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The Meaning of Agricultural Technology for Millennial Farmers in Providing Food Security: A Case from Indonesia

Yeni Yuliati [1], Alia Bihrajihant Raya [2,*] and Partini [3]

[1] Extension and Development Communication, Graduate School, Universitas Gadjah Mada, Yogyakarta 55284, Indonesia
[2] Study Program, Extension and Development Communication, Graduate School, Universitas Gadjah Mada, Yogyakarta 55284, Indonesia
[3] Department of Sociology, Faculty of Social and Political Sciences, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia
* Correspondence: alia.bihrajihant.r@ugm.ac.id

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Abstract: The digital divide in agriculture is a pressing problem that must be resolved to achieve national food security through the strengthening of technological transformation at the regional level. This study examines how millennial farmers in the UPTD BP4 Region III working area, Sleman Regency, Indonesia, construct the meaning of agricultural technology in relation to food security. Guided by a human-centered, socio-technical framing of technology adoption, the study asks why and how technology enters farmers' everyday practice and how this relates to the availability, access, and quality dimensions of food security. Using a qualitative critical-constructivist design, data were collected from 12 informants through in-depth interviews, two focus group discussions, field observation, and document review conducted between January and March 2025. Data were coded and analyzed in NVivo 14 using an iterative reduction-display-verification cycle continued until no new codes emerged across successive interviews, and validity was strengthened through technique and source triangulation. Findings show that millennial farmers meaning-making is concentrated in downstream, market-facing uses of digital technology, primarily marketing and distribution, while upstream (on-farm, production-side) applications remain dominated by mechanical rather than digital or IoT-based tools. This pattern demonstrates a clearer, evidenced contribution to the access dimension of food security than to availability or quality. A pronounced digital divide compounds this pattern across three layers: access, digital literacy, and utilization, and disproportionately disadvantages farmers engaged in food-crop cultivation relative to those in horticulture and downstream marketing. Technological transformation in this setting, therefore requires holistic policy intervention, pairing infrastructure investment with critical digital-literacy training and extension support, to build a digitally capable and inclusive millennial farmer ecosystem that balances food provision with profitability.

Keywords: agricultural technology; digital divide; food security; human-centered technology design; millennial farmers

1. Introduction

The global food crisis poses a significant threat to food security. According to the Global Report on Food Crises, nearly 282 million people across 59 countries, 21.5% of the population studied, faced food insecurity levels requiring humanitarian assistance in 2023 (Global Network Against Food Crises [GNAFC], 2024). This crisis is compounded by economic instability, climate change, geopolitical conflict, and disruption of global supply chains. In Indonesia, the food crisis has emerged alongside continued population growth: the population reached 278.69 million in 2023 (Badan Pusat Statistik [BPS], 2023), even as agricultural land continues to be converted to residential and non-agricultural infrastructure (Tranggono et al., 2023), reducing agricultural productivity and food availability.

Achieving food security is closely tied to Sustainable Development Goal (SDG) 2, zero hunger, one of seventeen global commitments to improve societal welfare that both developed and developing countries have adopted for 2030. In the era of information and communication technology disruption, food security can increasingly be pursued by leveraging technology as a key enabler across the dimensions of food security (Wolfert et al., 2017). Field observation, however, reveals a persistent digital divide in the agricultural sector. Many millennial farmers have adopted agricultural technology, but their engagement is often confined to its technical, downstream aspects; there is a discernible shift toward agripreneurship and market distribution rather than toward increasing food production itself (Wastutiningsih et al., 2024). This pattern requires urgent attention if national food security is to be strengthened through regional technological transformation.

This study explores in depth how millennial farmers in Sleman Regency, Indonesia, construct the meaning of agricultural technology as a vehicle for food security. Rather than treating digital technology as a neutral instrument, the study is guided by a human-centered, socio-technical framing of technology adoption, an approach in the tradition of the social shaping of technology (MacKenzie & Wajcman, 1999) that treats technology and social practice as mutually constitutive, rather than technology as an externally given tool that people either accept or reject. Understanding how millennial farmers make sense of agricultural technology in these terms can help identify the specific challenges they face and inform strategies to narrow the digital divide and support sustainable technology adoption.

This question is nationally significant: food security is named as a long-term development priority in Indonesia's Golden Vision 2045 and is governed by Law No. 18/2012 on Food and Law No. 41/2009 on the Protection of Sustainable Food Agricultural Land. As Hanani (2012) observes, a country's ability to meet its citizens' food needs does not automatically guarantee that government can achieve food self-sufficiency independently, since natural resource conditions vary substantially across regions. Although Sleman Regency is recognized for its achievements in food security, questions of availability, affordability, supply stability, and food utilization warrant continued attention.

Administratively, Sleman Regency's agricultural extension system is organized into eight working areas, each overseen by a Regional Technical Implementation Unit for Agricultural, Food, and Fisheries Extension (UPTD BP4). This study focuses on UPTD BP4 Region III, covering Seyegan, Mlati, and Tempel Districts, the site of the first millennial farmer group in Sleman Regency to be formally established, on 9 March 2022, by decree of the Sleman Regent, and subsequently the model for similar groups formed in other UPTD BP4 working areas. As of the time of the study, the group comprised 415 farmers, with a striking gender composition of 297 women and 118 men, a pattern of gender inclusivity that runs counter to agriculture's more typically male-dominated labor profile (Maulana et al., 2022). Within this framework, understanding how the Region III Millennial Farmer Group interprets agricultural technology offers a strategic lens on how technical literacy and technological transformation can be strengthened among younger practitioners, moving beyond a reductive view of technology as a mechanical tool toward an understanding of digital integration as a catalyst for social transformation.

Approached this way, millennial farmers do not merely adopt technological information; they also negotiate the social, cultural, and environmental contexts in which technology is used. Agricultural technology thereby becomes not just a tool but an integral part of the knowledge system and sustainable agricultural practice through which food security is pursued locally.

Research Objectives

Building on the discussion above, this study pursues three specific objectives, each addressed in a corresponding subsection of the results:

(1) Identify how millennial farmers in UPTD BP4 Region III categorize and use agricultural technology in their daily practice.
(2) To examine how millennial farmers construct the meaning of agricultural technology through the dialectical moments of externalization, objectivation, and internalization, and how a digital divide across access, literacy, and utilization complicates this meaning-making.
(3) To assess how these patterns of technology use and meaning-making relate to the availability, access, and quality dimensions of food security.

2. Literature Review

Technology does not emerge in a vacuum, it is actively constructed by people and social groups as key actors (Geels, 2006). Technological transformation, in turn, can be understood as systemic change driven by the integration of new technologies that reshape operational dynamics and business models (Angelopoulos et al., 2023). In agriculture, this refers to efforts to transform the food supply sector through the integration of digital technology, including the Internet of Things ((Krupitzer & Stein, 2024).). The digital technologies at issue include modern agricultural tools and machinery, information technology such as mobile devices and internet connectivity, drones, and artificial intelligence, driven by the need to address climate change and food security through inclusive digital practice.

Amid efforts to achieve national food security, the agricultural sector faces a challenge of farmer regeneration: young people are often reluctant to pursue agricultural careers because of negative perceptions of the sector's image and prospects. Susilowati (2016) notes that the aging of the farming population and the declining number of young agricultural workers threaten the sustainable development of the sector, its productivity, market competitiveness, and rural economic capacity, and, by extension, food security. Seo and Shirasawa (2024) similarly highlight the role of technology in strengthening productivity and young people's interest in farming careers. More recent social-science scholarship situates this within the broader digitalization of agriculture: Klerkx, Jakku and Labarthe (2019) review how digital agriculture, smart farming, and "Agriculture 4.0" reshape not only production but farm labor, business models, and rural social relations, and call for closer attention to who is included or excluded as digitalization proceeds. In response to declining youth interest, the Indonesian government has promoted a millennial farmer program; under Ministry of Agriculture Regulation No. 4/2019, millennial farmers are defined as those aged 19–39 who are adaptive to digital technology.

Food security itself comprises three fundamental dimensions, availability, access, and quality (utilization) (Roy et al., 2019). Availability concerns whether food is available through production, cultivation, livestock, or other sourcing; access concerns whether food is physically and economically reachable, including affordability; and quality (utilization) concerns whether food is nutritious and its nutrients can be absorbed. Sufficiency in these terms, quantity, quality, and sustainability, is the philosophical core of food security for all people (Arini & Suryana, 2023). Two recent studies illustrate how these dimensions are being re-examined under digital and geopolitical pressure: Lu, Zhang, Hong, He and Chen (2022) review China's food-system transformation and show that availability, access, and stability moved together, and often unevenly, as digital tools were introduced into production, storage, and trade; and Arghiroiu, Bobeica, Beciu and Mann (2025), in a bibliometric review of food-security scholarship since 2010, show that resilience-oriented framings of food security, including the access dimension emphasized by digital marketplaces, have become increasingly central to the literature since 2020. This reinforces why an access-only reading of digitalization's contribution to food security, as in the present study's findings, needs to be stated explicitly rather than assumed to also cover availability or quality.

Understanding individual values and social construction is equally important for interpreting agricultural innovation. McGuire (2002) argues that each individual holds a value system that shapes how they assign meaning to experience, drawing on past experience, attitudes, beliefs, and social-cultural context (as discussed in Jalaludin, 2005). This individual interpretation connects closely to Peter L. Berger's account of the social construction of reality, in which habitual actions retain meaning for individuals even once that meaning becomes embedded in common, taken-for-granted knowledge. Among millennial farmers, engagement with human-centered agricultural technology often begins as a pragmatic effort to raise productivity and profit; over time, that technology can become an integral, even unremarked, part of farming practice.

This paradigm shift is increasingly relevant when technology adoption is read through a human-centered, socio-technical lens that treats technology and social practice as mutually shaping one another, offering a way to understand the complexity of agricultural systems and food security without over-claiming the interdisciplinary scope of digital humanities proper. Digital humanities is itself a distinct interdisciplinary field that applies computational methods to humanities scholarship (Fenlon et al., 2024); it is not the analytic framework used in this study, and the two are not used interchangeably here. For the ethical and design implications of introducing digital tools into farming, this study instead draws on the responsible-innovation literature in smart farming (Van der Burg, Bogaardt & Wolfert, 2019), which asks who is included, whose values are embedded in a system's design, and how anticipated and actual use diverge, questions directly relevant to the digital-divide concerns examined below.

Although human-centered technology design offers substantial opportunities for progress, its implementation is not without challenges, particularly those related to the digital divide. The concept of the digital divide has evolved considerably: initially framed simply as the difference between those with and without physical access to technology (Shin et al., 2021), it now extends well beyond device ownership. The digitalization of agriculture can itself widen social disparities among farmers (Rotz et al., 2019); infrastructure limitations, gaps in digital literacy, and distrust of new technology can all hinder adoption among smallholders. Recent system-design work on digital agriculture in other transitional and developing agricultural economies, for example Karpov, Dorofeev, Smirnova, Kulibaba and Beresneva's (2026) proposal for an adaptive precision-agriculture software-hardware system in the Kyrgyz Republic, and Logachev and Fomin's (2026) design for an international digital system linking smallholders directly to consumers, illustrates both the promise of digital agriculture and the access barriers (connectivity, device cost, digital literacy) that determine whether such systems reach smallholder and millennial farmers rather than only larger, better-resourced operations. These cases reinforce why this study treats technology adoption as a socio-technical, not purely technical, process, and situates the digital-divide analysis as integral to understanding the meaning millennial farmers give to agricultural technology.

3. Methodology

3.1. Research Design

This study uses a qualitative design with a critical constructivist approach. Qualitative research investigates, describes, and explains qualities or social influences that cannot be adequately captured through quantitative measurement (Saryono, 2010). A critical constructivist approach does not aim to validate a single truth but instead engages the knowledge participants construct through the research process itself, analyzing and interpreting that knowledge into a broader understanding (Coghlan & Brydon-Miller, 2014). This approach was adopted because the study's central concern is how millennial farmers construct the meaning of human-centered agricultural technology, which required drawing out the deeper meanings embedded in informants experiences and perspectives.

3.2. Site Selection

The study was conducted in Sleman Regency, an area with substantial potential to support food security, with the UPTD BP4 Region III Millennial Farmer Group as the focal research site. The site was selected through purposive sampling, selecting a research location on the basis of specified criteria (Sugiyono, 2013), because the Region III group is an active millennial farmer group with a clear organizational structure and membership, a regular meeting schedule, and status as a pilot project in several Sleman Regency Government programs for sustainable agricultural development.

3.3. Informants

Following qualitative research guidance (Neuman, 2014), informants were selected for their in-depth knowledge of, and direct experience with, technological transformation among millennial farmers in UPTD BP4 Region III and its relationship to food security sustainability in Sleman Regency. Twelve informants were selected across three groups: (1) five supporting informants from provincial and district agricultural policy institutions; (2) the chair of the Region III Millennial Farmer Group; and (3) six key informants, comprising two farmers each from food-crop cultivation, horticultural cultivation, and marketing/distribution. Table 1 details each informant's institutional affiliation, role, and focus of inquiry; anonymized codes (SI = supporting informant, KI = key informant) are used throughout the Results to identify the source of each quotation.

Table 1. Research Informants.

Code	Institution	Role/Category	Focus of Inquiry
SI-1	Agricultural Human Resources Development Center (BPSDMP), DIY Province	Extension Coordinator	Regional farmer-regeneration strategy through the millennial farmer program; program growth trajectory
SI-2	Agriculture, Food, and Fisheries Office, Sleman Regency	Head of Extension Implementation Section	District policy on agricultural technology introduced to millennial farmers
SI-3	Agriculture, Food, and Fisheries Office, Sleman Regency	Head of Food Security Division	Food security issues and district technical/non-technical food policy
SI-4	UPTD BP4 Region III, Sleman Regency	Extension Coordinator	History and development of the Region III Millennial Farmer Group; group activities, mentoring, and evaluation since formation
SI-5	UPTD BP4 Region III, Sleman Regency	Field Extension Officer	Extension activities for millennial farmers; technology-introduction process; barriers; farmer characteristics and dynamics of technology-supported farming
KI-0	Region III Millennial Farmer Group	Group Chair	Group activities related to technology use; process of introducing technology to members
KI-1, KI-2	Region III Millennial Farmer Group	Members, food-crop cultivation	Reasons behind the decision to use agricultural technology in food-crop cultivation; digital-divide manifestations and barriers to access and use
KI-3, KI-4	Region III Millennial Farmer Group	Members, horticulture cultivation	Realities behind the decision to use agricultural technology in horticultural cultivation; digital-divide manifestations and barriers to access and use
KI-5, KI-6	Region III Millennial Farmer Group	Members, marketing and distribution	Variation in digital-divide experience across farmers; reasons for non-adoption of technology in production; experience and barriers in adopting technology for distribution and marketing

Semi-structured interview guides for the key informants (KI-0 through KI-6) covered: (1) the group's history and the process of introducing technology to members; (2) the specific technologies used in each informant's cultivation, distribution, or marketing activity, and the reasoning behind adopting or not adopting them; (3) barriers and enablers encountered in accessing and using agricultural technology; (4) the personal and collective meaning assigned to technology in relation to farming activity; and (5) perceived contribution of technology to food security, from both a production and a distribution standpoint. Interviews with supporting informants (SI-1 through SI-5) instead followed each informant's institutional focus of inquiry as summarized in Table 1.

3.4. Data Types and Sources

Primary data comprise information obtained directly from original sources through in-depth interviews with key informants (Narimawati, 2008; Sugiyono, 2013), covering millennial farmers' use of digital technology in support of food security sustainability in Sleman Regency. Secondary data, drawn from documents, archives, and literature related to millennial farmers' technology use (Sugiyono, 2013), were used to situate the primary findings within a broader context.

3.5. Data Collection Techniques

3.5.1. Observation

Observation involved direct, systematic recording of events, behaviors, and objects relevant to the study at the research site, to support the primary interview data. Observation was conducted intensively across UPTD BP4 Region III and covered: (1) millennial farmers' patterns of digital-technology use in daily agricultural activity, including smartphone use for social-media and messaging-app marketing and agricultural applications; (2) the state of technological infrastructure at farm sites, such as internet and electricity availability; (3) millennial farmers' interaction within farmer groups and with extension officers, particularly around technology adoption; (4) cultivation practices, whether conventional or technology-integrated, such as irrigation systems, heavy equipment, or green houses; and (5) agrotourism activity, such as pick-your-own tourism promoted through digital platforms.

3.5.2. In-Depth Interview

In-depth interviews (Riyanto, 2010; Bungin, 2010) were conducted face-to-face and openly, with informants aware of the researcher's presence and purpose (Gunawan, 2013), using the interview guides described above.

3.5.3. Focus Group Discussion (FGD)

Following Kitzinger and Barbour (1999), FGD explores a specific issue through group discussion focused on joint activity among participants to build shared understanding. Two FGDs were conducted: one with the group's policy-facing stakeholders (extension officers and district agricultural agency representatives) and one with millennial farmer members of the Region III group. Topics explored in the FGDs included: (1) local government policy and regulation on agricultural technology use; (2) barriers and challenges millennial farmers face in accessing, learning, and using agricultural technology, particularly regarding the digital divide; (3) drivers of technology adoption, such as the role of community, extension officers, and government programs; (4) the personal and collective meaning millennial farmers assign to technology in their agricultural activity; and (5) millennial farmers' views on technology's contribution to food security in their area, from both production and distribution standpoints.

3.5.4. Literature Study

Literature study involved gathering information relevant to the research topic from scientific books, research reports, theses, dissertations, regulations, official yearbooks, and both print and electronic written sources (Hermawan, 2019).

Fieldwork, comprising the in-depth interviews, both FGDs, and site observation, was conducted between January and March 2025.

3.6. Data Analysis

Data were analyzed using NVivo 14, a qualitative analysis software that supports organizing, coding, and interpreting diverse qualitative data and producing structured output (Bazeley & Jackson, 2013). Interview and FGD recordings were first transcribed, then imported into NVivo 14 for coding: segments of text were labeled with codes reflecting themes and concepts relevant to the research questions, allowing patterns, themes, and categories to be identified systematically across the dataset. An initial open-coding pass identified recurring words and categories; these were then grouped through axial coding into the broader analytic themes reported in the Results: technology categorization, meaning-construction through the Berger and Luckmann framework, digital-divide manifestation, and linkage to food-security dimensions. Coding was carried out by the lead researcher, with interpretive categories discussed and reviewed together with the two co-authors at each major coding stage to check interpretive consistency.

Consistent with Sugiyono (2011), analysis proceeded interactively and continuously through three linked activities carried out iteratively rather than as one-off steps (Figure 1): (1) data reduction, in which field data were summarized and focused on themes and patterns as data collection proceeded; (2) data display, presenting findings primarily as narrative text supported by tables and figures; and (3) conclusion drawing and verification, comparing findings against the research's underlying constructs to identify relationships, similarities, and differences. Data collection and coding continued until this iterative cycle reached saturation, that is, until successive interviews and the second FGD introduced no new codes or themes beyond those already identified from the twelve informants, at which point data collection was concluded.

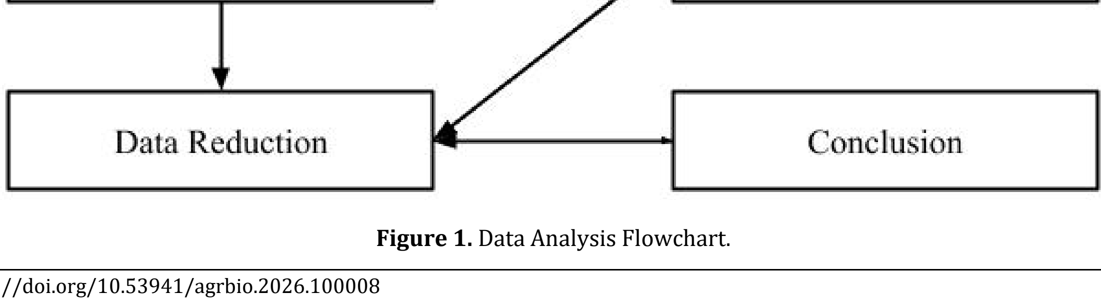

Figure 1. Data Analysis Flowchart.

3.7. Data Validity

Following Neuman (2014), the validity of the findings was strengthened through data triangulation, comparing results obtained through different approaches. Technique triangulation compared data obtained through observation, interviews, FGDs, and literature study for consistency on the same question, source triangulation compared accounts across the three informant categories, key informants, supporting informants, and the group chair, to test the convergence of findings. This approach aimed to minimize bias and increase confidence in the validity of the results.

3.8. Ethics and Informed Consent

This study was conducted as part of a master's thesis in Extension and Development Communication at the Graduate School, Universitas Gadjah Mada, under the supervision of the second and third authors. Consistent with standard practice for non-clinical qualitative social-science research of this kind at the university, the study did not require review by a clinical or biomedical ethics committee; procedural safeguards were nonetheless applied throughout. All informants were briefed on the purpose of the research and their right to decline participation or withdraw at any stage prior to interview or FGD participation, and verbal informed consent was obtained and recorded before each interview and FGD. Informants are identified in this article only by the anonymized codes shown in Table 1, and no personally identifying information beyond institutional role is reported.

4. Results and Discussion

4.1. The Reality of Agricultural Technology Use by Millennial Farmers

Technology's penetration into Sleman Regency's agricultural sector is now unavoidable. Mechanical and digital innovation is reshaping farming practice, particularly among millennial farmers, whose generational characteristics make them comparatively quick to adapt to new technology (Maiers, 2017). Yet adoption and implementation are neither linear nor uniform: while access to information and technology is broadly open, the extent of adoption is strongly shaped by how a given technology is interpreted by the farmer concerned. Characteristics of an innovation itself, its complexity, relative advantage, compatibility with users' values and experience, trialability, and observability, all shape how an innovation is understood and ultimately accepted or rejected (Rogers, 2003). This interpretation is subjective and shaped by socio-cultural, economic, and individual-experiential factors that ultimately determine whether a given millennial farmer integrates a given technology into practice.

NVivo 14 word-frequency analysis of the interview and FGD corpus shows the words "agriculture", "millennial", "farmer", "technology", "food," and "Sleman" as most dominant, confirming the study's central focus. Words such as "more", "like", "use", "have", "now," and "later" point to processes of comparison, categorization, ownership, and temporality in how technology is discussed; words such as "result", "land", "cultivation", "crop", "harvest", "chili," and "green house" situate that discussion within specific farming practice; and words such as "friend", "happy", "good," and "easy" point to an affective and evaluative dimension, technology is judged not only functionally but by how it shapes the overall experience of farming, including its social and emotional aspects.

A hierarchy-chart categorization of the coded interview data groups the technologies millennial farmers use into three categories: digital technology, mechanical technology, and cultivation method. The digital category includes subcategories such as "online", "marketplace", "Facebook", "internet," and "drone," indicating that the digital dimension now extends beyond communication into marketing, information-seeking, and operations. The mechanical category, comprising "machinery", "combine harvester", "tractor", "thresher", "cultivator", "diesel", "sprayer," and "water pump," occupies a comparably substantial share, underscoring that mechanization remains the backbone of cultivation practice. The cultivation-method category, comprising "conventional land", "hydroponics," and "aquaponics," shows that millennial farmers' practice is not confined to traditional methods alone.

From a critical constructivist perspective, this categorization reflects farmers actively selecting and integrating technology to fit their needs and understanding of modern practice, not passively accepting whatever innovation is presented. Digital-technology adoption, for instance, functions as a strategic response to market demand and the promise of efficiency offered by online platforms; the presence of "marketplace" and "Facebook" in the digital category shows how these platforms have become a new space for economic interaction and information exchange. Drone use, while not yet widespread on-farm, has attracted enough interest that some millennial farmers have begun assembling and renting out drones as a side enterprise, as one informant explained:

> *"Drones aren't used much here yet. But some of our millennial farmers have started building, assembling, and offering drone rental services."*

(Interview with KI-5, marketing/distribution, 9 February 2025)

Market potential weighs heavily in these choices, since millennial farmers are strongly oriented toward profit. Organically or semi-organically labeled produce commands a higher price than conventionally grown produce, which has pushed some farmers toward organic or semi-organic cultivation, as one key informant described:

> *"We make what we call semi-organic, but the base materials are still chemical; we also make what we call 'nuclear fertilizer.' It's chemical in origin, but we process and ferment it using M21 bacteria, pseudomonas, trichoderma, and so on, fermented for one to forty days. The result is healthier chili that needs fewer pesticides, using semi-organic materials."*

(Interview with KI-3, horticulture, 30 January 2025)

The persistence of "conventional land" cultivation alongside hydroponics and aquaponics in the coded data shows that, for many farmers, technology adoption does not always mean something new or sophisticated. Some farmers optimize conventional practice with a technological touch instead, such as a manual pesticide sprayer modified with a repurposed pressure-washer spray gun to apply water or liquid fertilizer. This reflects that the meaning and adoption of technology are contextual and inseparable from farmers' existing experience and knowledge. In the food-crop cultivation context, this also extends to local wisdom: the wiwitan ritual performed before rice planting and harvest, a Javanese expression of gratitude for an abundant harvest, remains actively practiced, as one food-crop informant explained:

> *"The wiwitan local wisdom in farming is logical and has a real effect, it shouldn't be dismissed. Offerings of rice, banana, and palm sugar placed in the paddy field must have a reason behind them... it will fertilize the soil. Those offerings feed soil organisms; it isn't mystical. Unfortunately, this logical local wisdom often isn't explained well, so we end up feeling like we were being misled."*

(Interview with KI-1, food-crop cultivation, 9 February 2025)

This account reinforces that millennial farmers' decisions about integrating technology are shaped by the surrounding cultural context, not by a purely technical calculus. Farmers evaluate new technology not as a standalone tool but by asking how it might synergize with inherited values, knowledge, and practice, making adoption a selective, identity-embedded process rather than a wholesale replacement of what came before.

Table 2 summarizes six technologies that recur across the coded interview material, together with their reported cost barriers and impact. Read together with the categorization above, the pattern is consistent with the classic finding in agricultural-innovation-adoption research that technology uptake varies with resource capacity, access to information, institutional support, and farmers' own perception of risk and benefit (Feder, Just & Zilberman, 1985), a finding this study's data corroborate directly rather than merely cite as background.

Table 2. Selected Agricultural Technologies Used by Millennial Farmers, UPTD BP4 Region III.

Technology	Characteristics and Reported Use	Cost/Adoption Barrier	Reported Impact
Green house	Structure for horticultural cultivation (chili, melon); increasingly common across Region III	High upfront cost; described by informants as expensive relative to smallholding scale	KI-3: prevents an estimated 90% of crop failure from weather and pests.
Drip irrigation	Automated watering, used especially where water sources are limited (Mlati, Tempel)	Moderate; regarded as a marker of a "progressive" farmer	Reduces manual watering labor; a marker of a "progressive" farmer.

Table 2. *Cont.*

Technology	Characteristics and Reported Use	Cost/Adoption Barrier	Reported Impact
Drone (spraying/monitoring)	Used for pesticide spraying on larger plots; some millennial farmers assemble and rent out drones as a side business	High; rental and purchase both considered expensive relative to smallholder plot sizes (efficient mainly above approx. 3 ha)	KI-1: manual spraying stayed more cost-effective on a 1000 m² plot; limited uptake in food crops.
Cultivator/transplanter	Mechanical land preparation and rice transplanting	Moderate; partly supplied through government distribution to farmer groups	Reduces manual hoeing labor; access sometimes limited by group dynamics (see Digital Divide).
Digital TDS meter	Trialed to measure nutrient concentration in hydroponic irrigation water	Low purchase cost	KI-4 discontinued use after probe corrosion caused inconsistent readings; reverted to manual measurement.
Marketplace and social media (Shopee, Tokopedia, Bukalapak, Lazada, WhatsApp, Instagram, Facebook, TikTok Shop)	Used for direct marketing and distribution of horticultural and floricultural products	No direct cost to farmers; primary barrier is digital literacy, not price	KI-5: Shopee turnover alone reached as much as IDR 100 million at peak.

4.2. Linking Technology Use to Food Security Dimensions

Because the technology categories identified above, digital, mechanical, and cultivation-method, map unevenly onto the three dimensions of food security introduced in the Literature Review, the coded material was analyzed separately against availability, access, and quality. Table 3 summarizes this mapping.

Table 3. Technology Use Mapped against Food Security Dimensions.

Dimension	Operational Definition	Evidence from This Study
Availability	Food is available through production, cultivation, livestock, or other sourcing (Roy et al., 2019)	Weakest evidence base. Digital and IoT technology has barely reached upstream (on-farm) cultivation; food-crop production still relies mainly on mechanical tools and, in places, manual cultivation (cangkul, sabit). Where production-side technology is used (green house, drip irrigation), it primarily reduces crop failure and labor burden rather than expanding the overall volume of food produced.
Access	Food is physically and economically reachable, including affordability (Roy et al., 2019)	Strongest evidence base. Marketplace and social-media-based distribution (Shopee, Tokopedia, WhatsApp, Instagram, TikTok Shop) measurably extends the reach of farmers' produce to a wider consumer base, with KI-5 reporting turnover as high as IDR 100 million via Shopee during a peak period, and multiple informants describing marketing and distribution as their most technologically developed activity.
Quality (Utilization)	Food is nutritious and its nutrients can be absorbed by consumers (Roy et al., 2019)	Limited direct evidence. The clearest quality-relevant finding is farmers' move toward semi-organic cultivation (reducing pesticide reliance) as a market-driven quality differentiator (KI-3) rather than a food-security-driven one; the fieldwork instruments did not probe nutritional outcomes for consumers directly, which is noted as a limitation below.

This mapping indicates that the technologies millennial farmers emphasize most, marketplace platforms and social media for distribution, speak most directly to the access dimension of food security. Evidence for availability and quality is comparatively thin in the present dataset. This is treated here as a substantive finding, technology adoption among Region III's millennial farmers is not yet evenly distributed across all three dimensions of food security, rather than as a gap in the analysis to be argued away. It also clarifies a claim in the underlying field data that requires qualification, while millennial farmers' technology use undeniably strengthens market access, the evidence does not support a parallel claim that it has meaningfully strengthened food availability or quality in the same period.

4.3. The Meaning of Agricultural Technology for Millennial Farmers in Providing Food Security

Taking as its starting point Berger and Luckmann's (1966) foundational premise that social reality is a social construction, this section examines how millennial farmers construct the meaning of agricultural technology in relation to food security provision. Berger and Luckmann's theory identifies externalization, objectivation, and internalization as three moments of the dialectic through which social reality is continuously produced and reproduced. Crucially, these are simultaneous, mutually reinforcing moments of an ongoing dialectic, not sequential stages that an individual or group passes through and leaves behind. Read dialectically, the same body of interview evidence below documents the interplay of externalization (the ongoing, everyday act of describing and acting on technology), objectivation (technology's hardening into a taken-for-granted feature of local farming life), and internalization (technology's absorption into farmers' own identity and values) as concurrent processes rather than a completed progression.

Fieldwork data show technology awareness to be widespread among millennial farmers in Region III, but its pattern of use varies significantly. Some farmers focus technology use on mechanization, relying on tools and machinery to raise efficiency in land preparation, planting, and harvest. Others extend into digital tools and the Internet of Things, though implementation remains largely confined to simple applications tied to marketing and distribution, internet use, online marketplace platforms, and social media to reach a wider customer base. In cultivation practice specifically, the dominant pattern combines long-familiar conventional methods with mechanical technology; IoT applications involving sensors, data analysis, and more complex automation are not yet common practice among the millennial farmers studied here.

4.4. Objectivation: Technology as an Established Social Fact

The green house illustrates how a technology moves from novel practice to established social fact within Region III's farming discourse. As green houses have become increasingly common for horticultural cultivation, prone to crop failure from extreme weather and pest pressure, the practice has become habitual and, in the group's everyday discourse, largely unremarkable, an objectivated feature of what "good" horticultural practice now looks like. This is illustrated by a key informant's account:

> *"Honestly, the real problem in farming is that harvests often don't meet expectations. So we've adopted a technology that's already common and proven effective: the green house. With a green house, roughly 90% of potential crop failure can be avoided, so this technology has become an important solution, especially for boosting horticultural production."*

(Interview with KI-3, horticulture, 6 February 2025)

This objectivation is at once material and economic: direct experience of using, maintaining, and benefiting from the green house has made it an inseparable part of farming reality for those who have adopted it. At the same time, the field data show that this objectivation coexists with unresolved structural limits. Technology is understood and discussed as a known, real object, but it has not, for all farmers, become an affordable one:

> *"Millennial farmers know about agricultural technology and its benefits. But for around 30% of them, that knowledge hasn't translated into actual use. The main constraint is cost, or capital. Why would someone know about a technology but not use it? It comes down to cost and capital."*

(Interview with KI-3, horticulture, 30 January 2025)

This account shows objectivation proceeding under real structural constraint: "expensive" and "capital" are not merely subjective impressions but reflect unequal access to economic resources. The same rationality is visible in how farmers weigh technology against local land conditions:

> *"Nowadays, transplanting doesn't have to be done by hand, there's the transplanter, and even spraying can be done efficiently with a drone. But we have to be realistic about farmland conditions in Indonesia, which are different from Japan's. There, they have large tractors that work very efficiently for wide fields, but that wouldn't suit conditions here, because our land is terraced and narrow."*

(Interview with KI-1, food-crop cultivation, 9 February 2025)

Cost, efficiency, and land scale are thus weighed together in determining how far a given technology is adopted and considered relevant, consistent with the diffusion-of-innovation account of relative advantage and compatibility with users' circumstances (Rogers, 2003): investment tends to track the potential increase in income or reduction in expenditure a technology offers, tempered by whether it fits the scale and shape of the land actually being farmed.

4.5. The Interplay of Objectivation and Internalization

Berger and Luckmann's theory does not specify a formal transition between dialectical moments, but the field data show objectivation and internalization operating together in a way worth foregrounding. Technology use has become institutionalized in Region III's farming culture, most visibly through the Sekolah Lapang (Farmer Field School) program run by the Sleman Regency Agriculture, Food, and Fisheries Office, and through partnerships with private-sector actors such as PT Indomarco Prismatama (Indomaret) and academic partners at Universitas Gadjah Mada. Being technologically literate has itself become a marker of being seen as innovative, productive, and competitive within the group's own discourse. At the same time, millennial and senior farmers in the same locality construct markedly different meanings around the same technologies, illustrating how social reality is built through interaction, language, and repeated practice rather than existing as a single objective fact (Berger & Luckmann, 1966):

> *"Agricultural technology really is a double-edged sword. It can be beneficial, or it can not be. Like, if I want to spray without it being so physically taxing, I have to figure out how to modify the equipment myself... A lot of senior farmers just gossip about it. Even just holding a phone is already an achievement for a lot of them, plenty still can't."*

(Interview with KI-2, food-crop cultivation, 22 February 2025)

For millennial farmers, technology is increasingly constructed as a necessity, a means of overcoming the limitations and inefficiencies of traditional practice; this openness is consistent with prior findings that millennials show greater ease and familiarity with technology than older generations, who tend to rely more heavily on conventional methods (Gursoy et al., 2013). Seeking out technical solutions independently through platforms like YouTube reflects a pragmatic construction of technology as a tool for simplifying, modernizing, and increasing the efficiency of farming, driven by the relative advantage millennial farmers perceive it to offer. For senior farmers, by contrast, inherited conventional practice remains the established, tested standard, against which newer technology can appear foreign, costly, complex, or even threatening to existing stability, a stance that reflects limited exposure, cost concerns, and unfamiliarity with the new at least as much as unwillingness to change.

4.6. Internalization: Technology as Identity and Motivation

For some millennial farmers, agricultural technology has moved further still, becoming not simply a rationally understood object but a taken-for-granted part of how they understand themselves as farmers, absorbed affectively as well as cognitively into their sense of what farming is. This is most visible in how several informants describe technology as the reason they entered farming at all:

> *"Technology has now become a major factor alongside that, for millennials, having technology available is what makes them interested in going into farming in the first place. Take tractor technology for making raised beds, for instance, it cuts down the labor needed for hoeing. Because it seems like these days, maybe 85% of the millennial generation can't hoe a field by hand anymore."*

(Interview with KI-0, group chair, 4 February 2025)

The 85% figure above is the informant's own impression, offered conversationally rather than as a cited statistic, and is reported here as a perception rather than a verified fact. Read this way, it still speaks to something real in the data: technology is described, across several informants, as a primary draw into agriculture for a generation with markedly less hands-on manual farming experience than earlier generations.

Shifting climate and weather patterns reinforce this. Where earlier generations could count on comparatively predictable seasonal patterns, today's greater unpredictability is described as pushing farmers toward technological solutions, drip irrigation prominent among them, particularly in Mlati and

Tempel, which are not reached by the Mataram or Van der Wijck irrigation canals and so face more acute water constraints. Automated drip irrigation is described by informants as both practically necessary and a marker of being a "progressive" farmer. Beyond operational change, some informants describe an emancipatory dimension to this internalization: technology as a means of addressing structural constraints, such as limited water access, and of reducing the physical burden of farm labor. For some, this internalization extends to describing technology as constitutive of life itself:

> *"Life just doesn't work without technology, that's how far it's gone, because it's genuinely hard to live without it now. My own farming business couldn't run without it either. Technology really is what life is today."*

(Interview with KI-6, marketing/distribution, 22 February 2025)

Framing technology as "life" points to a vision of social transformation through technology, but the same informants remain aware of unequal access. A critical reading holds these together: the emancipatory and identity-forming potential of technology internalization is real for those who have reached it, but it coexists with, and is partly produced against the backdrop of, the unequal access documented in the next section.

A central finding of this study is that no millennial farmer among the twelve informants described a relationship to agricultural technology consisting only of the earliest, most tentative externalizing gestures, with no trace of objectivation or internalization also present. This is unsurprising once externalization, objectivation, and internalization are read dialectically rather than as stages to be "reached": mechanization, modern irrigation, green houses, and environmentally attentive practice were not new to Region III when today's millennial farmers began farming. This is consistent with Hermawan et al.'s (2017) finding that Sleman Regency's population shows comparatively high human-resource capacity and a strong tendency to adopt technological innovation, including in agriculture; strong human resources and reasonably good access to information in this region have facilitated the reception and use of agricultural technology that, in many respects, already existed before this generation of farmers took it up. Millennial farmers in Region III therefore engage not with a blank technological landscape but with a social reality of agricultural technology that is already well-established and objectivated in local practice and discourse, an act of interpretation and internalization of an existing social reality rather than meaning-making from nothing. This existing social reality of agricultural technology in turn raises the question of how access to, and benefit from, that technology is distributed among millennial farmers themselves, the digital divide examined next.

4.7. The Digital Divide Among Millennial Farmers

Alongside the meaning-construction process described above, the data reveal a pronounced digital divide among millennial farmers within the same group, in both how they interpret and how they use agricultural technology. Some farmers have internalized technology as an inseparable part of modern farming and even as a primary draw into the profession; others remain at an earlier stage of adoption, facing a literacy gap in the knowledge and skills needed to implement technology further, particularly for digital and IoT categories. Consistent with the two-stage framing common in digital-divide scholarship, distribution of digital resources (an access question) and effective use of those resources (a utilization question) (Tang et al., 2024), the coded data show this divide cutting across three distinguishable dimensions: access, digital literacy, and utilization.

4.8. The Access Dimension

Access-related disparity is most visible in two forms. First, information about, and control over, existing farm machinery is unevenly distributed within the group itself. Even where government programs have distributed equipment such as threshers, diesel pumps, and combine harvesters to farmer groups, control over that equipment can become concentrated in a few hands:

> *"It's really that the technology or access available to the wider group is limited. Information isn't evenly shared... over there, there's a rice transplanter, and the only person who can operate it is him... if a farmer isn't quite aligned or is in some conflict with him, not everyone gets to use it."*

(Interview with KI-2, food-crop cultivation, 22 February 2025)

Second, infrastructure for digital and IoT technology, stable electricity and internet connectivity at the farm site itself, remains largely absent, even where Sleman Regency's Smart City program provides free internet access at public institutions and points across the district:

> *"The real constraint is more about access to supporting infrastructure, like needing internet, needing electrical wiring installed at the field... Actually, if that could be installed, IoT could be applied and everything would be a lot easier."*

(Interview with KI-3, horticulture, 30 January 2025)

Cost compounds both forms of access disparity. Where a technology is available but unaffordable given a farmer's capital, that farmer does not have equivalent access to farmers with greater financial resources, even though the technology nominally "exists":

> *"The constraint will come down to cost eventually; a lot of promising new technology, like drones, is expensive to rent, let alone buy. For a 1,000 square meter plot, manual spraying takes under an hour. Drones only really become efficient above 3 hectares. Manual spraying is tiring, sure, but a large drone actually ends up costing more."*

(Interview with KI-1, food-crop cultivation, 9 February 2025)

This scale-dependent cost calculus shows access disparity as layered rather than singular, it is not just whether a technology physically exists nearby, but whether its cost is proportionate to the scale on which a given farmer operates.

4.9. The Digital Literacy Dimension

A second, distinguishable layer concerns farmers' capacity to understand, evaluate, and apply digital information critically (Falloon, 2020), independent of whether access barriers have been resolved. Skepticism about whether new technology meaningfully outperforms familiar conventional methods was a recurring theme:

> *"Not everyone can change the mindset they already have. If they had the awareness to shift their own paradigm, to see that this technology is easy to learn, easier to apply... fine, that's for someone who's already ready to change. But for those who aren't open to it, they'll just say, 'why bother using that, the results are the same anyway'... That's what happens."*

(Interview with KI-6, marketing/distribution, 22 February 2025)

Reliance on social-media content as a primary information source, rather than more rigorously vetted sources such as books, journals, or direct consultation with extension officers, compounds this literacy gap:

> *"It's a bit unfortunate that a lot of farmers today are basically "YouTube graduates" in farming. And a lot of what's on YouTube only shows the successes, so the actual process is barely covered and hard to really understand. It's content that's basically just advertising, dressed up. Then when someone tries it once and it doesn't work, they don't know what to do next when they hit failure."*

(Interview with KI-3, horticulture, 6 February 2025)

An extension officer corroborated this pattern from the supporting-informant side, framing it as a broader mindset issue rather than a purely technical skills gap:

> *"With technology around, things should be so much easier. But why won't the younger ones move on it, when even the older farmers are willing to think it through? Honestly, that's the character of millennial farmers, hard to develop, always chasing profit without thinking about the wider ecosystem, and in the end it just becomes a zero-sum game."*

(Interview with Extension Officer SI-5, 24 January 2025)

Beyond mindset, farmers described genuine operational knowledge gaps even after adopting a digital tool, illustrated by one horticulture informant's account of discontinuing a digital sensor:

> *"We tried using a digital TDS meter to check nutrient concentration in the water... it wasn't effective, because the system has a metal probe that corrodes over time, so the readings were way off. It's digital, so how does the reading climb by itself? So we decided to stop using it and went back to the manual one."*

(Interview with KI-4, horticulture, 4 February 2025)

Together, these accounts show that access to a digital tool does not automatically translate into sustained, effective use; without the accompanying knowledge to operate, maintain, and troubleshoot it, farmers default back to whatever conventional method they already know how to use reliably.

4.10. The Utilization Dimension

A third, related but distinguishable dimension concerns how, and how deeply, farmers actually integrate technology into practice, even once they have both access and baseline digital skills (Scheerder et al., 2017). This dimension is where the study's central finding is most visible. Digital and IoT technology use among Region III's millennial farmers is concentrated almost entirely in downstream activity, distribution, marketing, and product processing, using platforms such as Shopee, Tokopedia, Bukalapak, Lazada, Facebook, Instagram, TikTok Shop, and WhatsApp:

> *"I used to actually want to sell floriculture products by renting a stall, but if the business isn't running yet, that didn't feel efficient. So eventually I tried the marketplace instead. We got onto Shopee, Tokopedia, Bukalapak, all the marketplaces, we put our products on all of them. Shopee sold the fastest for us. Back then, turnover on Shopee alone could reach 100 million."*

(Interview with KI-5, marketing/distribution, 22 February 2025)

Upstream (on-farm) cultivation, by contrast, still relies heavily on mechanical tools, and for some food-crop commodities, on traditional tools such as hoes and sickles. Several interlocking reasons emerged for this asymmetry. First, upstream digital and IoT technology, smart green houses, soil sensors, monitoring drones, smart irrigation, digital farm-management platforms, carries a significant upfront cost that remains out of reach for many smaller-scale millennial farmers. Second, training in upstream technology use remains limited in reach:

> *"We've never had the Farmer Field School here. We were offered it once, but it got pulled and given to another area instead. The program really hasn't reached all millennial farmers yet."*

(Interview with KI-3, horticulture, 6 February 2025)

Third, reliable electricity and internet remain unavailable at many field sites, particularly paddy land in harder-to-reach locations. Fourth, private and public-sector technology development itself has historically concentrated more on post-harvest efficiency and supply-chain digitization than on upstream cultivation tools, meaning fewer ready-made digital solutions exist for the production side in the first place. Fifth, the risk of a failed technology trial weighs more heavily on farmers already operating with limited capital and experience. Sleman Regency's own agricultural policy direction reinforces this downstream orientation:

> *"The concept behind agriculture in Sleman Regency itself is oriented toward agribusiness... we need a new formula for how to facilitate millennial farmers so they can build partnership networks for marketing agricultural products... even though millennial farmers are new to this, they share one vision: to grow the name of PT Petani Milenial Sleman."*

(Interview with SI-3, Food Security Division, 21 January 2025)

This district-level orientation toward agribusiness and downstream value-addition is coherent with farmers' own reported technology use, but it also means that, absent a deliberate counterweight, food security's availability and quality dimensions are structurally less likely to benefit from the same pace of technological investment as the access dimension already has.

Taken together, these access, literacy, and utilization gaps compound one another rather than operating independently, and they fall unevenly across the three key-informant categories in this study: food-crop cultivators (KI-1, KI-2) reported the fewest digital tools in active use and the most persistent reliance on manual and mechanical methods; horticultural cultivators (KI-3, KI-4) occupied a middle position, having adopted higher-cost production technology (green houses, drip irrigation) but also reporting the clearest instance of digital-tool abandonment (the TDS meter); and marketing/distribution farmers (KI-5, KI-6) reported the most extensive and successful digital-technology integration, concentrated entirely downstream. This distribution is itself evidence for the study's central claim: technology's meaning and use among Region III's millennial farmers is not evenly internalized across the food system but is concentrated where market logic offers the clearest and fastest payoff.

4.11. Limitations

This study has several limitations that should be acknowledged. First, the sample of 12 informants, while sufficient to reach thematic saturation for the purposes of this qualitative case study, is relatively small, and the findings reported here should be read as an in-depth account of this particular group rather than as a representative picture of millennial farmers generally. Second, the research was conducted within a single geographical area, the UPTD BP4 Region III working area of Sleman Regency; millennial farmer groups elsewhere in Indonesia may face different infrastructural, institutional, or cultural conditions that shape technology adoption differently. Third, and as a consequence of the first two points, the generalizability of these findings is limited: as is common for qualitative case studies of this kind, the aim has been analytical depth and contextual understanding rather than statistical generalization, and the conclusions below should accordingly be read as bounded by this case rather than as claims about millennial farmers in Indonesia as a whole. Fourth, the cross-sectional fieldwork window (January-March 2025) captures a snapshot of technology use rather than change over time. Finally, future research with revised interview guides, a larger and more geographically dispersed sample, and a longitudinal design could usefully address all four of these constraints.

5. Conclusions and Recommendations

Within the present case study, the meaning of agricultural technology to millennial farmers in UPTD BP4 Region III is currently concentrated in the logic of the digital market, most visibly in distribution and marketing, while upstream, production-side applications of digital technology remain comparatively underdeveloped and dominated by mechanical rather than digital tools. This pattern shows a clearer, evidenced contribution to the access dimension of food security than to availability or quality, among the millennial farmers interviewed for this study. A pronounced digital divide across access, digital literacy, and utilization compounds this pattern and falls unevenly across farmer categories represented in this sample, disadvantaging food-crop cultivators most and benefiting marketing and distribution-oriented farmers most. Read together with Berger and Luckmann's dialectical account of meaning-making, agricultural technology among the Region III millennial farmers interviewed in this case study is neither uniformly internalized nor uniformly rejected; rather, farmers continuously externalize, encounter as objectivated fact, and internalize technology in ways that are most complete precisely where market logic offers the clearest and fastest payoff, and least complete where upstream investment and infrastructure remain weakest.

Two concrete, evidence-linked recommendations follow directly from these findings and given the scope of this single-site case study, are offered as considerations for UPTD BP4 Region III and similarly situated millennial farmer groups rather than as generalized policy prescriptions. First, extension curricula for millennial farmer groups, delivered through strengthened Farmer Field School programming, should explicitly pair the marketing and distribution skills farmers are already adopting with targeted upstream-technology literacy, particularly IoT-based irrigation, soil, and monitoring tools, rather than treating digital skill-building as market-facing only; this study's evidence suggests informants are open to such training where it visibly demonstrates practical benefit, but a training gap remains for upstream applications specifically. Second, Sleman Regency's food-security policy should track the access, availability, and quality dimensions of food security separately when evaluating agricultural-technology programs aimed at millennial farmers, since, as this case study shows, a program can visibly strengthen access while leaving availability and quality comparatively untouched. Local government, together with the private sector, should also prioritize extending stable electricity and internet infrastructure to farm sites themselves, since this remains the most frequently cited barrier to upstream IoT adoption among the farmers interviewed here. More broadly, technological transformation in this setting requires holistic policy intervention to build a digitally capable and inclusive millennial farmer ecosystem, strengthening the role of millennial farmers and agricultural extension workers as intermediaries of the state in a more balanced digital ecosystem between food provision and profitability. Future research extending beyond this single case could usefully explore how an integrated agricultural ecosystem might pursue sustainable food provision and farmer profitability simultaneously, through technology-based business models, cross-actor collaboration mechanisms, and holistic upstream-to-downstream smart-farming practice.

Author Contributions

Y.Y.: conceptualization, methodology, fieldwork/investigation, formal analysis, writing, original draft. A.B.R.: supervision, conceptualization, methodology review, writing, review and editing. Partini: supervision, writing, review and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

This study, conducted as part of a master's thesis in Extension and Development Communication at the Graduate School, Universitas Gadjah Mada, involved no clinical, medical, or physically invasive procedures and posed no more than minimal risk to participants. Consistent with standard practice for non-clinical qualitative social-science research of this kind at the university, formal review by a biomedical or clinical ethics committee was not required. Procedural safeguards for participants, informed consent and anonymization, are described in the Methodology.

Informed Consent Statement

Verbal informed consent was obtained from all twelve informants prior to their participation in interviews or focus group discussions, after each was briefed on the purpose of the research and their right to decline or withdraw at any stage. Informants are identified in this article only by anonymized codes.

Data Availability Statement

The interview and FGD transcripts analyzed in this study contain information that could identify participants and are therefore not publicly available. De-identified data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used Grammarly to improve the language, grammar, and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the published article.

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