweyan and Jebres districts still engage in active horticultural farming, primarily through household gardens, community plots and small-scale farming units (Perda Kota Surakarta No. 4 Tahun 2021, 2021).

Surakarta experiences a humid tropical climate with average temperatures of 26–28°C and annual rainfall between 2,200 and 2,700 mm, supporting diverse horticultural crops such as leafy vegetables, chili, medicinal herbs, and ornamentals. Predominantly alluvial and regosol soil provide adequate fertility for intensive farming despite limited land availability. Amid urbanization pressures, the city maintains pockets of agricultural land, highlighting a unique land-use pattern. However, the digitalization of horticulture faces challenges, including unequal access to ICT infrastructure, low digital literacy among farmers, and land fragmentation. Still, the presence of adaptive farmers and urban farming communities reflects strong potential for localized agricultural digital transformation. Surakarta's diverse agroecological and socio-economic landscape makes it a valuable case for studying digital horticulture in urban settings.

3. METHODOLOGY

This study adopted a qualitative exploratory research design aimed at systematically identifying and structuring the factors that influence digital readiness among urban horticultural farmers. The qualitative approach was selected to enable deep contextual understanding of informants' perceptions, experiences, and challenges in adopting

digital technologies within the specific socio-ecological conditions of Surakarta City. This approach facilitates data triangulation by integrating expert perception exploration with data-based structural modelling.

The research was conducted from January to April 2025 in Surakarta, Central Java, which was purposively selected due to its distinctive characteristics as an urban area that still retains active horticultural practices amid urban development pressures. The study area encompasses five sub-districts known for their horticultural activity: Banjarsari, Laweyan, Jebres, Pasarkliwon, and Serengan. Data collection was carried out in two main stages. In the first stage, the research focused on identifying key factors influencing farmers' digital readiness through in-depth interviews with 20 selected informants, chosen via purposive sampling based on their relevance, expertise, and involvement in the horticultural sector. The informants consisted of 14 horticultural farmers and farmer group leaders, 3 agricultural extension officers from the Surakarta Agriculture Department, and 3 officials from the Cooperative and SME Agency with experience in agribusiness digital policy.

The interview protocol was guided by two key theoretical frameworks. The first is the Technology Readiness Index (TRI) developed by Parasuraman (2000), which assesses individual psychological readiness across four dimensions: optimism, innovativeness, discomfort, and insecurity. The second is the Technology-Organization-Environment (TOE) Framework proposed by (Tornatzky & Fleischer, 1990), which evaluates readiness in terms of technological, organizational, and environmental conditions. All qualitative data were obtained exclusively through individual interviews, focus group discussions (FGDs), and were triangulated with secondary sources, including government regulations, regional agricultural reports, and official documents related to digital transformation in agriculture. The entire process, from the preparation, data collection and analysis, was supervised by 10 experts from the field of agriculture and agribusiness. To facilitate the visualization of the research locations, Figure 1 presents a map showing the distribution of horticultural areas in the five sub-districts studied.

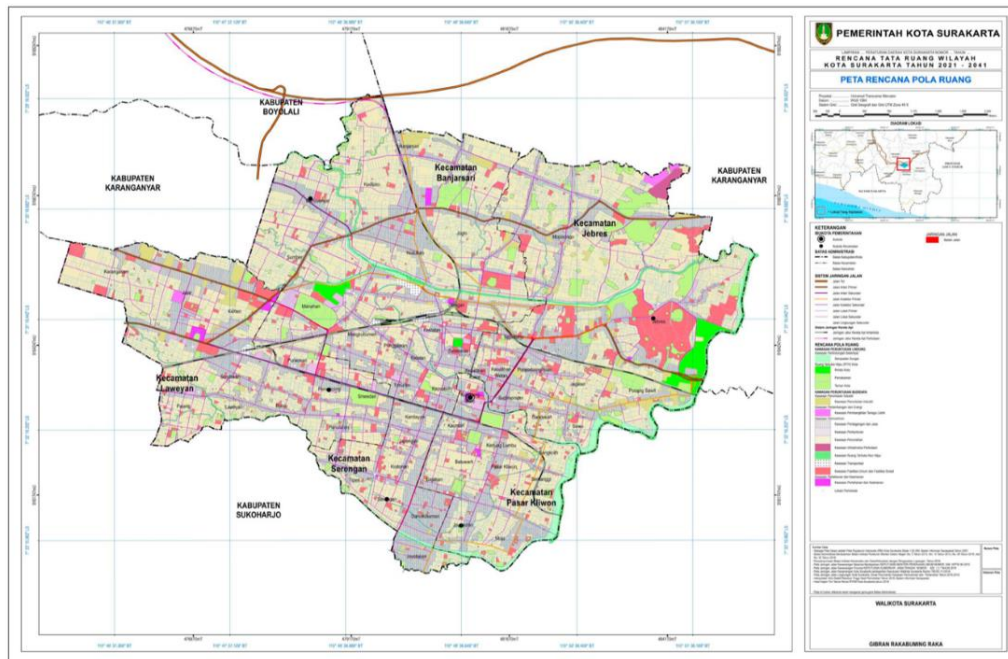


Figure 1: Maps Area of Surakarta. Source: Perda Kota Surakarta No. 4 Tahun 2021.

In the second stage, the study employed Interpretive Structural Modeling (ISM) and MICMAC (Cross-Impact Matrix Multiplication Applied to Classification) analysis to map the interrelationships among the identified factors and determine their systemic significance (Zhao et al., 2024). The ISM method was used to construct a hierarchical structure based on expert judgments regarding the directional influence between factors. This involved the development of a Structural Self-Interaction Matrix (SSIM), which was then converted into a reachability matrix and subjected to level partitioning to reveal the position of each factor within the system hierarchy. Table 1 describes a hierarchical structure of influence, drawing upon expert judgments regarding the directional relationships between key variables.

Table 1: Symbolic Criteria for Assessing the Direction of Relationships Between Factors.

Symbol	Description
V	Factor i influences factor j
A	Factor j influences factor i
X	Both factors influence each other
O	No relationship between the factors

Source: Authors'elaboration.

Mathematically, let $R = [r_{ij}]$ denote the reachability matrix, where $r_{ij} = 1$ indicates that factor i influences factor j , and $r_{ij} = 0$ otherwise.

The driving power (DP) of factor i is calculated as the total number of factors it influences, including itself:

$$DP_i = \sum_{j=1}^n r_{ij}$$

The dependence (D) of factor i represents the number of factors influencing it and is defined as:

$$D_i = \sum_{j=1}^n r_{ji}$$

These values are subsequently used in MICMAC analysis to classify variables into four categories: autonomous, dependent, linkage, and driving

variables.

4. RESULTS

This study identified five key factors influencing the digital readiness of horticultural farmers in Surakarta: agricultural technology, digital literacy, training and capacity, group institutions, and government support. Based on in-depth interviews with 20 informants, frequency analysis and reviews by the experts, we agreed on 5 main factors to analyze in this research which are agricultural technology, digital literacy, training and capacity, group institutionalism, and government support.

Using a Structural Self-Interaction Matrix (SSIM), we examined the directional relationships among these factors, applying the V, A, X, and O notation. The SSIM was then transformed into a binary

Reachability Matrix, revealing the structural interdependencies. Notably, government support, though less frequently cited, was linked to all other

factors, underscoring its central systemic role. A detailed breakdown of these findings is presented in Table 2.

Table 2: Factors Affecting Farmer Digital Readiness.

Dimension	Serial Number	Factor Name	Meaning	Reference Source
Technological Capacity	A1	Agricultural Technology	The availability, accessibility, and usability of digital agricultural tools such as IoT devices, sensor-based irrigation systems, and smart farming platforms.	(Bontsa et al., 2023; Jabbari et al., 2023; Uy et al., 2025)
Digital Competence	A2	Digital Literacy	Farmers' ability to understand, operate, and benefit from digital tools, applications, and platforms related to farming, including mobile apps and online services.	(Abdulai et al., 2023; Hasan, 2025; Uy et al., 2025)
Human Resource Development	A3	Training and Capacity	The extent of farmers' participation in structured or informal training programs aimed at increasing knowledge and skills for digital agriculture adoption.	(Alt et al., 2020; Jabbari et al., 2023; Michels et al., 2019; Uy et al., 2025; Zhang & Bao, 2023)
Institutional Support	A4	Farmer Group Institutions	The role and effectiveness of farmer groups or cooperatives in facilitating access to digital innovation, collective learning, market linkage, and policy advocacy.	(Abdulai et al., 2023; Bontsa et al., 2023; Gong et al., 2025)
Policy Environment	A5	Government Support	The extent of government involvement in developing policies, infrastructure, subsidies, and programs that support digital agriculture transformation among smallholder farmers.	(Hasan, 2025; Jabbari et al., 2023; K. Reji et al., 2025; Smidt & Jokonya, 2022; Thi Hoa Sen et al., 2024)

Source: Authors' elaboration.

As illustrated in Table 2, a qualitative analysis of in-depth interviews with key informants identified five main factors as determinants of horticultural farmers' readiness for digitalization in Surakarta. The factors under discussion are as follows: agricultural technology, digital literacy, training and capacity building, group institutions and government support.

Agricultural technology involves the use of digital tools such as IoT, AI, and big data to enhance agricultural efficiency, though its adoption is often hindered by high costs and inadequate infrastructure. Digital literacy, the ability to access and use digital tools, is essential for farmers to engage with these technologies, yet limited skills remain a barrier to integration. Training and capacity-building programs are crucial in improving farmers' understanding, reducing resistance, and increasing confidence in digital adoption. Institutional groups like cooperatives support this

process by facilitating knowledge exchange, collective access to resources, and market influence. Government support, through policies, subsidies, infrastructure, and training, plays a pivotal role in enabling inclusive digital transformation. While agricultural technology and digital literacy were most frequently cited as urgent issues, structural analysis indicates that government support exerts the greatest causal influence in driving digital readiness.

The indicator details were analyzed using the MICMAC model to classify these factors based on two main parameters: driving power (influence) and dependence (degree of dependence). The analysis yielded four classification quadrants: (1) autonomous variables (factors with low influence and dependence); (2) dependent variables (factors that are highly influenced); (3) linkage variables (factors that influence each other and are unstable); and (4) driving variables, as outlined in Table 3.

Table 3: Structural Self-Interaction Matrix (Ssim).

Factors	A1	A2	A3	A4	A5
Technological Capacity (A1)	-	A	O	O	O
Digital Literacy (A2)	V	-	V	V	O
Training and Capacity (A3)	V	V	-	O	O
Farmer Group Institutions (A4)	V	X	X	-	O
Government Support (A5)	V	V	V	V	-

Source: Authors' elaboration.

The outcomes of the Structural Self-Interaction Matrix (SSIM) compilation are presented in Table 3. This study adopts a systematic approach to mapping the interrelationships among factor pairs, drawing primarily on the perceptions and evaluations of expert informants as the key source of data. The symbols in the table indicate the direction of influence between factors: The symbol V indicates a unidirectional relationship where the row influences the column; A indicates a bidirectional relationship where the column influences the row; X indicates a

two-way relationship; and O indicates the absence of a direct relationship. For instance, the symbol V between 'Government Support' and all the other factors signifies that the government is perceived as actively influencing farmers' preparedness, whereas the symbol O in certain instances signifies the absence of direct influence according to the informants. This matrix constitutes the foundation for the construction of the Reachability Matrix, which is subsequently delineated in Table 4.

Table 4: Reachability Matrix.

Factors	A1	A2	A3	A4	A5
Technological Capacity (A1)	0	1	0	0	0
Digital Literacy (A2)	1	0	1	1	0
Training and Capacity (A3)	1	1	0	0	0
Farmer Group Institutions (A4)	1	1	1	0	0
Government Support (A5)	1	1	1	1	0

Source: Authors' elaboration.

As presented in Table 4, the SSIM matrix is transformed into a binary format, thereby producing the Reachability Matrix. This presents reachability relationships between factors, where a value of 1 indicates the presence of influence and a value of 0 indicates its absence. The rows of the table illustrate the factors that exert influence, while the columns demonstrate the factors that are influenced. As is evident, 'Government Support' has a value of 1 in all columns except its own, indicating that this factor exerts influence on the other four factors. This finding serves to substantiate the government's strategic function as the primary catalyst in the digitalization readiness system for horticultural farmers. Conversely, factors such as 'Agricultural Technology' have only one value of 1, meaning their influence is limited.

At the initial level, two surface-level factors are identified: agricultural technology and digital literacy. These represent observable indicators of digital readiness but remain heavily reliant on deeper systemic enablers. For example, improvements in digital literacy depend on the availability of training and technological infrastructure. Positioned at level 2, training and capacity act as mediating variables that bridge technological access and user competency. Empirical studies affirm the positive

impact of training on both digital literacy and technology adoption, while also enhancing farmers' confidence in digital tools. This aligns with Parasuraman's Technology Readiness Index (TRI), which suggests that effective training can mitigate feelings of discomfort and insecurity.

Institutional factors appear at level 3, serving as structural enablers that facilitate resource distribution, coordination, and connectivity among stakeholders. These institutions foster farmer networks, enable training access, and serve as intermediaries with actors such as extension agents or agri-tech startups. Local institutional capacity thus links individual agencies with broader policy frameworks.

At the base of the hierarchy (level 4), government support emerges as the system's driving force, as identified through Interpretive Structural Modeling (ISM). Its role spans regulation, funding, ICT infrastructure development, and the provision of incentives for training and technology adoption. While mentioned less frequently in interviews, its structural centrality underscores its critical function. Without strong policy interventions, progress at higher levels risks fragmentation and limited sustainability. This hierarchical framework is detailed in Table 4 and visualized in Figure 2.

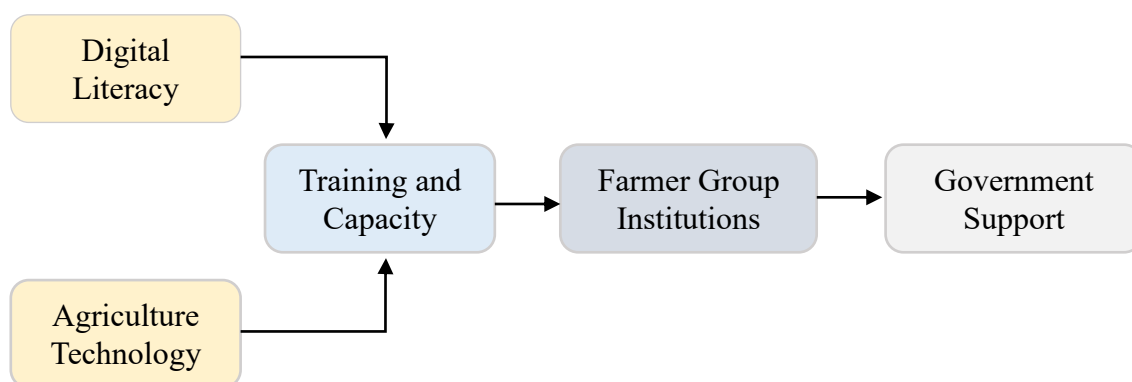


Figure 2: Ism Hierarchy: Factors Influencing Farmer's Digital Readiness.

Source: Authors' elaboration.

Figure 2 presents the flowchart depicting the hierarchical logic among the factors, progressing from foundational elements to surface-level manifestations. At the base, government support functions as the principal driving force, exerting influence over all subsequent components. Institutional groups function as intermediaries, enabling organizational integration, promoting training access, and facilitating information dissemination. At the intermediate level, training and capacity serve as the mechanism linking structural support with individual readiness. At the top, agricultural technology and digital literacy represent observable outcomes of digital readiness in the field. The diagram clearly reflects that progress at higher levels depends on reinforcement at foundational layers.

The ISM approach employed in this study effectively revealed the systemic hierarchy among key factors, clarifying their interdependence and roles in shaping digital readiness. These insights offer a strong foundation for more targeted policy and training interventions, particularly emphasizing institutional reinforcement and the government's catalytic role in advancing horticultural digital transformation.

5. DISCUSSION

The results of the Interpretive Structural Modelling (ISM) and MICMAC analyses in this study directly address the main issue raised in the introduction: the significant digital disparity among horticultural farmers, particularly in urban areas such as Surakarta City. This encompasses physical limitations, such as a lack of ICT infrastructure and digital devices, as well as cognitive and psychosocial factors, including low digital literacy, distrust of technology, limited capacity, and inadequate institutional support. Five key factors have been identified as determinants of digital readiness: (1)

agricultural technology; (2) digital literacy; (3) training and capacity; (4) group institutionalism; and (5) government support. Hierarchical mapping through ISM demonstrates that agricultural technology and digital literacy are positioned at the top level as dependent variables, reflecting the most readily observable surface conditions. However, these variables exhibit a high degree of dependency on additional factors. For instance, the mere availability of devices or internet access in Surakarta has not automatically led to greater digitalization among farmers due to their limited understanding of and trust in technology. This finding suggests that efforts to enhance digital literacy through infrastructure provision alone are inadequate and must be complemented by psychosocial and institutional interventions. These findings should also be interpreted within the socio-cultural context of Surakarta, where collective farmer groups, community-based learning traditions, and the cultural value of *gotong royong* influence how digital knowledge is shared, discussed, and adopted among farmers.

The findings of this study are consistent with extant literature on the adoption of digital technology in the agricultural sector, and further contribute to that literature, particularly regarding studies using the Technology Readiness Index (TRI) and the Technology-Organization-Environment (TOE) Framework. The robust position of government support as a pivotal variable within the ISM structure is consistent with the environmental context dimension of the TOE framework, which emphasizes that regulations, policies and institutional support are pivotal external factors driving technology adoption (Tornatzky & Fleischer, 1990). In the context of this study, the government's dominant role in providing digital infrastructure, incentives and training schemes is evident. These elements are deemed prerequisites for farmers'

readiness to adopt technology. The present study corroborates the conclusions of Johan (2024) and Zabelina (2020) which underscore the significance of systemic support and adaptive policies. However, the present study's contribution lies in its contextual approach, which emphasizes that digitalization policies cannot be uniform across the nation but must be tailored to the specific challenges faced by urban areas such as Surakarta.

The challenges confronting farmers in this region are multifaceted, including spatial constraints, high levels of land fragmentation, and a paucity of cohesive farming communities. This underscores the necessity of a comprehensive integration of agricultural and urban planning policies. In addition, training and capacity building are positioned at level two as linkage variables, thereby assuming a strategic mediating role within the system. The implementation of targeted training has been demonstrated to enhance the technical competence of farmers, thereby mitigating their psychological resistance to digital technology. This finding is consistent with the Technology Readiness Index (TRI) proposed by (Parasuraman, 2000), which asserts that training can mitigate discomfort and insecurity. Training functions as a conduit between the potential for technological adoption and the psychological preparedness to embrace digital transformation. The role of training and capacity as linkage variables supports the TRI concept that discomfort, and insecurity are the main psychological barriers to technology adoption. The present study offers empirical evidence that training can enhance technical competencies and strengthen farmers' mental readiness to embrace digital transformation. The integration of training as a component of technology acceptance is a critical aspect that highlights the significance of human ware in conjunction with hardware and software components.

These findings are consistent with those of Wang & Dong (2023), who demonstrated that expectations of benefits and external support through extension services determine farmers' readiness to adopt technology. The third factor identified is that of institutional factors at the group level, which emerge as a means of providing social support for the diffusion of technology and knowledge. The institutional structures of farmer groups and cooperatives have been shown to facilitate innovation diffusion through collective approaches and the empowerment of individuals (Srinivasan & Yadav, 2024). The existence of robust institutions enables farmers to gain access to training

opportunities, essential resources, and a broader array of digital market networks. As indicated by the MICMAC results, the position of the linkage variable confirms that the strengthening of institutions will have a dual impact, both horizontally and vertically, within the digitalization system. The group institutional aspect that emerges at the structural level in the ISM hierarchy emphasizes the importance of a collective approach in the digitalization process (Food and Agriculture Organization of the United Nations, 2021; Peraturan Menteri Pertanian Republik Indonesia Nomor 259 Tahun 2020 Tentang Rencana Strategis Kementerian Pertanian Tahun 2020-2024, 2020).

As Elizabeth (2023) emphasize, effective agricultural innovation systems are predicated on the active involvement of farmer organizations or groups. The present study lends further support to the notion that farmer groups should be regarded not merely as administrative entities, but rather as agents of innovation, diffusion and resource mobilization. In the context (Elizabeth, 2023) of mounting pressures associated with urbanization, the presence of group institutions is imperative for sustaining social solidarity and collaboration in accessing digital programs. The most fundamental factor is government support, which occupies the position of driving variable or root cause in the digitalization readiness system. Despite being mentioned less frequently than other factors, its position at level 4 of the ISM hierarchy indicates its strategic role in directing the entire system. In the absence of a regulatory framework and government support, policies, incentives, infrastructure provision and training will be unable to function optimally. This finding aligns with the findings of previous research (Johan et al., 2024; Sharma et al., 2020), which suggests that the digitalization of agriculture is heavily reliant on state support and intervention to create a conducive ecosystem.

While agricultural technology and digital literacy were frequently cited as critical needs in interviews, they are structurally dependent variables with limited influence on systemic change. This finding indicates that the provision of technology alone is insufficient to ensure sustainable adoption, and that the strengthening of other supporting systems is a prerequisite. This finding aligns with the conclusions of numerous digitalization studies, which posit that technology is merely a tool and its success is contingent on the preparedness of the surrounding people and institutions (Kitole et al., 2024; Mangurai et al., 2024). It is evident that this hierarchical structure has the capacity to identify not only key

factors, but also to map how causal relationships and dependencies between factors occur systemically (Istanabi *et al.*, 2023). The present study offers empirical evidence that digitalization readiness should be conceptualized as a complex system necessitating layered and coordinated interventions, rather than a linear condition.

The ISM hierarchy and MICMAC classification provide a robust foundation for the formulation of evidence-based digitalization intervention strategies for horticultural agriculture. Each tier of the hierarchical structure necessitates a distinct yet cohesive approach. At Level 1, the primary objective is to establish ICT infrastructure and enhance farmers' digital literacy by providing them with pertinent content that is readily comprehensible. However, it is important to note that these interventions cannot be considered in isolation, as MICMAC results indicate that these two factors are highly dependent variables with weak influence. Consequently, digitalization programs that exclusively concentrate on the provision of devices or brief training sessions will prove inadequate in the absence of support from more fundamental components.

Training and capacity at Level 2 have been identified as linkage variables that play a pivotal role. Interventions at this level are of crucial importance because they influence two areas simultaneously: strengthening farmers' digital competencies and increasing their uptake of government programs and institutional support. A pivotal aspect in the transition from knowledge to adoption is the incorporation of simulation-based training programs, technical assistance, and the utilization of locally developed applications.

Institutional capacity at level 3 must be strengthened through institutional incentives, formal legal recognition and integration with community-based digitalization programs. The enhancement of institutional capacity has been demonstrated to engender improvements in the effectiveness of training programs, thereby facilitating the establishment of a more effective connection between field actors and policymakers.

In conclusion, it is imperative that government support constitutes the fundamental starting point and primary priority in the formulation of strategies. It is incumbent upon local governments to develop data-driven policies, strengthen cross-sectoral collaboration and establish digital incentive systems for farmers and institutions. In the absence of concerted action, the digitalization system risks remaining both sporadic and unsustainable.

Subsequently, this study found that the digital readiness of horticultural farmers in urban areas such as Surakarta City is the result of complex interactions between individual psychological factors, institutional capacity, technological conditions and policy support. Utilizing the Technology Readiness Index (TRI) framework, the Technology-Organization-Environment (TOE) framework, Interpretive Structural Modelling (ISM) and MICMAC analysis methods, this study successfully identified five main interacting factors: government support; group institutional capacity; training and capacity; digital literacy; and agricultural technology (Kumar & Sharma, 2025; Risqi Arifia, 2024). The ISM modelling results demonstrate that government support is the fundamental cause of digital readiness, while agricultural technology and digital literacy are surface effects that are significantly influenced by the functioning of the underlying system (Ahmad & Qahmash, 2021). The training and capacity factors act as a crucial bridge to reduce psychological barriers and enhance farmers' cognitive readiness, while group institutionalism serves as a social connector, facilitating innovation diffusion and collaboration within the digital agricultural ecosystem.

The present study makes a theoretical contribution through the integration of three complementary analytical approaches, with a view to achieving a holistic understanding of digital readiness. In practice, the study provides a data-driven strategic roadmap to inform the design of more targeted and contextual interventions by policymakers, extension workers and farmer organizations. The present study explores the novel focus on small-scale horticulture in urban areas, which adds a new dimension to the extant literature on the digitalization of agriculture. The latter has hitherto been more focused on rural areas and large-scale agriculture. Consequently, this research not only addresses questions about the determinants of digitalization readiness but also provides a conceptual and operational approach that can be replicated in other regions facing similar challenges. Moreover, it functions as a foundational framework for the development of more inclusive and sustainable digital transformation-based agricultural policies.

6. CONCLUSIONS

The findings reveal that five interdependent factors government support, institutional capacity, training and digital capacity-building, digital literacy, and agricultural technology which constitute the backbone of farmers' digital readiness.

Among these, government support emerged as the primary driving variable, underscoring the pivotal role of state-led initiatives, regulatory frameworks, and infrastructural investments in fostering an enabling digital ecosystem. While digital literacy and agricultural technology were identified as the most frequently cited concerns by informants, ISM-MICMAC analysis reveals their dependence on more foundational system elements, particularly institutional scaffolding and policy coherence. This systemic understanding challenges the often-superficial narratives of digital adoption that overemphasize hardware provision or app deployment, instead advocating for multi-tiered, context-specific interventions. Effective digital transformation in agribusiness, especially in constrained urban environments, requires more than technological availability; it demands psychological readiness, targeted training, robust institutions, and sustained policy support. The role of farmer groups as innovation intermediaries and social enablers further illustrates the necessity of leveraging collective agency for broader technology diffusion. Theoretically, this study advances discourse by demonstrating the explanatory power of merging TRI and TOE frameworks within a structural model, thus bridging individual-level behavioral insights with macro-level system analysis. Practically, the resulting strategic roadmap offers actionable insights for policymakers, extension agencies, and development actors seeking to implement inclusive and sustainable digitalization policies in agrifood systems. Ultimately, this research affirms that the digital transformation of smallholder horticulture in urban areas is not a linear process, but a complex, layered system of dependencies, where success hinges not solely on innovation, but on the strength of governance, education, and institutional alignment.

Ethics Statements: This study was conducted in accordance with ethical research standards. All participants were informed about the purpose of the study, and their voluntary participation was obtained prior to data collection. Informed consent was secured from all interviewees and focus group participants. The identities of participants were kept confidential, and all data were used solely for academic and research purposes. The study did not involve vulnerable groups or sensitive personal data, and no ethical clearance number was required as per institutional and national research guidelines.

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7. LIMITATIONS AND FUTURE RESEARCH

This study is limited in scope as it focuses exclusively on urban horticultural farmers in Surakarta, Indonesia. While the insights generated are valuable, they may not be directly generalizable to rural farmers or to other agricultural subsectors that operate under different socio-economic, cultural, and technological conditions. Furthermore, the analysis primarily emphasizes determinants of digital readiness rather than actual adoption outcomes. Consequently, the study does not capture the long-term impacts of digitalization on key performance indicators such as productivity, income generation, market competitiveness, or sustainability.

Future research should therefore extend the investigation to rural farmers, diverse agricultural subsectors, and different regional contexts to identify similarities and differences in digital readiness across varying environments. Such comparative studies would enhance external validity and provide a more comprehensive understanding of digital transformation in agribusiness. Moreover, examining the actual impacts of digital adoption on farmer productivity, market access, income stability, and sustainability would complement readiness analysis by linking preparedness to tangible outcomes. In addition, future studies should analyze the role of government programs, extension services, and institutional frameworks in shaping digital adoption trajectories. This line of inquiry is critical, as policy interventions and institutional support often determine the scalability and inclusivity of digital transformation, particularly in resource-constrained settings. By addressing these dimensions, subsequent research can contribute to evidence-based policymaking and the design of more effective strategies for advancing sustainable and inclusive digitalization in agriculture.

Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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